DAMAGE MODELLING UNDER IMPACT RESPONSE OF A DYNAMIC LOADING

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In this paper an estimation of cumulative damage for dynamic loading conditions is described. Basis of this method consists in specification of a comparative amplitude of the harmonic cycle with zero stress and strain mean values. At the same time, a relative damage must be the same as that of actual cycle which has been identified by the rainflow method. The submitted approach enables to utilize the knowledge of cumulative damage process and fatigue life prediction under harmonic loading and to use it for any complex random loading spectrum with possible impact events.

INTRODUCTION

An investigation of a damage mechanics can be principally realized by two different ways. An empirical-experimental approach - as the first one - is very time- and economy-demanding, and therefore, it is not very suitable for a modern design technology. Much more effective research is based on computer-simulation methods. The methods utilize either real results (from laboratories or from service operation) or theoretic-calculation data of a simulated time history.

The most important in the procedure is to count closed hysteresis cycles in the running load history. The on-line numerical algorithm was made and published in several papers and monographs, e.g. Čačko (1).

Especially, under a dynamic loading with frequent impact events, hitherto developed cumulative hypotheses and failure criteria cannot provide satisfactory results due to a considerable variance of the

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estimation range. Therefore, a new method of a cumulative damage evaluation, which completely respects a total time history of a loading, has been elaborated.

THEORETICAL BASIS OF THE METHOD

The operational damage is produced owing to a cyclic deformation of the material under dynamic loading. A lot of theoretical and experimental work confirms that the fatigue damage has a cumulative nature. That means, the damage increment can be counted after closing of a hysteresis loop in stress-strain diagram. Therefore, the correct identification of closed cycles from the time loading history is the first precondition of the successful procedure.

For identification and counting of closed hysteresis loops, the well-known rainflow method is used. The classical rainflow method enables the counting procedure only after a definite block of closed hysteresis loops. Therefore, the entire time history before starting to count must be known. Then, of course, a running estimation of the cumulative damage is impossible.

The on-line algorithm of the rainflow counting was proposed by Čačko (1). This algorithm enables either to identify a sequence of closed cycles from service signal recording (Fig. 1) or to perform rainflow counting simultaneously to the process modelling (see Čačko et al (2)). The sequence can be registered either as a rainflow matrix, or the rainflow series can be utilized for the next processing.

Then, the fatigue evaluation can proceed from experimental data, where the operational life is predicted using various fatigue curves, diagrams and other statistical characteristics. This approach is, however, time-consuming and economy-demanding. Therefore, we try more and more to start from a simulation model of fatigue damaging (Fig. 2). The problem is how to specify the cumulative damage function.

No theoretical problem could arise, if we have a macroblock that is composed of cycles with a constant mean value and various amplitudes. The problem could arise, if the mean values of cycles are also changing, because the relative damage of individual cycles cannot be simply added in this case. The relative damage of a loading cycle with some definite amplitude and mean value under block loading need not correspond to the relative damage under pure harmonic loading. Moreover, the relative damage is significantly different in the case of a random loading.

SOLUTION OF THE PROBLEM

The problem of the loading mean stress/strain effect is usually solved in such a way that instead of a cycle with the actual amplitude σ_a (stress control or ε_a (strain control) and mean value σ_m (or ε_m respectively), we suppose the cycle with some comparative amplitude σ_a^* (or ε_a^*) and zero mean value of stress (or strain). At the same time, of course, the damage effect of both cycles must be identical.

It can be stated as a hypothesis (see Čačko (3)) that the comparative amplitude for a structural material can be completely determined as a function $\sigma_a^* = f(\sigma_a, \sigma_m, \varepsilon_m)$. The hypothesis is based on the concept that the relative damage of each definite closed cycle in stress/strain diagram is always the same, regardless of the previous loading history. Such an idea corresponds with energy hypotheses, i.e. it is assumed that a cumulative damage of closed cycle is equal to the energy which has been dissipated in a material during the cycle, and it is proportional to the area of hysteresis loop.

Defining the comparative amplitude is an essential problem of the method. Generally, it is possible to proceed from the projections of Haigh diagram $\sigma_A = f(\sigma_M)$ for different $\Delta\varepsilon_m$, where $\Delta\varepsilon_m$ denotes the shift of strain mean value of the actual cycle from the mean value of the corresponding cycle on the cyclic stress-strain curve. Such a diagram can be obtained like a classical Haigh diagram (for $\Delta\varepsilon_m = 0$) but for the material with a plastic prestraining. Then, we can construct the three-dimensional Haigh diagram using a composition of marginal dependencies (Fig. 3). Supposing that the actual cycle is equivalent to the cycle with $\sigma_m = 0$ and $\Delta\varepsilon_m = 0$, we can express the comparative amplitude as follows

$$\sigma_a^* = \sigma_a \frac{\sigma_P}{\sigma_H} \quad . \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

For small σ_m and $\Delta\varepsilon_m$ values (mainly in the case of a narrow-band random loading process), we can consider the relevant part of the area in Fig. 3 as a plane, and the relationship (1) can be linearized according to Fig. 4.

Thus, we obtain the approximate relationship

$$\sigma_a^* = \sigma_a + \psi_\sigma \sigma_m + \psi_\varepsilon \Delta\varepsilon_m \, , \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

where $\psi_\sigma = cotg\ \varphi_\sigma$ and $\psi_\varepsilon = cotg\ \varphi_\varepsilon$.

CONCLUSIONS

The submitted method enables to evaluate the cumulative fatigue damage and to estimate the fatigue life under random loading. According to the proposed procedure, the comparative amplitude for any closed cycle in the loading history is specified, and the relative damage is calculated in the same way as in the case of operation under harmonic loading with zero mean value. The comparative amplitude can be further calculated in order to respect the structure parameters, environmental effects, loading mode and other service conditions.

REFERENCES

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ACKNOWLEDGEMENT

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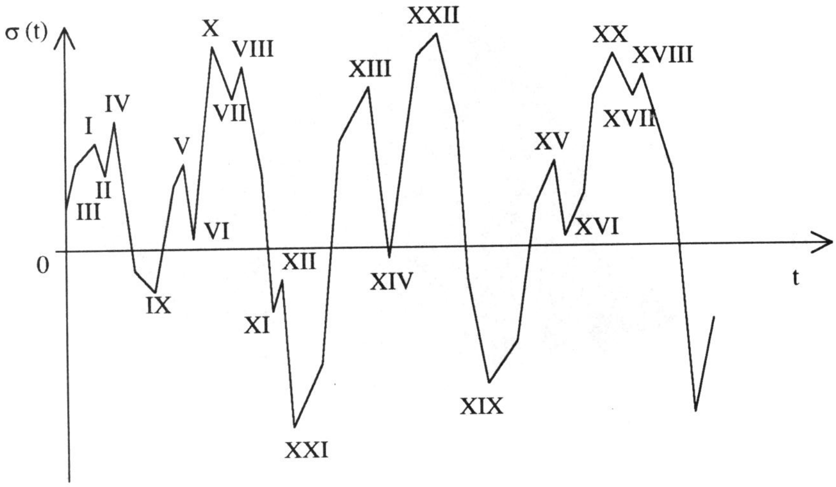

Figure 1 Time loading history and rainflow counting

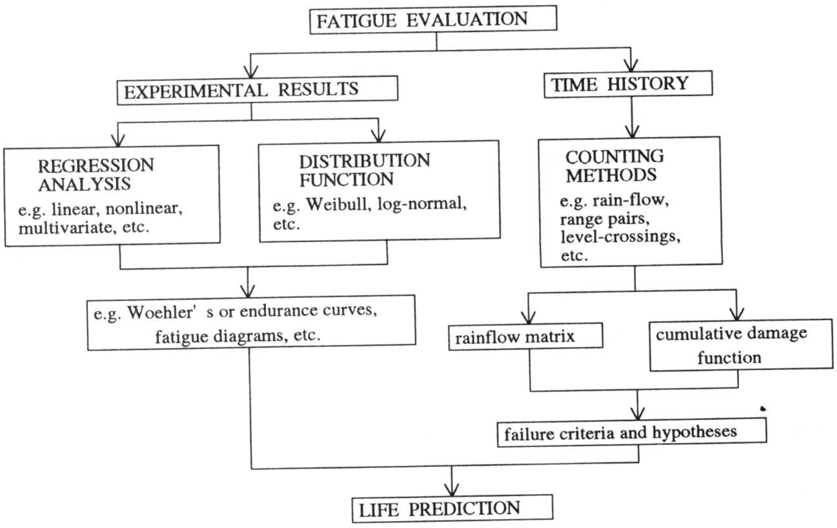

Figure 2 The procedure of fatigue life evaluation

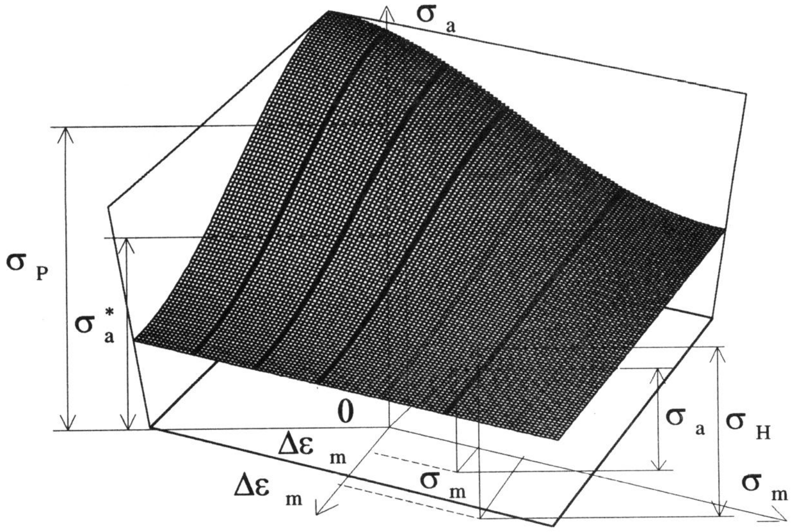

Figure 3 Identification of the comparative amplitude using the Haigh diagram

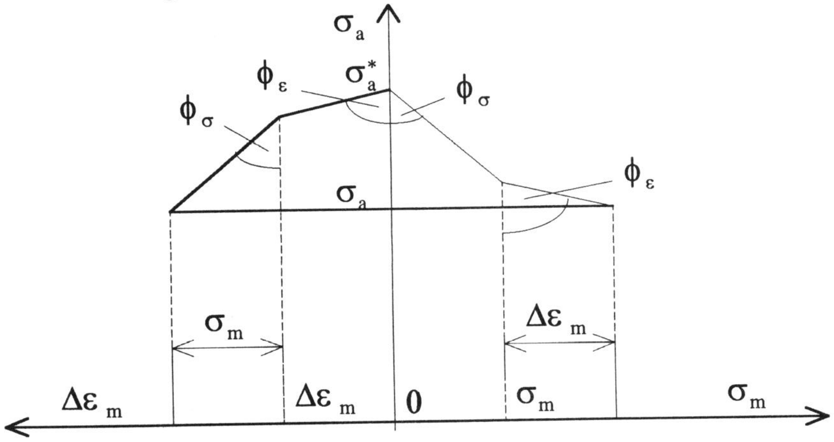

Figure 4 Description of the linearized Haigh diagram to calculate the comparative amplitude