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Low-pass-filter-based shock response spectrum and the evaluation method of transmissibility between equipment and sensitive components interfaces

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ABSTRACT

According to the features of the sources of pyroshock and ballistic shock, this study considers the pyroshock and ballistic shock generated by their respective impulsive sources as damped harmonic waves with different frequencies. According to the linear superposition assumption of damped harmonic waves in a linear elastic structure, a shock analysis method based on low-pass-filtered shock signals and their corresponding shock response spectrum (SRS), termed as low-pass-filter-based shock response spectrum (LPSRS), is proposed. LPSRS contains rich information of the frequency distribution of the shock excitation signal. A method to calculate shock transmissibility is proposed based on LPSRS and basic modal information of the equipment structure. LPSRS and SRS curves can be predicted at any given position of the equipment structure. The prediction method is validated by finite element method (FEM) simulation.

1. Introduction

A shock is a transient mechanical loading with high frequency and high amplitude. The shocks in military and aerospace engineering sectors are called ballistic shock and pyroshock, respectively [1,2]. These two types of shock normally do not cause damage to main structures of armoured vehicles and spaceship. However they may result in major functional failure of electronic and optical components, which may subsequently result in the total or partial loss of a mission. Most shock designs and test methods are usually provided based on shock response spectrum (SRS), since a shock measurement in time domain is inconvenient for engineering applications. SRS is generally described by the maximum absolute transient response of a single degree of freedom (SDOF) oscillator under given base excitation. It allows to characterize the shock effect on the response of a series of SDOF oscillators in frequency domain in order to estimate its severity. Different shocks can be compared in terms of their SRS curves, and an equivalence can be established between a real field shock and a simple shock produced in laboratory environment in terms of their SRS curves [2].

One of the issues associated with a shock test is to evaluate the shock environment (usually described by SRS) at the interface of a sensitive component, which is directly related to the safety of the sensitive component in the shock environment. A diagram describing an equipment interface and a component interface is shown in Fig. 1. Normally, measurements are only collected from equipment interface rather than component interface due to the inconvenience and uncertainty of measurement at component interface. Thus, it is difficult to specify the exact shock environment at component interface in terms of

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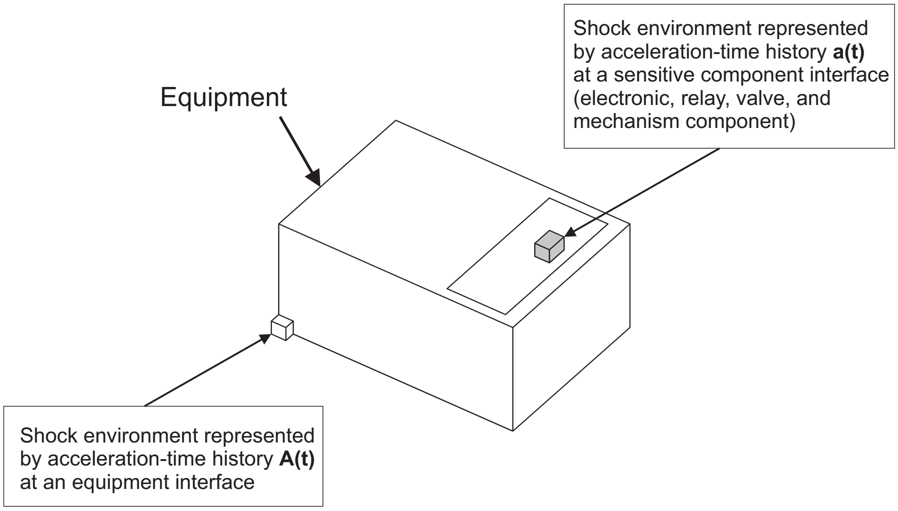

Fig. 1. Schematic diagram of equipment and component interfaces.

its acceleration-time history when SRS at equipment interface is known. Even for two different shocks with same SRS curve at equipment interface, their effects on the responses of a given component fixed to the same component interface to the equipment may differ from each other. Especially for small units (e.g. the order of the transition frequency magnitude[1] of a printed circuit board is about 6000 Hz) under far-field shock excitation (most frequency content is below 10 kHz), shock may be amplified at component interface due to resonance phenomena. Therefore, in standards, e.g., Mechanical Shock Design and Verification Handbook, sensitive components are required to be tested with whole equipment, rather than be tested directly as stand-alone components.

With SRS curve at equipment interface and an appropriate method, e.g. square root of the sum of squares(SRSS), the upper bound response of the equipment at the component interface (which is also the upper bound excitation at component interface) can be estimated. However, only with the upper bound excitation at component interface, the response of the component cannot be calculated. European Cooperation for Space Standardisation (ECSS) has used the shock transmissibility between equipment and component interfaces obtained from sine sweep tests (up to 2000 Hz) to determine the shock environment at component interface from the shock environment at equipment interface. Then a 6 dB corridor between SRS curves at component and equipment interfaces from 2000 Hz to a transition frequency is assumed. According to the ECSS handbook [2], this evaluation method relies mainly on rules-of-thumb, which cannot be considered as a reliable method. The use of a smaller corridor may lead to material failure, while the use of a larger corridor may result in increases of weight, design period and material cost. Therefore, a new and reliable shock transmissibility evaluation method based on shock propagation mechanism is necessary.

This study considers pyroshock and ballistic shock as the superposition of damped harmonic waves based on the feature of their shock generation mechanisms. In this case, it is proposed that the superposition of SRS amplitudes in different frequency bands, i.e., linear superposition of amplitudes, can be satisfied. With a low-pass-filter-based SRS (LPSRS) proposed in this paper, the shock environment at component interface can be predicted with some basic modal information of the equipment structure. LPSRS method for shock transmissibility also provides a theoretical support for laboratory shock test, with which it is possible to use simple shocks to test stand-alone sensitive components, rather than testing the sensitive components on whole equipment. The predicted result is validated by finite element method (FEM) simulation results.

2. LPSRS and transmissibility evaluation method

2.1. Linear superposition assumption

Before analysing shock transmissibility from equipment interface to component interface, it is necessary to understand the shock generation process and the basic features of pyroshock and ballistic shock. Pyroshock is a specific shock which is caused by the detonation of pyrotechnic devices, while ballistic shock is caused by the impact between a kinetic projectile and structure with possible involvement of blast effects. Fig. 2 is a schematic diagram to illustrate shock generation and its transmission from shock source to equipment interface for a rocket.

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[1] A structural response is considered as the superposition of a series of response modes. Transition frequency is a specific frequency of the structure, beyond which higher modes can be neglected in terms of its responses [3].