Analysis of Responses of Satellite Honeycomb Panel to Pointwise Explosive Induced Environment

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Abstract. The purpose of this article is to research the pyroshock responses of a satellite honeycomb panel and to find a new method to characterize shock test specifications. The near-field and mid-field pyroshock responses induced by a pointwise explosive of the satellite honeycomb panel were measured using shock sensors. The responses were analyzed with haar continuous wavelet transform method, and a new method of characterizing shock test specifications with wavelet coefficients is proposed.

1. Introduction
Pointwise explosives directly assembled on satellite panels are one of the main threats to on-board electronic equipments. The pyroshock load is a typical transient load[1]. For transient load, the Fourier transform or power spectral density analysis method, is no longer applicable [2]. In the past decades, shock response spectrum is widely used to evaluate the potential hazards of pyroshock load[3]. However, when used to describe pyroshock load, shock response spectrum has the following defects [1,4,5]: (1) The duration of the shock load cannot be seen; (2) The SRS does not allow to describe completely the frequency content of a signal. Some frequencies can be hidden by others peaks; (3) The dynamic amplification factor $Q=10$ is usually selected when calculating the shock response spectrum, but the dynamic amplification factor of the actual product may be much greater or much less than 10. For pyroshock load with multiple frequency components, the relationship between the shock response spectrum and the dynamic amplification factor $Q$ is complex and nonlinear. This will lead to overtest or undertest phenomenon when the shock test specification is characterized by shock response spectrum. At present, how to reasonably analyze and evaluate the high magnitude pyroshock is still a problem to be studied [4].

2. Theoretical background

2.1. Continuous wavelet transform.
Continuous wavelet transform (CWT) is a time-frequency domain analysis method proposed by Morlet to analyze seismic wave data[6]. For any $f(t) \in L^1(R)$, define [7]:

$$W_f(a,b) = \sqrt{a} \int_{-\infty}^{\infty} f(t) \psi\left(\frac{t-b}{a}\right) dt$$

(1)

Where, $f(t)$ is the signal, $\psi(t)$ is the wavelet generating function, $a$ is the scale parameter, $b$ is the translation parameter, and $W_f(a,b)$ is the wavelet coefficient.
When the permissive condition \( C_w = \int_{-\infty}^{\infty} \left| \hat{\psi}(w) \right|^2 dw < \infty \) is true, the following inverse transformation exists [7]:

\[
f(t) = \frac{1}{C_w} \int_{-\infty}^{\infty} W_f(a,b) \psi(a,b) (t) \frac{dadb}{a^2}
\]

(2)

And there are the following energy relationships:

\[
\left[ \int_{-\infty}^{\infty} |f(t)|^2 dt \right] = \frac{1}{C_w} \int_{-\infty}^{\infty} \left| W_f(a,b) \right|^2 \frac{dadb}{a^2}
\]

(3)

Where \( \hat{\psi}(w) \) is the Fourier transform of \( \psi(t) \). Equations (2) and (3) indicate that the wavelet transform of signal \( f(t) \) does not lose any information of the signal, and the wavelet coefficient reflects the energy of the signal under different frequency components at different times.

### 2.2. Haar wavelet transform [7]

Haar wavelet generating function is expressed as follows:

\[
\psi_H(t) = \begin{cases} 
1, & 0 \leq t < 0.5 \\
-1, & 0.5 \leq t \leq 1 \\
0, & \text{other}
\end{cases}
\]

(4)

... From Equations (1) to (4), it can be seen that compared with the shock response spectrum transform, the application of Haar continuous wavelet transform to the shock load processing has the following characteristics: (1) The shock response spectrum transform is non-invertible, while the wavelet transform is reversible. If the wavelet coefficient can be controlled in the shock test, the time domain shock load can be controlled indirectly. By restoring the wavelet transform coefficient of the shock load, the time domain signal of the shock load can be restored. (2) The shock response spectrum transform reflects the comprehensive effect of the shock load on the single-degree of freedom system with different frequencies, while Haar continuous wavelet transform reflects the peak information of the different frequency components of the shock load at different times. (3) The dynamic amplification factor is required to calculate the shock response spectrum, while the wavelet transform coefficient is independent of the dynamic amplification factor.

Therefore, Haar continuous wavelet transform and shock response spectrum transform have good complementarity, and it is expected to greatly improve the control accuracy of shock test specifications if the two transformations can be applied simultaneously in the shock test.

### 3. Measured responses of satellite honeycomb panel to pointwise explosive induced environment

In order to study the shock load characteristics of a pointwise explosive device on a satellite honeycomb panel, two shock sensors were posted near the explosive device to measure the shock load. The sampling rate of the shock sensors is set to 512KHz. The near-field measuring point is about 4CM away from the explosive device, and the midfield measuring point is about 20CM away from the explosive device. The measurement results show that the shock response of the honeycomb panel in the normal direction is much larger than the response in the in-plane directions. The time domain response curves of the measuring points on the honeycomb panel in the normal direction are shown in Fig. 1, and the shock response spectrum curves are shown in Fig. 2. As can be seen from Fig. 1, the time-domain curves of shock loads are too complex. If such load curve is directly taken as the test specification, it is too difficult to reproduce the curve and evaluate the test result. In current engineering practice, the shock test specifications are usually formulated according to the shock response spectrum curves as shown in Fig. 2. Shock response spectrum curve can show the shock
load's severity or its damaging potential well if the damping ratio of the equipment is known. However, test equipments' damping characteristics are usually very complex and unknown. Overtest or undertest phenomenon will occur when the shock test specification is characterized by shock response spectrum and the damping ratio of the equipment is much greater or much less than 10.

Fig. 1  Original signal of measured pyrotechnic shock (left: near-field, right: mid-field)

Fig. 2  Shock response spectrum of original signal (left: near-field, right: mid-field)

Fig. 3  Wavelet power spectra of original signal (left: near-field, right: mid-field)
4. Haar wavelet analysis.

4.1. Haar wavelet time-frequency diagram analysis

The wavelet time-frequency diagram can reflect the time decay law of different frequency components in the signal. Haar continuous wavelet analysis is carried out on the measured shock responses in the normal direction of the honeycomb panel. The wavelet time-frequency diagram of the near-field measurement point and the mid-field measurement point are shown in Fig. 3. It can be seen from the figure that the near-field shock load has abundant frequency components, and the duration time gets shorter as the frequency gets higher, while the response of the mid-field measurement point does not show this feature. The shock load duration of the near-field and mid-field points is not more than 20 ms. The maximum wavelet coefficient of the near-field measurement point is 6062 g, and the maximum wavelet coefficient of the mid-field measurement point is 1339 g.

4.2. Analysis of Haar wavelet coefficients

The shock load duration of pointwise explosive on satellite honeycomb panel is very short, and its risk degree is mainly related to the peak value and spectrum components. The wavelet coefficients reflect the variation of different frequency components in the load at different times. In order to characterize the spectrum characteristics of the load more clearly, the maximum absolute values of wavelet coefficients under different frequency components of the measured loads are plotted as the absolute maximum wavelet coefficient curve shown in Fig. 4. As can be seen from Fig. 4, the absolute maximum wavelet coefficient curve of the measured loads show an upward trend before 1000 Hz, and a downward trend after 10000 Hz.

It can be seen from Fig. 4 that the absolute maximum wavelet coefficient curve can clearly represent the peak characteristics of different frequency components of the shock load with one curve. This kind of curve can show the severity of shock load well, and has the characteristics of easy observation and comparison. If this kind of curve is introduced into engineering practice as the standard to evaluate the severity of shock load or as the basis to formulate the shock test specifications and carry out shock tests, it has a good implementation. At present, the shock test specifications of satellite engineering are usually determined by the envelope of shock response spectrum curves of measuring points on the satellite. If the shock test specifications are determined by the envelope of the absolute maximum wavelet coefficient curves of measuring points on the satellite, the test specifications' convenience for engineering application can also be achieved. Unlike the shock response spectrum curve, the absolute maximum wavelet coefficient curve is not related to the damping ratio which is difficult to determine accurately. Therefore, it has a good application prospect to use the absolute maximum wavelet coefficient curve to improve the control accuracy of shock test specifications.

Fig. 4 Maximum wavelet coefficients in absolute value (left: near-field, right: mid-field)
5. conclusion

Shock load of explosive product is one of the main threats to spacecraft. It is an important task to study the characteristics of the shock load of explosive products and to establish reasonable and reliable shock test specifications for spacecraft development. Because it is difficult to determine the dynamic amplification factor accurately, and the actual product is not a single degree of freedom system, the traditional method of using the shock response spectrum to determine the shock test specifications has hidden dangers that cannot be overcome. In order to research the pyroshock responses of a satellite honeycomb panel and to find a new method to characterize shock test specifications, the near-field and mid-field shock loads are measured using shock sensors and analyzed with the method of Haar continuous wavelet transform. The following conclusions can be drawn from the analysis results:

(1) The spectrum components of the near-field shock load of the pointwise explosive device on the satellite honeycomb panel is abundant, and the components with higher frequency last for a shorter time. The main spectral components of the near-field load and the mid-field load are medium and high frequency components within 1000-10000Hz.

(2) Wavelet time-frequency diagram can characterize the time-frequency characteristics of shock load well. Based on the wavelet time-frequency diagram, the maximum absolute values of the wavelet coefficients of the shock load under different frequency components are extracted, and the curve of the absolute maximum wavelet coefficients varying with frequency is drawn. The absolute maximum wavelet coefficient curve can clearly characterize the shock load spectrum.

(3) In the characterization of shock load, the absolute maximum wavelet coefficient curve obtained by Haar continuous wavelet transform and the shock response spectrum curve have a good complementarity. If the shock response spectrum and the absolute maximum wavelet coefficient curve can be controlled simultaneously during the shock test, the control accuracy of the shock test specification is expected to be greatly improved. Therefore, it is worth further studying the method of introducing the absolute maximum wavelet coefficient curve into the formulation of the shock test specifications and the implementation of the shock test of satellite components.

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