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Fatigue Life Design of Components under Variable Amplitude Loading with Respect to Cyclic Material Behaviour

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Abstract

Load carrying components are subjected to variable amplitude loading for an extensive proportion of their life time. The available methods for fatigue life design can be divided into global and local approaches with reference to the system in which they evaluate the stress vs. endurance relation. The so called material based approach considers the elastic-plastic material behaviour through a combination of the local and the global approach, improving the transferability of material fatigue properties to arbitrary geometries while reducing the numerical effort for fatigue life estimation.

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Keywords: variable amplitude loading; local approach; global approach; damage accumulation; fatigue life design;

Nomenclature

b	cyclic fatigue exponent
c	cyclic ductility exponent
D_i	damage sum, indices: (c)haracteristic, (s)pectrum, (t)heoretical
E	Young’s Modulus

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H	sequence length of the load spectrum
$HBV_{90\%}$	highly stressed volume
k/k^*	slope of the S-N-curve before/after the knee point
K_t	notch factor
K_f	fatigue notch factor
K_f'	cyclic ductility coefficient
n'	cyclic hardening exponent
N_i	cycles, indices: (r)upture, (k)nee point
M	mean stress sensitivity
R_i	load ratio, indices: (F)orce, (σ) stress, (ε) strain
P_i	damage parameter, indices: (B) according to Bergmann, (SWT) according to Smith, Watson, Topper
ε_i	strain amplitude, indices: (a)mplitude, (m)ean
σ_i	stress, indices: (a)mplitude, (l)ocal, (k)nee point, (m)ean, (n)ominal
χ^*	related stress gradient

1. Introduction

Reduction of time to market requires a lean virtual product development process, which is based on a computational fatigue life design. Suitable fatigue design approaches have to cover a profound implementation of the influence of component related cyclic material behaviour on the fatigue life as well as an appropriate evaluation of the load-time-history. State of the art fatigue assessment approaches for the dimensioning of components under variable amplitude loading can be divided into global approaches, such as, for example, the nominal stress/load concept, and local approaches such as the elastic-plastic notch base concept. Global approaches allow the estimation of fatigue life under variable amplitude loading using the damage accumulation hypothesis according to Palmgren and Miner. Limitations of this approach arise from the condition that S-N-curves under constant amplitude loading, including influences of stress concentration, mean stresses and other considerably complex factors have to be available. Local approaches may assess the stress-strain-state of a component under cyclic loading on the basis of elastic-plastic material behaviour through consideration of the impact of plastic strain on the material properties and the fatigue life. Despite granting excellent transferability of material properties to different geometries, fatigue life design under variable amplitude loading with local approaches is a complex task which may require nonlinear calculations for each load step of the load-time-history. Within a research project, examples of both types of fatigue design approaches were investigated with regard to their requirements, limitations, efficiency and quality of the fatigue life assessment. Based on the results of a comparison between different fatigue design concepts, a new approach was developed, combining the advantages of both global and local approaches.

2. Global vs. local approaches

Experimental determination of fatigue strength and the characterisation of the cyclic material behavior marks the starting point for both approaches, as shown by the flowchart in Fig. 1.

The local approach requires the determination of the cyclically stabilised stress-strain curve according to Ramberg and Osgood [1] as well as the strain-life curve according to Coffin, Manson and Morrow [2,3,4]. Using strain controlled fatigue tests with constant and variable amplitude loading at a load ratio of R_ε=-1, typical test programmes consist of 12 to 15 single tests. The material characterisation for the global approach has to include at least the determination of the influence of stress concentrations, mean stresses and component size with force controlled tests. Conventional experimentation programmes comprise tests on specimens with different notch geometries at load ratios of R=-1 and R=0 under constant and variable amplitude loading for the determination of the Wöhler and Gassner curves, resulting in large testing ranges of 80 to 100 specimens. Concluding the material characterization, all determined parameters have to be transferred from the specimen to the component geometry in order to derive either the damage parameter in case of the notch base concept or the component S-N-curve in the case of the nominal stress/load concept.