*2010 3rd International Conference on Computer and Electrical Engineering (ICCEE 2010)*
***IPCSIT vol. 53 (2012) © (2012) IACSIT Press, Singapore***
*DOI: 10.7763/IPCSIT.2012.V53.No.1.56*

# Application of Wavelet Transform to Process Electromagnetic Pulses from Explosion of Flexible Linear Shaped Charge

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**Abstract.** The application of wavelet transform in the analysis of electromagnetic pulses caused by explosion of flexible linear shaped charge (FLSC) is presented. The radiation of electromagnetic pulses was detected during explosion. However, a number of small signals are affected by the complex Electromagnetic environment so that analyzing this kind of electromagnetic radiation is hampered. Therefore, wavelet transform is used to process the measured signals. Result shows the true electromagnetic pulses of explosion can be extracted effectively by the method of wavelet transform. Through FFT analysis, it can be found that the major frequency of electromagnetic radiation caused by explosion of FLSC is below 2MHz.

**Keywords:** Shaped charge; explosion; electromagnetic radiation; electromagnetic pulse; wavelet

## 1. Introduction

The emission of electromagnetic pulses from chemical explosions was demonstrated in the 1950s[1~2]. Then, the phenomenon of electromagnetic pulses generating in explosions of chemical charges was investigated experimentally, and it was shown that an explosion near the earth can generate vertical electric pulses that varies on a millisecond time scale[3~6]. However, the knowledge about electromagnetic radiation during chemical explosion are data of experimental studies, empirical dependences, and models constructed on the basis of these data [7].

Flexible linear shaped charge (FLSC) is a chemical charge shaped to focus the effect of the explosive's energy and widely used as a pyrotechnic device in multistage separation of missile and rocket. It was found that FLSC can also generate electromagnetic pulses while exploding. To study the cause of electromagnetic radiation generating and the possible impact on electronic equipment, the radiation of electromagnetic pulses from explosion of FLSC was detected in test. However, the explosion experiment was carried out on open site and the measurement result was influenced by the complex electromagnetic environment. Therefore, the analysis and evaluation of the test data is often difficult.

The fourier transform is not useful because they lost any information on the time localization of the recorded signals in explosion test. In this paper, the wavelet transform method is proposed to process the measured signals. It is shown that the true electromagnetic pulses caused by explosion of FLSC can be extracted from the complex electromagnetic environment. Based on the above, the spectrums of electromagnetic radiation from explosion are calculated.

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## 2. Wavelet Tansform Theory

Although it is not possible to give all the background of wavelet theory here, for sake of clarity, the required basic concepts to understand the proposed derivation will be recalled.

Assume signal *f(t)* is a square integrable function, *φ(t)*is the mother wavelet function, if *φ(t)* satisfy the admissibility condition

$$C_\varphi = \int_0^\infty \frac{|\hat{\varphi}(\omega)|^2}{\omega} d\omega < \infty \tag{1}$$

The continuous wavelet transform (CWT) of *f(t)* is defined as

$$W_f(a,b) = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{a}} \varphi^*(\frac{t-b}{a}) dt \tag{2}$$

where *a* is the scaling index and *b* is the translation index.

The inverse wavelet transform is given by

$$f(t) = \frac{1}{C_\varphi} \int_0^\infty \int_{-\infty}^{\infty} W_f(a,b) \frac{1}{\sqrt{a}} \varphi(\frac{t-b}{a}) \frac{dadb}{a^2} \tag{3}$$

In the application, signal is usually obtained by sampling, and the discrete wavelet transform (DWT) is used to achieve calculation in discrete form. The DWT is performed by applying Mallat's algorithm. It gives rise to a two-band filtering tree in which *h(n)* is a low-pass filter and g(n) is a high-pass filter. The DWT coefficients of $a_i$ and $d_i$ are named approximation and detail coefficients respectively. At each level, only the approximation coefficients are low-pass and high-pass filtered leaving the detail coefficients unaltered. For the 3-level wavelet decomposition as shown in Fig. 1, the signal is decomposed by means of the sequences of the four coefficients associated to the terminal nodes of the tree. It can be reconstructed by means of the coefficients of the tree's terminal nodes as the following formal identity shows

$$f(t) = a_3 + d_3 + d_2 + d_1 \tag{4}$$

in which $a_3$ retains the lowest frequency part of the signal and $d_1$ is the highest frequency part.

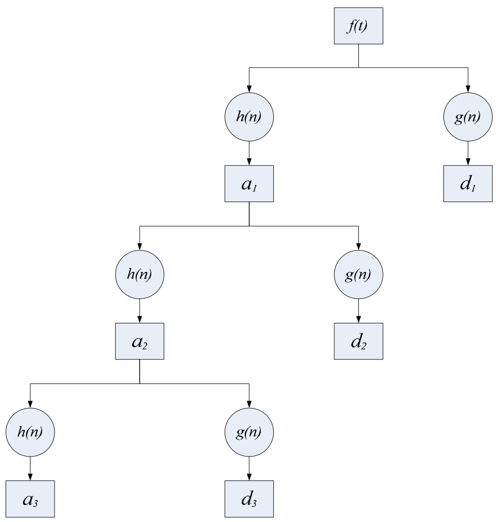


Figure 1. Filtering tree for 3-level wavelet decomposition.

As a means of signal analysis and signal processing, the wavelet transform affords the opportunity to represent the signal under analysis in both the time and frequency domain[8~9]. In this paper, the 7-order Daubechies wavelet function will be applied to calculate 5 level wavelet decomposition and reconstruction in MATLAB.

## 3. Noise and Interference Signals

In the FLSC explosion experiment, the electromagnetic radiation test was carried out simultaneously with other test projects. The electromagnetic pulses generated during explosion were recorded successfully by a dipole antenna connected to a high-speed sampling oscilloscope. However, the measured data contains complex background signals, which include corona, electrical noise, signals from test instruments, etc.

In time domain, the background signals usually appear as chaotic noises. However, they can show some regular characteristics in wavelet domain. Fig. 2 is the wavelet coefficients of background signals recorded when test instruments were stopped except for the oscilloscope. It can be seen that the background signals are almost site noises when other instruments were stopped.

From the time-frequency analysis, the wavelet coefficients of background signals recorded during explosion are obtained in Fig. 3. Besides the site noises, there is a high-frequency signal in $d_1$ component. This electromagnetic signal is generated prior to ignition and lasts in the period of explosion. Therefore, it can be concluded that this kind of high-frequency signal is generated from test instruments. For the true electromagnetic pulses of explosion, site noises and this high-frequency signal both need to be filtered.

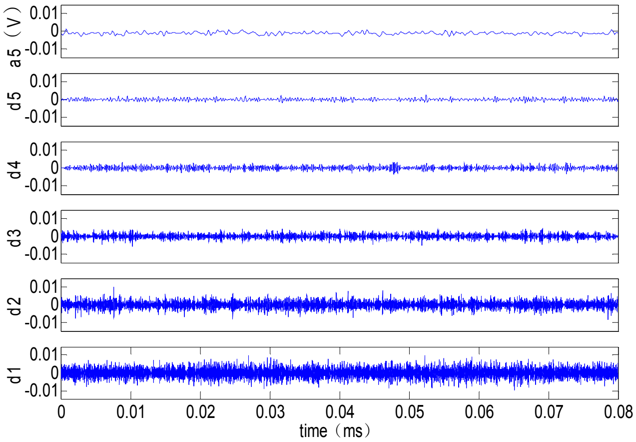


Figure 2. Wavelet coefficients of background signals recorded when test instruments were stopped except for the oscilloscope.

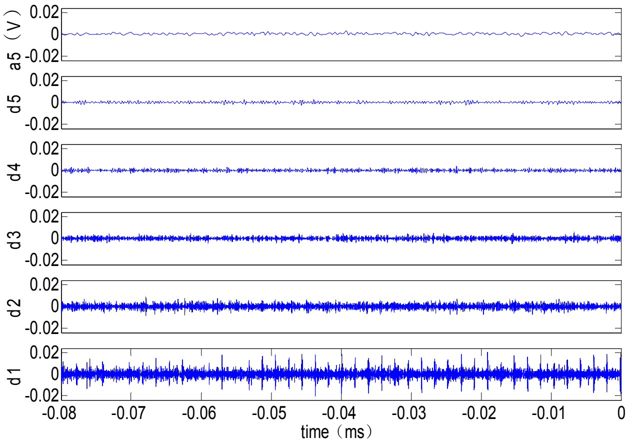


Figure 3. Wavelet coefficients of background signals recorded during explosion.

## 4. Measured Signal Processing

Measurement results show that the duration of explosion is only tens of milliseconds and a series of electromagnetic pulses are generated in this short time. The electromagnetic pulses are small in the beginning of the explosion, and then become larger as explosive movement grows up. After more than ten milliseconds, the electromagnetic pulses become smaller and fewer as explosive movement disappears gradually. However, a number of small pulses suffer severe interference from the complex electromagnetic environment.

Wavelet transform is appropriate for processing test data to extract the true electromagnetic pulses of explosion. The following are two typical examples.

## 4.1 Signal Processing Example 1

Fig. 4 shows the electromagnetic pulse generated at 9.98ms after ignition. The pulse peak is so small that its time-domain waveform is seriously affected by background signals. As a result, analysis of this electromagnetic radiation is hampered.

Wavelet coefficients of the measured signal is calculated by 5-level wavelet decomposition as shown in Fig. 5. It shows that the main energy of the true electromagnetic pulse from explosion is in the $a_5$ and $d_5$. As mentioned above, the interference signal from instruments is mainly in the $d_1$. The background noises concentrate in the higher frequency part more than in the lower.

Firstly, the component of $d_1$ must be completely filtered. And then other four high-frequency coefficients should be processed by the soft-threshold denoise method. Finally, the time-domain waveform can be reconstructed by summing up the lowest frequency coefficient and other four processed high-frequency coefficients. The restored signal as shown in Fig. 6 is one of the true electromagnetic pulses from explosion of FLSC.

Frequency spectrum of the true electromagnetic pulse extracted above is calculated by fast fourier transform (FFT) algorithm. Fig. 7 shows that its spectral components mainly concentrate in 0 ~ 2MHz.

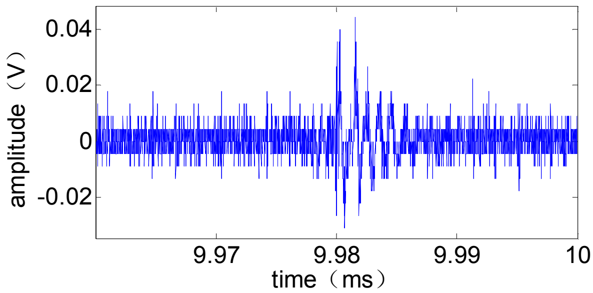


Figure 4. Time-domain waveform of the recorded signal at 9.98ms.

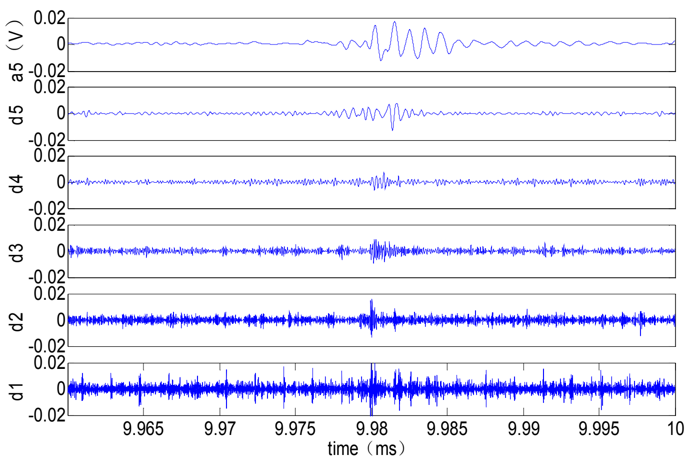


Figure 5. Wavelet coefficients of the recorded signal at 9.98ms.

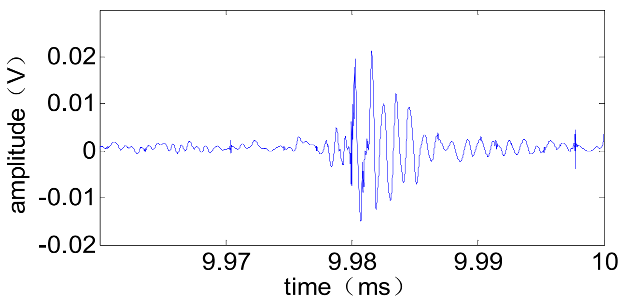


Figure 6. Time-domain waveform of the restored signal at 9.98ms.

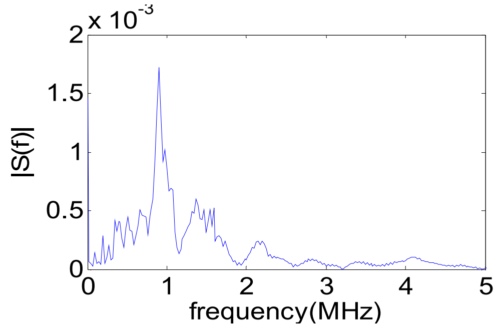

Figure 7. Frequency spectrum of the true electromagnetic pulse at 9.98ms.

## 4.2 Signal Processing Example 2

An electromagnetic pulse nearly submerged by the background signals was detected at 14.5ms after ignition as shown in Fig. 8. Its wavelet coefficients obtained from 5-level wavelet decomposition is shown in Fig. 9. It can be found that the main energy of electromagnetic radiation caused by explosion is in the approximation coefficient of $a_5$, while the interference signals mainly concentrate in the high frequency region.

The measured signal at 14.5ms can be processed using the same method mentioned in example l. The reconstructed time-domain waveform of the true electromagnetic pulse recorded at 14.5ms is in Fig. 10. Furthermore, frequency spectrum of the extracted electromagnetic pulse is obtained by FFT as shown in Fig. 11. As similar to the electromagnetic pulse at 9.98ms, the frequency spectrum of the true electromagnetic pulse at 14.5ms is also distributed below 2MHz.

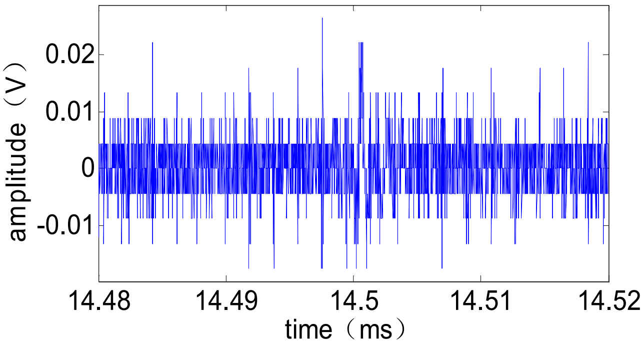

Figure 8. Time-domain waveform of the recorded signal at 14.5ms.

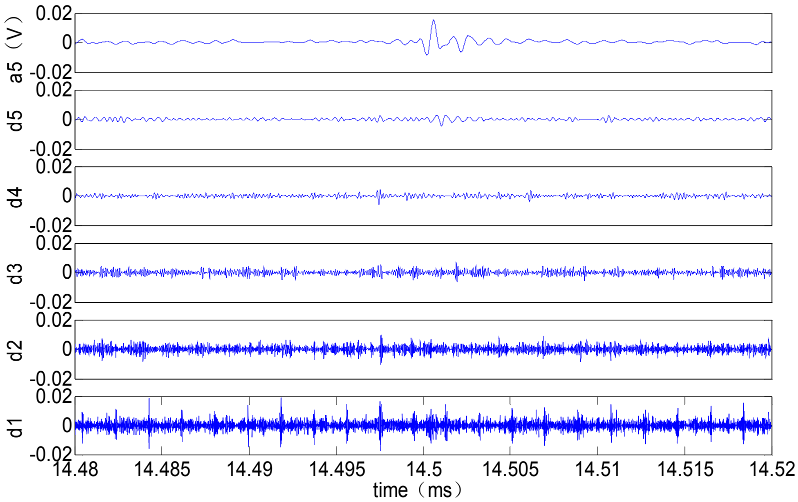

Figure 9. Wavelet coefficients of the recorded signal at 14.5ms.

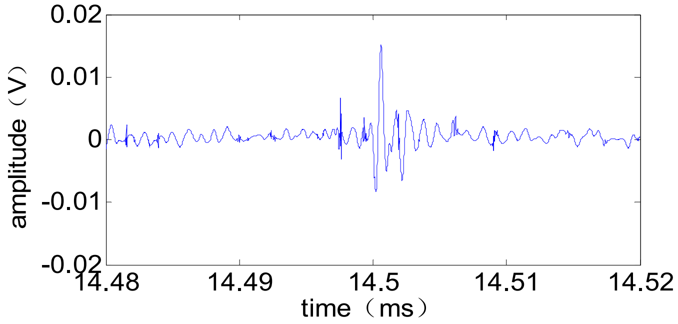

Figure 10. Time-domain waveform of the restored signal at 14.5ms.

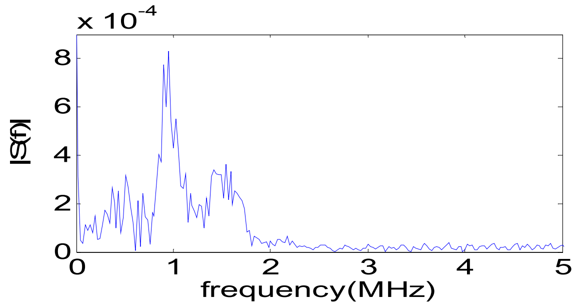

Figure 11. Frequency spectrum of the true electromagnetic pulse at 14.5ms.

## 5. Conclusion

A series of electromagnetic pulses were detected during explosion of FLSC. It is shown that the duration of electromagnetic radiation is tens of milliseconds and a number of small signals are affected by the background noises and interference signals caused by test instruments. Wavelet transform is applied to process the measured signals. The result shows that applying the method of wavelet transform to extract the true electromagnetic pulses of explosion is effective.

Through FFT calculation, it can be found that the frequency spectrums of the electromagnetic pulses at 9.98ms and 14.5ms are both distributed in 0 ~ 2MHz. Besides the two examples in this paper, most of the electromagnetic pulses during explosion actually have similar spectral characteristics. Therefore, it can be concluded that the major frequency of electromagnetic radiation caused by explosion of FLSC is below 2MHz.

## 6. Acknowledgment

This work was supported primarily by the National Basic Research Program of China (973 Program, No. 2010CB731800 ).

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