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

Fig. 1 *Image of turbojet engine TJ 100*

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 Inocel 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.

Tab. 1 *The chemical composition of nickel superalloy*

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.

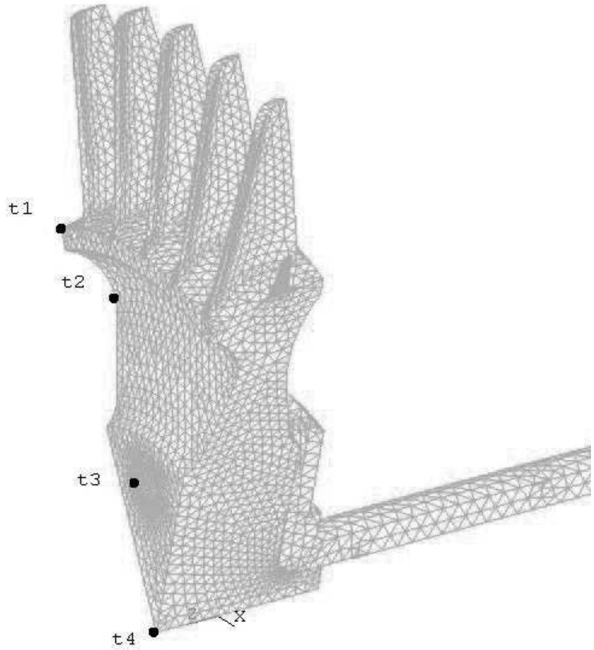

Fig. 2 Model of rotating blade wheel

3 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):

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

where **M** is the mass matrix**, C** is the damping matrix, **K** is the stiffness matrix, $\{\mathbf{f}(t)\}$ is the time varying load vector and $\{\mathbf{u}\}$, $\{\dot{\mathbf{u}}\}$, $\{\ddot{\mathbf{u}}\}$ 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.

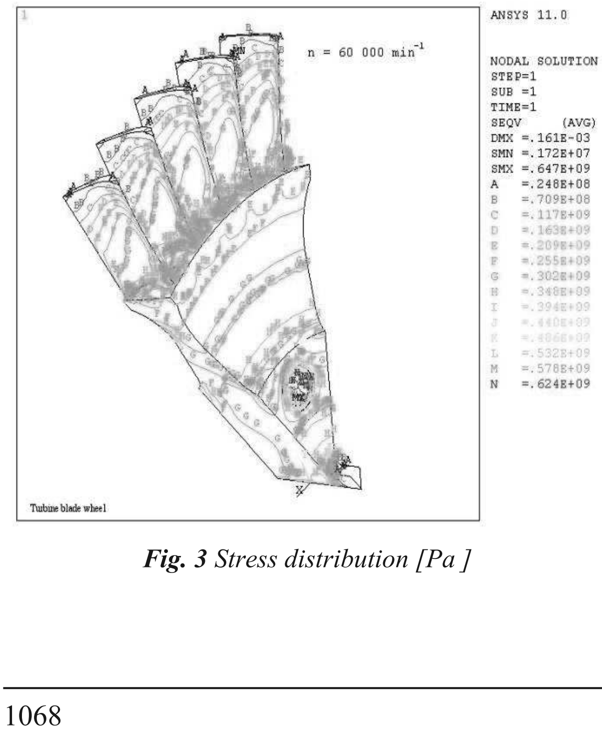

Fig. 3 Stress distribution [Pa]

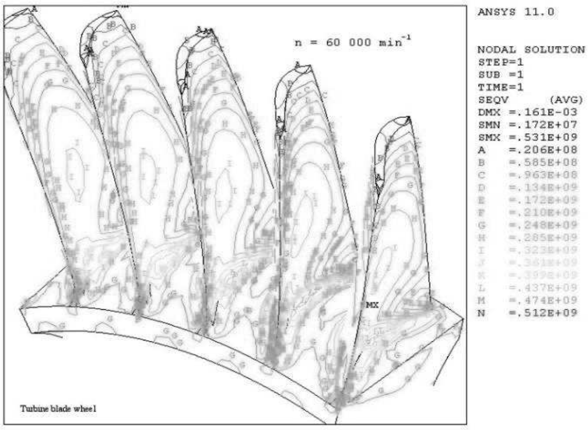

Fig. 4 Stress distribution [Pa]

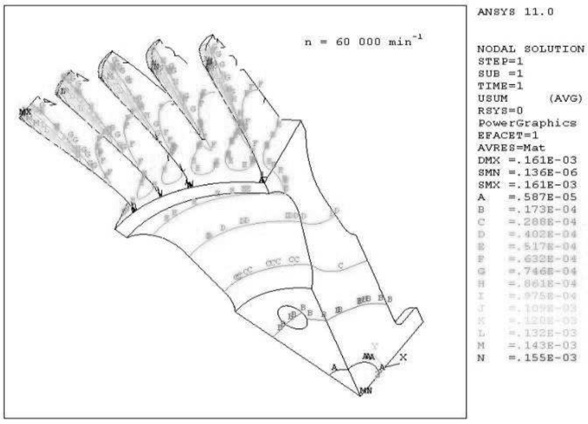

Fig. 5 Total displacement[m]

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

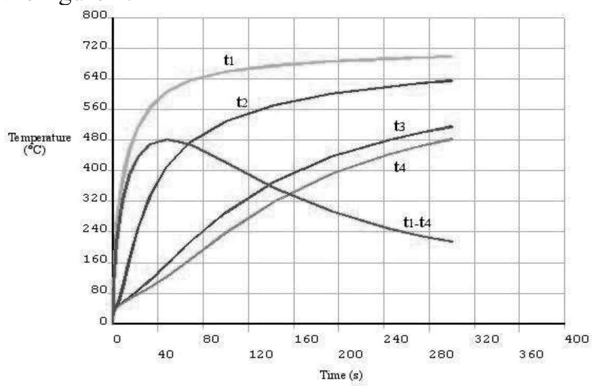

Fig. 5 The course of temperatures for individual points of rotating blade wheel

4 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

$$\left(-\omega_i^2[\mathbf{M}]+[\mathbf{K}]\right)\cdot\{\Phi_i\}=\{0\}. \qquad (2)$$

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

$$\ddot{x}_i + 2\xi_i \omega_i \dot{x}_i + \omega_i^2 x_i = \{\Phi\}_i^T \{f\}. \tag{3}$$

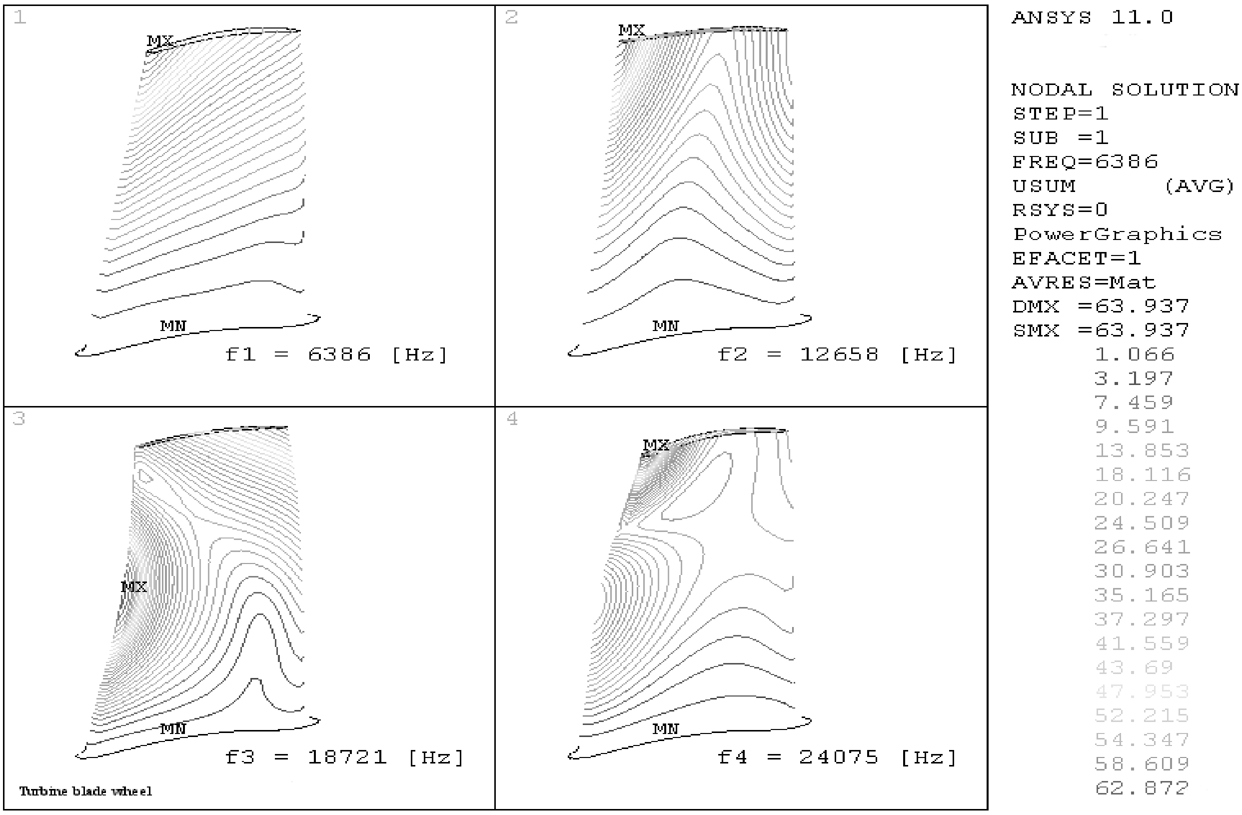

***Fig. 6** The first four eigenshapes of vibrations*

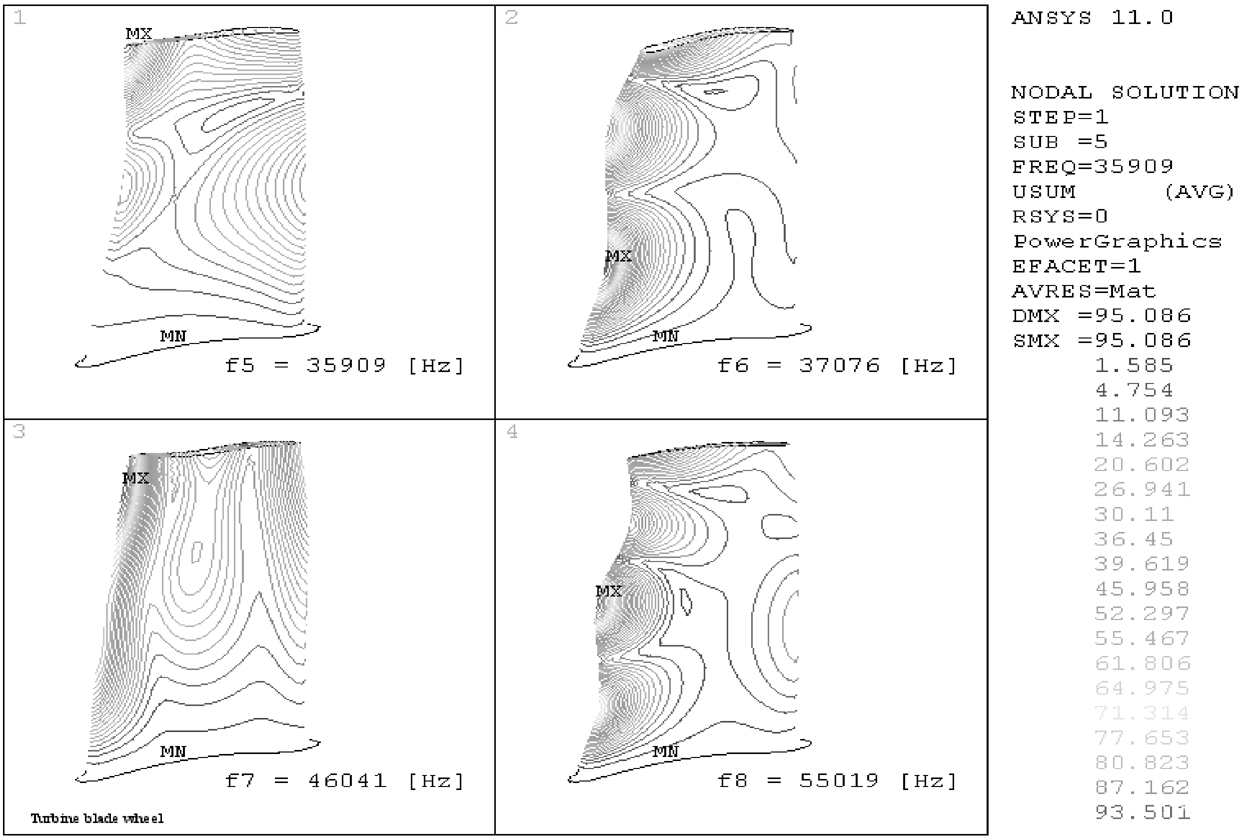

***Fig. 7** Further four eigenshapes of vibrations*

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.

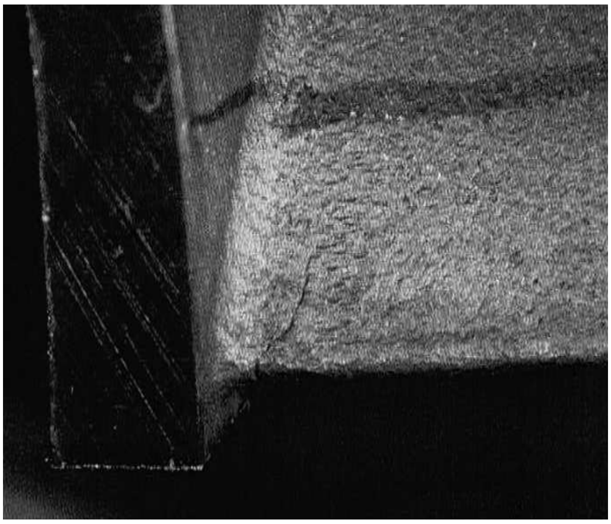

Fig. 6 *The turbine wheel with the crack of blade*

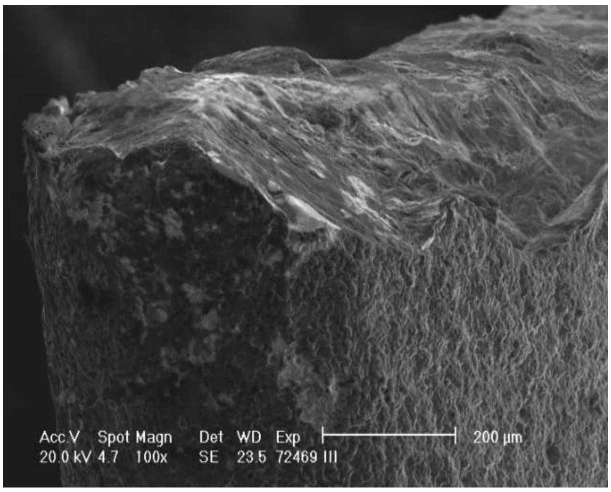

Fig. 7 *Fracture surface of the blade*

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References

[1] AZAR, J.,J. (1972). *Matrix Structural Analysis*, Pergamon Press, New York.

[2] BATHE, K., J. (1982). *Finite element procedures in engineering analysis*. Englewod Cliffs.

[3] BATHE, K., J., WILSON, E., L., PETERSON, F., E. (1973). SAP-IV, A *Structural Analysis Program for Static and Dynamic Response of Linear Systems*, Berkeley.

[4] MÁRIA BLATNICKÁ, MIROSLAV BLATNICKÝ, JÁN DIŽO, MILAN SÁGA, (2018). Comparison of Analytical Stress Analysis and Numerical Calculation of Mobile Work Machine Part, *Manufacturing Technology*, Volume 18, ISSN 1213-2489, pp.190-193.

[5] JÁN DIŽO, JOZEF HRUŠINEC, MIROSLAV BLATNICKÝ, (2018). Computational of Modal Properties of Two Types of Freight Wagon Bogie Frames Using the Finite Element Method, *Manufacturing Technology*, Volume 18, ISSN 1213-2489, pp. 208-214.

[6] JAN DIZO, MIROSLAV BLATNICKÝ, (2019). Evaluation of Vibrotional Properties of a Three-wheeled Vehicle in Terms of Comfort, *Manufacturing Technology*, Volume 19, ISSN 1213-2489, pp. 197-203.

[7] FRANTISEK KLIMENDA, JOSEF SOUKUP, MILAN ZMINDAK, (2016). Deformation of Aluminium Thin Plate, *Manufac- turing Technology*, Volume 16, , ISSN 1213-2489, pp. 124-129.

[8] ZUZANA STANKOVIČOVÁ, VLADIMÍR DEKÝŠ, PAVOL NOVÁK, MILAN SAPIETA, (2015). Numerical Simulation of Ther-moelastic Stress Analysis, *Manufacturing Technology*, Volume 15, , ISSN 1213-2489, pp. 925-930.

[9] TEPLÝ, B. (1990). *Metóda konečných prvkov*. VUT Brno.

[10] YONGYI LIAO, BAIYU LIAO, (2019). Dynamics Modeling and Modal Analysis of Machine ool Considering Joints Parameters, *Manufacturing Technology*, Volume 19, ISSN 1213-2489, pp. 267-272.

10.21062/ujep/419.2019/a/1213-2489/MT/19/6/1067