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Evaluation of fatigue damage with an energy criterion of simple implementation

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Abstract

Many theoretical methods for multiaxial fatigue life prediction are present in literature, most of them based on their effectiveness on knowledge of the entire stress time history. This represents the great applicative limit. The incapacity to study real situations, not only deterministic one, let the authors to develop a simple and rigorous criterion, which helps the designer who works in this area. The criterion is presented focusing the attention on the basic premise, highlighting its applicability, its practicality and its computational power. To do that, the Authors take into account the deterministic or random character of the individual constraint components and their degree of correlation. In order to verify the method, simulations of multiaxial loads conditions, developed in the time domain, will be carried out with various correlation levels between the stress components on which the method will be applied.

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Keywords: Multi-Axial Fatigue; Fatigue Damage in Frequency Domain; Energy Method for Multi-Axial Fatigue; Deterministic or Random stress componet ; correlated or not-correlated stress compnent.

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1. Introduction

Assessing the fatigue damage of stress on components by multiaxial phenomena is of fundamental importance for the designer today. The great variety and combinations of the stress components have made it clear that this phenomenon is extremely complex, Garud (1981). Defining the potential evolution over time of the stress tensor

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components and the correlation that these can have between them, is the starting point of this discussion. For this reason, particular multiaxial load conditions will be determined in time domains, with deterministic or random, correlated or uncorrelated components. The principal aim will be to treat the phenomenon in its most general case, as well as compare the fatigue power that these stress combinations have on mechanical components, Socie (1987). To do this, the authors will use a simple method that was widely discussed in a previous work Braccesi (2008) and that, in the present article, will be developed and expressed in its most extensive and explicit form. In this way, it will be possible to evaluate the contribution of the individual stress components and their correlation to one another. The proposed method can be included in the category of energy methods, Garud (1981), Park (2000), Elly (2007), Susmel (2013). This uses a frequency procedure to derive an alternating equivalent stress spectrum equivalent to be used as a simple monoaxial case. The use of a frequency domain procedure is useful for several reasons Bishop (1988). The first reason is its capacity to synthesize information, permitting rather reliable estimates very quickly. The second reason accounts for our inability to distinguish a stress load cycle in most real cases, Ellyin (2012), and the frequency domain allows us to properly determine useful parameters in defining equivalent stress. The critical phase of a procedure entirely developed in the domain frequency is, however, related to the determination of the fatigue damage. "Translating" the damage algorithms from the time domain into the frequency domain is, in fact, not easy to do. In the literature, there are several methods: Petrucci (2001), Benasciutti (2002), Zhao (1992), which, starting with the knowledge of the PSD signal, arrive at the value of fatigue damage. In this paper, for the estimation of damage, the Bendat (1964) method will be used to present and compare the value of damage from a series of test cases, either developed specifically by the authors or obtained from experimental tests taken from the literature, Papuga (2016). Such applications will attempt to demonstrate how the use of the proposed method is reliable; but, in particular, they will serve in the comparison of fatigue damage in a series of different multiaxial stresses. The authors would like to point out that, for this discussion, the simultaneous estimate of the alternating and mean stress distribution will be omitted, having deemed it sufficient to determine the single distribution of the amplitudes of alternating stress for the aim of the proposed work.

Nomenclature

t	time
$X(t)$	generic deterministic signal
$r(t)$	generic random signal
$\sigma_x(t)$	normal stress component
$\sigma_y(t)$	normal stress component
$\sigma_{xy}(t)$	shear stress component
$[\sigma(t)]$	stress tensor
S_{a_eq}	alternating equivalent stress frequency spectrum
f_o	frequency
S_i	frequency spectrum of the corresponding time signal $\sigma_i(t)$
$A\langle S_i\rangle$	auto-correlation operator of the signals S_i
$C\langle S_{i,}S_j\rangle$	cross-correlation operator of the signals S_i, S_j
$R[*]$	real operator
$k\ , c$	coefficients of the wohler curve in the form $c = N * \sigma^k$
λ_o	zero order spectral moment
$\Gamma(*)$	gamma function
D	damage
R_m	Ultimate strength
S_n	Tensile fatigue limit
$[G]$	Cross spectral matrix
φ_x	phase-shift normal stress angle
φ_y	phase-shift normal stress angle
φ_{xy}	phase-shift shear stress angle