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ScienceDirect

Procedia Engineering 150 (2016) 254 – 259

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2016

Model of Accumulation of a Cycle Fatigue Damage in the Multi-Parametric Random Loading

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Abstract

The article describes the method of estimation of the fatigue life under the multi-parameter random loading. This type of loading occurs when the investigated structure is exposed to the complex load in the form of independent random processes. The processes of changing the stress tensor components in the hazardous area are independent random processes. The proposed method is based on calculating of the microplastic deformations. To calculate microplastics, the structural material model built on the description of the diagram of deformation dependence by the Bridge Ramber-Osgood is used. To identify the model of accumulation of damaged conventional, mechanical and fatigue properties of the material are used. The article presents the fundamental equations of the method. The method of accounting of the mean stress is proposed. The adequacy of the approach is confirmed by comparing the calculation results with the experimental data. Under uniaxial harmonic and random loading calculation results using the proposed model coincide with those obtained by traditional methods. In terms of the plane stress state, the difference between the calculated and experimental values of the experimental durability does not exceed 30% which is quite satisfactory for the case of a high-cycle fatigue.

Peer-review under responsibility of the organizing committee of ICIE 2016

Keywords: Random process; Multivariable loading; Microplastic deformation; Structural model of the environment; Fatigue failure

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1877-7058
Peer-review under responsibility of the organizing committee of ICIE 2016
doi:10.1016/j.proeng.2016.06.758

1. Introduction

During design of the machines designated to work in heavy random loading forecasting of resource of heavy duty machines is often carried out on the basis of high-cycle fatigue theory. The choice of the estimation method of resource at the same time depends on the type of the stress state in the most loaded zone of the investigated details.

Currently, the most well-developed are the methods of estimation of durability in the case of a linear state of stress. Most frequently used schematization direct stress change process by a known method (maxima, complete cycles, etc.). Calculation of the accumulated damage is carried out using the corrected linear summation hypothesis [1, 2]. Also, methods based on the kinetic theory of damage accumulation can be used [3]. In [4] proposed a method of estimation of accumulated damage by the use of Markov processes. The calculation methods in case of plane and volume stress state with simultaneously changing stress tensor components are offered in [5-9]. The most difficult is the case, when the detail is subjected to complex loads described by independent random processes. The components of the stress tensor in the danger zone of the details are arbitrary random processes. Standard methods of calculation for this case are currently lacking.

2. Methods

In this paper we propose a method of estimation of fatigue life in general, multi-parameter loading. It is based on a structural model of the material [10] and the model of damage accumulation [11], originally developed for low-cycle fatigue. It is assumed that the fatigue is associated with microplastic deformation. Structural steel cyclic deformation diagrams are well described by the Ramberg - Osgood equation [12]:

$$\sigma_a = A{p_a}^m . \tag{1}$$

where, A and m is the constants factors (material properties), σ_a and p_a the amplitudes of the stress and plastic deformation. This expression allows us to calculate the amount of plastic deformation at any amplitude of the stress. Fatigue diagram throughout the range of the number of cycles at the same time is described by Coffin:

$$N_f p_a^{\alpha} = C . \tag{2}$$

where, N_f is the number of cycles before the failure; α and C is the characteristic of the material. For reliable simulation cycle fatigue parameters of this expression should be based on the characteristics of Wohler curve [13, 14].

To calculate the stories of microplastic strain a structural model of the environment is used. Elementary volume of the material is considered as a set of perfectly-plastic sub-elements with different values of yield strength. At complex stress state flow sub-surface are spheres in Mises deviatoric space. The centers of these undeformed areas are at the origin. The deformation of material occurs during movement of the point corresponding to the current deformation. When it reaches any flow surface and tends to go for it, there is a shift in the center of this surface so that this point is all the time was on the surface [10]. Position of the center of the yield surface represents the current value of plastic deformation of the respective sub-elements. By inelastic deformation is understood the mean value:

$$\overline{p}(t) = \left\langle \overline{p}^k(t) \right\rangle \equiv \sum_{k=1}^{N} p^k(t) g_k .$$

where, g_k is the constants, σ_T^k is the yield stresss of sub-elements, N is the number of sub-elements. Under proportional cyclic loading centers of the yield surfaces move in a straight line passing through the origin. Plastic strain amplitude is a change in plastic deformation since the time of last reverse:

$$\overline{p}_* = \overline{p} - \overline{p}_v .$$