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Research on Noise Reduction Method of Mining Rock Microseismic Signal Based on Geophone Array

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Abstract. The high stress and high rock burst risk brought by deep mining seriously threaten the safe and orderly development of mineral resources. The magnitude and spatial distribution characteristics of microseismic events caused by rock fracture can be used to evaluate and predict the stable state of mining rock. The correlation of channel signals in the same direction can be analyzed by arranging microseismic geophone arrays, and designed special filters for power frequency noise, blasting noise and circuit noise, which achieved better microseismic signal extraction effect, realized the suppression of random noise and improved the signal-to-noise ratio of microseismic monitoring signal.

1. Introduction

The high stress and rock burst risk brought by deep mining seriously threaten the safe and orderly development of mineral resources. In view of this situation, a series of high-tech monitoring technologies, such as microseismic monitoring, are gradually applied in the mine field, which greatly improves the mining enterprises' ability to detect and predict potential ground pressure risk. Microseismic monitoring technology evaluates and predicts the stable state of ore and rock by analyzing the magnitude and spatial distribution of microseismic events caused by ore and rock fracture. However, the underground environment of mine is bad, and there are many interference factors. The waveform signals generated by these interference factors are collected by microseismic monitoring system. How to screen out the real and effective microseismic signals from a large number of waveform signals is very important. It has become a key issue to determine the validity and accuracy of microseismic monitoring system^[1-3].

The noise contained in microseismic signal can be divided into coherent noise and random noise^[4-5]. Among them, the appearance of coherent noise in time has regularity, obvious kinematic characteristics, apparent velocity difference, spectrum difference or arrival time difference with the effective signal, so it can be removed by filtering, coherence, direction and other methods. Typical coherent noise includes surface wave, multiple wave, refraction and so on. Random noise includes blasting, vibration caused by mining machinery, ground vibration and so on in the process of mine operation. The factors are unpredictable, there is no uniform law to summarize, random occurrence, wide frequency band, no fixed propagation direction, and it is difficult to remove them. Therefore, it is



very important to deal with different types of noise in order to improve the signal-to-noise ratio of microseismic data.

On the other hand, because the microseismic signal produced by the fracture of ore and rock is a time-varying non-stationary signal and has the characteristics of sudden and transient in the time domain, it is difficult to accurately capture and extract the microseismic signal in the case of variable scale by using general analysis methods such as Fourier transform, while wavelet analysis, which has the advantages of multi-resolution analysis, is a time-frequency analysis. The method can characterize the local characteristics of signals in both time and frequency domains, which is very suitable for analyzing the transient energy spectrum of microseismic signals^[6-7]. However, in the application process of wavelet analysis, it is necessary to determine the parameters of each stage of wavelet analysis reasonably, otherwise the expected analysis effect can not be achieved, which is also the difficulty of wavelet analysis applied to the extraction and analysis of microseismic signal waveform.

Aiming at the random noise produced by mining blasting and vibration of mechanical operation, this paper analyses the correlation of channel signals in the same direction by arranging the array of microseismic geophones, and designs special filters for power frequency noise, blasting noise and circuit noise, which achieves better microseismic signal extraction effect, realizes the suppression of random noise and improves the signal-to-noise ratio of microseismic monitoring signal.

2. A Noise Reduction Method by Superposition of Signals Using Geophone Array

2.1 geophone array structure

This paper studies and implements a method to improve the signal-to-noise ratio of mine microseismic geophone. The basic principle is: increasing the number of sensitive units of geophone in the direction of maximum sensitivity, on the one hand, increasing the number of acquisition channels of vibration signals in the same direction from a spatial perspective, increasing the sample of channel signals, and analyzing the correlation of channel signals in the same direction. On the other hand, the signal-to-noise ratio (SNR) of the single geophone sensitive unit is improved by means of the non-correlation of random noise (i.e. the statistical law is in conformity with, its mean value is 0) to suppress the noise of the over-sampled data of the same geophone sensitive unit from the angle of time. The specific implementation is shown in Figure 1.

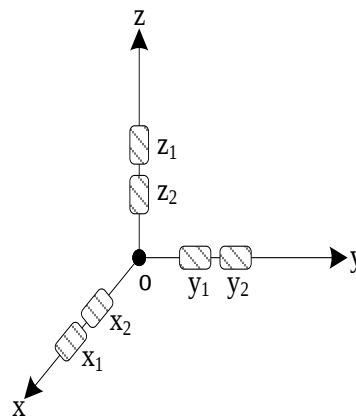


Figure 1. Diagram of geophone array structure

In the coordinate system o-xyz consisting of three maximum sensitivity directions of geophone sensing unit, x1, x2, y1, y2, Z1 and Z2 are geophone sensing units, namely:

The single component geophone adds one geophone sensing unit in the same maximum sensitivity direction.

Three-component geophone adds one geophone sensing unit in three maximum sensitivity directions.

$$S_{eff} = \pi R^2 - \pi r^2$$

2.2 Principle of noise reduction of geophone array

The Principle of noise reduction of geophone array: In the direction of maximum sensitivity of geophone sensitive unit, install (n+1) geophone sensitive units with equal sensitivity, the distance between geophone sensitive units is d, and the same vibration signal propagates to (n+1) geophone sensitive units in turn. Assuming that the time delay of two adjacent geophone sensing units receiving vibration signals is t, the equation of picking up vibration signals superposed in time domain is as follows:

$$V(t) = v(t) + v(t - \Delta t) + \dots + v(t - n\Delta t) = \sum_{i=0}^n v(t - i\Delta t) \quad (1)$$

Among them, Δt is the time difference between two adjacent geophone sensing units in picking up vibration signals. Fourier transform is used to obtain the equation of the vibration signal picked up by the geophone sensitive unit in frequency domain.

$$V(\omega) = \sum_{i=0}^n v(\omega) e^{j\omega i \Delta t} = v(\omega) \sum_{i=0}^n e^{j\omega i \Delta t} = v(\omega) e^{-j\omega \frac{n}{2} \Delta t} \frac{\sin(\omega \frac{(n+1)\Delta t}{2})}{\sin(\omega \frac{\Delta t}{2})} \quad (2)$$

Among them, $v(\omega)$ is the expression of $v(t)$ in frequency domain, j is the imaginary number unit after conversion from time domain to frequency domain, and ω is the frequency domain variable after Fourier transform.

$$V(\omega) = v(\omega) \cdot H(\omega) \quad (3)$$

It can be seen that the total amplitude of vibration signal picked up by the geophone sensing unit increases by (n+1) times than that of the single geophone sensing unit, which is independent of the arrival time of the signal, but only related to the frequency of the signal and the relative time difference of arriving at the sensitive units.

In addition, the relationship between the effective signal and random noise in the signal picked up by the combined sensitive unit is further analyzed, and it is found that:

It is known that the input signal $v(t)$ is a combination of effective signal and random noise, which can be expressed as:

$$v(t) = s(t) + n(t) \quad (4)$$

In the formula, $s(t)$ is the effective signal and $n(t)$ is the random noise.

Random noise has statistical regularity and obeys Gauss distribution. Its mean value is zero.

1) From a spatial perspective:

When the signals of the geophone sensitive units in the same direction are superimposed, the output signal is:

$$V(t) = v(t) + v(t - \Delta t) + \dots + v(t - n\Delta t) = \sum_{i=0}^n v(t - i\Delta t) = (n+1)s(t) + \sqrt{n+1}n(t) \quad (5)$$

After averaging the output signal, the following results are obtained:

$$\overline{V(t)} = \frac{V(t)}{n+1} = s(t) + \frac{\overline{n(t)}}{\sqrt{n+1}} \quad (6)$$

It can be seen that the random noise is not correlated because of the correlation of the effective signal, and the random noise is reduced to $\frac{\overline{n(t)}}{\sqrt{n+1}}$ in the average signal $\overline{V(t)}$ of the geophone sensing

unit, thus improving the signal-to-noise ratio.

2) From the perspective of time:

When the same geophone sensing unit realizes oversampling, since the oversampling frequency is much larger than the frequency of the vibration signal being sampled, it is assumed that the effective signal $s(t)$ remains unchanged and the number of oversampling at a single point is $(m+1)$. Therefore, the oversampled output signal is:

$$V(t) = v(t) + v(t - \Delta t) + \cdots + v(t - m\Delta t) = \sum_{i=0}^m v(t - i\Delta t) = (m+1)s(t) + \sqrt{m+1}n(t) \quad (7)$$

After averaging the output signal, the following results are obtained:

$$\overline{V(t)} = \frac{V(t)}{m+1} = s(t) + \frac{\overline{n(t)}}{\sqrt{m+1}} \quad (8)$$

It can be seen that because of the irrelevance of random noise, the random noise is reduced to $\frac{\overline{n(t)}}{\sqrt{m+1}}$ in the average signal $\overline{V(t)}$ superimposed by the geophone sensitive unit, thus improving the signal-to-noise ratio.

3. Effectiveness Testing of the Method

As an important measure of effective signal recognition rate, signal-to-noise ratio (SNR) is directly related to the quality of seismic data, and is often used to evaluate the quality of noise reduction methods. In this paper, the power signal-to-noise ratio (PSNR) is used to test the noise reduction effect of microseismic signals.

If d_{ij} is used as signal, s_{ij} is used as effective signal and n_{ij} is used as noise signal, then:

$$d_{ij} = s_{ij} + n_{ij}$$

$$SNR = \frac{E_s}{E_N} = \frac{\sum s_{ij}^2}{\sum n_{ij}^2} = \frac{\sum s_{ij}^2}{\sum (d_{ij} - s_{ij})^2}$$

Among them, $i=1, 2, 3, \dots$ is the sampling point, $j=1, 2, 3, \dots$ is the geophone unit channel, and the noise is random noise.

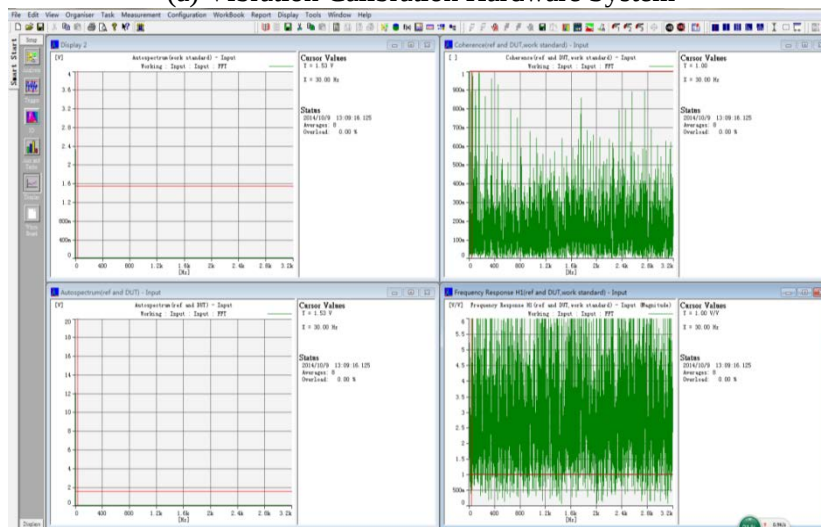
In this paper, the signal-to-noise ratio (SNR) of microseismic signal is estimated by using frequency domain estimation method. Firstly, the recorded data are Fourier transformed. The corresponding frequency components of microseismic signal and noise are different. In frequency domain, a range near the main frequency of signal can be approximated as the signal part, while the two sides can be regarded as the noise part. Specifically, a threshold (such as 40%) can be multiplied by the maximum amplitude in the spectrum, and the result can be used as the interval definition value of the effective signal part.

$$SNR = \frac{\sum_{\omega} |F_s(\omega)|^2}{\sum_{\omega} |F(\omega)|^2 - \sum_{\omega} |F_s(\omega)|^2}$$

The test experiment is based on the sensor vibration calibration system of Danish B&K Company (which has been verified by the Chinese Academy of Metrology). Given the vibration excitation with fixed effective amplitude and adjustable frequency (30Hz-1130Hz), by analyzing the correlation between the two geophone unit channels, the corresponding maximum amplitude mean square root is found in the frequency domain under the given frequency excitation, and according to the maximum value. By setting threshold and extracting effective signal, the signal-to-noise ratios of geophone stacking schemes at different frequencies are tested respectively.



(a) Vibration Calibration Hardware System



(b) Vibration Calibration Software System

Figure 2. B&K Vibration Calibration System

According to the statistical analysis of the data, it is found that based on the detector array structure, the effective signal can be extracted through channel correlation, which can suppress random noise interference and reduce noise. Compared with the single sensor unit, the signal-to-noise ratio can be increased by at least 1.9 times, that is, the effective signal recognition rate can be increased by more than 90%.

Table 1 Analysis of superimposed signal-to-noise ratio of geophone

Category		Channel 1			Channel 2		
Amplitude threshold 30%, coherence coefficient > 0.6							
Excitation frequency	Signal type	Signal S ²	Noise N ²	SNR improvement	Signal S ²	Noise N ²	SNR improvement
30Hz	Before processing	3.51	1.63E-04	2.26	3.51	7.26E-03	2.54
	After Processing	3.51	7.22E-05		3.51	2.86E-03	
60Hz	Before processing	5.73	1.79E-04	1.92	5.77	7.19E-03	2.63
	After Processing	5.73	9.34E-05		5.77	2.73E-03	
90Hz	Before processing	4.82	1.76E-04	1.96	4.88	7.31E-03	2.83
	After Processing	4.82	8.97E-05		4.88	2.58E-03	
120Hz	Before processing	4.14	1.16E-04	3.97	4.24	6.90E-03	3.15
	After Processing	4.14	2.92E-05		4.24	2.19E-03	
160Hz	Before processing	3.53	1.54E-04	2.12	3.62	7.30E-03	2.87
	After Processing	3.53	7.27E-05		3.62	2.54E-03	
210Hz	Before processing	3.02	1.71E-04	2.09	3.10	6.84E-03	2.82
	After Processing	3.02	8.15E-05		3.10	2.43E-03	
260Hz	Before processing	2.71	1.66E-04	2.10	2.79	7.04E-03	2.95
	After Processing	2.71	7.90E-05		2.79	2.39E-03	
330Hz	Before processing	2.63	1.79E-04	2.11	2.72	6.98E-03	2.82
	After Processing	2.63	8.47E-05		2.72	2.48E-03	
430Hz	Before processing	2.62	1.45E-04	2.37	2.72	7.10E-03	3.00
	After Processing	2.62	6.10E-05		2.72	2.37E-03	
630Hz	Before processing	2.37	1.51E-04	2.08	2.48	6.91E-03	3.06
	After Processing	2.37	7.26E-05		2.48	2.26E-03	
830Hz	Before processing	2.32	1.60E-04	2.27	2.43	6.89E-03	3.05
	After Processing	2.32	7.02E-05		2.43	2.26E-03	
930Hz	Before processing	2.30	1.51E-04	2.47	2.42	6.97E-03	3.05
	After Processing	2.30	6.12E-05		2.42	2.29E-03	
1130Hz	Before processing	2.30	1.36E-04	2.43	2.43	6.71E-03	2.94
	After Processing	2.30	5.62E-05		2.43	2.28E-03	

4. Conclusion

By arranging the array of microseismic geophone and analyzing the correlation of channel signals in the same direction and extracting effective signals, random noise interference can be effectively suppressed. According to the experimental results, the signal-to-noise ratio of the sensor array is at

least 1.9 times higher than that of the single sensor unit, which achieves a better accuracy of microseismic signal extraction, realizes the suppression of random noise and improves the Signal-to-noise ratio of the microseismic signal from the ore body.

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