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STUDY OF THE INFLUENCE OF CERAMIC THERMAL COATING ON THE AIRCRAFT BLADE VIBRATION

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Abstract

The paper analyzes the influence of the ceramic layer on the vibration of the high pressure stage turbine blades in take-off transient conditions. As reference model, the high pressure stage blades of the Tumanski R13 jet engine were considered. The analyse was done using the Ansys 14.5. The vibration eigenmodes and eigenvalues for the blade with and without a $ZrO_2/3\%Y_2O_3$ *deposited coating are compared.*

Key words: turbo engine, blade vibration, ceramic coating, vibration eigenmodes, eigenvalues

1. Introduction

The use of ceramic coatings for aircraft turbo engine blades allows a high efficiency of the engine and increases the life of the blades [1, 2]. Increasing efficiency occurs due to the possibility of increasing gas temperature in the high pressure stage inlet [5].

On the other hand the ceramic thermal barrier coating (TBC) influences the blades vibration. Vibration of turbo engines blades are very important engine durability and performances [4].

The paper analyzes the influence of the ceramic layer on the vibration of the high pressure stage turbine blades in take-off transient conditions. As reference model, the high pressure stage blades of the Tumanski R13 jet engine were considered. This jet engine equips the MIG-21 and SU-15 aircrafts. For the considered transient regime, the rotation speed increases from 6000 rpm to 12.000 rpm. The calculated tangential blade velocity is 251 m/s for the first rotation speed and 468 m/s for the second rotation speed. The overall pressure ratio increases from 3,5 to 8,9.

The vibration eigenmodes and eigenvalues for the blade with and without a $ZrO_2/3\%Y_2O_3$ deposited coating are compared.

2. The models used in the analysis

The turbine blade models used in the analysis were made in Catia V5 R19 according to the calculated parameters of the high pressure blades of the Tumanski R13 jet engine. On the second model a 0,3 mm coating made of $ZrO_2/3\%Y_2O_3$ was deposited on the outer surface of the blade. Technologically this coating is applied on the surface of the blade by atmospheric plasma spraying. The base material used is a Ni based super alloy. The CAD models were imported in the Static Structural module from Ansys 14.5. The material properties of the base material and the $ZrO_2/3\%Y_2O_3$ ceramic coating were defined in the Data engineering module from Ansys 14.5. The mesh used for the model without coating is presented in Fig. 1. The mesh consists of 3727 nodes and 1557 elements.

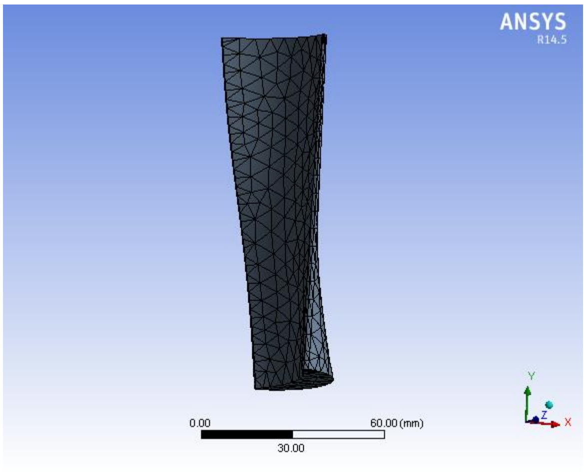

Fig. 1: The mesh used for the blade without coating

Fig. 2. presents the mesh used for the turbine blade with a $ZrO_2/3\%Y_2O_3$ coating. This mesh consists of 16004 nodes and 7646 elements.

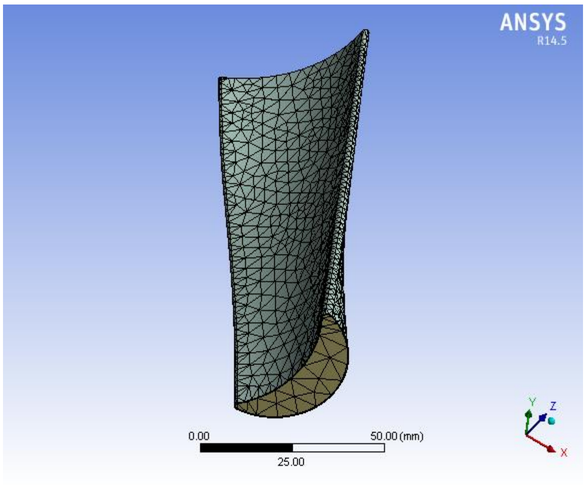

Fig. 2: The mesh used for the blade with coating

To analysis the vibrational harmonic response of the blades they were first pre-stressed at a tangential blade velocity of 251 m/s. This velocity corresponds to the idle speed of the jet engine. This idle speed causes stress in the blades materials due to the centrifugal force. The pre-stressing of the blades was done in the Static Structural module from Ansys 14.5. The module Modal was used to determine the eigenmodes of vibration of the turbine blades. The harmonic response module determined the behavior of the blades subjected to acceleration from the idels speed to the maximum tangential speed of 468 m/s. All the modules were assembler in an Ansys workbench schematic. The project schematic used for the analysis of the turbine blades is presented in Fig. 3.

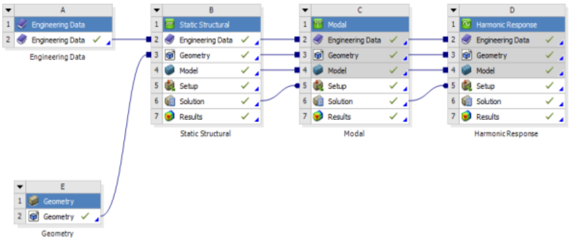

Fig. 3: The project schematic used for the turbine blades analysis

3. The vibration eigenmodes and eigenvalues of the turbine blades

The results obtained from the Modal module consist of the vibration eigenmodes and eigenvalues for the blade made only from the Ni base super alloy and the blade with a $ZrO_2/3\%Y_2O_3$ deposited coating. In the range from 0 to 2700 Hz were determined 6 different vibrational eigenmodes. In Fig. 4 are presented the vibration eigenmodes specific for the blade without coating. Each eigenmode is characteristic to a specific frequency. The frequencies specific for each vibrational mode of the turbine blade without coating are presented in table 1.

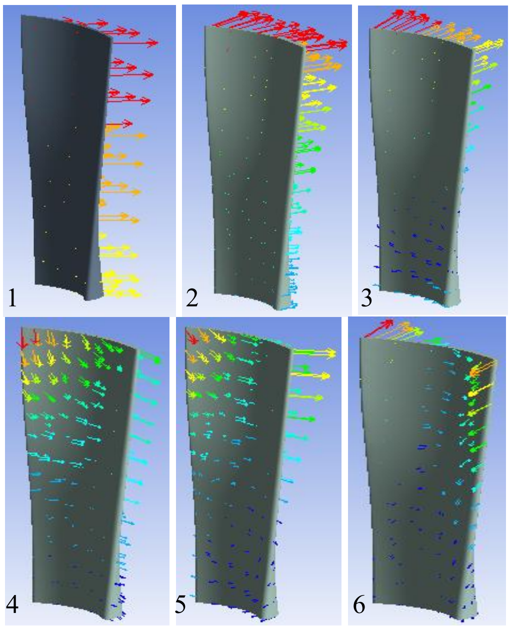

Fig. 4: The vibrational eigenmodes for the turbine blade without coating in a frequency range from 0 to 2700 Hz

Table 1: The specific frequency of each vibration mode for the blade without coating

Mode	Frequency [Hz]
1.	96,103
2.	561,34
3.	938,05
4.	1576,3
5.	1819,7
6.	2625,5

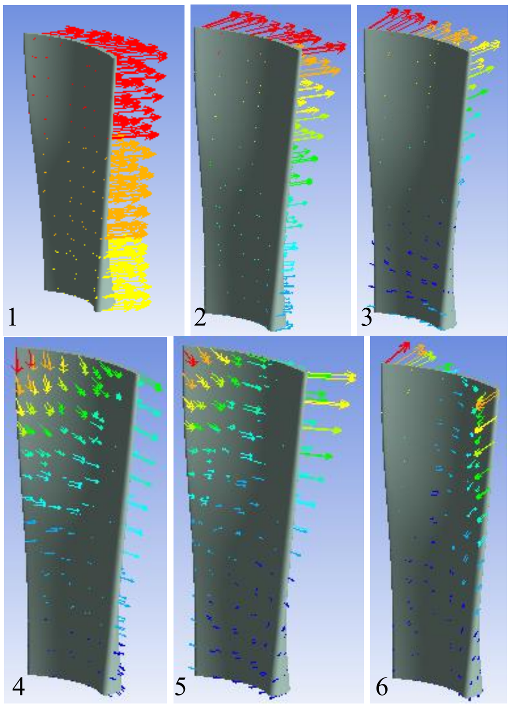

Fig. 5: The vibrational eigenmodes for the turbine blade with coating in a frequency range from 0 to 2700 Hz

For the turbine blade with deposited coating, the determined vibrational eigenmodes are presented in Fig. 5. These vibrational modes correspond to the frequencies presented in table 2.

Table 2: The specific frequency of each vibration mode for the blade with coating

Mode	Frequency [Hz]
1.	96,161
2.	532,23
3.	864,78
4.	1570,8
5.	1980,2
6.	2310,5

As can be seen from Fig. 4 and 5 the vibrational eigenmodes of the blade without coating and the ones of the blade with coating are very similar. From this fact we concluded that the presence of the deposited coating on the turbine blade has little influence on the vibrational eigenmodes of a turbine blade.

The vibrational eigenvalues of the turbine blades, or the frequencies at which the blade will enter in resonance if excited by a pulsation with the same frequency, are different due to the change in the stiffness of the blade. The deposited coating is responsible of this change due to the different material properties and the bonding forces that appear at the interface between the base material and the coating.

4. The response of the turbine blades under harmonic excitation

In the Harmonic Response module from Ansys 14.5, the turbine blades are subjected to an angular acceleration of 14,41 m/s^2. The blade accelerates in a rotation movement to the axis of the turbine stage shaft. The vibration amplitude varies with the increase of the excitation frequency. The maximum values of the amplitude are present in the blade enter in resonance. For the blade without coating the amplitude variation depending on the frequency is presented in Fig. 6. The amplitude picks correspond to the vibration eigenvalues determined previously (the frequency values at which the turbine blade will enter in resonance).

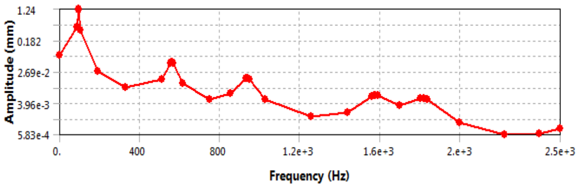

Fig. 6: The amplitude variation depending on frequency for the blade without coating

The entering in resonance of the turbine blade causes a phase angle change between the harmonic excitation and the vibrational eigenmode of the blade. The variation of the phase angle with increase of frequency is presented in Fig. 7.

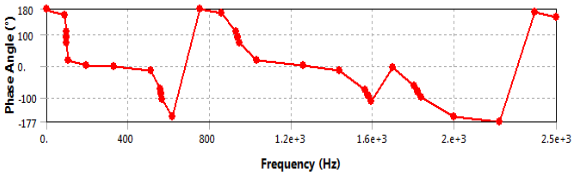

Fig. 7: The phase angle variation depending on frequency for the blade without coating

The stress distribution that appears on the turbine blades pressure side is presented in Fig. 8. The maximum stress value appears in the lower part of the blade in the area of the leading edge and the trailing edge. The maximum equivalent stress in this areas produced by vibration at a frequency of 96,103 Hz and at a phase angle of 89,908° has the value of 4,7 MPa. The damping coefficient had a value of 0,03 for this blade according to the material.

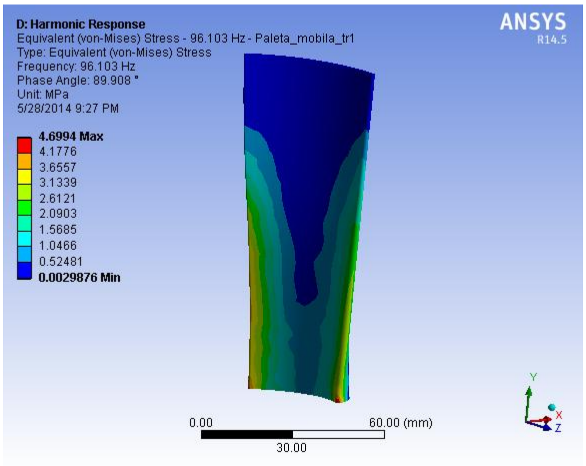

Fig. 8: The stress distribution on the pressure side of the blade without coating subjected to vibration

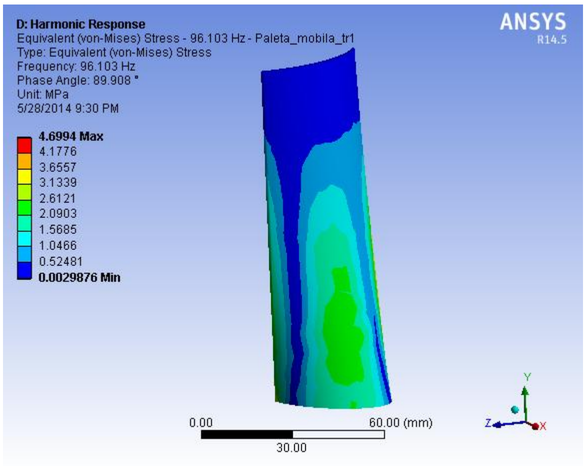

Fig. 9: The stress distribution on the suction side of the blade without coating subjected to vibration

The stress distribution on the suction side of the blade without coating, using the same parameters as on the pressure side, has a maximum value of 2,6 MPa. This value is located on the lower center of the suction side.

The presence of the ceramic coating changes the stiffness of the blade and also its damping coefficient. The blade with deposited coating had a damping coefficient of 0,06.

The variation of the vibration amplitude with the increase of the excitation frequency for the turbine blade with deposited coating is presented in Fig. 10. As in the previous case the amplitude picks show the frequency at which the turbine blade enters in resonance. The phase angle variation due to resonance and with the increase of frequency is showed in Fig. 11.

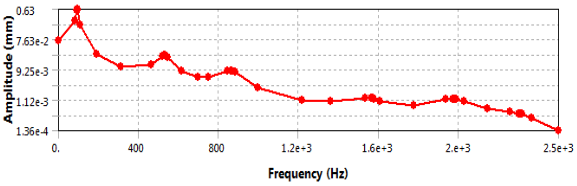

Fig. 10: The amplitude variation depending on frequency for the blade with deposited coating

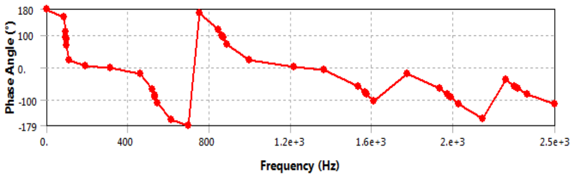

Fig. 11: The phase angle variation depending on frequency for the blade with deposited coating

At a frequency of 95,161 Hz and at a phase angle of 89,799º, parameters which coincide with the first vibrational eigenmode of the blade, the stress distribution on the pressure side of the turbine blade is presented in Fig. 12. The maximum equivalent stress caused by the vibration appears near the middle of the leading and trailing edges and has a value of 2,5 MPa.

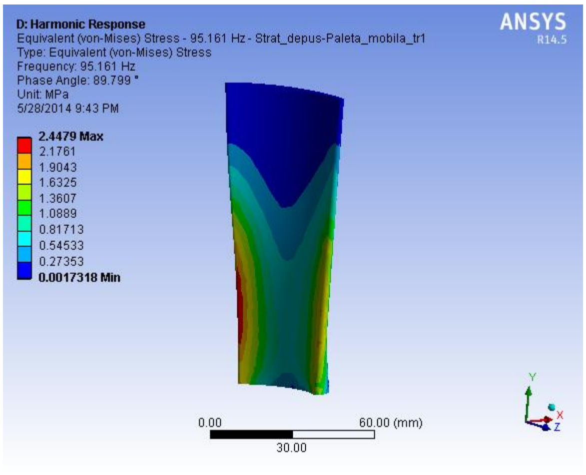

Fig. 12: The stress distribution on the pressure side of the blade with coating subjected to vibration

The stress distribution on the suction side of the turbine blade is presented in Fig. 13. The same frequency and phase angle parameters were used as on the pressure side. The maximum value of the stress appears on the center of the lower half of the section side. The value of the maximum stress is 2,2 MPa.

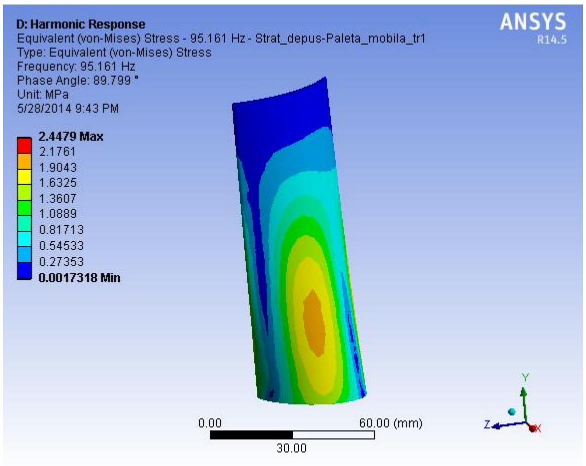

Fig. 13: The stress distribution on the suction side of the blade without coating subjected to vibration

The vibration amplitude decreases by applying a $ZrO_2/3\%Y_2O_3$ ceramic coating due to the increase of the damping coefficient of the turbine blade. This increase of the damping coefficient is caused by the porous nature of the deposited coating. The pores are produced due to the technological process of plasma spraying.

The decrease of the vibrational amplitude also leads to the decrease of the mechanical stress that appears in the turbine blades. The maximum stress obtained in the blade without coating is almost double then the stress that appears in the blade with a ceramic deposited coating (for the blade without coating the maximum stress has a value of 4,7 MPa and for the blade with coating has a value of the 2,5 MPa).

5. Conclusions

Even if the purpose of a ceramic deposited coating on a turbine blade is to obtain a thermal barrier which protects the base material of the blade and allows the turbine to function at a higher maximum cycle temperature, other benefits can be obtained. By increasing the damping coefficient of the blades, the vibrational amplitude at resonance decreases and the stress level that appears in the blade is much lower. These factors increase the life of the turbine blades (by lowering the stress level in transient regimes) and ensures a much safer service. The presence of the deposited coating has little influence on the eigenmodes and eigenvalues of the turbine blades.

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