Research on control method on super-Gaussian random vibration test

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Abstract. This paper studies the control of super Gaussian random vibration test. Experiments show that based on the proposed super Gaussian random vibration control strategy, the output power spectrum and kurtosis can be highly accurate and meet the requirements. The super Gaussian random vibration control system can significantly accelerate the fatigue failure process of the fan, improve the test efficiency, reduce the cost, and shorten the product development cycle.

1. Introduction

Vibration test is defined as the process where test piece is exposed to the simulated vibration condition created by exciter equipment, and desired aims can be realized. In practical, most of products suffer from the random vibration in the process of manufacture, transportation, the related random vibration test method has been revealed in vibration testing standard home and board, and random signal generated from vibration controller satisfies Gaussian distribution in the method above. Practically, although some of products may pass through test in terms of the traditional random vibration test, faults still happen in use. Actually, products are generally exposed under environment of the super-Gaussian random vibration. Gaussian random vibration given power spectrum is widely used in engineering, so far, application of super-Gaussian random vibration test is still confronted with some problems.

2. Vibration control principle

2.1. Super-Gaussian random signal

Gaussian signal is defined as random signal whose amplitude probability density conforms to Gaussian distribution while non-Gaussian signal is defined as random signal whose amplitude probability density dose not conform to Gaussian distribution. Non-Gaussian signal which is described by former fourth order accumulation statistical quantity during the random process contains sub-Gaussian signal and super-Gaussian. the first order central moment in random process describes the signal mean value μ, the second order central moment in random process describes the signal variance σ, the third order central moment in random process describes the signal skewness degree S, the fourth order central moment in random process describes the signal kurtosis K, the relation between skewness degree and kurtosis can be expressed as:

\[ S = \frac{E[X - E(X)]^3}{E[X - E(X)]^{3/2}} \]  (1)
The characteristics of Gaussian random signal can be described by mean value and variance, skewness degree of Gaussian random signal is a constant 0 and Kurtosis value is also a constant 3. At least one of them for skewness degree and kurtosis value of non-Gaussian random signal is different from those of Gaussian signal.

Skewness degree describes the degree that random signal distribution deviates from symmetrical distribution, kurtosis describes waveform characteristic parameters of random signal amplitude. Kurtosis value of Gaussian signal is considered as a benchmark, where non-Gaussian signal with Kurtosis value less than 3 is called sub-Gaussian signal and non-Gaussian signal with Kurtosis value greater than 3 is called super-Gaussian signal. The central region of amplitude probability density of super-Gaussian signal is relatively narrower than that of Gaussian signal, and margin region tail of amplitude probability density of super-Gaussian signal is relatively longer than that of Gaussian signal. Jiang Pei’s investigation \(^{(6)}\) indicates that super-Gaussian signal has a greater impact on the accumulation fatigue damage of testing piece comparing with Gaussian and sub-Gaussian, therefore, the faults of products can be adequately excited. This paper mainly investigates the super-Gaussian random signal with skewness degree 0, and super-Gaussian random vibration test control is also realized on the shaker.

2.2. Basic control principle

Figure 1 shows the process of test of super-Gaussian random vibration.

3. Generation principle for super-Gaussian random signal

It is clearly seen in Fig. 1 that control signal is divided into two channel signals, output signal \(h(n)\) is produced by implementing frequency spectrum equalization, the other is output signal \(A(n)\) produced from Kurtosis equalization, then, two signals is carried out convolution operation to produce the drive signal \(x(n)\) to transmit to the vibrator. The signal used by super-Gaussian random vibration test is realized through modulation of signal, the specific relation between signals are shown in Fig. 2.
4. Simulation and experiment

The simulation search is carried out by using Matlab so that validity of super-Gaussian random signal produced from Poisson Process is able to be verified. Fig. 3 shows the piece of the super-Gaussian random signal in time domain, the probability density function of super-Gaussian random signal is calculated and comparison with probability density function of Gaussian random signal is made, probability density of super-Gaussian random signal has dense value scope nearby the mean value and has a relatively longer tail, partial signal value is even beyond the range 3σ and some signal value reaches 6σ, which satisfies the requirement of control system.

In order to verify the control strategy, the experiment of super-Gaussian random vibration test is carried out. Since the vibration test system is constantly accompanied with non-linear and noise signal, which actually better bears out effectiveness and practicability of the control strategy. The vibration experiment is shown Fig. 4, Fig. 5 shows the picture of the software, power spectrum control is shown in Fig. 6, control response spectrum matches well with reference spectrum, good control accuracy is realised, thus, requirement of ±3dB in engineering can be obtained. Fig. 7 shows the output response signal in the time domain. Fig. 8 shows the probability density of response signal, Fig. 9 shows that kurtosis value is fluctuating around reference value, but still satisfies the requirement of engineering with high accuracy.
5. Highly Accelerated life Testing (HALT)

A group of fans chosen randomly from a company to carry out Highly Accelerated life Testing (HALT) based on the Super-Gaussian random vibration test system. One of them is conducted Gaussian random vibration test, the other is implemented Super-Gaussian random vibration test, then two methods can be compared with each. Fig. 10 shows the strenuous vibration test on site.

There are two groups of fans in the first experiment, each group consists of two fans. Fig. 11 shows that fan is fixed by designed clamps on the electromagnetic shaker. Both tests were carried out until fatigue failure of the fan components. The results are shown in Table 1.

| Vibration environment | Gaussian Random | Super-Gaussian Random |
|-----------------------|-----------------|----------------------|
| Testing piece I (min) | 98              | 68                   |
| Testing piece II (min)| 92              | 74                   |
| Mean time (min)       | 95              | 71                   |

Comparison between two groups of experiment indicates that super-Gaussian random vibration can dramatically speed up the fatigue failure process for products based on the same value of mean square root and bandwidth.

There are three groups of fans in the second experiment, each group also consists of two fans, super-Gaussian random vibration tests are carried out by using different kurtosis value. The test results are list in Tab. 2.

| Kurtosis value | 3 | 7 | 10 |
|----------------|---|---|----|
| Testing piece I (min) | 103 | 68 | 57 |
| Testing piece II (min) | 95 | 74 | 45 |
| Mean time (min)       | 99 | 71 | 56 |
The results of different super Gaussian random vibration tests show that the kurtosis value of the excitation signal has a great influence on the kurtosis value of the response signal. If the super-Gaussian random vibration signal has the same rms value and frequency bandwidth in each case, the latter will increase with the gradual increase of the former, and the super Gaussian distribution of the response signal is more significant, so the fatigue of the test piece, the failure is increased, that is, as the kurtosis value increases, the product fatigue failure will gradually increase.

6. Conclusion

The super-Gaussian random signal generated from Poisson process is used in vibration control system. The control principle of super-Gaussian random vibration test is investigated in this paper. Super-Gaussian random signal, which is taken as drive signal of control system, is modulated by making use of digital filter theory. Furthermore, the required filter is designed by using power spectrum, amplitude of Poisson points generating from Poisson process are assigned as Gaussian distribution, then, both power spectrum and kurtosis for super-Gaussian random vibration test are simultaneously and independently controlled through the convolution operation between signals. Based on the proposed super-Gaussian random vibration control strategy, the simulation and experiment indicates that the high control accuracy of output power spectrum and kurtosis can be achieved; it contributes to the application in engineering.

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