Mine Seismic Exploration Instrument Development and Application Based on $\Sigma$-Δ 24-Bit A/D Converter

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Abstract. In order to solve the problems of low resolution and poor detection accuracy of current mine seismic exploration instruments, this paper used the data acquisition station of the 24-bit $\Sigma$-ΔA/D converter and the NetBEUI LAN signal transmission protocol to design and develop a synchronization based on the principle of electromagnetic induction. The instrument is a new generation of high-speed, high-resolution mine seismic equipment, and may be applied to geological structure exploration of coal underground channel wave seismic, underground two-dimensional seismic, transient multi-point Rayleigh wave and other seismic work methods. This paper used this instrument to carry out a joint exploration test of channel wave transmission and reflection on a mining face, and through analysis of the collected data, a total of 8 faults and 1 collapse column were delineated, which were confirmed in the later mining face and further verify the accuracy and practicability of the instrument in the safe and efficient mining of coal mines.

1. Introduction
In many fields such as coal resource geological exploration and engineering disease detection, ground seismic exploration technology is a geophysical method that has been developed into a widely used exploration method. However, as the exploration depth of coal resources increases, ground seismic exploration technology is also beginning to face many challenges. For example, the resolution of ground seismic is low, and it is difficult to meet the geological requirements for efficient and safe mining; at the same time, during the mining process of coal mines, due to unproven faults, collapsed pillars and other geological structures, the mining conditions are complicated and the mining costs increase. The reduction of coal recovery rate even leads to geological disasters, causing huge economic losses [1-2]. Therefore, before mining, it is very important to find out the geological structure of the coal mining area. For the above technical problems, scientific researchers have launched the application research of underground coal mine seismic exploration technology [3-5]. This article develops a new generation of high-speed, high-resolution mine seismic exploration instrument, which is suitable for geological structure survey of various seismic working methods such as underground channel wave seismic, underground two-dimensional seismic, and transient multi-point Rayleigh wave. It mainly detects other geological anomalies such as small faults, collapse columns, old kiln goafs, igneous rock intrusions, coal seam bifurcating and thinning zones, coal seam erosion and petrification in the mining face or panel.
2. Channel wave seismic exploration

2.1 The principle of channel wave seismic exploration
Channel wave seismic exploration is a kind of geophysical method that uses guided waves excited and propagated in the coal seam to detect the discontinuity of the coal seam. It is a branch of seismic exploration. Channel wave seismic exploration can detect geological anomalies such as small faults, collapsed pillars, coal seam bifurcation and thinning zones, mined-out areas, and abandoned roadways. It has large detection distances, high accuracy, strong anti-interference ability, easy identification of waveform characteristics, and final intuitive results advantages, especially over other coal mine exploration methods on the detection accuracy and distance, and it is one of the most effective detecting methods [6-7].

2.2 Channel wave formation
In coal-bearing strata, the coal seam is a low-speed seismic trough. The interface between the coal seam and the surrounding rock generally presents a good reflecting surface. Compared with the surrounding rock of the roof and floor, the coal seam always appears at a low velocity and density, and thus appears with low wave impedance. Seismic waves are excited in the coal seam, and the longitudinal and transverse waves excited are centered on the seismic source, propagate around in the form of spherical body waves, and are incident on the roof and floor interfaces at different angles. When the incident angle is less than the critical angle, most of the energy will be transmitted to the surrounding rock, and only a small part of the energy will be reflected back to the coal seam; When the incident angle is greater than or equal to the critical angle, the seismic wave energy incident to the roof and floor interface will be totally reflected back to the coal seam, and reflected many times in the coal seam, and finally confined in the coal seam. In the low-velocity trough of the coal seam, the upward and downward waves interfere with each other and superimpose, and most of the harmonic components cancel each other, weaken, and gradually disappear; Only when all kinds of harmonics meet certain conditions, they interfere with each other in the trough to form a standing wave perpendicular to the coal seam and propagate forward in the coal seam, which forms a trough wave, also called a coal seam wave.

2.3 Overall hardware design
Due to the interference of different body waves, the formed channel waves have different characteristics, and the channel waves are usually divided into two types:

(1) Love-type: it is formed by the interference of SH wave, and the particle is in the plane parallel to the coal seam plane and perpendicular to the propagation direction.

(2) Rayleigh-type: it is formed by the mutual interference of P wave and SV wave, and its particle moves elliptically in the plane perpendicular to the coal seam and parallel to the wave propagation direction.

2.4 Channel wave seismic exploration
Channel wave seismic exploration has the characteristics of large detection distance, high accuracy, strong anti-interference ability, easy identification of waveform characteristics, and intuitive results. According to the arrangement of seismic source and geophone, it can be divided into transmission exploration method, reflection exploration method and transmission-reflection combined exploration method [8-9].

2.4.1 Transmission exploration method
When detecting with transmission exploration method, it is necessary to select two roadways around the detection area, excite them in one roadway, and arrange geophones in the other roadway to receive channel wave. Then, according to the presence, strength, and correlation of the transmitted channel wave signal to determine the continuity of coal seams and their geological anomalies in the fan-shaped area covered by the rays between the shot point and the receiving array. The maximum detection capability
is 300 times of the thickness of coal. As shown in Figure 1, due to the influence of faults and other structures, the working surface is divided into transparent, translucent, and opaque areas. The geophones in transparent area normally receive channel wave, some geophones in translucent area normally receive channel wave, and some geophones in opaque area fail to receive channel wave. Therefore, it can be inferred that there may be faults or other geological anomalies with short distance greater than the thickness of coal seam. Transmission wave method is a basic, common and important method in channel wave seismic method, which can effectively determine the geological structure between two roadways, as shown in Figure 1.

![Fig. 1 Transmission exploration method](image1)

**2.4.2 Reflection exploration method**

In the reflection exploration method, the shot point and the geophone are arranged in the same roadway or on the same working surface, and whether the front coal seam is discontinuous can be confirmed according to whether the non-roadway reflection channel wave can be received. Its characteristic is that the position of discontinuities in the coal seam can be detected in advance in the same roadway. The combination of the projection method and the reflection method can improve the detection effect. The maximum detection capability is 100 times of the thickness of coal, as shown in Figure 2.

![Fig. 2 Reflection exploration method](image2)

**2.4.3 Transmission-reflection combined exploration method**

When the shot point is located in the ventilation roadway, the geophone in the ventilation roadway receives the reflected wave signal, and the geophone in the transportation roadway receives the transmitted wave signal.

**3. Hardware circuit design**

The seismograph system consists of five parts: the central control station, the data acquisition station, the power box of the acquisition station, the blast synchronization trigger device and the geophone. The system block diagram is shown as in Figure 3.
3.1 Central control station
The central control station is a central control system with a computer as the core, which is composed of seismic data recording hardware, intrinsically safe power supply circuit, liquid crystal display and brightness adjustable circuit. It mainly completes the functions of data acquisition parameter setting, control data acquisition, data storage, on-site seismic record quality monitoring, real-time processing and seismic record playback. Since the instrument is mainly used in coal mines, the entire circuit is of intrinsically safe type.

3.2 Data acquisition station
The data acquisition station is a special equipment used to acquire seismic signals and is the core component of the seismograph system. The main principle is to digitize the seismic wave signals received by a large number of geophone arrays arranged on the detection working surface, and then transmit the data to the central control station for recording and processing through a network cable after being digitized in the acquisition station.

![Circuit schematic diagram of the acquisition board of the acquisition station](image)

Fig. 4 The circuit schematic diagram of the acquisition board of the acquisition station

The seismic data acquisition station developed in this paper can be remotely controlled through the network to distribute the engineering exploration layout. The single station has a channel capacity of 24 channels, and the number of collection stations can be expanded by the project, up to 1000 channels. The acquisition station adopts the 24 bit Σ-ΔA/D converter patented by Crystal semiconductor company and Geometrics company. According to Σ-Δ, the principle of modulation can increase the dynamic range of A/D converter to more than 120dB, which ensures the data quality of high-precision exploration. Each acquisition station is composed of acquisition circuit board with 8 signal channels in each group. The schematic diagram of acquisition board is shown in Figure 4. Each acquisition board is composed of preamplifier circuit, A/D conversion circuit, ADSP and data transmission interface circuit. The acquisition board sends the analog seismic signal to ADSP for digital processing after amplification, filtering, and A/D conversion, and then sends it to the central control station for storage. In addition, the acquisition board is also responsible for the downstream cascade acquisition station link routing channel.

3.3 The power box of acquisition station
The power box of the acquisition station is a dedicated power supply for the data acquisition station. The principle is to output an intrinsically safe power supply for the data acquisition station after the battery pack is stabilized in two stages. The power supply can work continuously for more than 8 hours and has over-current, over-voltage and temperature protection.

3.4 Detonating synchronous trigger device
In coal mine seismic exploration engineering, it is very important to ensure the time synchronization of blasting data acquisition, and the time synchronization also directly affects the subsequent processing and interpretation of seismic exploration data. Therefore, this paper has developed a synchronous trigger device based on electromagnetic induction, whose synchronous trigger delay is less than 10 μs.

In seismic data acquisition, the trigger signal of acquisition station is low-voltage pulse signal below 5V, so the trigger device needs to convert the high-voltage pulse generated by mine detonator into low-voltage pulse signal. The principle block diagram of synchronous trigger device is shown in Figure
5. When the detonator detonates, a synchronous induction pulse is generated by the current pulse transformer, and the electromotive force is turned into a safe low-voltage trigger signal through the rectification and limiting circuit of the bridge and output to the collection station, so as to achieve the synchronization of the detonator and the data acquisition time.

3.5 geophone

The geophone developed in this paper is an electromagnetic induction geophone, which is a device that converts mechanical vibration into electrical signals. Due to the different absorption degree of low-frequency signal and high-frequency signal in different geological bodies, the energy of low-frequency signal and high-frequency signal receiving seismic wave varies greatly. Therefore, in order to meet the requirements of geophone in different geological conditions, the intrinsically safe geophone developed in this paper can be divided into three kinds of products: 40 Hz, 60 Hz and 100 Hz according to natural frequency.

4. Performance and signal channel conformance test

In order to further verify the performance indicators of mine seismographs, this article mainly uses the seismograph self-check system provided by Geometrics to measure the drift, noise, gain accuracy, gain consistency, harmonic distortion, phase consistency, crosstalk isolation, etc. of the instrument's 24 channels. The indicators have been tested for performance, and the requirements for each indicator are shown in Table 1. After testing, all signal channels have reached the design indicator requirements.

| Test content                  | Measurements |
|------------------------------|--------------|
| DC drift/mV                  | <0.01.0003   |
| Noise/mV                     | < 0.001      |
| Gain accuracy/%              | < 1          |
| Gain consistency/%           | < 0.75       |
| Harmonic distortion/%        | < 0.003      |
| Harmonic distortion/%        | < 0.8        |
| Crosstalk isolation ODD (EVEN)/dB | > 102       |

Fig. 5 Block diagram of the blast synchronization trigger device

Table 1. Performance Test Table

Fig. 6 Signal channel conformance test
In the signal channel consistency test, double acquisition stations are used for data acquisition, and hammering switch is used for trigger signal. The geophone of each channel is arranged at the same distance from the source, and the test waveform is shown in Figure 6. It can be seen from Figure 6 that the signal channel acquisition waveform of the acquisition station is complete, the initial jump time difference is the same, there is no obvious visual difference, and the waveform consistency is good. The selected parameters are as follows: the distance between the geophone and the source is 1.5m, the sampling rate is 1/4ms, the recording length is 0.128s, and the delay is 0ms.

5. Application examples

5.1 Overview of the working face

In order to verify the application effect of the developed mine seismic exploration instrument, an industrial test was carried out on the 5316-working face of a mine. The working face has a strike length of 1938m and a slope length of 219.7m. The working face is composed of roadway 53032, open cuts, roadway 5316, and connecting roadway 53162. The channel wave exploration area is the area surrounded by these 4 roadways (no detection is conducted outside of the stopline, and the observation system layout extends to 200m outside of the stopline). The probe length of roadway 53032 of working face 5316 is 1145m; the detection length of 5316 cut is 270m; the detection length of 53162 roadway is 1444m. The total length of the detection roadway is 3129m, and the detection area is (1444 × 270) m², as shown in Figure 7.

According to the field conditions of underground exploration, the joint exploration method of channel wave transmission and reflection is selected in this test. The transmission method is adopted in roadway 53032 and the reflection method is adopted in roadway 53162. A total of 2 central control stations and 9 data acquisition stations are put into operation. Each acquisition station includes 24 channels, 9 power boxes of acquisition stations, 1 synchronous trigger device, 173 100Hz geophones, and one 200F mining capacitor detonator.

The survey was carried out at 5316 working face. Detector points and shot points are respectively arranged along the cut-off of 53032 roadway, 53162 connecting roadway, 53162 roadway and 5316 working face (no detection is conducted outside the stop line, and the layout range of observation system in the design is 200m outside of the stop line). As shown in Figure 7, 53032 roadway is in the above, 53162 roadway is at below, G represents the detection point, S represents the shot point, and the red box part in the figure is the reflection layout.

Fig. 7 Construction layout of channel wave detection in 5316 working face
Fig. 8 The original data of the 24th channel waves

(1) Detection point:
   Transmission method: the distance between roadways is 8m, 125 effective roadways are arranged in roadway 53032;
   Projection method: the distance between roadways is 4m, 48 effective roadways are arranged in roadway 53162.

(2) Shot point: it is arranged in the cut and roadway 53162, with a distance of 10m, a total of 158 shots and 153 effective shots, including 133 shots in roadway 53162 and 20 shots in cut. The transmission method received 153 shots and the reflection method received 44 shots.

(3) Observation system: sampling frequency is 1/4ms, recording length is 2S, and preamplifier gain is 24dB.

5.2 Construction technique requirement
The 53032 roadway conditions of 5316 working face tested in this test are complex, which are influenced by the support of wooden frame, bottom drum and coal shot of the roof and floor. In view of the disclosure inside the roadway and the changing trend of coal seam, the following technical requirements are available in the actual construction.

5.2.1 Coupling
The geophone used in this test should be connected to the side bolt. In order to ensure the quality of channel wave data acquisition, the patented product of our institute, the docking device of underground geophone and bolt, is used to ensure good coupling.

5.2.2 Blasthole depth
Because the coal seam of 5316 working face is relatively soft in this test, in order to avoid the loose circle, the specific requirements of hole depth should be made. Through the quality analysis of different hole depth data, the final determination is 3M hole depth, and the seal mud length is not less than 1m.

5.2.3 Amount of explosives
For channel wave earthquake, the selection of dose quantity directly affects the quality of the collected data. Through the test of 150g, 200g, 250g and 300g, from the analysis of signal-to-noise ratio and channel wave energy mass of four groups of images, the most appropriate charge quantity of 300g is finally determined.
5.3 Data acquisition and analysis
As shown in Figure 8, the original data of the 24th shot shows three typical groups of waves. The first one is the refraction longitudinal wave from surrounding rock. The calculated speed is 3900m/s, and then the refraction transverse wave from surrounding rock is 1800m/s, and the energy group with the strongest energy is channel wave with the velocity of about 900m/s.

5.3.1 Transmission method

As shown in Fig. 9 (a) and (b), channel wave records of the 20th shot and 49th shot are collected by transmission method respectively. It can be seen from Fig. 9 (a) that the channel wave energy display is abnormal, and the energy of channel wave decreases gradually after 37 channels. In 125 receiving records in roadway 53032, the energy generation changes after 37 channels, indicating that the energy caused by geological structure block is reduced after 37 channels; It can be seen from Fig. 9 (b) that the energy changes after 74 channels, indicating that the energy of the channel wave is reduced due to the geological structure barrier after 74 channels. Through the analysis of the two potential channel wave abnormal areas.

5.3.2 Reflection method
As shown in Figure 10, it is the original reflection trough wave record. By extracting the airy phase and analyzing the superimposed section, we can clearly see the shape of the reflection interface, which may indicate the segment coal intersection line of the fault.
6. Analysis of research data

6.1 Analysis of transmission channel wave data

The interpretation of the transmission data is mainly based on the channel wave attenuation CT imaging. It can be seen from Figure 11 that the color from blue to red represents the degree of attenuation. The redder the color, the more severe the energy of the channel wave is absorbed. There are often faults or collapsed columns in this area; blue represents the area with stronger energy. The channel wave can pass through normally. The anomaly area has a certain shape, and different shapes often represent different geological phenomena. For example, faults are generally "stripe" anomalies, while the anomalies of collapsed columns are distributed in "flakes". The size of attenuation is used to determine the size of abnormal body, such as fault fall. Through the analysis and interpretation of the abnormal body, the transmission detection roughly delineated 7 faults and 1 collapse column.

Figure 10: Record of the original reflection channel wave

Figure 11: Image results of transmission channel wave
6.2 Data analysis of reflection channel wave

![Fig. 12 Result of reflection channel wave imaging](image)

Although the detection range of the reflected channel wave is not large (the arrangement length is less than 400m), it is of great significance. First, the fall of the fault is small. According to the exposure along the trough, it should be about 2m, which is less than 1/2 of the thickness of the coal seam; Second, the angle between the fault and the channel is nearly 45°, which breaks through the restriction that the reflection trough wave requires that the fault strike be nearly parallel to the observation roadway, and provides a reference for the application of the reflection channel wave exploration in the next step. Through the analysis and interpretation of the abnormal body, a fault is roughly delineated in this reflection exploration, as shown in Figure 12.

6.3 Overall analysis and research

The 5316 working face channel wave detection research projects collected a total of 153 channel wave data, of which 153 were received by transmission mode with 125 channels, and 44 by reflection mode with 48 channels. The seismic wave field rays cover the whole working face with high density, and the channel wave energy imaging method is used to process and analyze the characteristics. The fault predicted in the diagram is slightly different from the ground earthquake prediction in position, strike and fall, which needs to be verified by drilling and mining in the later stage. Through the comprehensive analysis and interpretation of the abnormal body, 8 faults and 1 collapse column are roughly delineated in this exploration.

7. Conclusion

Channel wave seismic is a more reliable method of mine geophysical exploration. It can not only detect the discontinuities in the working face, but also detect the discontinuities in the driving face and the side of the roadway. It has a wide range of applications and is not affected by the dip angle and the thickness of the coal seam. Compared with the traditional underground seismic instruments, the mine seismic exploration instrument has the advantages of strong single station channeling ability, small volume and light weight, With high detection accuracy and stable performance, it is suitable for geological structure investigation of various seismic working methods in coal mines, and provides advanced mine geophysical exploration technology and equipment for solving coal mine safety production and efficient mining geological guarantee technology. The success of this test indicates that channel wave seismic will still be the preferred technology for underground geological structure exploration, which can solve the geological problems that cannot be solved by surface seismic exploration and has great development potential.

References

[1] Cheng Jianyuan, Wang Pan, Wu Hai, et al. The development process and trend of seismic exploration instruments [J]. Coal science and technology, (2013)
[2] Cui Huanyu, Zhu Jianmin. Exploration of coal geological structure by channel wave seismic technology [J]. Coal and chemical industry, (2013)

[3] Jiang Qiyan, Wu Rongxin, Zhou Guanqun. Application of channel wave seismic exploration method in coal seam structural exploration [J]. Mine engineering, (2021)

[4] Zhang Jinying. Application of seismic exploration in coal mine water prevention and control [J]. Petrochemical technology, (2020)

[5] Liu Huizhou. Application of channel wave seismic exploration in underground geological anomaly detection [J]. Intelligent City, (2020)

[6] Guo Yinjing, Ju Yuanyuan, Fan Xiaojing, Zhang Jianhua. Research progress of channel wave seismic exploration [J]. Coal field geology and exploration, (2020)

[7] Zhao Hulin. Shallow discussion on channel wave seismic exploration [J]. Natural resources in North China, (2019)

[8] Application of the transmission channel wave tomography in the detection of hidden structure in coal mining face [J]. Mining safety and environmental protection, (2018)

[9] Li Gang. Research and application of reflection channel wave imaging method in coal mine [J]. Coal engineering, (2016)