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Deriving Gaussian Fatigue Test Spectra from Measured non Gaussian Service Spectra

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Abstract

A well-known problem is the transition from measured random vibration service loads to synthetically generated test signals. They are used for experimental vibration tests modelling the fatigue potential of long-lasting real service loads within a limited test interval. The challenge of this transition is caused by the non-Gaussian character of the service loads and the fact that the fatigue loads that have to be kept for the tests are caused by the response vibrations of an arbitrary structure. The analysis presented here is based on the finding that the non-Gaussian character of the service load is a function of frequency.

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1. Introduction

Fatigue problems in mechanical systems are often related to random vibrations. Methods for the analysis of the impact of these vibrations on the fatigue strength of dynamical structures are a subject of ongoing research activities. Especially in the area of non-Gaussian vibrations engineers still have to accept a lack of reliable tools. These tools are related to theoretical techniques that are applied on fatigue strength calculations as well as to experimental methods used for fatigue testing. The analysis presented here is related to the generation of test spectra used for experimental

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fatigue strength tests for dynamical systems. Usually these tests are based on an accelerated testing which means that a measured random service load signal (e.g. an acceleration signal of a railway bogie) of a limited duration (e.g. some hours) is taken as a sample representing the total lifetime of the system (in railway engineering this total lifetime may have values of up to 30 y); then this sample signal is manipulated in a way that it causes the same fatigue load on the tested component in a limited test duration (e.g. 200 h). As this test signal acts as an excitation of a vibration system (e.g. some bogie mounted equipment), it cannot simply be replicated faster because this would change its spectral properties and consequently the response of the excited vibration system. A typical procedure to solve this problem is to derive the power spectral density (PSD) from the measured signal and then to use this PSD as a test signal together with an amplification factor, which is derived from the acceleration factor, the slope of the S-N curve and Miners rule. Usual test equipment is able to derive Gaussian distributed time signals from this test PSD. Consequently this described procedure is based on the assumption of a Gaussian distribution of the measured time signal.

In real life random signals are often not exactly Gaussian but as long as the deviation from the theoretical Gaussian assumption is small, the error in the tested fatigue life is acceptable. Especially in railway engineering this assumption often causes relevant deviations in the fatigue life that must not be neglected. Therefore numerous procedures and improvements have been proposed (e.g. [1, 2, 3, 4, 5]) dealing with the impact of non-Gaussian distributions on fatigue load in different ways. The material presented in this paper is based on the finding that the deviation of the probability distribution of a measured signal from the theoretical Gaussian distribution is not just one single characteristic for the entire frequency range of the signal. The presented results show that this deviation depends on the frequency of the signal. A filtering of non-Gaussian time signals for limited frequency bands usually shows a non-constant deviation from the Gaussian distribution over the frequency spectrum of these time signals. Consequently the difference between the fatigue load of a non-Gaussian signal and its corresponding Gaussian signal is also depending on the signal’s frequency. Based on this fact, a procedure for the derivation of test spectra is developed. For the presentation of the material in the following sections it is assumed that readers are familiar with basic concepts of random vibrations (Fourier-series, frequency response function, probability distribution, power spectral density, see e.g. [6]) and fatigue damage calculations (e.g. Rainflow counting, Palmgren-Miner rule, S-N curve).

2. Analysis of a measured non-Gaussian vibration signal

Fig. 1(a) shows the acceleration $a_M(\mathrm{t})$ measured at the bogie frame of a rail vehicle. The measurement has a duration of $T_M = 1250$ s and a standard deviation of $\sigma = 1.12\ \frac{\mathrm{m}}{\mathrm{s}^2}$. Based on the assumption that this acceleration is repeated for a total service life time of $T_{tot} = 27 \cdot 10^7$ s its equivalent fatigue load $a_{M,equ}$ may be calculated by applying Rainflow Counting (mean stresses neglected), a S–N–diagram and Miners rule

$$a_{equ}^k N_{equ} = \sum_i a_i^k N_i \tag{1}$$

where k is the exponent of the S–N–diagram, N_{equ} is the number of reference load cycles for the equivalent load a_{equ} , a_i is the load of the i–th load class and N_i is the number of load cycles of the i–th load class (here $k = 3$ and $N_{equ} = 10^7$ are used as typical values for steel materials, for a comparison also $k = 5$ is used later).