Identification of Effective Events Recorded by Optical Fiber Microseismic Monitoring System

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Abstract. At present, the development of microseismic monitoring system based on electronic sensors is restricted by the problems of power supply, electromagnetic interference and etc. How to select effective microseismic events from the massive and uninterrupted raw data is also a huge problem. In this paper, the DFB laser is used to demodulate the external vibration signal detected by the FBG sensor. The first arrival time of the P wave and the end point of the signal are picked up by using the improved STA/LTA algorithm. The method of calculating the optimal time window width is established by using the characteristics of periodic vibration wave. The criterion of the effective signal is established by using the maximum energy ratio of the effective signal. The resolution of this demodulation method is 0.01 pm. The criterion of effective signal discrimination can be used to accurately determine whether a channel event belongs to an effective signal or a noise signal. The microseismic monitoring system based on optical fiber sensor meets the needs of monitoring in a harsh mine environment, and the effective event discrimination criterion based on signal deviation is feasible.

1. Introduction
Using a sensor to measure vibration wave is one of the most effective means to detect the internal structure of rock mass [1]. The microseismic sensor can be divided into velocity type and acceleration type. The basic structure of most acceleration-type microseismic sensors is composed of springs, mass blocks, and sensor elements. The basic principle is that the seismic wave acts on the mass blocks to make them vibrate, and generates an acceleration, which drives the corresponding sensor elements to convert the acceleration into corresponding electrical and optical signals. Therefore, the acceleration value can be measured by measuring optical signals. Traditional microseismic accelerometers are not only susceptible to electromagnetic interference but also have some shortcomings such as poor response to low frequency and long response time [2]. At the same time, the traditional microseismic wave field detection system generally has some problems, such as low sensitivity, small dynamic range, electric leakage, power supply difficulties, which limit the development of oil and gas exploration and safety monitoring technology. Sensors and signal demodulation devices based on optical fiber sensing technology [3-7], because of their inherent advantages of no power supply and anti-electromagnetic interference in harsh conditions such as mines, have broad prospects for research, development, and application [8].

The automatic picking of microseismic event, phase identification or P wave first arrival time judgment methods include energy ratio method, AIC algorithm, neural network algorithm and etc. [9-10]. The energy ratio method has high accuracy in identifying the P wave phase of local earthquakes [11]. The energy ratio method is the fastest and most widely used algorithm [12-13]. This method...
mainly uses the characteristic functions of short-term average (STA) and long-term average (LTA), such as absolute amplitude, the sum of squares or envelope surface, and then calculates the ratio of the characteristic functions of STA and LTA. When the ratio is greater than the pre-set threshold, the channel signal is considered as an effective signal or the point is considered as the starting point of the effective signal. So as to avoid the omission of small energy microseismic events caused by setting a fixed threshold, Wu et al. [14] proposed a discriminant frequency estimation pattern recognition method based on STA/LTA, which improved the discriminant accuracy. He et al. [15] proposed a quadratic autoregressive model to deal with the energy change rate curve near the first arrival, so as to realize the accurate picking of the first arrival time of P and S waves. Compared with STA/LTA and AIC, the new algorithm has higher accuracy and reliability in picking up the first arrival time of S wave.

The principle of a microseismic monitoring system based on optical fiber sensing is described in this paper. Based on the sample data collected by the system and using the improved STA/LTA algorithm, the criteria for distinguishing the effective signals of microseisms are established, and the screening of the effective events of microseisms is realized.

2. Principle of Optical Fiber Microseismic Monitoring System

Fiber Bragg Grating (FBG) is used as the sensor in the FBG vibration sensing system. The basic design idea of matching FBG vibration sensor is to transform the external vibration into the strain of FBG. This strain will cause the change of the central reflection wavelength of FBG. The wavelength change can be transformed into the change of voltage through the wavelength demodulation system, and the vibration signal detection can be realized. The vibration analog signal monitored by the sensor is converted to an analog voltage signal by photoelectric conversion. Then the analog voltage signal is converted into a discrete digital signal by digital acquisition card, and stored in the host computer of signal acquisition.

The basic design idea of FBG microseismic accelerometer is to detect the strain of FBG caused by ground vibration, and then obtain the corresponding voltage change value by photoelectric conversion. The premise is that the temperature is stable, and when the temperature changes sharply, temperature compensation is needed to eliminate the interference caused by temperature, and finally realize the detection of the vibration signal [16].

The principle diagram of demodulating FBG by DFB laser is shown in figure 1. The power of the laser is controlled and the temperature feedback is controlled by a microcontroller, so that the wavelength of the laser is in the center of the slope of the FBG reflection peak and has stable power. Owing to the spectral bandwidth of DFB laser is very narrow, it can be regarded as an ideal monochromatic light relative to the reflection spectrum of FBG. The wavelength of the FBG microseismic sensor is placed at -3dB of the reflection spectrum. When the sensor is vibrated by the outside, the FBG is stretched or compressed, which makes the refractive index change. The wavelength of the FBG will move left or right, and the frequency of the change is the same as that of the external vibration. Correspondingly, although the wavelength of the DFB laser is stable, the position of the sideband changes, along with the FBG moving up and down and therefore the vibration acceleration signal can be obtained by detecting the intensity change of the DFB laser reflected by the FBG by the photoelectric detector. Whereas the amplitude of vibration cannot make the wavelength of DFB laser beyond the range of sideband, otherwise frequency doubling or distortion will occur. At the same time, the grating spectrum shifts due to the influence of temperature. At this time, the wavelength can be adjusted to the appropriate position of the grating by adjusting the temperature of the DFB laser. By demodulating with this method, the resolution can be less than 0.01 pm, which can greatly improve the sensitivity and response frequency of vibration sensor based on FBG [16].

$$I = \alpha \times (I_0 R + \beta I_0 \Delta \lambda) mA$$  \hspace{1cm} (1)

$I$ is the current signal output by the system, $\alpha$ is the attenuation coefficient of optical cable, $A$ is the response of photoelectric detector, $I_0$ is the output optical power of DFB laser, $R$ is the reflectivity of
DFB laser at -3dB of grating, $m$ is the system noise caused by the coupling of annulus, FBG sensor, and fiber. When the reflectivity of FBG changes to $\Delta s$, the intensity changes to $I_0\Delta s$.

![Diagram](image)

**Figure 1.** Interrogation principle of the system.

### 3. Identification of Effective Microseismic Events

#### 3.1. Calculation of Energy Eigenvalue and Sliding Window Width

The ratio of short-term average value to long-term average value (STA/LTA) algorithm is often utilized for automatic identification of effective signals of seismic events and P wave first arrival time picking [17], however, there is no unified understanding on automatic picking of endpoints and window width of sliding time.

When the signal amplitude exceeds a certain threshold, the system begins to record the microseismic signal. Several points before and after the trigger point are recorded. The sample points before the trigger point contain the first arrival point of the seismic wave with special significance, that is, the first arrival time of the P wave. The signal before the first arrival time of the P wave is the background noise signal, and the signal after the first arrival time of the P wave is the effective signal. There is a great difference in the energy ratio of the windowed P wave. The energy of the signal before and after the endpoint is also very different. It is an effective signal before the endpoint and a noise signal after the endpoint. The STA/LTA algorithm can be used to accurately pick up the duration of the microseismic signal. The improved STA/LTA algorithm of vibration wave with the stability factor is:

\[
A_1 = \frac{\left[ \sum_{i=T_1}^{T_3} x^2(t) \right]^\frac{1}{2} + 3 \left[ \sum_{i=T_0}^{T_2} x^2(t) \right]^\frac{1}{2}}{n}
\]

\[
A_1 = \frac{\left[ \sum_{i=T_1}^{T_3} x^2(t) \right]^\frac{1}{2} + 3 \left[ \sum_{i=T_0}^{T_2} x^2(t) \right]^\frac{1}{2}}{n}
\]

$A_1$ is the energy eigenvalue, $T_1$ is the starting point of the time window, $T_0$ is the midpoint of the time window, $T_3$ is the end point of the time window, $x(t)$ is the sampling point recorded by the system, $T$ is the total time length of a channel, $n$ is the total number of sample points.

When the time window length of a periodic wave is equal to 2 times period, the energy ratio before and after the time window reflects the case of two adjacent periods. The interval between two adjacent peaks (troughs) where the maximum amplitude point is located is taken as the time window length of microseismic monitoring signal. The maximum amplitude point corresponds to the main frequency $f_0$ of the signal and the sampling frequency $f_s$, then the time window width $TWL$ can be expressed as:
The corrected energy ratio method of sliding time window can accurately pick up the first arrival time and the end time of the microseismic P wave. Based on the correction energy ratio algorithm, the TWL determined by equation (3) must be used as the sliding window width of A1.

$$TWL = \frac{2 \times f_c}{f_0}$$  (3)

3.2. Effective Event Discrimination Criterion

When the signal amplitude is a fixed value and is not zero, the energy ratio $A_1$ is 1. Therefore, when the maximum value of a channel signal $A_1$ (MAXA1) deviates from 1 in the positive direction, the stronger the minimum value of $A_1$ (MINA1) deviates from 1 in the negative direction, the greater the signal-to-noise ratio of the signal and the signal transforms from noise signal to effective signal. Therefore, the following effective signal discrimination criteria are established by combining MAXA1 and MINA1:

$$\sigma_1 = \sqrt{\frac{1}{2}[(MAXA_1 - 1)^2 + (MINA_1 - 1)^2]}$$  (4)

$\sigma_1$ is the signal deviation. The larger the $\sigma_1$ value, the stronger the signal, the smaller the $\sigma_1$ value, the stronger the noise. The signal is a straight line without fluctuation when $\sigma_1$ equals 0.

4. Verification of Field Monitoring Data

So as to judge whether an event is effective or ineffective, it is necessary to study the $A_1$ value characteristics of the monitored microseismic events. Five microseismic events were recorded by 8 channels of optical fiber microseismic monitoring system. The time-domain signals of five events are shown in figures 2-6.

From the time-domain signals of five events, it can be seen that channel 3 of each event is 50Hz power frequency interference signal. In order to calculate the value of $A_1$, TWL needs to be determined first. The known sampling frequency $f_s$ is 2000 Hz. The main frequency $f_0$ of the signal needs to be analyzed. From the above time-domain signal, we can see that event 2 has the strongest energy and its frequency spectrum is shown in figure 7.

The signal frequency band of event 2 is mainly in 5-200 Hz, and the main frequency of the signal is about 100 Hz. The frequency bands of event 1 and event 4 are similar. Therefore, the main frequency of the signal is 100 Hz. The value of TWL is 40.

MAXA1 and MINA1 calculated according to TWL are shown in table 1. MAXA1 and MINA1 fluctuate up and down close to 1. In event 1, the signal-to-noise ratio of seven channels except channel 3 is low. The minimum value of MAXA1 is 1.685 of channel 8, which is basically the noise signal. In event 5, except channel 4 and channel 5, the rest are basically noise signals. By setting a threshold, MAXA1 or MINA1 can basically determine whether a channel event belongs to an effective signal or a noise signal.

In the monitored five events, channel 3 recorded signals are all power frequency interference and the value of $\sigma_1$ was less than 0.25. The threshold value of effective signal discrimination $\sigma_1$ was 1 based on event 1 and event 5. That is, when $\sigma_1$ of a channel of an event is greater than 1, the signal belongs to the effective signal and enters the subsequent data processing flow, while the channel signal of $\sigma_1 < 1$ belongs to the ineffective signal and will be discarded. The event is judged to be an effective event if $\sigma_1 \geq 1$.

By utilizing signal deviation, an effective signal discrimination criterion is established, and event screening is implemented. Effective events are saved for subsequent signal analysis and processing.
Figure 2. Time-domain signal of event 1.

Figure 3. Time-domain signal of event 2.

Figure 4. Time-domain signal of event 3.

Figure 5. Time-domain signal of event 4.

Figure 6. Time-domain signal of event 5.

Figure 7. Frequency-domain signal of event 2.
Table 1. MAX\textsubscript{A1} and MIN\textsubscript{A1} of five microseismic events.

| Event number | Channel number | MAX\textsubscript{A1} | MIN\textsubscript{A1} | \(\sigma_1\) |
|--------------|----------------|------------------------|------------------------|-------------|
| 1            | 3.101192       | 0.397275               | 1.545685               |             |
| 2            | 2.964333       | 0.428377               | 1.446609               |             |
| 3            | 1.124447       | 0.888742               | 0.118037               |             |
| 4            | 2.717165       | 0.452586               | 1.274425               |             |
| 5            | 2.070513       | 0.611099               | 0.80537                |             |
| 6            | 2.707794       | 0.678573               | 1.228795               |             |
| 7            | 3.437327       | 0.375708               | 1.779087               |             |
| 8            | 1.685233       | 0.52333                | 0.90237                |             |
| 1            | 301.461473     | 0.604741               | 212.458529             |             |
| 2            | 392.607776     | 0.459287               | 276.908778             |             |
| 3            | 1.302515       | 0.828879               | 0.2457618              |             |
| 4            | 174.529391     | 0.792932               | 122.703896             |             |
| 5            | 511.80896      | 0.532014               | 361.196631             |             |
| 6            | 216.987064     | 0.761713               | 152.726011             |             |
| 7            | 380.0411       | 0.591454               | 268.022688             |             |
| 8            | 350.320337     | 0.754916               | 247.00684              |             |
| 1            | 3.199177       | 0.315073               | 1.628727               |             |
| 2            | 3.505616       | 0.257973               | 1.847798               |             |
| 3            | 1.154738       | 0.869595               | 0.14309                |             |
| 4            | 5.121377       | 0.267997               | 2.959863               |             |
| 5            | 4.930279       | 0.389469               | 2.812458               |             |
| 6            | 5.010001       | 0.206256               | 2.890514               |             |
| 7            | 2.981878       | 0.324459               | 1.480574               |             |
| 8            | 4.548415       | 0.439297               | 2.34024                |             |
| 1            | 2.562791       | 0.356037               | 1.1952                 |             |
| 2            | 3.383161       | 0.35133                | 1.746458               |             |
| 3            | 1.145736       | 0.874411               | 0.136036               |             |
| 4            | 5.678078       | 0.564476               | 3.322205               |             |
| 5            | 6.728622       | 0.419573               | 4.071487               |             |
| 6            | 5.275714       | 0.225799               | 3.072549               |             |
| 7            | 3.324262       | 0.497642               | 1.681451               |             |
| 8            | 2.95904       | 0.362857               | 1.456672               |             |
| 1            | 2.098895       | 0.364202               | 0.897722               |             |
| 2            | 3.017332       | 0.546212               | 1.462114               |             |
| 3            | 1.146553       | 0.871531               | 0.137808               |             |
| 4            | 5.239057       | 0.690401               | 3.00545                |             |
| 5            | 6.91715        | 0.536887               | 4.196852               |             |
| 6            | 2.239671       | 0.621776               | 0.916471               |             |
| 7            | 2.44352        | 0.40054                | 1.105238               |             |
| 8            | 1.947198       | 0.502573               | 0.756511               |             |

5. Conclusions
The optical fiber microseismic system based on DFB laser demodulating the change of reflected light intensity of FBG meets the needs of monitoring in the harsh mine environment. Vibration acceleration
signal can be obtained by detecting the intensity change of DFB laser reflected by FBG through the photoelectric detector. The optical fiber microseismic monitoring system solves the problems of electromagnetic interference, sensor power supply and long-distance transmission of signals in underground mine, and provides a new technical scheme for monitoring and early warning of mine dynamic disasters.

A method for calculating energy eigenvalue and the time window width is established based on STA/LTA algorithm with adding stability factor.

By calculating the energy eigenvalue of microseismic signal and the width of the sliding window, the discrimination criterion of the effective microseismic signal is established based on the signal deviation $\sigma_1$. The effective events can be screened out accurately when the threshold is set to 1.

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