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Vibration-Fatigue Damage Accumulation for Structural Dynamics with Non-linearities

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Abstract

Structural damage in mechanical components is frequently caused by high-cycle vibration fatigue. The non-linearities, frequently observed in real structures at increased excitation levels, significantly influence the damage accumulation. As the modal analysis bases on linear theory, the non-linearities are hard to include. Based on a new experimental identification of the non-linearities, this research proposes the corrected linear damage-accumulation estimation. With the proposed correction, the linear modal analysis is used for damage estimation of structures with non-linearities.

The proposed approach is applied to a real-life case of steel-sheet attached with rivets. Several samples are exposed to an accelerated vibration-fatigue test with increasing and also decreasing excitation levels. It is shown that with the experimentally identified non-linearity correction, the numerical fatigue life-time was within the 10% of the experimentally identified life-time. Experimentally, it was shown that rivets same by design, but produced by different manufacturers, have a significant difference in the fatigue life-time; this difference was clearly identified with the proposed correction to the linear damage-accumulation estimation.

Further, the frequency response function based identification of the non-linearity can be identified before the structure is exposed to fatigue loads resulting in new possibilities of vibration-fatigue analysis of non-linear systems.

1 Introduction

Fatigue failures in metallic structures are a well-known technical problem [1]. Fatigue damage increases with the applied load cycles in a cumulative manner. Cumulative fatigue-damage analysis plays a key role in the life-time prediction of components and structures subjected to field load histories [2]. Probably the first systematic fatigue testing was undertaken by Wöhler [3], who concluded that the cyclic stress range is more important than the peak stress and introduced the concept of an endurance limit. Palmgren [4] introduced the first damage-accumulation theory, which is now known as the linear rule, and then Miner [5] expressed the linear rule in mathematical form as a summation of the damage with different loadings, which were calculated as the ratio between the number of applied cycles and the number of total cycles until failure for the ith constant-amplitude loading level. Recently, based on a linear accumulation rule, Zambrano and Foti [6] proposed damage indices for predicting the life of aerospace structures or seismic-resistant structures subjected to a low-cycle fatigue phenomenon. Marco and Starkey [7] proposed a non-linear, load-dependent damage rule based on an exponentiated Miner's damage accumulation of