Numerical Modal Analysis of the Turbo-jet Engine Rotor Blades

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The given paper is closely connected with the numerical modal analysis of eigenfrequencies and eigenshapes for turbine blades of the turbojet engine with the help of the mathematic modelling. The mathematic model was created in Pro-Engineer program and it was subsequently created to the ANSYS program in order to apply finite element method. Distribution of the stress in the turbine blades is presented in [Pa]. The presented results of the eigenshapes and distribution of the stress are obtained in the graphic form.

Keywords: modal analysis, eigenfrequencies, eigenshapes, stress, finite element method

1 Introduction

The turbo-jet engine TJ 100 is normally used as a small power driving unit which can be installed as auxiliary engine into light and ultralight planes, sailplanes as well as gliders. The design of this small auxiliary turbine engine TJ 100 can be seen hereinafter (Fig. 1). TJ 100 is single-shaft engine with single-stage radial compressor, annular combustion chamber and single-stage axial turbine which consists of rotating integral guide (distribution) and turbine blade wheel (it is starter-generator) together with output nozzle.

The intake air is compressed in the radial compressor wheel and then it pass through the radial and axial diffuser into the annular combustion chamber where it is mixed together with the fuel. The mentioned fuel is sprayed by the fuel nozzles. The residue gases of combustion which occurs during the burning process of fuel in the combustion chamber expand through the single-stage axial turbine and they get out through the output nozzle at the high speed into the atmosphere and this is the way for creation of motor thrust. The compressor running is provided by axial turbine. Rotor is placed on ball bearings which must be lubricated with pressure oil.

The basic operating parameters for turbojet engine TJ 100:
- Operating engine speed (revolutions per minute):
  - idle engine speed - 30 000 rpm
  - maximum output engine speed (100%) - 60 000 rpm
- Maximum fuel consumption is 60 litres per hour
- Temperature of gas in front of turbine is about 890 °C

Stator as well as rotor turbine blades are made of nickel superalloy Inconel 713 LC. The chemical composition of this nickel superalloy is shown in table 1.

2 The computational model

The computational model of rotating turbine blade wheel is shown in fig. 2.

| Chemical element | C  | Cr  | Ti  | Al  | B  | Zr  | Nb  | Mo  | Ni  |
|------------------|----|-----|-----|-----|----|-----|-----|-----|-----|
| wt.%             | 0.05 | 12.08 | 0.75 | 5.91 | 0.01 | 0.10 | 2.02 | 4.58 | bal. |
The calculation of the blade construction loaded by the dynamic loading

The mathematical model for turbine blades was created with eight nodal volume elements. Stability equations [1, 2, 3, 9] were solved using (1):

\[
[M] \ddot{u} + [C] \dot{u} + [K] u = f(t). \tag{1}
\]

where \(M\) is the mass matrix, \(C\) is the damping matrix, \(K\) is the stiffness matrix, \(f(t)\) is the time varying load vector and \(\{u\}, \{\dot{u}\}, \{\ddot{u}\}\) are the displacement, velocity and acceleration vectors, respectively.

Dynamic analysis of the blade construction includes solution of the stability equations (1). Stress distribution [4, 7, 8] is presented in [Pa] and it can be seen in the Fig. 3 and Fig. 4. On the Fig. 5 is total displacement.

The figure 6 shows the course of given temperatures for individual points of rotating blade wheel according to the figure 2.

The calculation of the eigenfrequencies and eigenshapes for turbine blades

Mathematical model can be expressed in form (1). Modal and frequency analysis [5, 6, 10] were done according to known equation in the form

\[
-\omega_i^2 [M] + [K] \{\Phi_i\} = \{0\}. \tag{2}
\]

where \(\omega_i\) is i-th eigenfrequency, \(\{\Phi_i\}\) is the eigenvector representing the nodal shape of i-th eigenfrequency.
ncy. We calculated eigenfrequencies and from the eigenfrequencies, there were calculated frequency characteristics with the modal damping $\xi = 0.001$. The motion equation for i-th eigenshape is in accordance with:

$$\ddot{x}_i + 2\xi\omega_i \dot{x}_i + \omega_i^2 x_i = \{P_i\}^T \{f\}.$$  (3)

**Fig. 6** The first four eigenshapes of vibrations

**Fig. 7** Further four eigenshapes of vibrations
This relationship is generalized problem of the eigenvalues where solution is made by the semi-automatic-space iterative method. This method is based on the idea of the inverse iteration conversion with several vectors at the same time. In Fig. 6 and Fig. 7 we can see first eight eigenfrequencies of vibrations calculated by the help of the underspace method.

5 Summary

The results obtained on the base of frequency analysis, thermal loading of turbine blades as well as distribution of main stresses pointed out the areas for which the loading of turbine wheel and blades is the highest. The given results can help us to specify the areas representing the possible initiation and distribution of crack relating to turbine blades. Figure 7 represents such crack of turbine wheel and figure 8 represents fracture surface of the blade.

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