THE TURBINE ENGINE BLADES STRESS-STRAIN STATE UNDER THE VIBRATION LOAD

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Abstract: The problem of turbine engines blades stress-strain state has been studied. All calculations have been provided for the cooled blades constructions, used in the turbo machinery manufacturing. The investigation's purpose was to develop the new adaptive mathematical model of turbine engine bladed disks with circular damping links stress-strain state by means of finite elements method. The foregoing approach to the finite elements method was borrowed from the literature on finite elements method. The main mathematical models and some types of the finite elements can't be used for the correct description of the foregoing problem. The matter is that turbine blades have constructional non-homogeneity, which hardly ever could be correctly explained, using well-known finite elements and their mathematical dependences. On the other hand the variable aerodynamic force influence has also been taken into consideration. That is why the new model, which consists of sections, including disk's sector, the whole blade and parts of damping links, has been developed. The finite elements methodology has been used for the dynamic stresses of this section calculation. Such approach gives an opportunity to describe the stress-strain state of the whole bladed disk as the superposition of the developed sections.

Keywords: turbine blades, geometrical parameters, constructional non-homogeneity, stress-strained state, vibration load, finite elements method.

1. Introduction

Nowadays the main aim of turbomachinery constructions development is to increase the engines power and durability. On the one hand it is economically profitable, but the other hand the increase of engine's power causes new additional loads on its working elements. That is why the problems of turbine engines most important parts durability under the vibration load study is rather important. The main attention should be paid to the turbine engine rotor that works under the non-stationary dynamic load. Other important fact is that with the increase of turbine power the temperature of gas float sharply increases too. All this negative factors constantly influence the turbine engine blades, cause the appearance of the fields of dynamic and thermal stresses on their surface, that are non-linear and sharply differentiate for different constructional parts of blades. All this negative factors should be taken into consideration and studied during the process of turbine engine rotor design.

The foregoing problem of course has been studied for several years, but it still has many aspects that have not been studied yet. First attempts to calculate the parameters of turbines and compressors stress-strain state has been made on the base of Core theory [1, 2]. But such methodology has several important disadvantages – the blades are considered to look like as twisted rods of variable transverse section, that are anchored into the rotor. But this approach is incorrect, because the blades shape can't be correctly described by the rods. In the work [3] the turbine blades stress-strain state has been studied by means of the initial parameters method. But it is unclear how the authors have found the frequencies and amplitudes of blades vibration. In the work [4] the author tries to find dynamic stresses on the blades surface by the asymptotic methods of mechanics usage.

On the other hand the turbine blades stress-strained state could be found by the usage of finite elements method (FEM). The authors of [5–7] try to calculate the field of stresses on the blade's surface, caused by the dynamic load. But in the work [5] the authors didn't take damping between the blade and disk into consideration. In works [6, 7] the problem is linearized, so the achieved results are not correct.

The experimental methods are very expensive and the achieved results have a significant in accuracy [8].

That is why we are able to say that the problem of turbine engines stress-strain state calculation has several aspects, which are not studied yet. So the main aim of our work is to work out the new more correct mathematical model of the turbine engines blades stress-strain state on the base of finite elements method. To achieve the aim of research we need to:

– form the cooled turbine blade finite elements model on the base of the curvilinear finite elements;

– find the influence of the blade's constructional non-homogeneity on its stress-strained state under the vibration and thermal load.

2. Methods

The turbine blade is considered like a three dimensional solid continuum. That is why the main method that is used in our research is the finite elements method. The main idea for us is to discrete the blade into a number of finite elements, which shape can satisfactorily describe the blade's geometric parameters. As it is known turbine blades have slim curvature, so we can use curvilinear isoparametric finite elements for the problem solution. This type of discretization gives us an opportunity to describe the blade's geometry in an appropriate way and take into consideration its constructional non-homogeneity [9].

When the turbine blade mathematical model is formed by means of finite elements method we need to find the field of stresses on its surface, caused by vibration and thermal load. For the problem solution we use the Lagrange variation principle. So we receive a system of matrix equations. This system is solved by the usage of Cholesky principle for the case of banded matrixes.

3. Results

For the mathematical model adequacy and calculation algorithm efficiency verification the fields of stresses on the blade's surface has been calculated. The influence of the blade's geometric parameters on the stresses value has been studied. The results of calculation are given in the table form. All results received by the usage of the developed algorithm are compared with the numerical experiment data.

Firstly we study the influence of the blade's feather parameters on the maximum dynamic stresses on its surface value (**Table 1, 2**).

The results, given in **Table 1, 2**, show that value of maximum stresses increases with the increase both of cooling holes quantity and their diameter.

Next we studied the influence of the cooling blade's internal cavity on its stress-strain state. The matter is that there is a net of special cooling channels in the cavity. The walls of these channels can be considered as a number of stiffeners for the blade's external surface [10].

The data given in the **Table 3–5** shows the influence of the cooling channels geometric parameters on the maximum dynamic stresses on the blade's surface value.

Table 1
The influence of the cooling holes quantity on the maximum dynamic stresses value

Holes quantity q	Maximum stresses value, Pa	
	Calculated data	Numerical experiment data
1	2024	2017
2	2032	2022,5
4	2038	2026
6	2043	2030
8	2047	2039
10	2050	2042

Table 2
The influence of the cooling holes diameter on the maximum dynamic stresses value

Holes diameter d, mm	Maximum stresses value, Pa	
	Calculated data	Numerical experiment data
0,2	2289	2998
0,3	2301	2009
0,5	2307	2015

Table 3
The influence of the cooling channels walls thickness on the maximum dynamic stresses value

Cooling channels walls thickness b, mm	Maximum stresses value, Pa	
	Calculated data	Numerical experiment data
1,5	2362	2027
2,0	2316	2019
2,5	2308	2013
3,0	2290	1997

Table 4
The influence of the cooling channels walls height on the maximum dynamic stresses value

Cooling channels walls height, c, mm	Maximum stresses value, Pa	
	Calculated data	Numerical experiment data
5,0	2018	2004
8,0	2022	2009
10,0	2029	2014
12,0	2038	2024
15,0	2045	2031
20,0	2051	2036

Table 5
The influence of the cooling channels walls tilt angle on the maximum dynamic stresses value

Cooling channels walls tilt angle, β, deg	Maximum stresses value, Pa	
	Calculated data	Numerical experiment data
0	2316	2017
5	2313	2030
10	2296	2005
15	2278	1989

The results, given in the **Table 3–5** show that the net of cooling channels for the turbine blade stress-strain state play the same role as stringer stiffeners for the elastic narrow shells.

4. Discussion

The main results of the research are represented in the **Table 1–5.** They show the influence of the turbine blade's constructional inhomogeneity on its stress-strain state parameters.

The data represented in Table 1 shows that the increase of the cooling holes quantity on the blade border causes the increase of the dynamic stresses value on the its surface. The explanation of this fact is the following. It is well-known that the holes are the stress concentrators. That is why the increase of the holes number causes a sharp increase of the stress concentrators on the blade surface too. So the stresses range and their value increases too due to this dependence.

The same dependencies can be seen in the **Table 2.** As the hole is a stress concentrator, then the extremum of stresses is localized near the hole border. So if the holes diameter increases, it will cause the localization of stresses on the larger part of blade's surface.

Summarizing the calculated data, given in the **Table 1, 2** and comparing them with the results of numerical experiment we have to shift our attention on the fact that the increase of the holes quantity and their diameter causes a sharp increase of the dynamic stresses. But we need to take into consideration that in practice the holes are used to cool the blade internal and external surfaces. So it is obvious for designer to find balance between the demands of turbine blade strength and its thermoelasticity.

On the other hand, the data given in the **Table 3–5** shows the dependencies between the turbine blades internal geometric parameters and the value of the dynamic stresses on their external surface. As it has been said earlier the internal cavity of turbine blade consists of a net of cooling channels. So we need to analyze the influence of these channels geometric parameters on the blade's dynamic stresses value.

The data represented in the **Table 3** shows that the increase of the cooling channels walls thickness causes a decrease of the dynamic stresses value. This fact can be explained due to the increase of the whole blade strength.

The opposite dependencies can be seen while the data in **Table 4** is analyzed. The matter is that the increase of cooling channels walls height causes the sharp increase of the blade's feather stiffness. According to the fact that the blade works under the dynamic load the sharp increase of its bending rigidity causes the increase of the blade dynamic stresses value.

In the **Table 5** we can see the correlation between the cooling channels walls tilt angle and the value of the turbine blade dynamic stresses value. As the cooling channels walls are considered to be stiffeners for the whole blade, then it is obvious that the increase of the tilt angle value causes the increase of the blade strength. That is why the value of the dynamic load on the blade external surface decreases with the increase of the cooling channels walls tilt angle.

So summarizing the data, given in the **Table 3–5** we can say that the influence of the cooling channels geometric parameters on the turbine blades stress-strain state is rather positive than negative. Giving practical recommendations for the designers we should say that for the purpose of the dynamic stresses value decline it is suitable to increase the value of cooling channels walls thickness and tilt angle. On the other hand the value of channels walls height should be reduced. But according to the technological process of turbine blades manufacture the maximum tilt angle of cooling channels wall can't be more than 15 degrees.

In the conclusion it should also be said that the obtained data can be a base for further researches in the area of turbine blades durability under vibration load. The mathematical model used for this researched can be modified and also used for new, more complete researches, describing the stress-strain state of the whole turbine rotor.

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