THE EFFECT OF TWO-FREQUENCY LOW-CYCLE LOADING ON THE FATIGUE LIFE OF STEELS AND WELDED JOINTS

K. Kálna

Some parts of nuclear power equipment (NPE) are subjected mostly to two-frequency loading during their service. Oscillations with a lower stress amplitude are superimposed on the basic slow loading with high stress (or strain) amplitude. The damage cumulation law, which is valid relatively well for random loading, seems to be less suitable for two-frequency loading. According to the design specifications [1] the service life of parts at two-frequency loading may be 10 to 20 times lower than that at single-frequency loading. The decrease in life depends on both the ratio of loading frequencies and amplitudes, and the material characteristics.

To verify the effect of two-frequency low-cycle loading on the fatigue life of NPE and the validity of the law of linear cumulation of material damage under this mode of loading, the following experimental program was carried out.

1. BACKGROUND

The law of linear material damage during fatigue loading by varying cycle amplitude was derived by Miner [1] for high-cycle fatigue and aluminum alloys in the form

\[ D = \sum \frac{n_i}{N_i} = 1, \]  

where \( n_i \) is the number of loading cycles at the \( i \)th level, and \( N_i \) is the fatigue life at the \( i \)th level.

The Miner hypothesis (Palmgren–Miner’s) is used nowadays for different structural materials and different loading modes in the field of high-cycle and low-cycle fatigue. For some loading spectra the sum of partial damages \( D \) varies in a wide range. Law (1) gives the worst results for the combination of low-cycle and high-cycle fatigue, when crack retardation due to overloading takes place [2].

In order to verify the damage cumulation law at two-frequency low-cycle loading, let us introduce the designation according to Fig. 1.

The number of cycles to failure is \( N \), the first index denotes frequency \( f \), and the other-strain, \( e \), thus \( N_{fe} \). Partial numbers of cycles at two-frequency loading are designated similarly \( n_{21}, n_{22} \). For the evaluation of results of the low-cycle fatigue test, simplified relationships are used:

Fig. 1. Damage calculation scheme for two-frequency low-cycle loading.

\[ \varepsilon_{at} = \varepsilon_{ae} + \varepsilon_{ap} = C_e N^{-me} + C_p N^{-mp} \]  
(2)

\[ S_a = K_e \varepsilon_{ap}; \quad S'_a = K_e \varepsilon_{ap}. \]  
(3)

Figure 2 shows straight lines 1 and 2 expressed by the relationships

\[ N_1 = (C_1/\varepsilon_{ap})^{1/mp_1} \]  
(4)

\[ N_2 = (C_2/\varepsilon_{ap})^{1/mp_2}. \]  
(5)

Assuming that the straight lines have the same slope, then \( mp_1 = mp_2 = m \) is valid. Equation (1) for two-frequency loading can be written in the following form:

\[ (n_{21}/N_{11}) + (n_{22}/N_{12}) = D. \]  
(6)

If we designate the ratio of frequencies \( f_2/f_1 = F \) and the ratio of plastic strain amplitudes \( \varepsilon_{ap_1}/\varepsilon_{ap_2} = E_p \), by substitution and modification of Eqs. (4)-(6) we obtain

Fig. 2. Record of loading course for \( F = 100; \ E_p = 4. \)