Micro seismic Signal Recognition and Spectral Analysis

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Abstract. It is of difficulty to identify and isolate micro seismic monitoring signals in micro-seismic research. However, spectral analysis of the signal characteristics is an important mean to analyze the differences of various signals. By using theoretical and empirical methods to find the differences between effective signal and noise signal, the monitoring signal can be identified. Through the introduction of Fast Fourier transform (FFT) and Short-time Fourier transform (STFT), the spectrums of micro-seismic signals, blasting signals and mechanical drilling signals with obvious features are calculated and analyzed. Thus the law of amplitude spectrum, frequency spectrum, time-frequency spectrum and phase spectrum between different signals are obtained. The micro-seismic signal's energy is small and its frequency is low (about 30Hz), whose dominant frequency appears only once in the time. The blasting signal's energy is huge and its releasing speed is fast, whose dominant frequency is with wide distribution (about 80~150Hz). The shock will occur several times, probably inspired by rock blasting wave and micro-seismic damage. For the mechanical drilling signal, its frequency is chaotic. The comparative analysis of spectral distribution of different signals is helpful to obtain the basic characteristics of the signals in essence, so as to provide a better approach to identify and separate micro-seismic monitoring signals and research the law of rock deformation and failure accurately.

Keywords: Micro seismic signal; Recognition; Time-frequency spectrum; Phase spectrum.

1. Introduction

By getting micro-seismic signals released during the process of rock deformation and failure, micro-seismic monitoring technology is using to feedback the rock damage process, which is widely used in disaster monitoring and prediction of mining [1-2], oil and gas exploitation [3], underground cavern [4-5]. In addition to the micro-seismic signals, the signals collected from micro-seismic monitoring system are mingled with the detonation wave, signals of artificial percussion or mechanical vibration [6]. The interference waves are difficult to separate from the signal system and will affect the judgment of stability of the rock. Many scholars both at home and abroad mostly studied and identified the micro-seismic monitoring signals by empirical methods [7-10]. Some scholars studied single rock mass elastic wave [11] or explosion wave [12-13], without comparative analysis of all sorts of signal waves uniformly. Nowadays, the signal study mainly comes from the spectrum characteristics analysis, such as amplitude spectrum, frequency spectrum, and the research methods including Fourier transform, wavelet transform, Hilbert Huang transform and distribution of Bonn-Jordan [14]. The signal time- frequency spectrum signature has not been researched sufficiently. The time, energy, phase research of the dominant frequency have great significance to fully understand the characteristics of micro-seismic signals. This paper will identificate the micro-seismic monitoring signals collected in a hydropower station underground plant in Western China and comparatively analyze the differences of various signal spectrum characteristics, which will provide a better judgment method of processing the micro-seismic signals rapidly and studying the rock mass stability accurately.

2. Signal components and identification

The environment underground space is more complex and there are many signals generated in the process of construction. which are generated by human activities, such as artificial tapping, drilling, blasting, and by rock failure or fault rupture, such as micro-seismic signals.

3. Components of micro seismic signal

The cause of seismic source can be divided into several categories [6]:

Staff activities, such as walk, talk, artificial tap on a rock, equipment installation or debugging.

Blasting in the process excavation of the underground powerhouse.

Rock failure. The elastic stress wave will produce when rocks or discontinuity are acted by external forces (such as pull, pressure and shear forces). The main work of seismic monitoring is to capture, process and analyze the signal.

Mechanical vibration. A large number of vibration produces in the process of shoveling, transporting, ventilating and drilling rock.

Electrical signals released by lighting equipments and power equipments, which should be eliminated because they are invalid signals. As is known to all, the frequency of the electrical signal is usually fixed, which about 50Hz is.

4. Signal identification

Microseismic signal identification methods can be divided into experience recognition and theoretical recognition. The signal types can be determined by the seismic time, fault distribution and source location in experience ways. The seismic source type can be determined by rock failure properties, focus mechanism and the signal spectrum characteristics in theoretical ways. And in engineering, the monitoring signals can be comprehensively identified by combing theory with experience.

There are many noises created during underground project construction. Waveforms collected by micro-seismic monitoring are often very complicated, and are generally difficult to identify the category directly, which need to be disposed under certain conditions to gain the information contained in the elastic wave. The type of stress wave with obvious waveform features can be distinguished directly. After preliminarily analyzing the data monitored from underground powerhouse of hydropower station, the followings amplitude spectrum can be got: the micro-seismic waveform (figure 1), blasting waveform (figure 2), drilling waveform (figure 3) and electrical signals, etc.

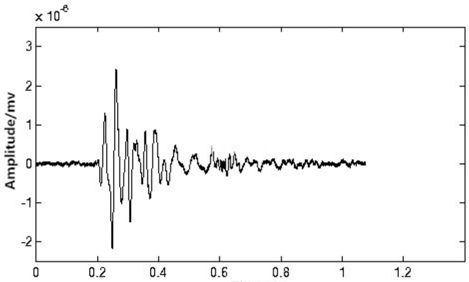


Fig.1 Microseismic Signal (MS-1)

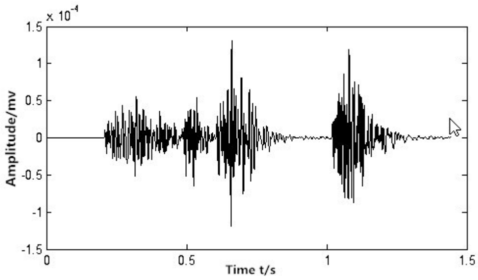


Fig.2 Blasting Signal (BS-1)

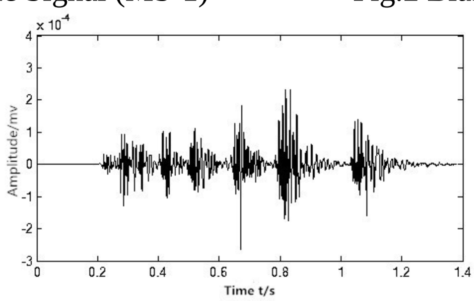


Fig.3 Mechanical drilling Signal (MD-1)

5. The time-frequency principle

Spectral analysis has become a standard method in microseismic studies.The microseismic signal can be identified from the spectral characteristics by using time-frequency technical, which provides a new method for forecasting the dynamic disaster, such as stability of surrounding rock of underground space.

The Fast Fourier Transform (FFT) is often used to analyze signal in frequency domain, whereas it cannot analyzed appearing time of different frequencies in time domain. In order to effectively solve the conflicts between time domain and frequency domain, Gabor(1946) proposed Short-Time Fourier Transform (STFT) method, namely 'local time domain method'. A finite time window function is multiplied before Fourier transform in order to achieve signal localization in the time domain. And assuming that the non-stationary signal is stable in analysis window within a short time interval. A set of local frequency spectrum can be obtained by moving the windows through the time axis. Through the analysis of the discrepancy of local spectrum in different time, the time-variant characteristic of signals can be obtained.

The based formula of STFT is:

$$STFT_z(t,f)=\int_{-\infty}^{+\infty} z(t')\eta^*(t'-t)e^{-2\pi f t i}dt \tag{1}$$

Where $\eta(t)$ is short-time window function. In particular. When $\eta(t)\equiv 1$, short-time Fourier transform becomes traditional Fourier transform .

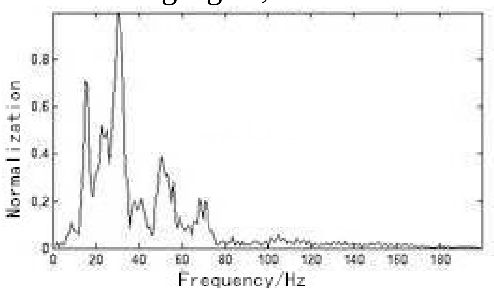
Therefore, we can use STFT to analyze the frequency in each time period and research the characteristics of microseismic signals in time-frequency domain.

6. The case analysis

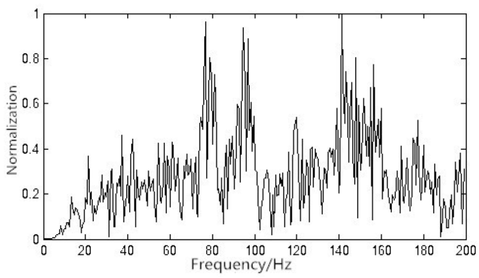
The signals collected by microseismic monitoring system can be analyzed to obtain the frequency spectrum, time-frequency spectrum and phase spectrum of microseismic signal (MS-1), blasting signal (BS-1) and mechanical drilling signal (MD-1).

7. Frequency analysis

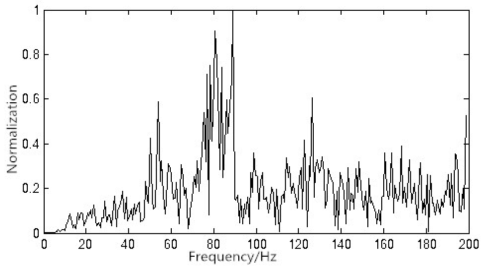
The frequency distribution of above signals can be obtained by using FFT, which are shown in Figure 4. The dominant frequencies of different signal vary greatly. For microseismic signals, it is about 30Hz. For blasting signal, it is about 80~150Hz; and it is about 90Hz for mechanical signal.



(a)MS-1 Frequency Diagram



(b)BS-1 Frequency Diagram

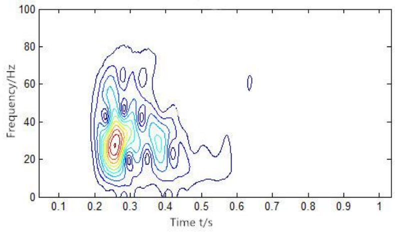


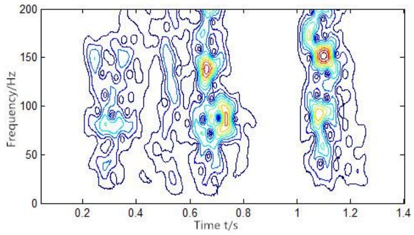
(c)MD-1 Frequency Diagram

Fig.4 The frequency spectrum of different signals

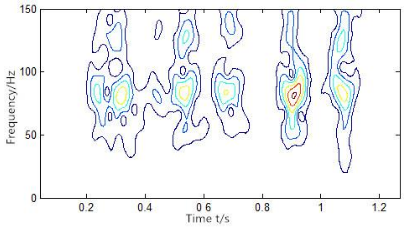
8. Time-frequency analysis

The original signals shown in Fig.1, Fig.2 and Fig.3 are analyzed by STFT to obtain a time-frequency distribution diagram respectively, shown in Figure 5. We can see the corresponding frequency of different signals in respective time point. For microseismic signal MS-1,the dominant frequency is about 30Hz, occurring at time of about 0.25s. For blasting signal BS-1,it has two dominant frequencies: namely 90Hz and 140Hz.And there are also time sequences:the frequency of 140Hz occurs about 0.65s and 90Hz occurs about 0.75s. It shows that the blast will cause many shocks in rocks and every frequency of the shock is independent because of they are missing within the range of 0.8s to 1.0s. For mechanical drilling signal MD-1, the dominant frequency is about 90Hz, whose interval time is about 0.3s.





(a) MS-1 Time-frequency Diagram (b)BS-1 Time-frequency Diagram

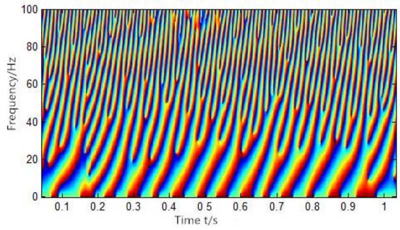


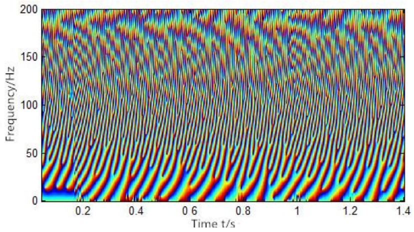
(c)MD-1 Time-frequency Diagram

Fig.5 Time-frequency Spectrum

9. Phase analysis

The instantaneous phase is shown in figure 6. The duration of microseismic signal are longer with slow damping of amplitude and clear phase diagram. The phase changes at 30Hz is more direct. However, the phase of blasting signal shown in figure 6(b) has a large span frequency from 60Hz to 140Hz.The signal with a shorter duration is mixed rapidly and transiently. And the changed phase shows that the blast signals includes microseismic signals.





(a)MS-1 Phase Diagram (b)BS-1 Phase Diagram

Fig.6 Phase Distribution

10. Conclusions

Through processing and analyzing the micro-seismic monitoring signals collected in underground powerhouse, basic laws and characteristics of seismic signals are summed up.

a) Signals collected by micro-seismic monitoring system compose of micro-seismic signal, blast signal, drilling signal and tapping signal, which need discrimination analysis from spectral signature.

b) The frequency of micro-seismic wave is less than that of blasting wave. The energy of blast signals is large and releases in high speed, while that of micro-seismic signals is small and releases in low speed.

c) The time-frequency distribution of seismic signals is regular and the dominant frequency appear only one time, while that of blast signals is relatively scattered and the dominant frequency appears many times. From time axis, we can find that different dominant frequencies of blast signals appear at different time. The frequency of the mechanical drilling is more cluttered.

d) STFT can be used in Matlab software to obtain the time-frequency of signals collected in microseismic monitoring system, which is very convenient to the signal wave analysis.

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