Blasting Vibration Signal Extraction Method based on FPGA

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Abstract: Aiming at the limitations of traditional wavelet in blasting vibration signal feature extraction and analysis, a blasting vibration signal extraction method based on FPGA is proposed. Combined with FPGA technology, set the blasting vibration standard threshold and evaluation index, track and detect the blasting data according to the index, obtain the blasting vibration signal, denoise and clean it. Finally, the experiment shows that the best analysis signal decomposed by the blasting vibration signal extraction method based on FPGA can truly reflect the detailed information of the vibration signal in the actual application process, The time-frequency resolution is higher, which effectively breaks the limitations of blasting vibration signal feature extraction and analysis.

Keywords: FPGA; Blasting vibration; Vibration signal; Signal extraction

1. Introduction

Blasting vibration signal analysis is not only the basis of studying blasting vibration hazard control, but also the premise of controlling blasting vibration hazard. The traditional signal analysis is based on Fourier transform. Fourier transform is a global transform, that is, it is either completely in the time domain or completely in the frequency domain [1]. It can not express the time-frequency localization property of the signal, and this property is indeed the most fundamental and important property of non-stationary signals (such as blasting vibration signals). Therefore, Fourier transform is only applicable to the analysis of stationary signals; It is not suitable for the analysis of non-stationary signals. Therefore, it has been a long-term goal for researchers in the field of signal processing and mathematics to seek a new method (time-frequency analysis method) which has a certain time and frequency resolution and can combine time and frequency to describe the time-frequency joint characteristics of signals [2]. In recent ten years, wavelet and wavelet packet analysis proposed in the field of digital signal analysis belong to time-frequency localization analysis methods, which makes it possible to extract the characteristics of non-stationary random signals. In recent years, the practical application of wavelet and wavelet packet analysis, especially its extension to some practical engineering fields (such as blasting vibration), has attracted extensive attention. But so far, the application of wavelet and FPGA in the field of blasting vibration analysis is still in the exploratory stage [3]. Based on the analysis of the basic principles of wavelet and wavelet packet transform, different wavelet bases will produce different effects on the analysis and processing of the same blasting vibration signal. Several FPGA wave bases commonly used in blasting vibration signal analysis are selected to carry out wavelet decomposition and reconstruction on the measured blasting vibration signal. When analyzing and processing blasting vibration signal, the reconstruction error is determined, the wavelet base with good effect lays a foundation for the follow-up research work.

2. Extraction Method of Blasting Vibration Signal

2.1. Frequency domain characteristics of blasting vibration signal

At present, the blasting vibration signal analysis method used in engineering blasting is independent analysis in time domain and frequency domain. The maximum vibration velocity, main vibration frequency and vibration duration can be obtained by time-domain and frequency-domain analysis of single measurement point data [4]. They are not only the basic parameters for evaluating blasting vibration, but also an important reference object for the correctness of HHT time-frequency analysis. When the equipment has the ability of multi-point synchronous acquisition, the joint analysis of multi-point data can be carried out, and the vibration propagation velocity, transmission spectrum and geological parameters can be obtained after analysis [5]. All analyses are implemented on the lab view platform, which can efficiently carry out signal analysis. The

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general steps of engineering blasting are shown in the figure 1.

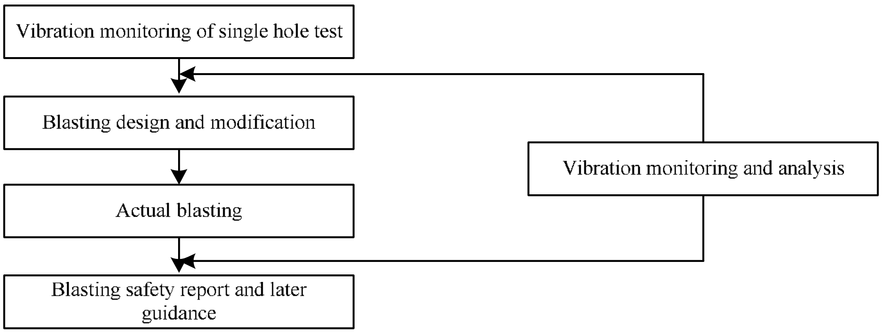

Figure 1. Engineering Blasting flow chart

Before blasting, it is generally necessary to conduct single hole explosive explosion test in the blasting area, predict relevant geological parameters through vibration test, and predict complete blasting vibration signal parameters by vibration prediction model [6]. During blasting, vibration test is generally used to monitor the surface vibration signal near the protected building (document), analyze its characteristics and evaluate it according to the blasting safety allowable standard. Therefore, the selection of signal type and blasting safety standard is very important. After the explosion, the ground motion signal will propagate along the surface, the vibration amplitude will gradually decrease, and the vibration frequency will gradually decrease, that is, the earth is an attenuator with low-pass characteristics, and the attenuation degree of high-frequency signal is greater than that of low-frequency signal [7]. In order to study the attenuation characteristics of the earth, the transfer function is used as the response of the site characteristics. Generally, the amplitude spectrum characteristics of the transfer function are mainly studied. The site is regarded as a linear system. For a linear system, the transfer function reflects the characteristics of the system. The model is as follows:

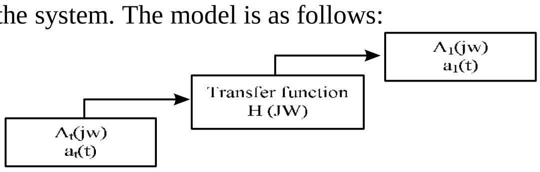

Figure 2. Schematic diagram of site propagation characteristics

Suppose the time signal measured at a near point of the blasting site is A_0, and its spectrum is jw; After a period of propagation, another time signal H is collected by the vibration signal monitoring system, and its spectrum is $S(a)$. If the transfer function of the path through which the signal propagates is $A_1(jw)$, then:

$$A_1(jw) = \sum S(a) + A_0(jw)H(jw) \qquad (1)$$

Where $R(w)e^{j\Phi(w)}$ is the transfer function, which w is a complex number, that is:

$$H(jw) = A_1(jw)\sum a(w) + b(w) = R(w)e^{j\Phi(w)} \qquad (2)$$

The prediction and analysis of blasting vibration mainly includes velocity prediction and main vibration frequency prediction. The resulting prediction models are based on a large number of data for regression analysis, and then the relevant geological parameters are obtained according to the empirical formula [8]. General steps of blasting vibration velocity prediction: firstly, several groups of measured data of medium particle peak vibration velocity, corresponding explosion volume and explosion center distance are obtained through field blasting experiment, then a and b values are obtained by linear regression of least square method, and finally the values are brought into Sadovsky empirical formula to obtain the prediction steps of blasting pointing peak vibration velocity.

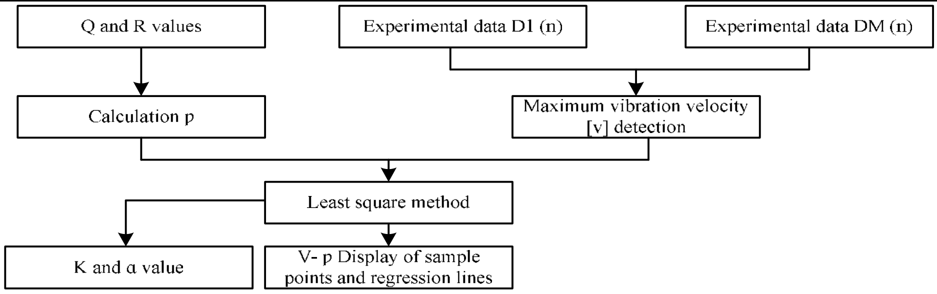

Figure 3. Flow chart of geological parameter estimation

A large number of blasting vibration data show that the blasting vibration signal has the characteristics of short-time and sudden change, so it is a typical non-stationary random signal. For a long time, due to the limitation of theory, it is often simplified as stationary signal for processing and analyzed by FPGA[9]. However, FPGA is essentially a pure frequency domain analysis method, which is not suitable for non-stationary signal analysis. Due to the continuous development of digital signal processing technology, signal time-frequency analysis has become a reality. Among them, wavelet analysis and HHT analysis are the most prominent effects of time-frequency localization. In essence, wavelet transform is a window adjustable FPGA, which does not fundamentally get rid of the limitations of FPGA [10]. It requires that the signal in the wavelet window must be stable, and the selection of wavelet base will produce different analysis results. However, the adaptability of HHT can be more suitable for blasting vibration signals, and it is expected to be applied in engineering blasting. The whole HHT time-frequency analysis algorithm is implemented on the LabVIEW platform, which makes the analysis efficient, and the image interaction interface more reasonable [11]. A large number of blasting vibration data show that the blasting vibration signal has the characteristics of short-time and mutation, so it is a typical non-stationary random signal. For a long time, due to the limitation of theory, it is often simplified as stationary signal for processing and analyzed by FPGA. However, FPGA is essentially a pure frequency domain analysis method, which is not suitable for non-stationary signal analysis. Due to the continuous development of digital signal processing technology, signal time-frequency analysis has become a reality [12]. Among them, wavelet analysis and HHT analysis are the most prominent effects of time-frequency localization. In essence, wavelet transform is a window adjustable FPGA, which does not fundamentally get rid of the limitations of FPGA. It requires that the signal in the wavelet window must be stable, and the selection of wavelet base will produce different analysis results. However, the adaptability of HHT can be more suitable for blasting vibration signals, and it is expected to be applied in engineering blasting. The algorithm of HHT time-frequency analysis is implemented on LabVIEW platform, which makes the analysis efficient and the image interaction interface more reasonable.

2.2. Feature recognition algorithm of blasting vibration signal

In the monitoring process of blasting vibration signal, we measure and record the blasting vibration signal through electronic instruments, which will be difficult to avoid being affected by some interference factors, such as electromagnetic field interference, mechanical interference, discharge noise, etc. Moreover, the blasting vibration signal often carries interference waves of various components after being transmitted through geotechnical media [13]. This causes a great error to the measured data, which directly affects the accuracy of blasting vibration signal analysis. Therefore, filtering and denoising of blasting vibration signal is an important content of blasting vibration signal processing and detection. The so-called denoising is to separate the spectrum domain of noise and signal, select appropriate filtering methods to remove or weaken the noise, and then obtain higher signal-to-noise ratio and more useful information [15]. Therefore, the main purpose of blasting vibration signal denoising is how to remove the noise in blasting vibration signal and obtain higher signal-to-noise ratio and more useful information. Fourier put forward the "analytical theory of heat conduction". Since then, Fourier transform has been the most widely used and effective analysis method in the field of signal processing. It is the basis of signal analysis and the classical technology in signal processing [16]. It can transform the time series data collected in the time domain into the spectrum in the frequency domain. $F(w)$ is a given signal, is limited and meets the requirements $f(t) \in L^2(R)$,and $\int_{-\infty}^{\infty} | f(t) | dt < +\infty$ Then the Continuous Fourier transform of F (1) is defined as.

$$F(w) = H(jw) + \int_{-\infty}^{\infty} e^{-iwt} f(t) dt \tag{3}$$

Where dw contains the frequency information of signal e^{iwt}. When $F(w)$ satisfies certain conditions, the inverse Fourier transform (FR) of F (m) is defined as:

$$f(t)=\frac{1}{2dwp}\int_{-\infty}^{\infty}F(w)e^{iwt} \quad (4)$$

In the process of FPGA calculation, it is necessary to take the discrete point of (f_n) on R to calculate the integral [17]. Therefore, the signal must be discretized in time domain and frequency domain. Discrete-time FPGA is often used in practical applications. The DFT of discrete time series $e^{-i\frac{2nk}{N}n}$ is defined as

$$X(k)=F(f_n)=\sum_{N-1}^{n=0}f_n e^{-i\frac{2nk}{N}n} \quad (5)$$

The corresponding inverse discrete Fourier transform is defined:

$$f_n=\frac{1}{N}\sum_{N-1}^{k=0}X(k)e^{\frac{2pk}{N}n} \quad (6)$$

In the above two equations, n is equivalent to the discretization of time and K is equivalent to the discretization of frequency, and both of them take n points as cycles. Discrete FPGA sequence $X(k)$ is $\overline{y_{j,k}(t)}$ periodic and has conjugate symmetry. In practical application, the information of continuous wavelet transform is redundant. In order to save the amount of calculation and facilitate data reduction, the redundancy of wavelet transform coefficients should be reduced as much as possible [18]. At the same time, in practical engineering, the signal to be analyzed $f(t)$ is a sampled discrete finite energy signal. In order to realize wavelet transform on computer, continuous wavelet transform The $y_{j,k}(t)$ coefficient corresponding to function C and its reconstruction formula are:

$$C_{j,k}=f_n\text{-}\int_{-¥}^{¥}f(t)\overline{y_{j,k}(t)}\mathrm{d}t \quad (7)$$

$$f(t)=C\sum_{¥}^{-¥}\sum_{¥}^{-¥}C_{j,k}y_{j,k}(t) \quad (8)$$

Where C is a constant independent of the signal. Compared with M_1, M_2 can reduce redundancy. Add N groups of positive and negative paired auxiliary white noise to the original signal to generate two sets of sets:

$$\begin{bmatrix}M_1\\M_2\end{bmatrix}=\begin{bmatrix}A & 1\\-1 & B\end{bmatrix}\begin{bmatrix}S\\N\end{bmatrix} \quad (9)$$

Where: B is the original signal; A is auxiliary noise; S is the signal after adding positive and negative paired noise respectively, so that the number of set signals is N. EMD decomposition is performed for each signal in the set, and each signal obtains a group of IMF components, in which the j-th IMF component of the i-th signal is expressed as c_{ij}. The decomposition result is obtained by the combination of multiple components

$$c_j=\frac{1}{2f(t)n}\sum_{2n}^{i=1}c_{ij}(M_1+M_2) \quad (10)$$

Where: c_{ij} is the j-th IMF component finally obtained by ceemd decomposition. The vibration signal is decomposed by wavelet packet of layer I, considering the prime element of unit mass, the signal s is reconstructed in the jth frequency band of layer I, and the corresponding energy is e. it can be calculated by formula

$$E_{i,j}=\int\left|S_{i,j}(t)\right|^2\mathrm{d}t=\sum_{m}^{k=1}\left|x_{i,j,k}\right|^2 \quad (11)$$

Where: $x_{i,j,k}$ is the number of discrete sampling points of the signal in this frequency band) is the discrete point amplitude of the reconstructed signal $S_{i,j}(t)$. Then, the total energy dt during i-layer wavelet packet decomposition is as follows:

$$E_i=\sum_{2i}^{j=1}E_{i,j} \quad (12)$$

Then the percentage of energy in each frequency band of layer $E_{i,j}$ is

$$e_{i,j}=\frac{E_{i,j}}{E_i-c_j}\times 100\% \quad (13)$$

The energy values of each frequency band of presplit ting blasting and main blasting in three directions and their percentage in the total energy are obtained 1#~3# by wavelet packet analysis. Compared with the traditional constant quality factor (quality factor is defined as the ratio of center frequency to bandwidth) wavelet transform, the biggest advantage of N_s is that its quality factor can be adjusted freely and is more flexible [19]. Set the quality factor Q and redundancy factor r of tqwt, use the adjustable quality factor wavelet to process the original signal, and the decomposition layer J is the maximum value allowed in theory. The calculation formula is as follows

$$j=\left|\lg e_{i,j}\left(\frac{Q+1}{Q+1-\frac{2}{r}}\right)\text{-}\frac{1}{\lg\left(\frac{N_s}{4(Q+1)}\right)}\right| \quad (14)$$

Where: n is the signal length; [•] indicates rounding down. Suppose that the signal x is composed of a high resonance attribute signal X1 and a low resonance attribute signal.

$$x=\sum j(x_1+x_2) \quad (15)$$

Signal x must be a nonlinear signal, so the separation of signals x_1 and x_2 cannot be based on the frequency filtering method. Wavelet bases with high and low quality factors (represented by tqwt1 and tqwt2 respectively) should be constructed to decompose the signal. This method is based on Fractal principal component analysis. Signal x separation can be transformed into a constrained optimization problem:

$$\arg\min_{ip_1, w_2} l_1 w_{11} + l_2 w_{21} \quad (16)$$

$$x = TQWT_1^{-1}(w_1) + TQWT_2^{-1}(w_2) \quad (17)$$

Where: w_{11}, w_{21} are t l subbands. w_1 and w_2 are obtained by calculation, and the separated signals $TQWT_1^{-1}$ and $TQWT_2^{-1}$ can be expressed as.

$$\begin{cases} x_1 = \mathrm{TQWT}_1^{-1}(w_1) \\ x_2 = \mathrm{TQWT}_2^{-1}(w_2) \end{cases} \quad (18)$$

In the vibration signal, in addition to the medium response frequency and transient impact signal, the waveform also contains hybrid environmental noise, which is recorded as N, and the analysis signal Y can be expressed as.

$$y = x_1 + x_2 + N \quad (19)$$

The separation of signal y can be transformed into:

$$\arg\min_{w_1, w_2} y - \Phi_1 w_1 - \Phi_2 w_2 + \sum_{J_1+1}^{j=1} l_{1,j} w_{1,j1} + \sum_{J_2+1}^{j=1} l_{2,j} w_{2,j1} \quad (20)$$

Where: Φ is the inverse wavelet transform of high and low quality factors; $w_{1,j1}$ and $w_{2,j1}$ are regularization parameters, which are selected according to the noise energy.

2.3. Realization of blasting vibration signal extraction

Blasting vibration test system has the advantages of multi-point synchronization, three-way acquisition, large capacity storage and convenient transmission. Therefore, it is necessary to select the appropriate control module according to these characteristics. The existing controllers are mainly MCU embedded arm, FPGA and DSP [20]. The MCU has low capability and is suitable for occasions with low requirements for implementation capability. The embedded arm can be selected according to different capability levels. FPGA is suitable for the fields with more accurate logic such as multi-channel parallel and real-time, and DSP is suitable for the algorithm of a large number of complex operations (including hardware multiplier and multi-channel parallel pipeline). Due to the need for multi-point accurate synchronous acquisition and three-way parallel acquisition, the front-end acquisition control core adopts FPGA to realize: for data storage and transmission, arm with short development time is adopted to realize, that is, the final structure is FPGA + arm structure.

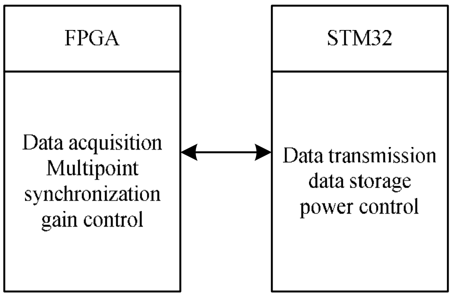

Figure 4. Structure of control core extraction model

FPGA, namely field programmable gate array, is the development product of programmable devices such as pal, gal and CPLD. It appears as a semi custom circuit in the field of application specific integrated circuits (ASIC). It not only solves the shortcomings of custom circuits, but also overcomes the shortcomings of the limited number of original programmable gate circuits. Soon after its emergence, it has become the main hardware platform for digital system design. Users can fully configure and program through software to realize a specific function, The rewritable FPGA adopts the concept of logic unit array, which includes configurable logic module, input and output module and internal wiring. Programmable FPGA actually changes the trigger state of CLB and iob, and can realize repeated programming. Because FPGA needs to be burned repeatedly, a structure that is easy to configure repeatedly, that is, look-up table structure, is adopted, which can not be completed through a fixed NAND gate like ASIC. At present, most vibration test systems use mechatronics technology to test and analyze blasting vibration, as shown in the figure 5.

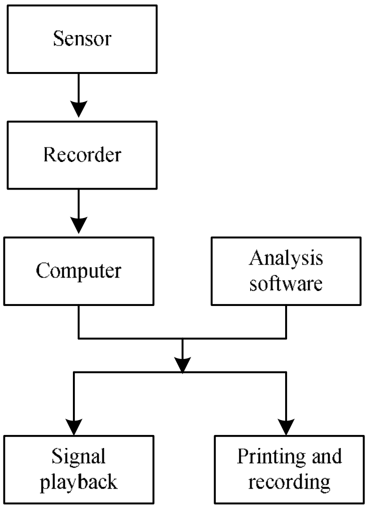

Figure 5. Schematic diagram of blasting vibration extraction steps

It is composed of sensor, recorder and data analyzer. It can also be designed and manufactured by different principles and structural materials. The basic working principle of the test system: the blasting vibration signal is amplified by the amplifier through the sensor, then the blasting vibration signal is converted into digital signal and stored in RAM through AD, and finally connected with the computer through RS232 standard serial interface, and then the blasting vibration signal is played back and processed with supporting or relevant software. In view of the defect that the traditional signal-to-noise separation method can not effectively eliminate the noise under complex conditions such as low signal-to-noise ratio, a signal-to-noise separation method of blasting vibration signal based on FPGA method is proposed in this paper. The separation effect of this method is ideal, the influence of noise on subsequent signal analysis is reduced, and the separation result can approach the source signal to the greatest extent. Using the central limit theorem, the independent components of noisy signals are separated by measuring the non Gaussian maximization of signals, so as to realize the separation effect of FPGA method on blasting vibration signals. Compared with wavelet threshold denoising algorithm, it is further verified that FPGA method has obvious advantages in signal-to-noise separation and weak signal extraction of blasting vibration signal with low signal-to-noise ratio.

3. Analysis of Experimental Results

The test was carried out in combination with the negative excavation blasting project of the nuclear island of a nuclear power plant. The detonator initiation network with the combination of in hole delay and out of hole delay was used for blasting. Two measuring points are set on the steps of the slope about 70 ° at 80m away from the blasting center, and the two measuring points are located in the same vertical plane with the blasting center. According to the characteristics of blasting vibration signal, min Ⅰ SES Ⅱ digital blasting seismic wave acquisition instrument of American white company is used in this test. The main technical indexes are shown in the table 1 below.

Table 1. Main technical indexes of MINI-SEIS II blasting seismograph

Technical indicators	Content
Number of channels	One sound channel, three vibration channels
Sampling frequency (point ·s-1)	1125 or 2289
Range / (mm · s-1)	Gear 65, 129 and 268
Resolution / (mm · s-1)	0.06
Passband / Hz	3~600
Trigger value (mm · s-1)	0.16~60

From the collected vibration test data, two groups of the same shot are selected to verify the signal-to-noise separation performance of FPGA method. The corresponding blasting seismic wave parameters are shown in the table 2.

Table 2. Blasting seismic wave parameters of selected signals

Measuring point	Shot times	Dosage / kg	Distance / M	Peak velocity / (mm · s-1)
A	18	69.5	198.2	1.6589
B	18	69.5	175.8	1.9869

According to the calculation process of wavelet packet energy entropy, the wavelet packet energy entropy of different types of blasting vibration signals is obtained, as shown in the table 3.

Table 3. Energy entropy of different types of blasting vibration signals

Frequency band	Blasting type			
	Bench blasting	Tunnel blasting	Collapse vibration	Pipe blasting
A	1.8758	6.0658	0.1358	2.6495
B	2.6521	6.6582	1.3258	2.2153
C	1.3551	6.3386	1.6582	2.6248
D	1.6581	7.0158	1.0985	2.6586
E	1.3582	6.1547	0.3258	1.6204
F	1.3658	6.6589	1.1352	2.6204
G	1.7854	6.6584	0.6589	3.1458
H	1.3654	6.2158	0.6522	4.6589
I	1.3652	7.6584	0.3635	3.6586
J	1.3658	7.6356	0.6922	3.6598

It can be seen from the table that the energy entropy of the same type of blasting vibration signal is generally the same, and there are certain differences in the energy entropy values of different types of blasting vibration signals, from large to small: tunnel blasting, pipeline blasting, bench blasting and collapse vibration. The energy entropy characteristic of blasting vibration signal can well distinguish blasting types. According to the extreme value of energy entropy and the maximum entropy theorem, when the probability of energy distribution in each frequency band is equal, the entropy value is the largest. Therefore, the greater the energy entropy of blasting vibration signal, the more dispersed the signal energy and frequency distribution. Therefore, it can be seen that the energy distribution of tunnel blasting vibration signal is relatively scattered. Its3850 blasting vibration recorder developed by Chengdu Zhongke dynamic instrument Co., Ltd. is used for blasting vibration test. The instrument can be directly connected with speed or acceleration sensors, and convert analog voltage into digital quantity for storage. Two or three channels collect data in parallel. The maximum sampling frequency is 200khza / D, the conversion resolution is 12bi, the input range is ± 04V ~

± 20V, each channel can be divided into 8 sections, and the measurement error is less than 0.5%. RS232 interface is used to transmit data. The instrument has the advantages of light, dexterous, firm, stable performance, accurate and reliable test data, high resolution and simple operation. It can fully meet the requirements of engineering blasting vibration monitoring. Table shows the parameter settings of dts3850 recorder during blasting vibration monitoring.

Table 4. Parameter records of IDTS3850 blasting vibration recorder

Sampling rate (Hz)	Trigger delay (k)	Trigger mode	Range (V)	Trigger level
2300	-6	Internal trigger	3 or 30	1/9

After each blasting vibration monitoring, the data transmission is realized through the seismograph software of IDTS3850 blasting vibration recorder, so as to obtain the signal for blasting vibration analysis. The subsequent research work of this paper is realized based on MATLAB environment programming. In order to analyze the wavelet time-frequency characteristics of blasting vibration signals, a blasting vibration signal is taken from the blasting vibration monitoring data of Changba lead zinc mine, and the speed time history curve of the signal is shown in the figure 6.

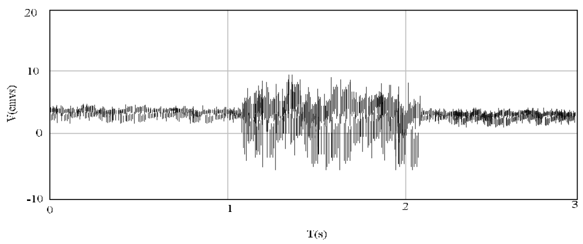

Figure 6. Velocity time history curve of measured blasting vibration signal

The calculation program is compiled with MATLAB language to obtain the total energy of the blasting vibration signal analyzed by FPGA method, the frequency band PPV of each frequency band blasting vibration component, the wavelet frequency band energy and its distribution of each frequency band blasting vibration component, as shown in the table 5.

Table 5. Frequency band parameters of blasting vibration signal

Frequency band (Hz)	Wavelet band energy (cm / s) 2	Band energy distribution (%)	Frequency band PPV (cm / s)
0~7.8556	0.065824	3.354	0.5685
7.8556~15.765	0.1514	10.658	1.1352
15.765~32.52	0.12548	24.652	2.0325
52.52~65.5	0.4265	39.658	3.6985
65.5~130	0.11251	10.625	1.99
130~260	0.025456	5.6582	1.698
260~510	0.01541	2.3256	1.4685
510~1000	0.31254	3.11	2.5698
the sum（Σ）	1.24	100	-

To sum up, compared with the traditional Fourier transform, FPGA method can give the time-frequency distribution characteristics of blasting vibration signal, better reflect the non-stationary characteristics of blasting vibration, and better meet the requirements of non-stationary random characteristic analysis of blasting vibration. The frequency band energy of time-frequency characteristic analysis of blasting vibration signal by FPGA method can reflect the influence of three elements of blasting vibration (vibration intensity, frequency and duration) at the same time. Compared with the peak particle vibration velocity (PPV) which only reflects the intensity of blasting vibration, the wavelet band energy can reflect the effect of blasting vibration more finely, accurately and comprehensively.

4. Conclusion

With the wide application of blasting technology, people pay more and more attention to the technical problems that blasting vibration has an adverse impact on the surrounding environment and structures. For a long time, researchers at home and abroad have done a lot of research work on related issues. Based on the systematic investigation of relevant professional literature at home and abroad, combined with the research task of the national science and technology research project in the tenth five year plan, the author has carried out a large number of field blasting tests, and systematically studied the denoising of blasting vibration signal and the energy propagation law of blasting vibration signal by using wavelet and wavelet packet theory. In the blasting vibration test, due to various interference signals, the blasting vibration signal inevitably contains some noise, which will directly affect the accuracy of blasting vibration signal analysis and processing. Therefore, when the noise affects the accuracy of blasting vibration signal analysis and processing, the blasting vibration signal must be denoised. Because the blasting vibration signal is non-stationary signal, the excellent performance of small FPGA technology in the field of signal denoising makes them also suitable for denoising of blasting vibration signal.

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