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Frequency based fatigue analysis and temperature effect

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ABSTRACT

This paper proposes a temperature modified Dirlik method to estimate the high cycle fatigue damage for uniaxial loadings caused by random vibrations directly from a power spectral analysis. Besides, the methodology for combining the frequency based fatigue analysis with the temperature effect is represented. This approach is based on a new definition of loading as a random Gaussian process. The fatigue damage estimation of the high pressure die-cast aluminium alloy $AlSi_9Cu_3$ is investigated at elevated temperatures. Finally, numerical simulations on the known power spectral densities with different shapes at different temperatures are performed in order to establish proper dependence between the temperature modified Dirlik method, the rainflow cycle counting, the linear cumulative fatigue damage and the spectral bandwidth parameters. The proposed method enables computationally fast fatigue damage estimation for the random loadings and the temperature histories.

1. Introduction

It is a common conviction that most failures observed in real systems are due to fatigue. However, the fatigue phenomenon is a quite complicated process that is affected by large scatter [1,2]. The external loads measured in real systems are often quite irregular [3].

Aluminium alloys show an increased interest as possible construction materials in the automotive industry due to their low mass density, weight reduction and consequently fuel saving [4,5]. They are used in several automotive applications like turbine housings, engine support brackets, blocks and frames. Automotive components are subjected to random stress loadings (see Fig. 1). Besides, they can also be exposed to temperature loadings.

Traditionally, fatigue damage is determined from the time loading history, usually in the form of stress or strain [6–14]. There are two possible alternative methodologies usually adopted in the fatigue assessment of real systems, i.e. the time and frequency-domain methods [2,7]. Historically, the time-domain methods are older and more often applied in practice. To determine the fatigue damage that an irregular load causes to the material, cycle counting methods and damage accumulation models are adopted generally. Amongst all counting methods, the rainflow (RFC) method is widely regarded as the best counting procedure [3,7,15] while the Palmgren–Miner linear damage rule [1,6] is usually adopted for its simplicity.

The alternative approach is fatigue analysis in the frequency-domain (the so-called spectral method approach) [2,7]. These methods are developed on the model of random processes for the irregular loads where the stationary zero mean random processes [14,16,17] are presented by the power spectral density (PSD) functions [2,6] described with the spectral moments and bandwidth parameters [2,6].

The frequency-domain methods are based on the power spectral density of the process that estimates the statistical distribution of rainflow cycles. Finally, in combination with the Palmgren–Miner rule [1,6] and known S–N curves [2,3,18–21] they estimate the fatigue damage or the fatigue lifetime. Many works [6,22–24] show that the original Dirlik (ODK) method [25] is much better than other existing spectral methods of estimating rainflow fatigue damage. This method does not take into account the influence of temperature effect for the fatigue damage calculation.

The goal of the paper is the improvement of fatigue damage estimation with the temperature effect of automotive components made of aluminium alloys in the frequency-domain approach. Another goal is to reduce the calculation time for the fatigue damage estimation. To reach these goals the temperature modified Dirlik (TMDK) method was developed from the ODK method.

2. Theoretical background

2.1. Random process and the power spectral density

Most real fatigue loadings are random processes [16] in respect of frequency and stress amplitude. If the spectral fatigue analysis techniques are used, the power spectral density (PSD) of stress is usually the input required for fatigue lifetime prediction. The PSD is simply an alternative way of representing an equivalent time

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