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Design and Coupled Field Analysis of First Stage Gas Turbine Rotor Blades

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ABSTRACT

A gas turbine is a device designed to convert the heat energy of fuel into useful work such as mechanical shaft power. The gas turbine in its most common from is a rotary heat engine operating by means of series of processes consisting of air taken from the atmosphere increase of gas temperature by constant pressure combustion of the fuel the whole process being continuous. Turbine Blades are the most important components in a gas turbine power plant. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor. The turbine blades are mainly affected due to static loads. Also the temperature has significant effect on the blades. Therefore the coupled (static and thermal) analysis of turbine blades is carried out using finite element analysis software ANSYS. It was observed that in the preliminary design, the rotor blades after being designed were analyzed only for the mechanical stresses but no evaluation of thermal stress was carried out.

In this paper the first stage rotor blade of the gas turbine is created in CATIA V5 R17 software. The material of the blade is Ni-Cr alloys. This model has been analyzed using ANSYS11.0. The gas forces namely tangential, axial were determined by constructing velocity triangles at inlet and exist of rotor blades. The convective heat transfer coefficients were calculated using the heat transfer empirical relations taken from the heat transfer design dada book. After containing the heat transfer coefficients and gas forces, the rotor blade was then analyzed using ANSYS 11.0 for the couple field (static and thermal) stresses.

Keywords: Gas turbine blade**,** Structural and Thermal Analysis, Finite Element Analysis

1. INTRODUCTION

The gas turbine is a power plant, which produces a great amount of energy for its size and weight. The gas turbine has found increasing service in the past 40 years in the power industry both among utilities throughout the world. Its compactness, low weight and multiple fuel application make it a natural power plant. Today there are gas turbine, which runs on natural gas, diesel fuel, crude, vaporized fuel oils, and biomass gases. The last 20 years has seen a large growth in Gas Turbine Technology. Thus, with the increase in compressor pressure ratio there has been increased in the thermal efficiency from about 15% to over 45%. It is similar to petrol and diesel engines in working medium and internal combustion but is akin to the steam turbines in its aspect of the steady flow of the working medium. Turbine Blades are the most important components in a gas turbine power plant. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor.

2. DESCRIPTION

In this work static and thermal analysis of the first stage rotor blade of the gas turbine made of Ni-Cr alloys was carried out.

Table1. Material properties of Ni-Cr alloys (10% Chromium and 90% Nickel).

Material Properties	Magnitudes
Density	8900 Kg/m^3
Modulus of elasticity	206.84Gpa
Poisson's ration	0.33
Thermal expansion coefficient	1.340e^{-5}K
Thermal conductivity	90.7 W/m-K

3. MODELLING

With the dimensional parameters the gas turbine blade is first modeled using the CATIA V5 R17 software and then after it is going to be meshing and analysis is done using ANSYS software by converting the design in IGS software and imported to ansys for finding the stresses in the blade.

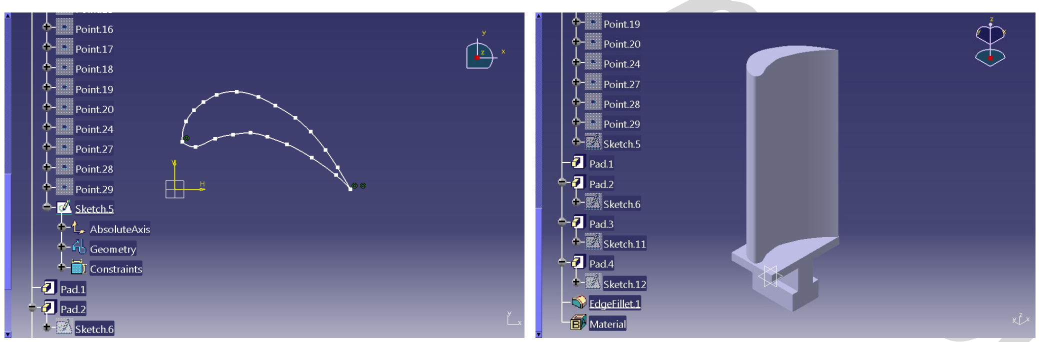

Fig.1: The geometric model of the Gas turbine blade using CATIA.

4. EVALUATION OF TANGENTIAL, AXIAL FORCE AND CENTRIFUGAL FORCE

The design features of the turbine segment of the gas turbine have been taken from the "Preliminary design of a power turbine for marinisation of as existing Turbo-jet engine. It was observed that in the above design, after the rotor blades being designed they were analyzed only for the mechanical stresses but there was no evolution of thermal stresses. As the temperature has a significant effect on the overall stresses in the rotor blades a detailed study is carried out on the thermal stresses. The first stage rotor blade of the gas turbine is analyzed for the mechanical stresses and the radial elongation resulting from the tangential, axial and centrifugal forces. The inlet velocity triangle and exit velocity triangles for the 1st stage rotor blade is shown in figure

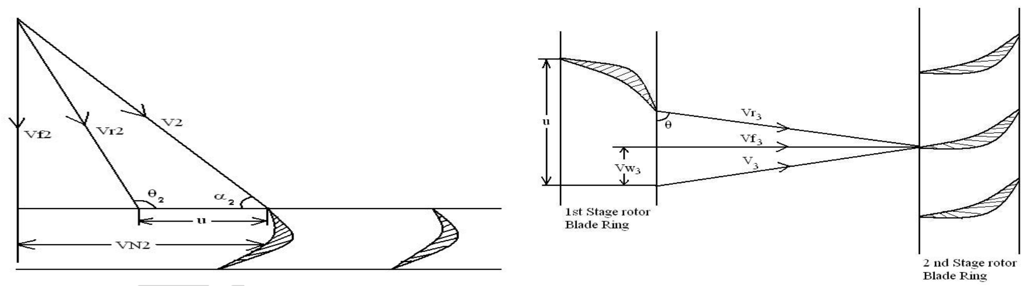

Fig.2: The inlet velocity triangle and exit velocity triangles for the 1st stage rotor blade

The gas forces namely tangential and axial were determined by constructing velocity triangles at the inlet and exit of the rotor blades. For obtaining the temperature distribution, the convective heat transfer coefficients on the blade surface exposed to the gases are fed into the software. The radial elongations in the blades are also calculated temperature distributions and elongations are evaluated at several sections in the rotor blade.

Evaluation of tangential (Ft), axial force (Fa) and centrifugal force (Fc) on each rotor:

Tangential Force $Ft = m\,[Vf_2 + Vf_3]$ Newton

Axial Force $Fa = m\,[V_{w2} + V_{w3}]$ Newton

Where m is the mass flow rate of gases through the turbine Kg/s

m = 70.925 Kg/s

Total axial force on first stage rotor

Fa = 458.88 N

Total tangential force on first stage rotor

Ft = 29783.88 N

Number of blades passages in first rotor =120

Tangential force on each rotor blade,

Ft = Ft / No of Blade passages

Ft = 248.199 N

Axial force on each rotor blade,

Fa = Fa / No of Blade passage

Fa = 3.82 N.

Ft = 248.199 N, Fa = 3.82 N.

From Euless's energy equation, Power developed in the first stage rotor

$P = m [Vw_2 +/- Vw_3 3] U$

The distance $X= (M_1X_1+M_2X_2+M_4X_3)/M_1+M_2+M_3$

Where M_1, M2, and M_3 are masses of volumes 1, 2 and 3 from the axis of revolution.

Total mass $M = M_1+M_2+M_3$

Centrifugal force $Fc = M^* (2\pi n/60)^{2*} X$ and its value is found to be as 38038.733N

Fc=38038.733N

For first stage rotor blades,

Temperature of gases at inlet Ti = 839.22

Temperature of gases at exist Te = 732.88

Mean fluid temperature Tmf =Ti-Te/2

Nud is found to be as 247.329

Nud = hs D/K so $h_s = 379.921\ W/m^2K$

5. COUPLED FIELD ANALYSIS OF FIRST STAGE GAS TURBINE ROTOR BLADES

On blades we perform Coupled-field analysis. The Coupled-field Analysis is:

1. Static Analysis.
2. Thermal Analysis.

5.1 Static Analysis

Static analysis was carried out to know the mechanical stresses and elongation experienced by the gas turbine rotor blades, which includes the parameters such as the gas forces are assumed to be distributed evenly, the tangential and axial forces act through the centroid of the blade. The centrifugal force also acts through the centroid of the blade and in the radial direction.

Tangential forces (Ft) = 248.199 N
Axial force (Fa) = 3.82 N
Centrifugal force (Fc) = 38038.73 N

5.2 Thermal Analysis

Thermal analysis was carried out to know the thermal stresses such as the temperature distribution, thermal gradients and thermal fluxes of the gas turbine rotor blades. Thermal analysis plays an important role in the designing of many components such as heat exchangers, turbines, internal combustion engines and piping systems. Heat flux equal to zero was applied on the areas of base and top of the blade. Both sides of the base of the blade comes in contact with similar areas were assumed to be insulated. In the convection boundary condition, convection heat transfer coefficient and temperature of the surrounding gases (T) have to be specified on the areas subjected to convection.

RESULTS

Table 2. Static Analysis Results

SOLUTION	STRUCTURAL
Deformation in X-direction	-0.003 to 0.04
Deformation in Y-direction	-0.0075 to 0.0977
Deformation in Z- direction	0.0413 to 0.0438
Stress in X-direction	-1708 to 2301
Stress in Y-direction	-2505 to 2557
Stress in Z- direction	-8820 to 5096

Table 3. Thermal Analysis Results

SOLUTION	THERMAL
Temperature Gradient in X direction	-966.402 to 256.194
Temperature Gradient in Y direction	-300.437 to 73.37
Temperature Gradient in Z direction	-31.519 to 31.719
Heat flux in X direction	-5043 to 19038
Heat flux in Y direction	-1445 to 5919
Heat flux in Z direction	-626.287 to 620.99
Temperature Distribution	1006 to 1112

The following figures from fig.3 to fig.8 shows the Static Results such as maximum Deformation induced in X, Y and Z directions and maximum stress induced in X, Y and Z directions

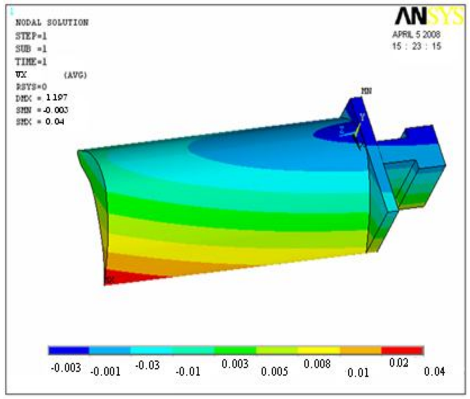

Fig.3: The Deformation in X-direction

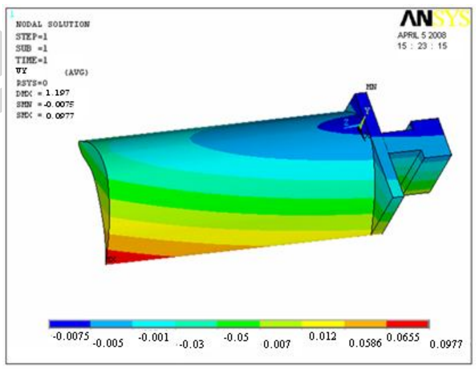

Fig.4: The Deformation in Y-direction

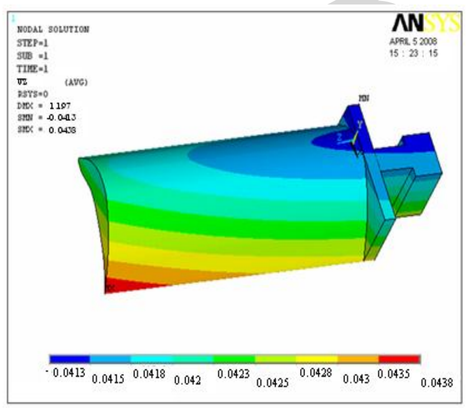

Fig.5: The Deformation in Z- direction

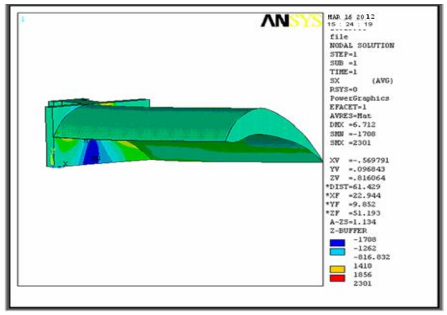

Fig.6: The Stress in X-direction

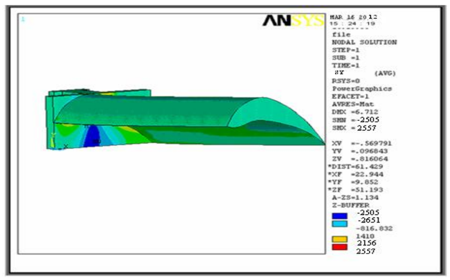

Fig.7: The Stress in Y-direction

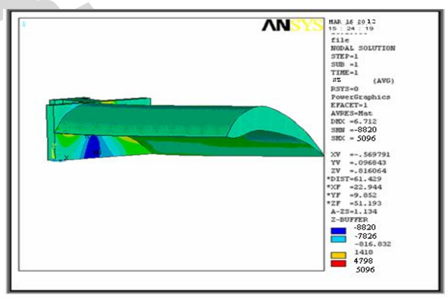

Fig.8: The Stress in Z- direction

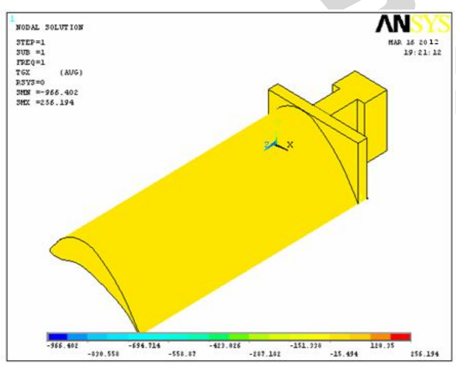

Fig.9: The Temperature Gradient in X direction

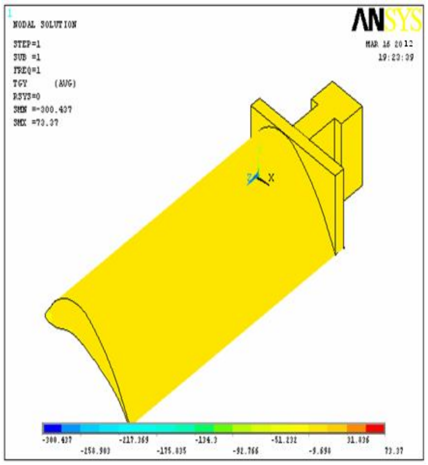

Fig.10: The Temperature Gradient in Y direction

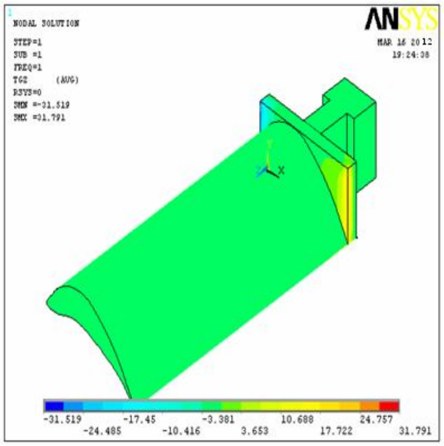

Fig.11: The Temperature Gradient in Z direction

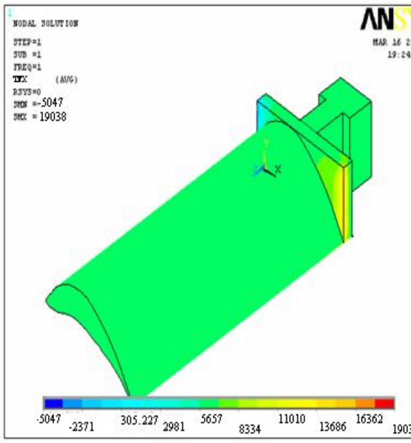

Fig.12: The Heat flux in X direction

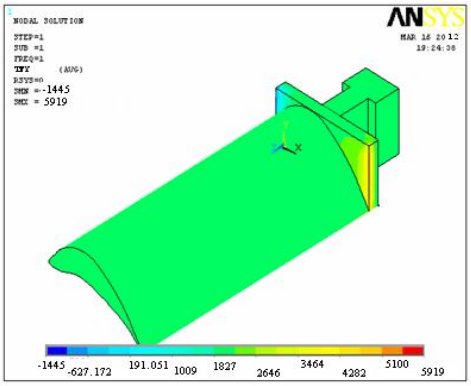

Fig.13: The Heat flux in Y direction

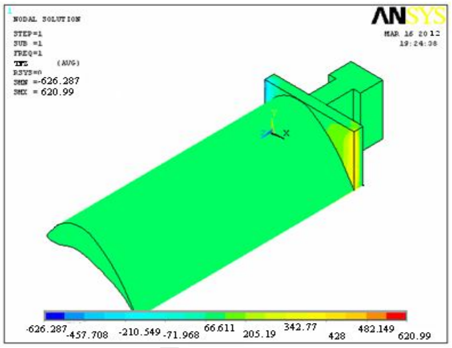

Fig.14: The Heat flux in Z direction

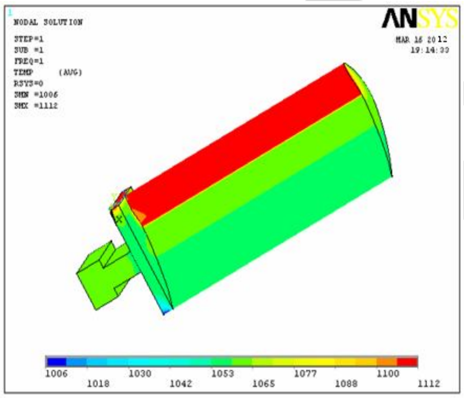

Fig.15: The Temperature Distribution

The above figures from fig.9 to fig.15 shows the Thermal Results such as maximum Temperature Gradient in X, Y and Z directions and Heat flux in X, Y and Z directions

CONCLUSIONS

The following conclusions are drawn from the present work.

1. The maximum Deformation induced in X, Y and Z directions are 0.04, 0.0977 and 0.0438mm
2. The maximum stress induced in X, Y and Z directions are 2301, 2557 and 5096 Pa
3. The maximum Temperature Gradient in X, Y and Z directions are 256.19, 73.3and31.71 K/m
4. The maximum Heat flux in X, Y and Z directions are 19038, 5919 and 620.99 W/m^2

The structural and thermal analysis is carried out. From the Work the Maximum stress induced is within safe limit. Maximum stresses are observed at the root of the turbine blade and upper surface along the blade roots. So it can be suggested that Design and Analysis of Blade is Safe. This information will supplement to optimize the mechanical design of the rotor blades for power turbines.

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