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Fatigue life prediction model for accelerated testing of electronic components under non-Gaussian random vibration excitations

Yu Jiang [a,*], J.Y. Tao [a], Y.A. Zhang [a], G.J. Yun [b]

[a] Science and Technology on Integrated Logistics Support Laboratory, College of Mechatronic Engineering and Automation, National University of Defense Technology, Changsha, China
[b] Department of Mechanical and Aerospace Engineering, Seoul National University, Seoul, South Korea

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ABSTRACT

In this paper, a novel fatigue life prediction model for electronic components under non-Gaussian random vibration excitations is proposed based on random vibration and fatigue theory. This mathematical model comprehensively associates the vibration fatigue life of electronic components, the characteristics of vibration excitations (such as the root mean square, power spectral density, spectral bandwidth and kurtosis value) and the dynamic transfer characteristics of an electronic assembly (such as the natural frequency and damping ratio) together. Meanwhile a detailed solving method was also presented for determining the unknown parameters in the model. To verify the model, a series of random vibration fatigue accelerated tests were conducted. The results obtained show that the predicted fatigue life based on the model agreed with actual testing. This fatigue life prediction model can be used for the quantitative design of vibration fatigue accelerated testing, which can be applied to assess the long-term fatigue reliability of electronic components under Gaussian and non-Gaussian random vibration environments.

1. Introduction

Random vibration environments have long been the cause of many fatigue induced failures of electronic components. To ensure electronics' robustness and reliability during their operation or transportation, timely validation of the long-term durability of electronic components under their service vibration environment is needed. It is usually done by laboratory vibration testing. However, operational life under normal vibration conditions could be too long so that the laboratory vibration tests at those levels would not be possible.

Accelerated testing provides the reduction in time and cost compared with the testing at normal conditions. In recent years, vibration fatigue accelerated testing methods have been continuously under development [1–5]. However, the vibration loadings are usually limited to sinusoidal or Gaussian random vibration, and the random vibration fatigue damage calculation is based on the assumption of Gaussian distribution. However, the dynamic environment shows non-Gaussianity in some practical applications, such as the ground vibration generated by wheeled vehicles travelling over irregular terrain. Fig. 1 plots the time history of a truck body vertical acceleration from road vibration measurements.

Because traditional Gaussian random vibration tests cannot accurately represent the non-Gaussian vibration environments with high-peak characteristics seen in the real-life use of some electronic products, the latest MIL-STD-810G test standard also requires test engineers to "ensure that test and analysis hardware and software are appropriate when non-Gaussian distributions are encountered" (refer to Method 525 on Page 514.6A-5 in literature [6]).

In this study, a link is to be established between the non-Gaussian vibration excitation and fatigue life, which will facilitate the design and statistical analysis of the accelerated vibration testing of electronic components.

2. Theoretical model

2.1. Model for Gaussian random vibration excitation

Through a series of derivations based on random vibration fatigue theory described in literature [7], the fatigue damage under Gaussian random vibration excitation can be calculated by:

$$D = k_1 T_G \left[\frac{G_a(f_1)}{\xi}\right]^{b/2} {f_1}^{(1-b/2)} \tag{1}$$

where D is cumulative fatigue damage, k_1 is a proportional constant, T_G is the duration of Gaussian random vibration excitation, $G_a(f_1)$ is the magnitude of the acceleration PSD of the random vibration excitation at f_1, f_1 is the first-order natural frequency of an electronic assembly,

* Corresponding author.
E-mail address: jiangyu@nudt.edu.cn (Y. Jiang).

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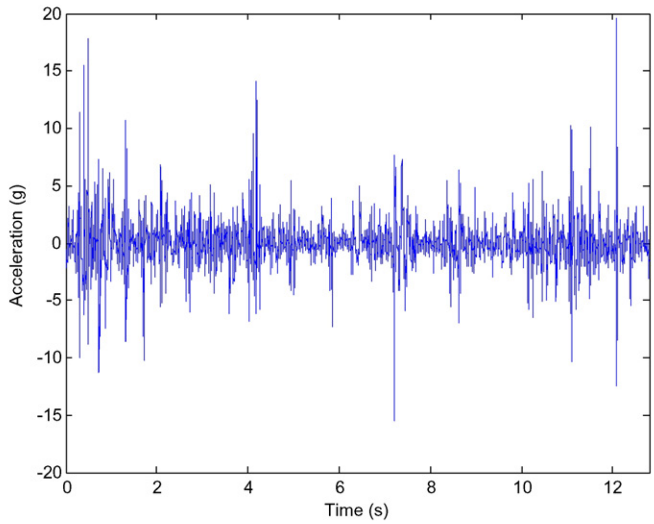

Fig. 1. Time history of a truck road vibration data.

$b$is the constant fatigue parameter that depends on the material of electronic components, and ξ denotes the equivalent damping ratio.

Fatigue failure is generally regarded to occur if $D=1$. Then the vibration fatigue life T_G subject to Gaussian random vibration excitation can be obtained as:

$$T_G=\frac{f_1^{(b/2-1)}}{k_1}\left[\frac{\xi}{G_a(f_1)}\right]^{b/2} \tag{2}$$

2.2. Model for non-Gaussian random vibration excitation

If the random stress response approximates a stationary non-Gaussian distribution, it is possible to add a non-Gaussian correction factor λ in Eq. (1) to describe the impact of the kurtosis value of the stress response on the cumulative vibration fatigue damage:

$$D=\lambda k_1 T\left[\frac{G_a(f_1)}{\xi}\right]^{b/2} f_1^{(1-b/2)} \tag{3}$$

According to fatigue theory, the higher the kurtosis value, the larger is the peak value, and the more extended the fatigue damage. So λ directly depends on the kurtosis value of stress responseK_s:

$$\lambda=1+\alpha(K_s-3) \tag{4}$$

where α is a proportional coefficient.

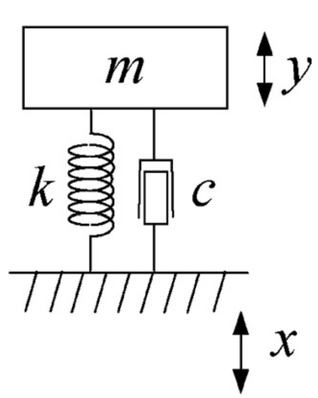

Fig. 2. Dynamic model of a base-excited SDOF system.

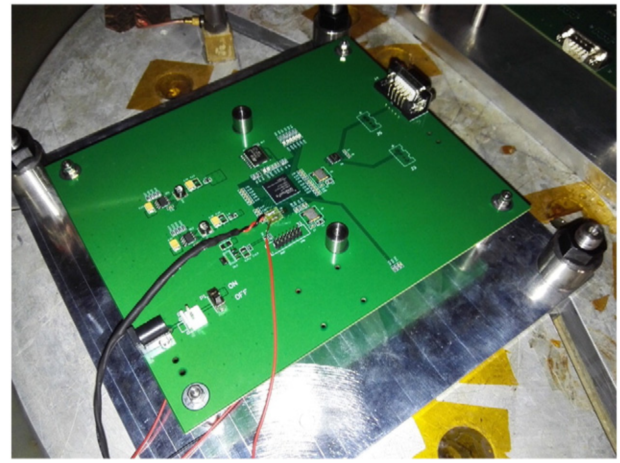

Fig. 3. Specimen of an electronic assembly mounted on a shaker.

Obviously, if the stress response is Gaussian, i.e. $K_s=3$, $\lambda=1$, Eq. (3) becomes Eq. (1). If the stress response is super-Gaussian, i.e. $K_s>3$, $\lambda>1$, the super-Gaussian stress response will accelerate the process of the fatigue damage.

The influence factors for K_s can be further analysed based on the random vibration theory. As the first-order mode of an electronic assembly plays a decisive role in the structural response, a single degree of freedom model under basic excitation is established for analysis as shown in Fig. 2.

The transfer function between the acceleration response y and basic acceleration excitation x can be derived as:

$$H(s)=\frac{Y(s)}{X(s)}=\frac{cs+k}{ms^2+cs+k} \tag{5}$$

Given

$$\omega_1=\sqrt{\frac{k}{m}},\quad \xi=\frac{c}{2\sqrt{mk}} \tag{6}$$

hence

$$H(s)=\frac{2\xi\omega_1 s+\omega_1^2}{s^2+2\xi\omega_1 s+\omega_1^2} \tag{7}$$

where$\omega_1=2\pi f_1$. f_1 denotes the first-order natural frequency, and ξ is the damping ratio. These two parameters characterise the structural

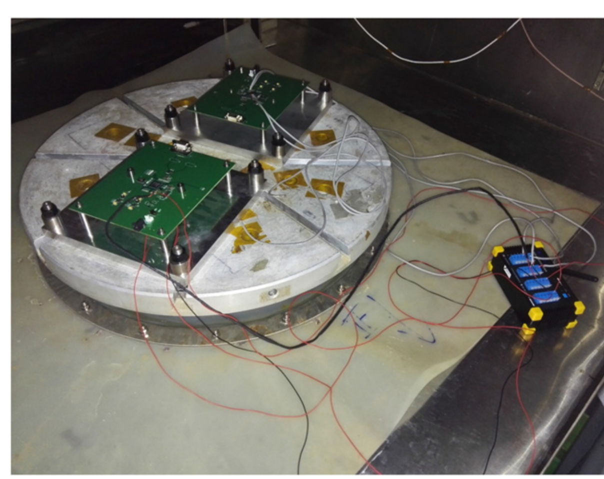

Fig. 4. Experimental setup for a vibration fatigue test.