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Researching Coal and Rock Character Recognition Based on Wavelet Packet Frequency Band Energy

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Abstract: At present top coal caving is done by workers at the fully mechanized top-coal caving face, where the production rate is low and the workers' safety is under threat. In order to reduce the casualties, realize "less people" even "no people" and the high-efficient and high-yield of coal mine, the coal and rock character recognition was researched on underground, the method based on the wavelet packet frequency band energy analysis, for coal and rock identification was proposed. Using the self-developed mine portable vibration data recorder to pick up the vibration signals at the hydraulic support tail beam under the different conditions of coal caving, gangue caving and roof rock caving in the fully mechanized top-coal caving face. The conclusion has been drawn after analyzing the vibration signals by the wavelet packet frequency band energy: When coal caving, the Edge band focus on 1250 Hz~1562.5 Hz and 2187.5 Hz~2500 Hz, when gangue caving, the Edge band focus on 0~625 Hz and 937.5~1250 Hz, when roof rock caving, the Edge band focus on 1875~2187.5 Hz and 3750~4062.5 Hz. The result shows that different edge bands under the different conditions can be used as the criterion for the coal and rock character recognition in the fully mechanized top-coal caving face. And research results could provide a new idea and the method for the coal and rock character recognition.

Keywords: Coal and rock characters recognition, fully mechanized top-coal caving face, vibration signals, wavelet packet frequency band energy.

1. INTRODUCTION

The fully mechanized top-coal caving face has been widely applied in thick coal seam mining in China, and is used as one of the main methods of thick coal seam mining [1, 2] for high yield and high efficiency, low consumption, safety and good economic benefits. At present, the close timing of coal export during the top coal caving are judged by the worker's intuition and experience based on whether there are gangue and in how much quantity in the coal (coal and rock characters). Due to harsh environment, dust, and darkness, it is difficult for workers to judge the coal and rock characters that inevitably cause their "less fall" and "over fall" status. "Less fall" not only leads to the low coal recovery rate, but also increases the risk of goaf spontaneous combustion. "Over fall" would result in coal quality decline, invalid transport, increased washed coal cost and render coal mine workers' health and personal safety under serious threat.

This study involves: using the self-developed YHJ(C) mine portable vibration recorder to pick-up the vibration response signal at the hydraulic support tail beam excited by coal, gangue and roof rock caving; using the method of the wavelet packet frequency band energy to analyze those data; and finding the difference under those conditions.

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2. WAVELET PACKET FREQUENCY BAND ENERGY

2.1. Wavelet Decomposition

Wavelet decomposition [3, 4] is a time-frequency localization analyzing method to realize time and frequency change at the same time.

Satisfied allow conditions:

$$\int_{-\infty}^{+\infty} \psi(t)dt = 0 \tag{1}$$

$\psi(t)$ is mother wavelet function. By flexing and translating $\psi(t)$, get

$$\psi_{a,b}(t) = |a|^{-\frac{1}{2}} \psi(\frac{t-b}{a}) \tag{2}$$

a reflects the scale function, b shows translational position at t axis, $\psi_{a,b}(t)$ is the wavelet function.

In practical application, signal and parameter a, b in wavelet function are discrete variable. Setting $a = 2^m$, $b = 2^m n$, we can get

$$\psi_{m,n}(t) = 2^{-\frac{m}{2}} \psi(2^{-m}t - n), (m, n \in Z) \tag{3}$$

$\psi_{m,n}(t)$ is wavelet function generated binary discrete wavelet.

Fig. (1). The YHJ(C) mine portable vibration recorder.

If binary discrete wavelet $\psi_{m,n}(t)$ satisfies the condition of orthonormal basis of normed linear space $L^2(R)$, and the binary orthogonal scaling function is generated by mother wavelet function $\psi(t)$, get

$$\varphi_{m,n}(t) = 2^{-\frac{m}{2}}\varphi(2^{-m}t-n) \; (m,n \in Z) \tag{4}$$

$\psi_{m,n}(t)$'s wavelet space W_m and $\varphi_{m,n}(t)$'s scale space V_m are complementation in the $L^2(R)$'s space. Scale space V_{m-1} is the straight sum of V_m and W_m.

So $x(t)$'s orthogonal wavelet decomposition is

$$x(t) = \sum_{m=1}^{N}\sum_{n\in Z}d_n^m\psi_{m,n}(t) + \sum_{n\in Z}c_n^N\varphi_{N,n}(t) \tag{5}$$

N is the exploded layer number, d_n^m is wavelet coefficients, c_n^N is scale coefficients at the N layer. $\varphi_{N,n}(t)$ is binary orthogonal scaling function when $m=N$.

2.2. Wavelet Packet Decomposition

Wavelet decomposition only decomposes the low frequency part and gives up decomposing of the high frequency part. But wavelet packet decomposition [5] make up for the shortage.

Assuming that $\varphi(x)$ and $\psi(x)$ are one of V_0 and W_0 orthonormal basis respectively. Because $V_0 \in V_{-1}$ and $W_0 \in V_{-1}$, $\varphi(x)$ and $\psi(x)$ belong to the space of V_{-1}, namely $\varphi(x)$, $\psi(x)$ are linear unfolded by orthogonal basis $\varphi_{-1,n}(x)$ in the space of V_{-1}:

$$\varphi(x) = \sqrt{2}\sum_k h_0(k)\varphi(2x-k) \tag{6}$$

$$\psi(x) = \sqrt{2}\sum_k g(k)\varphi(2x-k) \tag{7}$$

Among them, $h_0(k) = \langle\varphi, \varphi_{-1,k}\rangle$, $g(k) = \langle\psi, \varphi_{-1,k}\rangle$.

Assuming $u_0(x) = \varphi(x)$, $u_1(x) = \psi(x)$, two dimension equation can be written:

$$u_{2n}(x) = \sqrt{2}\sum_k h(k)u_n(2x-k) \tag{8}$$

$$u_{2n-1}(x) = \sqrt{2}\sum_k g(k)u_n(2x-k) \tag{9}$$

u_n is orthogonal wavelet packet of packet orthogonal scaling function $\varphi(x)$.

2.3. Frequency Band Energy Analysis.

Sum of the energy of each band signal:

$$E_j = \sum_{k=1}^{n}X_k^2(t) \tag{10}$$

E_j represents the wavelet packet energy at last j layer, X_k represents spectrum coefficient of discrete points after being decomposed by layer wavelet packet.

Use the total energy $E_0 = \sqrt{\sum_{i=1}^{n}E_j^2}$ to normalize the energy signal feature vector $E = [E_1, E_2, E_3, E_4 \cdots E_n]$, get

$$E' = [E_1/E_0, E_2/E_0, E_3/E_0, E_4/E_0 \cdots E_n/E_0] \tag{11}$$

The above make the theoretical foundation of frequency band energy of wavelet packet analysis.

3.   ACQUIRE THE COAL AND ROCK'S VIBRATION SIGNAL

3.1. Mine Portable Vibration Recorder and Test

YHJ(C) mine portable vibration recorder [6, 7], as shown in Fig. (**1**), is the self-developed 4 channel coal mine vibra-
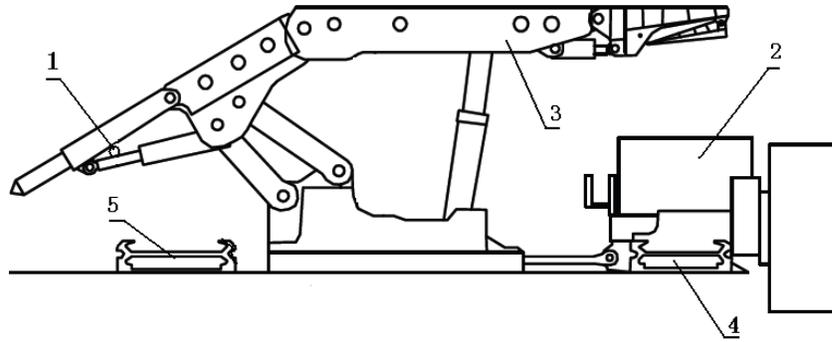
1-point at back beam; 2- coal winning machine; 3- hydraulic support; 4- front scraper conveyor; 5-Rear scraper conveyor.

Fig. (2). Site equipment layout and measuring point location.

tion signal acquisition instrument. Its sampling frequency is 0~250 kHz, and can collect, record and store the mine equipment vibration signal data, and provide technical support and guidance for the daily maintenance and repair of the equipment.

Site equipment layout and observation points. This test was carried out at 922 fully mechanized top-coal caving face of Dongpo coal mine in Shanxi province. The vibration data was collected at the hydraulic support tail beam under the coal caving, gangue caving and roof rock caving conditions. Sampling frequency was 10 kHz. The point at 143# hydraulic support was selected after field investigation and communication with workers. Fig. (**2**) shows arrangement of measurement points, and 1# point collected the vibration data at the hydraulic support beam normal direction.

Fig. (**3**) is the time domain waveform figure under various work conditions.

(**a**) coal caving

(**b**) gangue caving
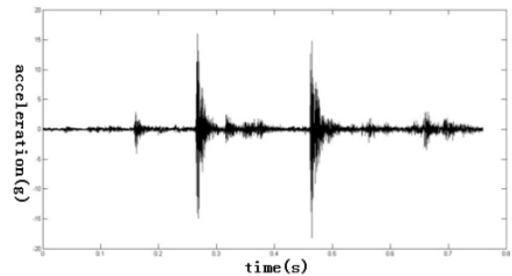
(c) roof rock caving

Fig. (3). The time history of vibration signal at the measurement point of the hydraulic support tail beam under various work conditions.

Results can be obtained from Fig. (**3**).

The vibration amplitude is about 3 g generated under the condition of coal caving. No obvious phenomenon of impact load happened.

The vibration amplitude is about 8 g generated under the condition of gangue caving. Obvious phenomenon of impact load happened.

The vibration amplitude is about 15g generated under the condition of roof rock caving. Obvious phenomenon of impact load happened.

3.2. Frequency Band Energy of Wavelet Packet Analysis.

Based on the regularity comparability of wavelet coefficient, choose the db2 wavelet packet basis, and 4 layer of wavelet packet to analyse the vibration signals. 0~5000 Hz have been decomposed to 16 bands, and getting the time - frequency diagram, as shown in Fig. (**4**).

Calculate the energy of each band under various work conditions, and the energy histograms have been gotten as normalized, as shown in Fig. (**5**).

From Fig. (**5**) conclusions can be drawn:

When coal caving, the energy between A5 band and A8 band, namely 1250 Hz~1562.5 Hz and 2187.5 Hz~2500 Hz is higher than in other conditions.
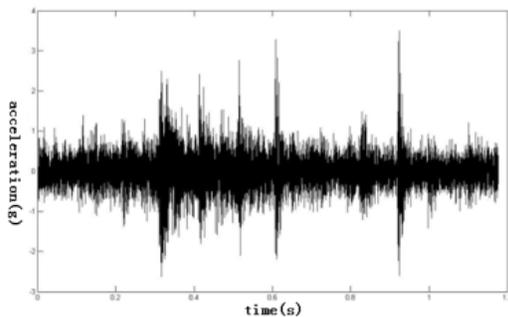
(**a**) coal caving
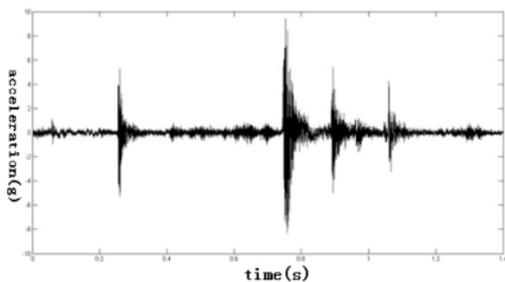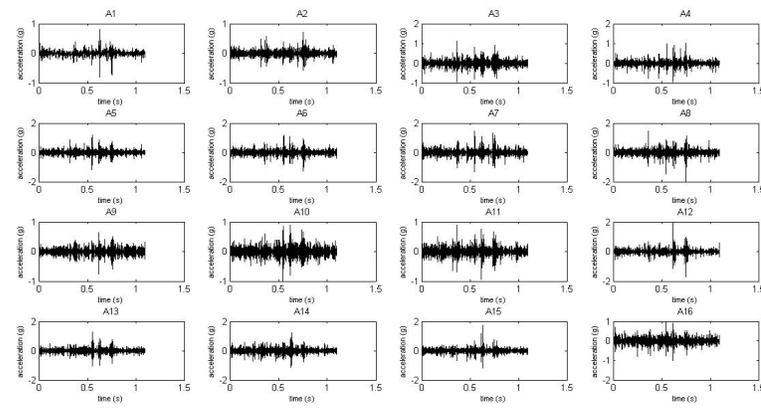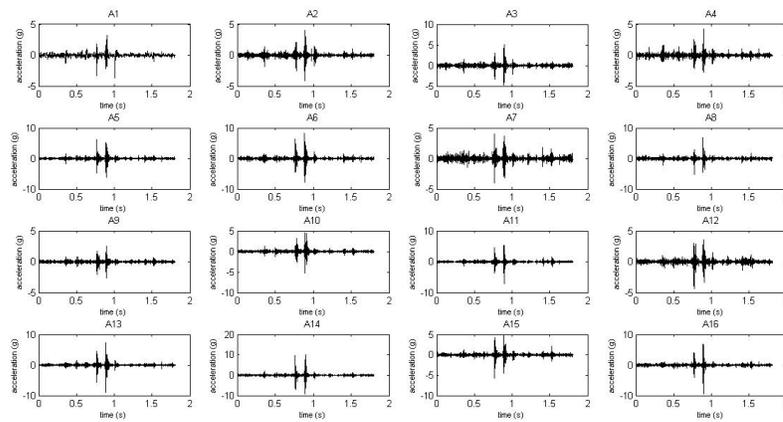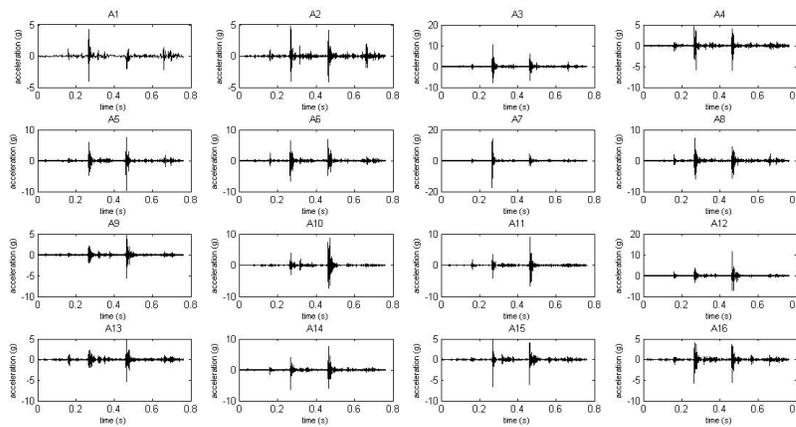
(**b**) gangue caving

(**c**) roof rock caving

Fig. (4). Wavelet packet decomposition of vibration signals under various work conditions.

When gangue caving, the energy among A1 band, A2 band and A4 band, namely 0 Hz~625 Hz and 37.5 Hz~1250 Hz is higher than in other conditions.

When roof rock caving, the energy between A7 band and A13 band, namely 1875 Hz ~2187.5 Hz and 3750 Hz ~4062.5 Hz is higher than in other conditions.

4. DISCUSSING THE DATA ANALYSIS RESULTS

The results found in this paper are universal for different coal mines and different working faces. But the specific frequency band threshold under various conditions applies only to this test of working face. For other fully-mechanized cav-
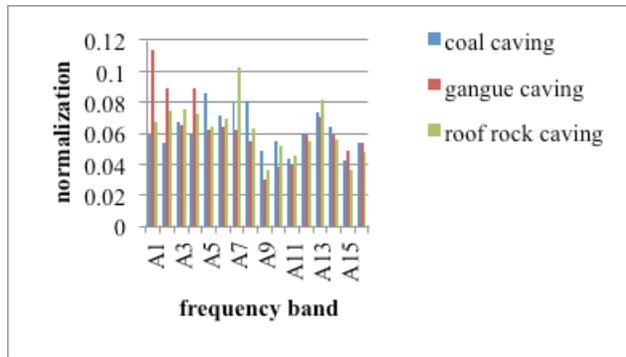
Fig. (5). The frequency band normalized energy histograms of vibration signal at the measurement point of the hydraulic support tail beam under various work conditions.

ing face, the method proposed in this paper along with test and analysis can be used to ensure the threshold under the various conditions. Concrete judgment of coal and rock character recognition can been done.

5. SUMMARY

The amplitude at the time domain waveform figure is different at the measurement point of the hydraulic support tail beam under various work conditions. The amplitude is about 3 g when coal caving, 9 g when gangue caving and 15 g when roof rock caving.

The wavelet packet frequency band energy analysis has shown the following: the edge band concentrate on 1250 Hz~1562.5 Hz and 2187.5 Hz~2500 Hz when coal caving, 0 Hz~625 Hz 与 937.5 Hz ~1250 Hz when gangue caving, 1875 Hz~2187.5 Hz and 3750 Hz ~4062.5 Hz when roof rock caving. The edge band is different obviously, and it can be the gist of coal and rock character recognition under various working conditions.

The method of the wavelet packet frequency band energy analysis can decompose the coal and rock's vibration signal of nonlinear and non-stationary into bands, calculate the energy of each band to find the difference. It can be the powerful tool of coal and rock recognition at fully mechanized top-coal caving face.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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