FATIGUE STRENGTH OF MODEL ACTIVE GAS TURBINE
BLADES SUBJECTED TO PROGRAMMED TEMPERATURE
CHANGES CLOSE TO OPERATING TEMPERATURES

B. N. Sinaiskii

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The operational testing of high power gas turbines has shown that one of the main reasons for the premature failure of active turbine blades is fatigue.

In attempting to make a reliable determination and forecast of the fatigue strength and life of active turbine blades it is important to study the principles governing damage accumulation during the fatigue testing of design elements and testpieces under conditions approximating to the operating values [1].

Results are given here of an investigation of the fatigue strength and life of design elements, i.e., model blades under isothermal conditions subjected to programmed temperature changes simulating the thermal conditions of the active turbine blades of gas turbines during use.

With the object of reproducing the static tensile stresses from centrifugal forces during fatigue testing, the testpiece was made in the form of a double-locking model of an active turbine blade from cast grade ZhS6K nickel based creep resisting alloy. The manufacturing technique for the model blade corresponded to that used for the cast active turbine blades of gas turbines.

In order to obtain comparative fatigue strength and life characteristics, polished cylindrical testpieces of diameter 9 mm made from ZhS6K alloy were tested. Both the testpiece and model blade materials were heat treated under typical conditions for the alloy: heating to a temperature of 1210-1220°C, maintaining this temperature for 4 h, and quenching from 1210-1220°C with air cooling. The chemical composition and mechanical properties of the material corresponded to the technical specification, the surface finish being 11th class. Also, in order to ensure that testpiece production was similar to blade production, the testpieces were annealed in an argon atmosphere after mechanical treatment to remove residual stresses. A light defectoscope was used to prove the absence of cracks on the testpieces. A type TsDM Pu-10 universal testing machine was used for model blade fatigue testing [2] with sign-constant cyclic tensile loads at a constant mean stress of $\sigma_m = 20$ kgf/mm$^2$, corresponding to the static stress resulting from the centrifugal forces on the blade masses. Testpieces in grade ZhS6K alloy were fatigue tested with symmetric and asymmetric cycles, at a constant mean tensile stress of $\sigma_m = 20$ kgf/mm$^2$. The loading frequency was 15 Hz using $5 \cdot 10^6$ cycles as a test basis.

In order to ensure that the test conditions approximated to the operational conditions, the model blades and testpieces were heated to the required temperature by a gas burner unit, thus providing a means of reproducing the corrosive action of the combustion products, and the greater rates of heating and cooling of the items being tested which are characteristic of the transient processes taking place in gas turbine engines.

Fatigue curves for a 50% failure probability were obtained by regression analysis of the fatigue testing results.

Isothermal testing was carried out over the temperature range 800-1000°C, corresponding to the working temperature of the turbine blades.

Figure 1 shows the fatigue curves for testpieces in ZhS6K alloy at temperatures of 900 and 1000°C under symmetrical load cycle conditions and with the application of a constant static component. Analysis
of the results shows that the limiting amplitudes of the alternating failure stresses are markedly reduced, the cycle being asymmetrical over the entire range of blade lives investigated. At 900°C this reduction is 35-55%, depending on the test basis. At 1000°C the fatigue strength under symmetrical load conditions is reduced even more. These data illustrate the necessity of calculating the static components in estimating the fatigue properties of heat resistant blade materials.

Fatigue curves are shown in Fig. 2 for model blades and testpieces in ZhS6K alloy with an asymmetrical cycle and at temperatures of 800-1000°C. When log σ_max is plotted against log N, straight lines with correlation coefficients γ = 0.86-0.97 are obtained. The fatigue strength of the testpieces and blade models is markedly reduced on raising the temperature from 800 to 1000°C, whereas the difference in endurance increases in proportion to the number of cycles comprising the test basis. For example, at a stress σ_max = 40 kgf/mm² and temperatures of 800 and 1000°C the endurance value differed by a factor of about 10 to 15. At a stress of σ_max = 25 kgf/mm², close to the maximum value in active turbine blades, on increasing the temperature from 800 to 1000°C the blade life is reduced by a factor of 200-250 (at 800°C the blade life is obtained by extrapolation). Consequently, blade operation at maximum temperatures leads to significant material damage.

According to the test results there were small differences between the fatigue strengths of the model active turbine blades and of the polished cylindrical testpieces in ZhS6K alloy when tested under sign-constant cyclic tensile loading and at 800, 900, and 1000°C. The fatigue curves corresponding to a 50% probability of failure are practically coincident. The utilization factor of the fatigue life [3] Φ = (σ₁)/σ₁₀ is almost unity. On the other hand, for heat resistant alloys undergoing deformation, the fatigue strength of the blades is below that of the polished cylindrical testpieces [3-5]. The results, together with the data in [3], show the engineering possibility of raising the fatigue strength by the use of cast materials for turbine blades.