

Experimental Prediction of Shock Response Spectra of Point-Wise Explosive Pyroshock in a Space Launcher Composite Structure Using Laser Pulse Excitation and In-line Filtering

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ABSTRACT

Numerous pyrotechnic devices have been employed in satellite launch vehicle missions, generally for the separation of structural subsystems such as stage and satellite separation. The detonation of the pyrotechnic devices generates shock waves characterized by high accelerations and vibrations which cause the failure of electronic components. To reduce the possibility of failure, many researchers have attempted to develop various experimental and numerical simulation methods for investigating pyroshock behavior to determine the appropriate placement of sensitive equipment. However, most of those methods have limitations such as low flexibility and high costs in the experimental methods and relatively low efficiency and reliability in the numerical methods. This study proposes a simple experimental method for pyroshock prediction using only laser pulse excitation and in-line filters for composite structure. Overall configuration of SRS (Shock Response Spectrum) curve of conditioned laser shock was adjusted with laser fluence changes and its tails were tailored using in-line and numerical filters to match those of real pyroshock. The simulation results present the SRS curves match throughout the frequency range of interest with high accuracy, which is an advantage over the numerical methods that can match either low or high frequency range. At the same time, this method has relatively low costs and high flexibility compared to the conventional experimental methods, demonstrating that this approach could be one of the promising solutions for pyroshock investigation.

KEYWORDS: Pyroshock, laser shock, experimental pyroshock simulation, shock response spectrum

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INTRODUCTION

Pyrotechnic devices are widely used in many space applications. They are used to perform releasing, cutting, pressurization, ignition, switching, and other mechanical work to initiate flight sequences during space missions. Such explosive separation devices generate a shock environment that could have a destructive effect on the structure and hardware, especially on electromechanical and optical equipments. The environment is so complex and subsequent studies revealed that little adequately information is available to describe the basic mechanism of shock transmission and predict shock response. Therefore improved guidelines for pyrotechnic design, development and qualification are clearly needed (Chang 1986; Bement 1995; Lee et al. 2012). The

pyroshock prediction methods are generally categorized by experimental and finite element methods (FEM). Conventional experimental methods have a lot of limitations: In the case of shaker test, frequency range and level are limited. Simulation by hand held impact hammer has low reproducibility. Excitation with a bolt shot device has a very high level amplitude and good reproducibility compared to other experimental methods but costly. On the other hand, finite element method (FEM) and statistical energy analysis (SEA) have high reproducibility and flexibility compared to the experimental method. However, most FEM models are restricted to frequency ranges that are too low to be useful for pyroshock response prediction. SEA is better suited for high frequency pyroshock prediction but SEA has limitation for low frequency mode application. In this study, we have

proposed a simple experimental method for pyroshock prediction using only laser pulse excitation and several types of filter which has a good match throughout the range of interest with high accuracy for a space launcher composite structure. The real pyroshock signals were measured simultaneously using non-contact sensing methods and then the conditioned laser shock signals were achieved using amp-integrated PZT sensor and laser excitation for 4 points from near to far field on the composite sandwich panel. Overall configuration of SRS (Shock Response Spectrum) curve of the conditioned laser shock was tuned with laser fluence changes and its tails were tailored using in-line and numerical filters to match those of real pyroshock. To verify the accuracy of proposed method, the MAD (Mean Absolute Difference) value between SRS curves of the real pyroshock and the experimentally conditioned laser shock was calculated and used for evaluating the accuracy of suggested method.

EXPERIMENTAL PROCEDURE AND RESULTS

Pyroshock Signal Acquisition

The configuration of initiator and overall experimental setup are shown in [Figure 1](#). The experimental specimen can be considered a structural member of space launcher and it was 1.2 m long $\times$ 0.7 m wide CFRP sandwich panel with a 12.68 mm thickness. The basic composition of the initiator was research department explosive and its mount made of stainless steel tube. It was mounted at the bottom edge of the specimen plate. To measure the high intensity shock induced by explosive, laser Doppler vibrometer (LDV) was adopted in this study due to its non-contact sensing characteristics and its suitability for the measurement of high acceleration and high frequency pyroshock even at near field. The maximum measurement range of this LDV for acceleration is 9,600,000 g and a frequency of 2.5MHz, well covering the range expected for the pyroshock wave. The four LDVs were used for simultaneous measurement with sensing laser focused normal to the designed sensing points as shown in [Figure 2](#). The bandwidth of interest for the pyroshock was up to 100 kHz; hence, the signals were filtered at lowpass 100 kHz by the controller of the LDV and registered by a 1 GHz digitizer at a sampling time interval $T=0.2 \mu s$ and sampling length $N=1,000,000$ data. The velocity signals achieved by the LDVs for 20 repetitions and corresponding signals were converted to accelerations using numerical backward differentiation.

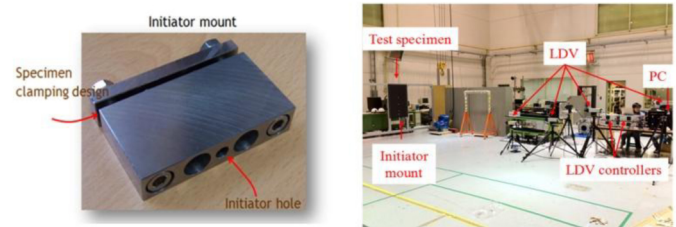


Figure 1. Initiator mount (on the left) and overall experimental setup to obtain pyroshock signals (on the right).

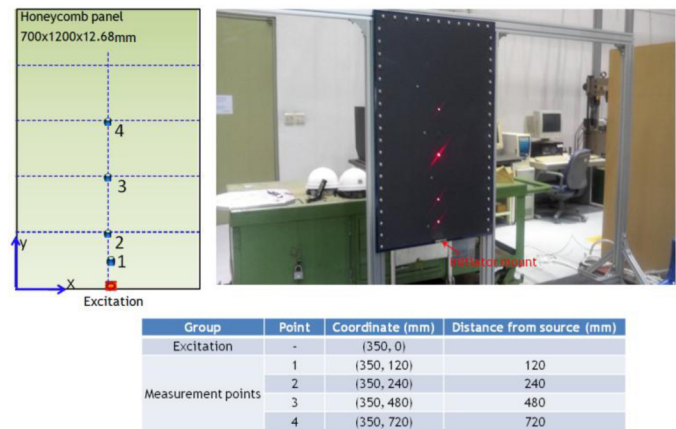


Figure 2. Layout of explosion point and sensing points for pyroshock characteristics.

Laser Shock Signal Acquisition

The hardware of the laser pyroshock simulator (LPS) and its algorithm are presented in [Figure 3](#). The stand-off distance between the specimen and LMS was 3m and laser diameter was 5.4 mm. The excitation part of the LPS consists of a Q-switched Nd:YAG diode-pumped solid-state laser (QL) and a galvanometric laser mirror scanner (LMS) which has two laser mirrors with 1064 nm reflective coating for maneuvering the laser impingement point. The sensing part of the system consists of an amplified-integrated R-cast sensor model M304A and in-line filters and a digitizer. Most importantly, this sensor is omni-directional suitable for point-wise source simulation. The excitation and sensing part are synchronized using a PC, which also stores the data and processes the result. In order for measurement to be possible the amplitude of the response must have a higher signal to noise ratio. Hence the response was measured 200 times and averaged.