RESIDUAL LIFE PREDICTION OF THE ROTATING DISKS OF THE AIRCRAFT ENGINES

V.N.Shlyannikov, B.V.Iltchenko, V.B.Burmistrov*

For the operating damages having a form of both corner and semielliptic blind crack as well as curvilinear through the thickness crack the method for prediction the residual life of the rotating disks of the aircraft engines was elaborated. Above method is based on a numerical analysis of the stress-strain state using the FEM and on an elastic-plastic model of the crack growth taking into account the loading sequence. Variants of loading have taken into account an interchannel tooth torsion and broach angle to the axis of disk rotation.

INTRODUCTION

Rotating disks of gas turbine engines (GTE) are the elements of structures operating under the complex stress state conditions. One of the places restricting a disk fatigue life on the whole, is the blade groove-type root attachment with a disk. As it is seen from the stand tests of disk, in the points of radius conjugation of interchannel tooth contact surface with a channel bottom there are arisen cracks of cyclic origin. Moreover, the crack growth trajectories does not coincide with operating loads directions (Figure 1). Similar problems belong to the mixed fracture mode section of the crack mechanics. Deformation beyond an elasticity limit in zone considered of stress concentration in the compressor disk predetermines a need to use of crack growth elastic-plastic models for a residual life prediction.

* Physical-Technical Institute of the Kazan Scientific Centre of the Russian Academy of Sciences

NUMERICAL ANALYSIS OF STRESS-STRAIN STATE

As an object of investigations the disk of compressor appears having a lock coupling "dovetail attachment" type, made of titanium alloy (Figure 1). Description of an interchannel tooth geometry in the FEM framework has been performed with a help of three-dimensional 32-nodal elements. A power action on the interchannel tooth has been simulated by means of transfer of forces (which arise at the engine maximum rotation) through the blade contact surfaces, as well as by means of tangential stress action. Among the varied parameters under the FEM-calculation of an interchannel tooth there are the following ones:

- channel broach angle to the disk axis of rotation $\gamma=0^\circ; 26^\circ; 45^\circ$;
- ratio between the radial and tangential stresses $\eta=\sigma_r/\sigma_\theta=0; 0.26; \infty$;
- presence or absence of the moment of torsion acting on an interchannel tooth.

For each of 18 possible combinations of the geometric parameters varied and the loading conditions the distributions of three-dimensional stresses, strains and displacements were obtained over a whole interchannel tooth and further the plots of stress intensity in the place of crack situation were deduced separately. Above plots of stress intensity would be used further to calculate stress intensity factors (SIF) for the cracks of a typical form in the region where a blade is connected with a disk of compressor. Stand tests of disk have showed that unthrough the thickness cracks have the quarter ellipse form with the semiaxle ratio l/c = 0.2 ÷ 0.6. SIF have been calculated in the two points of crack front $C(r=l, \varphi=0^\circ)$ and $D(r=c, \varphi=90^\circ)$ the crack depth l being increased from 0 up to 2.16 mm with a step of 0.36 mm. The SIF calculation is carried out for all the combinations of the channel broach angle values γ, the stress ratio η with a taking into account and without a taking into account an interchannel tooth torsion for the crack semiaxels ratio $l/c=0.2; 0.4; 0.6$. In Figure 2 a typical surface of SIF change obtained as a calculation result is shown depending on the geometric factors analyzed (γ) and on the loading conditions (η) of an interchannel tooth.

MODEL FOR PREDICTING CRACK GROWTH

The modern method for prediction of crack growth rate and fatigue life under a cyclic loading is based on a taking into account the material plastic properties in the region around crack tip. Moreover, the process of deformation inside the plastic zone is described by both the law cycle fatigue equation and the models of state for the case of small-scale yielding. Consequently, the crack growth rate depends on the loading conditions and on characteristics of material deformations. When elaborating the model for prediction the crack growth under mixed deformation modes one has pursued the following object: to express the crack growth characteristics under an arbitrary biaxial loading via the corresponding parameters of an uniaxial symmetrical tension proceeding from an elastic-plastic situation analysis in region around the crack tip. As result the equation is obtained in which one has used the parameter of strain energy density by Sih (1) as an equivalent parameter of stress intensity factors K_1 and K_2

$$\left(\frac{da}{dN}\right)_{\eta} = C_o \left\{ \frac{\sqrt{1-\lambda_o+\lambda_o^2}\,[A(\lambda)+\gamma B(\lambda)]}{\sqrt{1-\lambda+\lambda^2}\,[A(\lambda_o)+\gamma B(\lambda_o)]} \right\}^{-n/\beta} (S_{max})^{m_o} \qquad (1)$$

in which λ-is the main stress ratio in an elastic-plastic region around the crack tip, n-is the strain hardening exponent, β-is the Manson-Coffin exponent, C_o, m_o-are the material constants in Paris equation under an uniaxial symmetrical tension, S_{max}-strain-energy density factor. To calculate a fatigue life the equation (1) is solved as follows

$$N_f = \sum_{i=0}^{f-1} \frac{\Delta a_{i+1}}{C_o \left\{ \frac{\sqrt{1-\lambda_o+\lambda_o^2}\,[A(\lambda)+\gamma B(\lambda)]}{\sqrt{1-\lambda+\lambda^2}\,[A(\lambda_o)+\gamma B(\lambda_o)]} \right\}^{2n} \left(\frac{\sigma^2 a_i \pi}{4}\right)^{m_o} \left(S_{max}\right)^{m_o}} \qquad (2)$$

Accordingly, by solving (1) about crack length we obtain the equation which permits to take into account a change of the stress amplitude during a cyclic loading the Wheeler (2) factor C_{pi} being provisionally introduced in (1)

$$a_l = a_o + \sum_{i=1}^{l} C_{pi} \left\{ C_o \left\{ \frac{\sqrt{1-\lambda_o+\lambda_o^2}\,[A(\lambda)+\gamma B(\lambda)]}{\sqrt{1-\lambda+\lambda^2}\,[A(\lambda_o)+\gamma B(\lambda_o)]} \right\}^{2n} \left(\frac{\sigma^2 a_i \pi}{4}\right)^{m_o} \times \right.$$

$$\times \left(S_{max}\right)^{m_o} \Big\} \Delta N_i \qquad (3)$$

in which $C_p = (r_{py}/r_{py-1})^P$, while r_{py} and r_{py-1} are the sizes of plasticity zones corresponding to the present and previous values of the stress amplitude.

RESULTS AND DISCUSSION

Proceeding from the above SSS analysis for different variants of geometry and loading conditions of compressor disk having the angled cracks of different forms the calculation of crack growth trajectories and duration for the loading spectrum corresponding to typical flight was carried out (Figure 3). Results of life prediction on the crack growth stage have been compared with experimental data obtained by the stand tests of disk. Good agreement was shown. Taking into account both the torsion of interchannel tooth and the operating loading spectrum as it is established are principal factors under prediction of residual life of disks having the cracks of different form. Proposed elastic-plastic model of crack growth prediction for the mixed fracture modes describes the testing results correctly.

REFERENCES

(1) Sih, G.C., Int. Journ. Fract. Mech., Vol.10., 1974, pp.305-321.

(2) Wheller, O.E., Journ. of Basic Eng., Vol.94.,1972, pp.181-186.

Figure 1

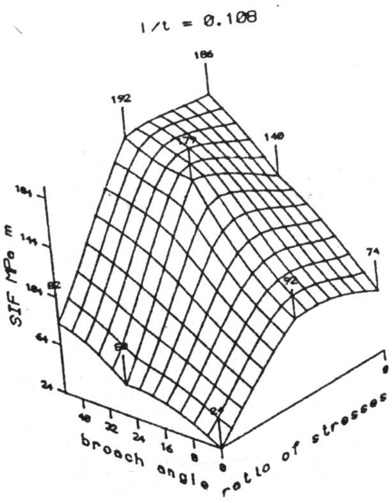

Figure 2

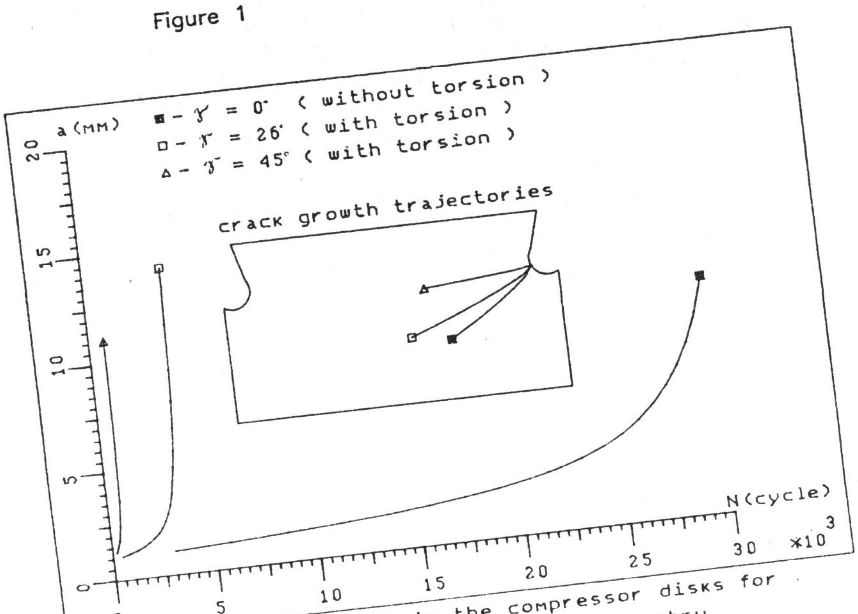

Figure 3. Crack growth in the compressor disks for different variants of geometry