Vibration Noise Rejection Method Based on Empirical Mode

Baojun Wang, Heng Liu*, Meng Cai, Bingchuan Xu, Wei Liu
63870 Unit, Huayin 714200, China.

*Corresponding author: 1986lh1986@163.com

Abstract. In order to get rid of vibration noise signal in the shock wave test, according to the measured shock wave pressure signal and the interference signal, the signal is decomposed by EMD to calculate the correlation of the components. Then the signal, strong correlation with the interference signal, is selected to carry out noise reduction and synthesis processing, and the parameters such as pressure peak and action time are extracted. The verification shows that the proposed method can effectively eliminate the interference signal caused by vibration during the test.

1. Introduction
Shock wave overpressure peak and impulse is an important indicator to measure the damage effect of ammunition. Shock wave overpressure testing technology is an important part of the field of explosive dynamics and impact dynamics research, and is also the basic method to determine its killing power in the weapon warhead technology. Since the shock wave overpressure value cannot be accurately calculated by analytical methods and numerical simulation methods in the field, it is the most important and effective way to obtain the shock wave pressure parameter value by the actual measurement method. However, during the test, it was found that the interference signal was serious during the measurement, and the measured shock wave pressure data had large error and poor consistency, which caused the reliability of the measurement data to be reduced. At present, the spectrum analysis of the shock wave pressure signal is generally carried out, and its spectral characteristics are analyzed, and then filtered by a signal processing method such as wavelet transform. However, this processing method has such problems as follows: First, the shock wave pressure signal is different from the ordinary low frequency signal, generally a steep front signal, and has rich high frequency component. Second, the spectrum of the interference signal is from low frequency to high frequency, and intersects with the spectrum of the shock wave pressure signal.

In this paper, the difficulty of filtering the shock wave signal is studied. According to the measured shock wave pressure signal and the interference signal, the signal is decomposed by EMD to calculate the correlation of the components. Then the signal, strong correlation with the interference signal, is selected to carry out noise reduction and synthesis processing, and the parameters such as pressure peak and action time are extracted.

2. Analysis of Shock Wave Vibration Factors Affecting
Although the propagation law of ground-explosive waves in the near-Earth explosion has been systematically studied, due to its complexity, the influence of some interference factors in the test process is still unclear. Especially the coupling mechanism in the propagation process with the test device is very little studied, but it is very helpful to solve the problem that the shock wave pressure is
“inaccurate”. Combined with the explosion process, the main sources of error caused by the shock wave overpressure test include: the unevenness of each space direction during the explosion of the drug pack; Performance and measurement uncertainty caused by electromagnetic interference and thermal shock; uncertainty introduced by measurement of various instruments and equipment on site.

When the explosive explodes, the ground shock wave pressure test device is affected by vibration from both sources. On the one hand, when the incident shock wave acts on the ground, it will cause vibration of the ground to induce seismic waves. When the seismic wave propagates to the shock wave pressure testing device, it will inevitably cause vibration of the device. On the other hand, when the shock wave reaches the mounting plate of the test device, it is sure to excite the vibration of the mounting plate. In addition, the probability of the device being hit by the shrapnel and stones flying at the moment of explosion is greatly increased, so that a large amount of vibration noise is superimposed on the shock wave signal.

According to the regulations of the relevant national military standard, the resonant frequency of the pressure sensor should be greater than 75 kHz, the rise time is not more than 20 us, and the overshoot should be as small as possible. At present, there are two main types of pressure sensors that meet the above criteria: piezoresistive pressure sensors and piezoelectric pressure sensors. However, in the actual measurement of the explosion pressure field, the silicon sensitive unit of the piezoresistive pressure sensor is also sensitive to the light generated by the explosion, which is converted into an electrical signal output, which affects the test of pressure. Piezoelectric pressure sensors have the advantages of high natural frequency, stable performance, high signal-to-noise ratio, and are increasingly used in explosion pressure field overpressure testing. Piezoelectric pressure sensors are available in high-resistance charge output type and ICP type. The high-resistance charge type sensor is a sensor that directly outputs the charge generated by the piezoelectric material, but the ICP sensor outputs the voltage by integrated the charge-transfer circuit into the sensor. Under the same conditions, the ICP sensor has a larger response than the high-resistance charge output sensor, so it is more obvious in bad environment.

3. Empirical Mode Decomposition (EMD) Data Processing and Correction Method

On the basis of the aforementioned interference signal measurement, the signal is decomposed by EMD, and the correlation of the components is calculated separately, and the signal, strong correlation with the interference signal, is calculated to filter. The main steps are as follows:

3.1. Signal decomposition

According to the short duration and the frequency bandwidth of the shock wave signal, and it belongs to the transient non-stationary signal, it is especially important to choose the appropriate data processing method. The empirical mode decomposition (EMD) is a data processing method that can be applied to nonlinear and non-stationary signals. Therefore, it is proposed to use the EMD algorithm to process the shock wave signal. The advantage of this method is that the decomposition process is adaptive and there is no need to set the basis function.

The main idea of the EMD algorithm is to decompose the signal to be analyzed into a series of Eigen mode functions (IMF). The shock wave test signal to be analyzed is $S(t)$, the IMF component $S_i(t)$, and the residual component $R_n(t)$, which can be obtained by decomposition:

$$ S(t) = \sum_{i=1}^{n} S_i(t) + R_n(t) \tag{1} $$

Where the number of EMD decomposition isn.

The EMD algorithm mainly includes the following steps: first find all the extreme points on $S(t)$, use the cubic spine function to interpolate the found extreme points, and fit its upper envelope curve $S(t)_{\text{max}}$ and the lower envelope curve $S(t)_{\text{min}}$, connecting the upper and lower envelopes in order to obtain the mean curve $m(t)$. 


Consider $h_1(t)$ as the original signal and repeat the above process to obtain the data.

$$h_{1f}(t) = h_{1(f-1)}(t) - m_{1(f-1)}(t)$$

The standard deviation SD value between two consecutive calculation results is used as a criterion for judging whether $h_{1f}(t)$ belong to an IMF component.

$$SD = \sum_{t=0}^{l} \left| \frac{h_{1(f-1)}(t) - h_{1f}(t)}{h_{1(f-1)}(t)} \right|^2$$

The signal cutoff time is $l$. When SD is in the interval [0.2, 0.3], the linearity and stability of the IMF can be guaranteed, and the IMF can have corresponding physical meaning.

The above decomposition process is based entirely on the local characteristics of the test signal. After decomposing the response signals $S_i(t)$ $(i = 1 \sim n)$ of a certain test, each signal component $S_{1f}(t)$ and $R_{1f}(t)$ are obtained. It is necessary to classify the response signal components of the respective sensors to facilitate the elimination of the interference signals.

### 3.2 Additional signal conversion

Since the excitation signal of the reference pressure sensor is consistent with the shock wave pressure sensor during the calibration process, the interference signal of the standard sensor can be separated by the method.

### 4. Simulation

When testing the ground shock wave pressure signal, in addition to the sensor used to measure the shock wave pressure, the sensitive surface is flush with the plane on which the steel plate is mounted, and is installed in the through holes 3 and 4 as shown in the Fig.1, and the sensor is also installed to measure the vibration. Its manufacturer and model are exactly the same as the sensor for measuring the shock wave pressure signal, but installed in the blind holes 1 and 2 as shown in the Fig.1. The sensor sensitive surface and the wall in the blind hole have a certain distance. In this way, the sensor installed in the blind hole cannot feel the pressure signal of the shock wave, but can only feel the vibration signal of the mounting plate.

![Figure 1. Through-holes and blind holes](image)
Based on the above theory, the field explosion test was carried out. The measured waveform is shown in Fig. 2. The blue curve is the shock wave pressure signal curve measured by the sensor in the through hole, and the red and green curves are plate vibration signal curve measured by the sensors in the blind hole. The correlation analysis shows that the correlation coefficient of the vibration signals measured by the sensors in the two blind holes is as high as 0.9340, which is highly correlated. Except the shock wave pressure signal at the front end of the pressure sensor measurement curve in the through hole, the subsequent shock wave pressure curve is also substantially consistent with the vibration signal, and then it can be preliminarily judged that the signal measured by the sensor contains a large number of vibration signals. Because each sensor is in a different position on the mounting plate, there is a slight difference in the time the vibration arrives.

**Figure 2.** Sensor waveforms from the through-holes and blind holes

It is not difficult to find from Fig. 2 that the vibration signals measured by the same type of sensors are highly similar, and the vibration signal has a large interference to the shock wave pressure signal, which may seriously affect the reading of the shock wave pressure peak and the calculation of the specific impulse. Therefore, it is possible to remove the vibration interference signal in the shock wave pressure signal measured in the through hole by using the vibration signal measured by the sensor in the blind hole. First, the spectrum analysis of the shock wave signal and the vibration signal is performed as shown in Fig. 3. The shock wave signal and the vibration signal are mainly concentrated in the low frequency band. The trend term of the vibration signal can be extracted from the collected vibration signal and be removed from the shock wave pressure signal.

**Figure 3.** The low-frequency spectrum of the sensor signal through-hole and blind-hole

In order to verify the effectiveness of the method, it is proposed to use the vibration signal measured by the sensors in the two blind holes. The signal 1, as shown by the red curve in Fig.3, is to be considered as unknown vibration signal, and the signal 2, as shown by green curve in Fig.3, is to be considered as known vibration signal. If the method can greatly reduce the signal 1 by using the signal 2, it is considered that the method can effectively filter the vibration signal. If the signal 1 and the signal 2 are directly subtracted, the demising effect is not obvious. There are three main reasons. First, some of the
high-frequency interference in the vibration signal is a random signal. Direct subtraction may increase the high-frequency interference of the signal. Second, because the two blind holes are located at different positions of the mounting plate, there is a certain time difference between signal 1 and signal 2. Third, the response amplitude of different sensors to the same vibration is different.

Therefore, EMD is used to extract effective information of the vibration signal. The 13th IMF component after the EMD decomposition of the vibration signal 2 and its corresponding spectrum diagrams is shown in Fig.4. In order to distinguish the noise component from the signal component, the energy distribution of each component is obtained. Through calculation, it is considered that the first 10 components obtained by EMD decomposition can be filtered out as noise components.

Figure 4. EMF component and its corresponding spectrum

5. Conclusion
In this paper, based on the measured shock wave pressure signal and interference signal, the EMD is used for signal decomposition, and the correlation of the components is calculated separately. Then the signal, strong correlation with the interference signal, is selected to carry out noise reduction and synthesis processing, and the parameters such as pressure peak and action time are extracted. Verification shows that the proposed method can effectively eliminate the interference signals caused by vibration during testing.

References
[1] Zhang Yanfang, “Research on Shock Wave Signal Processing Method,” [D]. Shanxi: North University, 2011.
[2] Guo Wei, Yu Tongchang, Wang Jianlin, “Ground measurement technology of air shock wave pressure,” The 3rd National Explosive Mechanics Experimental Technology Exchange Conference [C]. Hefei: University of Science and Technology of China, 2004: 287-292.
[3] Zhou Li. Research on overpressure intelligent probe in explosion field [D]. Shanxi: North University, 2012.
[4] XIONG Zujian, BAI Chunhua, LIU Changlin, “Study on the field pressure field test method of FAE weapon explosion state,” [J]. Journal of Explosives, 2002, (1): 41-44
[5] He Zhiwen, “Research on Dynamic Characteristics of Shock Wave Overpressure Test,” [D]. Shanxi: North University, 2014.
[6] Zhang Liheng, Wang Shaolong, Yan Qin et al, “Research on Data Processing Method of Explosion Shock Wave Test,” [J]. Measurement & Control Technology, 2010, 30(3): 107-110.