Preliminary Study on Fatigue Damage of Band Split PSD

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1. Introduction

Vibration aging test is an essential process of equipment qualification [1]. But, in some cases, the required vibration level cannot be achieved by the test equipment. In such cases, PSD (Power Spectral Density) band split can be considered.

However, since the fatigue damage effect of band split PSD may not be equivalent with the fatigue damage due to original PSD, careful approach should be taken. In this paper, effect on fatigue damage due to PSD band split is studied by comparing FDS (Fatigue Damage Spectra) for a sample reference PSD and its band split PSD sets.

2. Methods

2.1 Sample Reference PSD

PSDs can be in various shapes. In this study, BLWN (Band Limited White Noise) PSD sample with frequency range of 1 ~ 1,000 Hz and PSD level of 1 g^2/Hz is used as the reference. Parameters of damping factor, fatigue exponent (m), excitation duration and split frequency are fixed as 5%, 4 and 10 seconds, 499.5 Hz respectively.

2.2 PSD Band Split

The sample reference PSD may be split without reducing conservatism by increasing magnitude or excitation duration of the band split PSDs. But those two are not desirable in many cases due to economic reasons. As an alternative, band overlap technique shown in Fig.1 can be a good approach.

To find optimized overlap band size, analyses are carried out by varying the overlap band ratio (L_2/L_1) from zero to 25%. Then, fatigue damage ratios are calculated by Eq.1 for the band split PSD sets.

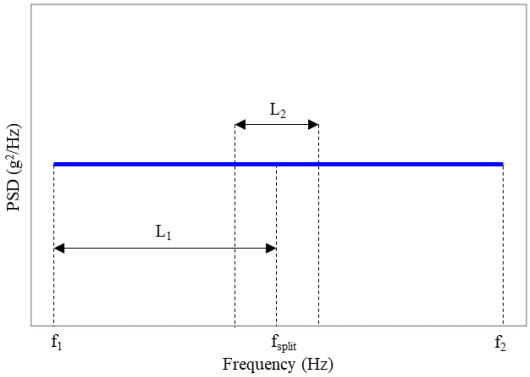

Fig.1. Overlapping case of band split PSD.

$$\text{Fatigue Damage Ratio(f)} = \frac{\text{Reference FDS(f)}}{\text{Split FDS1(f)+Split FDS2(f)}} \qquad \text{Eq.1}$$

2.3 FDS calculation method

Dirlik method of Eq.2 [2], which is known to be accurate for estimating rainflow [3] fatigue damage [4] in frequency domain, is used.

$$D_{Dirlik} = \frac{E[P] \cdot T}{C} \int_0^\infty x^m P_{RR}(x) dx \qquad \text{Eq.2}$$

Where,

$E[P] = \sqrt{\frac{M_4}{M_2}}$: rate of peaks

T = duration

$C = N \cdot S^m$: material constant

m = fatigue exponent (slope factor of the S-N curve)

$P_{RR}(z) = c_1 \frac{1}{\tau} e^{-z/\tau} + c_2 \frac{z}{\alpha^2} e^{-z^2/2\alpha^2} + c_3 z e^{-z^2/2}$

: rainflow range probability density function

$z = \frac{x}{2\sqrt{m_0}}$

$x_m = \frac{m_1}{m_0}\sqrt{\frac{m_2}{m_4}}$

$c_1 = \frac{2(x_m - \gamma^2)}{1+\gamma^2}$

$\alpha = \frac{\gamma - x_m - c_1^2}{1 - \gamma - c_1 + c_1^2}$

$c_2 = \frac{1 - \gamma - c_1 + c_1^2}{1 - \alpha}$

$c_3 = 1 - c_1 - c_2$

$\tau = 1.25(\gamma - c_3 - c_2\alpha)/c_1$

$m_n = \int f^n G(f) df$: n-th moment of PSD(G(f))

$\gamma = \frac{m_2}{\sqrt{m_0 m_4}}$: irregularity factor

3. Result & Review

3.1 Band Split without Overlap

Fig.2 is the fatigue damage result with no overlap (0%). It implies that the fatigue damage is not so different if the natural frequency of the equipment to be tested is far from the band split frequency. But, if the natural frequency is close to the band split frequency or not known, additional measure is necessary to secure conservatism.

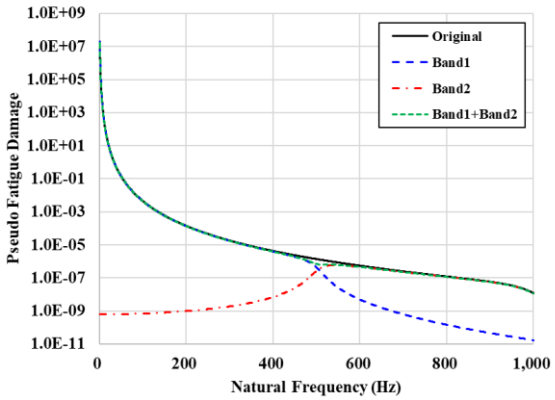

Fig.2. Fatigue Damage Spectrum

3.2 Band Split with Overlap

Fig.3 shows the calculation result of fatigue damage ratio as to various overlap band sizes. It implies that considering around 10 % additional fatigue damage would be enough if the natural frequency can be confirmed to be far enough from the band split frequency. But, if it is not confirmed, 100% additional fatigue damage is needed.

The fatigue damage ratio curves for band overlapped cases in Fig.3 indicate that such over-conservatism can be avoided by applying band overlap technique. For example, in case of not knowing natural frequency, the required additional margin reduces to 40% from 100% by applying only 5% band overlapping.

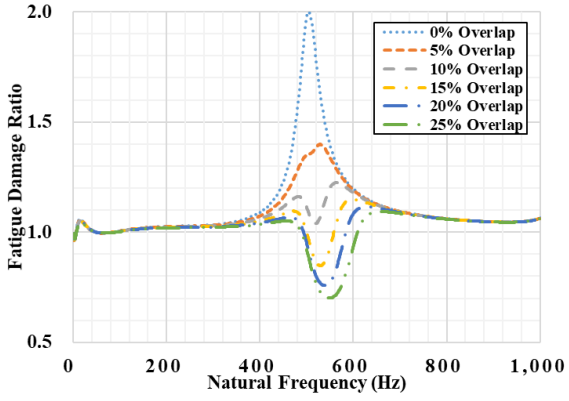

Fig.3. Fatigue Damage Ratio

4. Conclusions

In this paper, effect on fatigue damage by band split BLWN PSD is studied. For equivalent test using band split PSD, same PSD level and duration is not enough. Therefore, overlapped band split with amplification of band split PSD level can be solution for fatigue damage equivalent testing. If there is an information on natural frequency of the equipment to be tested, more economic test with little overlapping or amplification can be achieved. Especially for the case that the natural frequency of the equipment is far less than the band split frequency, series test of band split PSD test with same duration, no amplification and no overlapping can have equivalent fatigue damage effect with of the original PSD. It is noted that complexity and nonlinearity of the test equipment carefully considered for this application because FDS is calculated by response of linear SDOF (Single Degree of Freedom) model.

In this paper, only a case with fixed parameters of fatigue exponent, damping ratio, excitation duration and split frequency and BLWN PSD is studied. However, fatigue damage result can be different depending on these parameters including shapes of PSDs. Further study will be carried out for these cases.

REFERENCES

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