



# Based on the virtual experiment study of the impact of load sequence on the calculation process of random vibration fatigue damage.

Yuzhu Wang, Roger Serra, Pierre Argoul

## ► To cite this version:

Yuzhu Wang, Roger Serra, Pierre Argoul. Based on the virtual experiment study of the impact of load sequence on the calculation process of random vibration fatigue damage.. *Procedia Structural Integrity*, 2019, 19, pp. 682-687. 10.1016/j.prostr.2019.12.074 . hal-02531526

**HAL Id: hal-02531526**

**<https://hal.science/hal-02531526>**

Submitted on 16 Mar 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/338151063>

# Based on the virtual experiment study of the impact of load sequence on the calculation process of random vibration fatigue damage.

Article in *Procedia Structural Integrity* · December 2019

DOI: 10.1016/j.prostr.2019.12.074

CITATIONS

4

READS

124

3 authors:



Wang Yuzhu

CHINA ACADEMY OF RAILWAY SCIENCES

8 PUBLICATIONS 13 CITATIONS

SEE PROFILE



Roger Serra

Institut National des Sciences Appliquées Centre Val de Loire

157 PUBLICATIONS 632 CITATIONS

SEE PROFILE



Pierre Argoul

Université Gustave Eiffel

165 PUBLICATIONS 1,219 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Cable vibration & damage detection [View project](#)



crowd modelling [View project](#)

## Fatigue Design 2019

# Based on the virtual experiment study of the impact of load sequence on the calculation process of random vibration fatigue damage.

Yuzhu WANG<sup>a\*</sup>, Roger SERRA<sup>a</sup> et Pierre ARGOUL<sup>b</sup><sup>a</sup>INSA Centre Val de Loire, Laboratoire de Mécanique G. Lamé, Campus de Blois, Equipe DivS, 3 rue de la chocolaterie, 41000 Blois, France<sup>b</sup>IFSTTAR, Laboratoire Mast – EMGCU, 14-20 Boulevard Newton, Cité Descartes, 77447 Marne-la-Vallée Cedex 2, France

---

## Abstract

At present, the linear fatigue accumulation theory proposed by Miner is used to calculate the fatigue problem of random vibration. In this process, the loading order of the loads is ignored, so that the results obtained are riskier. The nonlinear fatigue cumulative damage theory takes into account the effects of the load loading sequence, but the calculation becomes more complicated. Many scholars have shown that the fatigue calculation of alternating loads is not strictly linear, and the high and low order will affect the damage index. This phenomenon will be more obvious in the random vibration process. In this paper, the effects of loading sequence on the calculation of non-Gaussian random vibration fatigue damage are studied by virtual experiments. Through the phase selection method, 7 sets of excitations with different kurtosis were loaded onto the notched specimen. Through the calculation results of fatigue damage in the notch sensitive area, it was confirmed that the damage calculated by linear and nonlinear cumulative damage formula was improved with the increase of kurtosis. The results can make a significant difference.

© 2019 The Authors. Published by Elsevier B.V.

Peer-review under responsibility of the Fatigue Design 2019 Organizers.

*Keywords:* Vibration fatigue, Random vibration, Damage cumulative calculation;

---

## 1. Introduction

Random vibration fatigue refers to the fatigue damage that occurs when a structure receives a random vibration state and an alternating load. When structural failure occurs, the structure is loaded far below the yield limit. The main

cause of structural failure comes from the cumulative damage caused by alternating loads. In response to this process, the predecessors proposed different fatigue damage accumulation theories in the research process. The more commonly used linear damage accumulation theory proposed by Miner. This theory ignores the stress loading order and simply superimposes the damage values at various levels of stress.

For many mechanical components, the working load is in the form of non-Gaussian random vibration. In this working state, the load subjected to fatigue damage of the structure is an alternating load, and the severity increases as the kurtosis of the excitation increases. If you ignore the effects of the load-loading sequence during this process, the calculation results will deviate significantly from the real value.

The interaction of the load under the alternating load and the effect of the load sequence all have an impact on the fatigue crack growth rate, which in turn affects the remaining life of the structure. The current research results indicate that the residual compressive stress of the crack discontinuity and the crack closure effect caused by the plasticity of the crack tip are the main factors causing the expansion rate of the element. Many experts have proposed some crack propagation rate models to explain this phenomenon. In this paper, the exponential cumulative damage model is selected. (Manson & Halford, 1981)(Gao, Huang, Lv, Zuo, & Wang, 2015)

In this study, through a virtual experiment, a series of acceleration signals with the same kurtosis, which are the same as the RMS, are applied to clamping part of the notched specimen by ABAQUS, and the response stress at the notch position at different kurtosis is obtained. The stress cycle distribution is obtained by rain flow counting. Both linearized. damage accumulation theory and nonlinear damage accumulation theory are used to perform damage calculation.

## Nomenclature

N	Number of cycles
$N_f$	Number of fracture
D	Damage indicator
C,m	The material constants are related to the stress ratio and the stress concentration factor
PSD	Power Spectral Density in $g^2/Hz$
PDF	Probability Distribution Function
$G(f)$	Input acceleration by frequency domain
$W(f)$	Response acceleration by frequency domain
$H(f)$	Frequency Response Function
$L_e$	Failure time
$S_f$	Fatigue limit stress
$a_0$	Initial crack length
$a_f$	Crack length of the final fracture
$n, N_f$	The number of cycles of the load when the corresponding crack length is reached
$a_f$	Crack propagation parameter
$n_{req}$	Equivalent cycle number

## 2. Non-Gaussian signal and Kurtosis control

Typically, a Gaussian signal is modulated to obtain a specific non-Gaussian signal. There are many ways to carry out this process. The phase selection method proposed by Steinwolf is used in this paper (Cornelis, Steinwolf, Troncosi, & Rivola, 2015). By fast Fourier transform, a time domain signal can be described as a superposition of harmonics in the frequency domain.

$$x(t) = \sum_{n=1}^N A_n \cos(2\pi n \Delta f t + \varphi_n) \quad (1)$$

The amplitudes of the harmonics are obtained

$$A_n = \sqrt{2\Delta f S(n\Delta f)} \quad (2)$$

Then the  $n$ th centre moment could be written as

$$M_z = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T \{x(t)\}^z dt = \frac{1}{T} \int_0^T \{x(t)\}^z dt, z > 2 \quad (3)$$

After the kurtosis formula could be written as

$$K = \frac{M_4}{M_2^2} = 3 - \frac{3}{2} \left( \frac{\sum_{n=1}^N A_n^4}{(\sum_{n=1}^N A_n^2)^2} \right) + \left( \frac{1}{2} \sum_{n=1}^N A_n^2 \right)^{-2} \left\{ \frac{3}{2} \sum_{\substack{i+j=k \\ i \neq j}} A_i A_j^2 A_k \cos(\varphi_i + 2\varphi_j - \varphi_k) + \frac{3}{2} \sum_{\substack{i+j=2k \\ i < j}} A_i A_k^2 A_j \cos(\varphi_i + \varphi_j - 2\varphi_k) \right. \\ \left. + 3 \sum_{\substack{i+j=k+m \\ i < j, k < m, l < k}} A_i A_j A_k A_m \cos(\varphi_i + \varphi_j - \varphi_k - \varphi_m) + 3 \sum_{\substack{i+j+k=m \\ i < j < k < m}} A_i A_j A_k A_m \cos(\varphi_i + \varphi_j + \varphi_k - \varphi_m) + \frac{1}{2} \sum_{i=3j} A_i A_j^3 \cos(\varphi_i - 3\varphi_j) \right\} \quad (4)$$

To ensure that the mean and RMS of the non-Gaussian signal are same as before, only the distribution is changed. So to make the  $K$  fitted for the requirement by modulating the specific  $\varphi$ , the non-Gaussian distribution time series with specific  $K$  could be found. It should be noted that as the bandwidth increases, the amount of calculation becomes very large and also affecting the amount is the sampling frequency and data length. In general, the required non-Gaussian data is obtained in a combination of several methods.

### 3. Theory of fatigue cumulative

What is now commonly used for fatigue calculations is the fatigue damage linear accumulation principle from Miner in 1945 (MA. Miner, 1945).

$$D = \sum \frac{n_i}{N_i} = \frac{1}{C} \sum n_i S_i^m \quad (5)$$

Where  $n_i$  is the number of cycles in the stress amplitude  $S_i$ , which was obtained by rain flow counting.  $N_i$  is the cycles of fatigue failure limit corresponding S-N curve at the same stress amplitude. When  $D=1$ , it means structural failure.

The nonlinear cumulative damage theory holds that there is mutual interference between the load history and the damage. The cumulative rate of damage increases with the number of cycles and is more consistent with the actual situation. The representative one is the damage curve method.

Referring to the crack propagation equation proposed by Manson and Halford in 1981,

$$a = a_0 + (a_f - a_0) \left( \frac{n}{N_f} \right)^{a_f} \quad (6)$$

Crack propagation parameter as follow

$$a_f = \frac{2}{3} N_f^{0.4} \quad (7)$$

Therefore, the structural cumulative damage  $D$  can be written as

$$D = \frac{a}{a_f} = \frac{1}{a_f} [a_0 + (a_f - a_0) \left( \frac{n}{N_f} \right)^{a_f}] \quad (8)$$

Using the principle of equivalent damage, the number of cycles at the load level can be equivalent to the number of cycles of the reference load level to calculate the final damage. The maximum load is usually used as the reference load.

$$D_i = \left( \frac{n_i + n_{req}}{N_{i,f}} \right)^{\left( \frac{N_{i,f}}{N_{ref}} \right)^{0.4}} \quad (9)$$

#### 4. Random vibration virtual experiment

According to the phase selection method, non-Gaussian signals at different kurtosis are obtained according to Gaussian signal modulation, and each group of signals is applied to the specimen holding portion by a total of 14 random vibration acceleration excitations by two different time series. This process is completed by the virtual experiment and records the response stress of the critical nodes. (Wang, Serra, & Argoul, 2019)

In order to speed up the experiment and ensure the damage to appear in the observable position, the specimen is designed with two notches and the stress is concentrated at the notch position by changing the cross-sectional area, which means that the crack initiation and expansion area has been knowing. Through the CAE design, the length of the specimen is adjusted so that the displacement of the second bending mode is at the maximum position in the middle of the first notch.

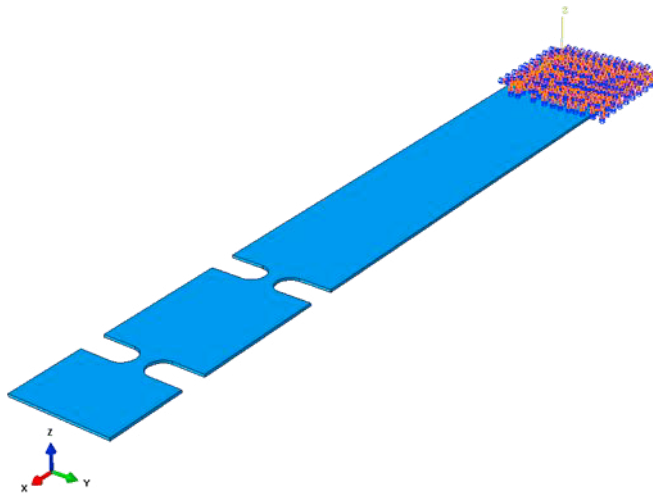


Fig. 1. Two notch specimen & excitation



## 5. Results

Rain-flow counting is performed on the time series of response stress, and the stress spectrum of different kurtosis is obtained. The number of spectrum grade is selected. 24. At the same time, according to the material parameters, the linear damage accumulation principle and the nonlinear damage accumulation principle are used to calculate the damage and calculate the relative error. The results are as follows.

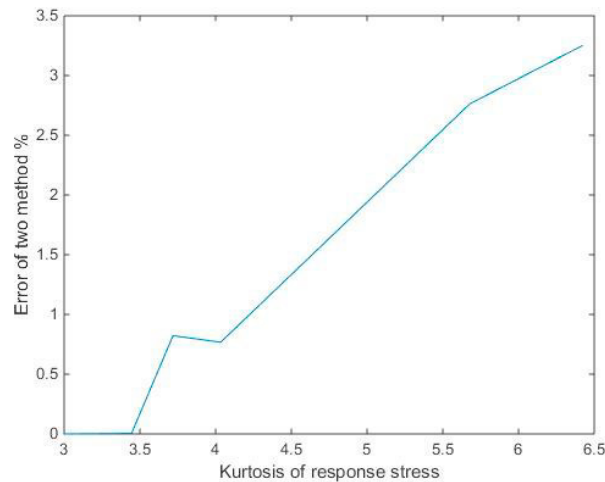


Fig. 3. The difference of two principle

## 6. Conclusion

Through virtual experiments, non-Gaussian time domain signals of different kurtosis are used to verify the effect of kurtosis on the load sequence in the fatigue damage calculation process. From the result analysis, it is known that with the increase of the kurtosis, the linear damage accumulation theory is used, and the neglected damage is gradually increased. Unfortunately, this formula does not take into account the effects of changes in stress amplitude. Part of the future work is to introduce the influence of stress amplitude changes on the calculation of fatigue damage in this process.

## Acknowledgments

This contribution has been elaborated under the China Scholarship Council.

## References

- Cornelis, B., Steinwolf, A., Troncossi, M., & Rivola, A. (2015). Shaker Testing Simulation of Non-Gaussian Random Excitations With the Fatigue Damage Spectrum As a Criterion of Mission Signal Synthesis. *International Conference on Engineering Vibration*, (September), 7–10.
- Gao, H., Huang, H. Z., Lv, Z., Zuo, F. J., & Wang, H. K. (2015). An improved Corten-Dolan's model based on damage and stress state effects. *Journal of Mechanical Science and Technology*, 29(8), 3215–3223. <https://doi.org/10.1007/s12206-015-0721-x>
- Manson, S. S., & Halford, G. R. (1981). Practical implementation of the double linear damage rule and damage curve approach for treating cumulative fatigue damage. *International Journal of Fracture*, 17(2), 169–192. <https://doi.org/10.1007/BF00053519>
- Wang, Y., Serra, R., & Argoul, P. (2019). *Influence of Gaussian Signal Distribution Error on Random Vibration Fatigue Calculations*.