INVESTIGATION OF THE ACCUMULATION OF DAMAGES 
IN NONSTATIONARY LOW-CYCLE RIGID LOADING

M. A. Daunis and R. A. Stasyunas

In doing work on improving the reliability and life of certain parts and design elements of modern machines it is important to know the properties of their materials under conditions of elastic -plastic cyclic nonstationary deformation.

As is known [1, 2], fatigue failure in low-cycle loading is well described by the Coffin equation

\[ \Delta N_f^n = C, \]  

and for determining fatigue damages use is made of the rule of linear totalling of relative lives [3-6]

\[ \sum \left( \frac{n}{N_f} \right) = 1, \]

where \( \Delta \) is the amplitude of plastic deformation; \( N_f \) is the number of cycles until failure; and \( n \) is the accumulated number of cycles at one of the levels of loading.

However, in determining fatigue damage of materials which are cyclically increasing or decreasing in strength by linear totalling of relative lives there is adjustment on the basis of damageability of the cycles with dissimilar plastic deformation. In connection with this it is proposed to use for such materials linear totalling of cyclic relative deformations accumulated in the process of elastic-plastic deformation [7]:

\[ \sum \frac{k_i \delta_k}{C_n k_i^{m-1}} + \sum \frac{k_i \delta_k}{C_n k_i^{m-1}} + \ldots + \sum \frac{k_i \delta_k}{C_n k_i^{m-1}} = 1, \]

\[ \sum k_i \delta_k^{(av)} k_i^{m-1} = C_n. \]

Experimental checking of the proposed relationships was done under nonstationary symmetric \( R = -1.0 \) and asymmetric \( R = -0.75, -0.5 \) cyclic loading in tension-compression. The testing was done on test machines with mechanical excitation of the force. To provide high accuracy in contactless reversing of the load producing machine in providing the specified value of force or deformation and also for automatic changing to the different levels of loading after the specified number of cycles electronic programming equipment was used [8, 9].

Three contrasts of cyclic properties of a material were investigated: cyclically stable anisotropic 45 steel, anisotropic 15Kh2MFA steel which loses strength cyclically, and isotropic D16T1 aluminum alloy which gains strength cyclically, under nonstationary rigid loading (limited deformation) to four two step and one ten step programs (Fig. 1). The samples of cylindrical form with a gauge length 10 mm in diam. and 23 mm long were tested in the characteristic condition for the materials: for 15Kh2MFA steel

hardened and tempered at a high temperature, for D16T1 alloy hardened and artificially aged, and for 45 steel in the as received condition.

The basic mechanical properties of the materials tested are shown in Table 1.

Totalling of the accumulated damages of 15Kh2MFA heat-resistant steel and D16T1 alloy is done taking into consideration redistribution of the plastic deformations according to Eq. (3). Since 45 steel is a cyclically stable material and the value of the plastic deformation in cyclic deformation changes very little the accumulated fatigue damages for this steel are determined by linear totalling of the relative lives [Eq. (2)].

The average values of the sums of linear totalling both on the basis of relative deformations [Eq. (3)] and on the basis of relative lives [Eq. (2)] for all of the investigated materials are shown in Table 2.

It must be mentioned that for programs with a single change in amplitude deformations all of the investigated materials show deviations from the linear rule of totalling relative lives. In changing from lower deformations to greater the sums of the relative lives exceed unity and with a reverse order of a single change in amplitude deformations they are less than unity (Table 2). Similar deviations in testing to such programs have been noted in other work [3, 10]. The use in such cases of linear totalling of relative deformations gives better convergence of results. For other programs the differences between the sums of relative lives and of relative deformations are insignificant (Table 2).

A comparison of the experimental data for all two step programs, treated with the help of linear totalling of relative deformations and relative lives for 15Kh2MFA steel and D16T1 alloy, indicates that the best convergence of results occurs in totalling of relative deformations (Figs. 2 and 3). The use of Eq. (3) narrows the spread of experimental data for 15Kh2MFA steel by ~10% and for D16T1 alloy by 15-18%.

In determining the amount of accumulated damage by the deformation method it is important to study the rules of the change in plastic deformation during nonstationary loading. Both under conditions of stationary and nonstationary rigid loading there is in relation to the cyclic properties of the material a change in the plastic deformation or the width of the elastic-plastic hysteresis loop, which is taken into consideration with the help of the method described below.

In totalling relative deformations for two step loading with a single change in the method of deformation and a program of half cycles \( k_1 \) and \( k_2 \) Eq. (3) is simplified at the first and second levels, respectively, to the form