International Journal of Mining Science and Technology 26 (2016) 683–690

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Signal characteristics of coal and rock dynamics with micro-seismic monitoring technique

Ding Yanlu [a,b], Dou Linming [a,*], Cai Wu [a], Chen Jianjun [a], Kong Yong [a], Su Zhenguo [a], Li Zhenlei [a]

[a] State Key Laboratory of Coal Resources and Mine Safety, China University of Mining and Technology, Xuzhou 221116, China
[b] Department of Civil Engineering, University of Hong Kong, 999077, Hong Kong, China

ARTICLE INFO

Article history:
Received 9 October 2015
Received in revised form 13 February 2016
Accepted 16 April 2016
Available online 1 June 2016

Keywords:
Mine shock
Coal and gas outburst
Micro-seismic signal
Spectrum characteristics
Fractal characteristics

ABSTRACT

In this study, differences of signal characteristics between mine shocks and coal and gas outbursts in coal mines were examined with the micro-seismic monitoring technique and time–frequency analysis. The duration of the mine shock is short while the coal and gas outburst lasts longer. The outburst consists of three stages: the pre-shock, secondary shock and main shock stage, respectively. The velocity amplitude of the mine shock is between 10^{-5} and 10^{-3} m/s, which is higher than that of the outburst with the same energy level. In addition, in both cases, the correlation between the velocity amplitude and energy is positive while the correlation between the signal frequency band distribution and energy is negative. The signal frequency band of the high energy mine shock is distributed between 0 and 50 Hz, and the low energy mine shock is between 50 and 100 Hz. The fractal characteristics of mine shocks were studied based on a fractal theory. The box dimensions of high energy mine shocks are lower than the low energy ones, however, the box dimensions of outbursts are higher than that of mine shocks with the same energy level. The higher box dimensions indicate more dangerous dynamic events.

1. Introduction

Disastrous accidents frequently happen in coal mines along with the mining scale and depth increasing every year in China. Coal and rock dynamic disasters including rock bursts and coal and gas outbursts become more frequent and stronger impacts gradually. They also bring serious mine safety problems and cause significant economic losses to the country [1,2].

The mine shock refers to the shock phenomenon with loud noises and shock waveform of surrounding coal and rock mass of the roadway or working face in coal mines without being thrown out [2]. The rock burst is one subset of mine shocks, and it is a coal and rock dynamic disaster induced by mine shocks [1]. Essentially, the rock burst and coal and gas outburst are non-linear dynamic failure mechanics processes of rocks under non-equilibrium conditions [3]. The mine shock and coal and gas outburst are affected by mining activities, mechanics properties of the coal and rock, stress field and dynamic disturbance. The mine shock is a requirement for rock burst. The occurrence conditions of mine shocks have much relationship with the formation of rock bursts. The coal and gas outburst is one of the complex mine gas dynamic problems. Coal or rock masses and gases are thrown out with tremendous impact to destroy the excavation face and ventilation system. Furthermore, some serious casualties such as gas-asphyxiating accidents and gas explosions would occur during the process of the outburst [4]. There are a series of familiar characteristics between rock bursts and coal and gas outbursts [5]. They are caused by the partial failure of coal and rock masses in a high-stress area with a brittle fracture. Similar measures are taken to prevent rock bursts or coal and gas outbursts. For example, the mining liberated seam as the regional prevention and treatment measure, water injection technology and pressure release blasting can be used to transfer the stress concentration to deep earth [6].

Rock bursts and outbursts appeared in the extremely brief period with many disruptive factors and background noises, the diversity of failures led to predicting rock bursts and outbursts more difficult. Therefore, it is scientific to promote the accuracy and efficiency for rock bursts or outbursts through the study of the characteristics of mine shocks. In this paper, a Poland SOS micro-seismic monitoring system was applied to monitor and predict rock bursts and outbursts in coal mines. The waveform characteristics of rock bursts and outbursts were analyzed and compared with each other, then the similarities and differences of micro-seismicity rules between rock bursts and outbursts were revealed.

* Corresponding author. Tel.: +86 13952261972.
E-mail address: lmdou@126.com (L. Dou).

http://dx.doi.org/10.1016/j.ijmst.2016.05.022
2095-2686/

2. Characteristics of micro-seismic signals

The Poland SOS micro-seismic monitoring system is used in many coal mines currently. As shown in Fig. 1, the micro-seismic monitoring system is comprised of the signal acquisition station, recorder system and analyzer system in the primary station on the ground and detection probes underground. Detection probes receive the electric signal transformed by the speed signal of the coal and rock shock at first. Then the electric signal is transferred to the primary station on the ground via the communication cable. The signal data can be collected, enlarged and transferred through the signal acquisition station, and the signals are recorded and saved by the recorder system. Finally, the analyzer system analyzes and calculates the location and energy of the mine shock.

The occurrence time and duration of the rock burst and the outburst can be directly reflected by micro-seismic signals. However, these preliminary data cannot reveal the focal mechanisms. Therefore, further studies of micro-seismic signals are required. The signal analysis and processing aims at revealing the hidden information deeply and extracting the useful data. The micro-seismic signal analysis and processing can be always one of the main research directions currently [7].

Recognition of natural earthquake and blasting is the main study of micro-seismic signals at home and abroad while micro-seismic signals of rock bursts and outbursts in coal mines are rarely studied. Mine shocks and outbursts are induced by coal and rock fracture. Their micro-seismic signals are unstable signals together with blasting signal. But the focal mechanism, duration, signal frequency band distribution and amplitude of velocity are different among them [8]. Micro-seismic signals were identified by the power spectrum and magnitude-frequency characteristics based on time–frequency analysis of mine shocks and coal and gas outbursts [9,10]. Energy distribution of micro-seismic signals of blasting and rock failure was studied on the basis of wavelet packet transform, and the energy and frequency band of blasting and rock failure was different [11]. Precursory information of roof fall was valid identified by studying the mutation characteristics of roof activities built on multi-resolution wavelet analysis [12]. Lu studied the precursory information before the roof falls according to the fast Fourier transformation of shock waveform time–frequency analysis [13].

The purpose of the micro-seismic signal analysis is to distinguish different kinds of waveforms and their characteristics generated by different reasons correctly [14]. The shock waveforms of mine shock and coal and gas outburst were studied on the basis of FFT theory.

$$S_{WF}(\omega,\tau)=\int_{-\infty}^{+\infty}e^{-i\omega t}\omega(t-\tau)S(t)dt$$

$$B(f)=\int_0^T B_H(t)e^{-2\pi ft}dt$$

where $\omega(t-\tau)$ is called a window function in the analysis of signals.

2.1. Micro-seismic signal characteristics of mine shock

Different mine shocks lead to different fracture mechanisms of coal and rock, and the spectrum signatures of mine shock are reflected by distinct energies. The spectrum signatures of mine shock are similar. For example, the spectrum signature of higher energy mine shock usually shows lower spectrum, on the contrary, the lower energy mine shock presents higher spectrum according to the development trends of mine shock.

Only one shock signal was monitored while mine shock happened, and its energy usually was greater than 10^4 J, and some can reach 10^8 J. The duration time range lasted from several seconds to a dozen seconds. The typical micro-seismic waveform of mine shock is shown in Fig. 2.

Different energy levels of mine shock were monitored by a SOS micro-seismic monitoring system in Haizi coal mine and Huating coal mine. Further, different energies of shock events were filtered for analyzing the energy frequency spectrum.

(1) Waveform and spectrum characteristics of high energy mine shocks

As shown in Fig. 3, the energy of mine shocks is 10^5–10^7 J, the velocity amplitudes are 5×10^{-4}–1×10^{-3} m/s, and the durations are 2000–3000 ms. These micro-seismic signals have low frequency signal band range from 0 to 50 Hz. The basic frequencies of these events are approximately 20–45 Hz.

(2) Waveform and spectrum characteristics of low energy mine shock

The low energy mine shock events (10^2–10^4 J) show that the velocity spectrum was between 5×10^{-5} and 1×10^{-4} m/s and they last from 500 to 1500 ms in Fig. 4. According to the spectrum diagrams, the signal bands are between 50 and 100 Hz, the basic frequencies are between 30 and 100 Hz.

Based on the comparison of the two different energy levels, high energy mine shock events generally have the characteristics of longer durations, higher decay rates and lower basic frequencies. On the contrary, lower energy mine shock events have fewer durations, lower decay rates and higher basic frequencies.

2.2. Micro-seismic signal characteristics of coal and gas outbursts

The phenomenon of coal and gas outbursts is generated along with the changes of environment (destabilization in rupture process of rock, such as generation and development of micro-fracture) in the mine disasters [15]. Micro-seismic activities of the development process in coal and rock will appear before coal

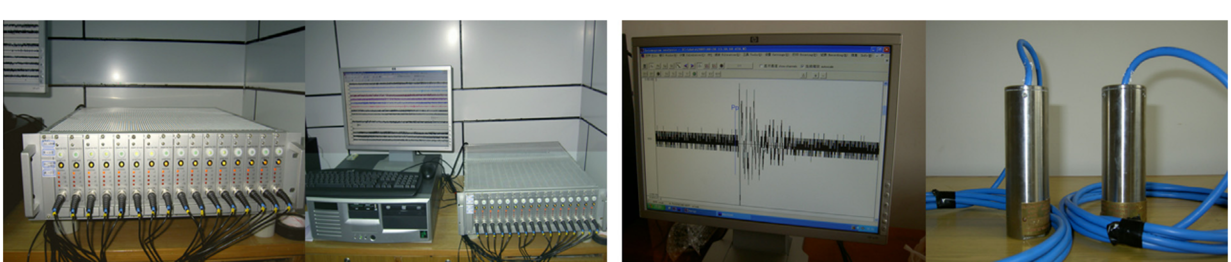

Fig. 1. SOS micro-seismic monitoring system.