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Design and Analysis of Gas Turbine Blade

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***Abstract**:*

Gas turbines have an important role in electric power generation. Gas turbine technology is used in a variety of configurations for electric power generation. Turbine rotor blades are the most important components in a gas turbine power plant. Turbine blades are mainly affected due to static loads. Also the temperature has significant effect on the gas turbine rotor blades. This paper summarizes the design and steady state thermal analysis of gas turbine rotor blade, on which Cosmon software is used for deign of solid model of the turbine blade. ANSYS14.5 software is used for analysis of finite element model generated by meshing of the blade and design calculation is computed by using MATLAB software. The materials of the gas turbine rotor blade are chosen as copper, titanium and nickel. The existing turbine blade material is copper. The gas turbine rotor blade height is 0.0826m, rotor blade chord is 0.0645m, rotor blade thickness is 0.0129m and the numbers of gas turbine rotor blade are 92 blades. The gas turbine rotor blade inlet temperature is 1622°C and rotor blade outlet temperature is 1478°C. Total thermal heat flux of theoretical result for copper is 2.6453MW/, for titanium is 0.9927MW/m2 and for nickel is 1.9559MW/m2. Simulation result of total thermal heat flux for copper is 3.0060MW/m2, for titanium is 1.1503MW/m2 and for nickel material is 2.1810MW/m2. According to the comparison of the theoretical result and simulation result, titanium material has the least heat flux. So this material is better than the two other materials.

Keywords

Keywords Ansys14.5, Cosmo, gas turbine, rotor blade, steady state thermal 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.

The objective of this study is to design for the gas turbine rotor blade. The specification data for open cycle gas turbine is obtained from 'Ahlone Power Station', Yangon Division in Myanmar. The gas turbine is normally operating in high pressure and its rotor blades are contacting gas with extremely high temperature. 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.

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2. DESIGN PROCEDURE OF GAS TURBINE ROTOR BLADE

Figure 1 shows the open cycle gas turbine in power station. Gas turbine consists of three main components. These are compressor, combustion chamber and turbine. The compressor that is used to compress the air, and then the compressed air enters into the combustion chamber with high pressure. In the combustor, the fuel and air are mixed and burnt. After that, the combustion gases are entered into the turbine. The turbine expands the gases and exhaust to the atmosphere.

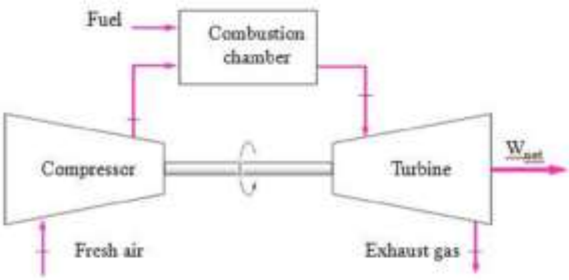

Fig1. Open cycle gas turbine

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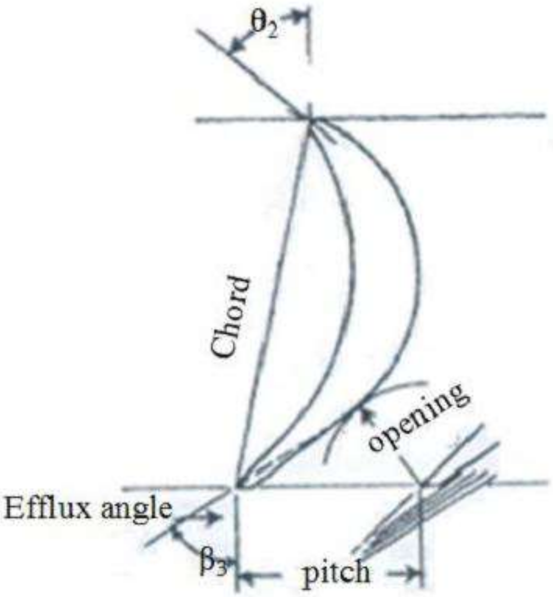

Fig2. Conventional blade profile of rotor blade

In this paper, the blade profile is symmetrical about the centre line. It has a thickness /chord ratio t/c is 0.2, a leading edge radius is 12%thickness and a trailing edge radius is 6%thickness. When scaled up to a t/c is 0.2 and used in conjunction with a parabolic camber line having the point of maximum camber a distance of about 40% chord from the leading edge, the blade profile leads to a blade section similar to that shown but with a trailing edge. All such blade profiles may be referred to as conventional blade profiles. The rotor blade is divided into three equal sections. These are root section, mean section and tip section. To design the turbine rotor blade, the blade speed at mean radius can be calculated

In this work, the steady state thermal analysis of the gas turbine rotor blade is made of copper, titanium and nickel materials were carried out.

TABLE I
Material properties of Copper

Material Properties	Value	Units
Density	8900	kg/m^3
Modulus of elasticity	110	GPa
Poisson's ratio	0.37	-
Thermal expansion coefficient	2.40e-5	/K
Heat capacity	300	J/kg-K
Thermal conductivity	400	W/m-K
Allowable temperature	2000	°K

TABLE II
Material properties of Titanium

Material Properties	Value	Units
Density	4510	kg/m^3
Modulus of elasticity	105	GPa
Poisson's ratio	0.33	-
Thermal expansion coefficient	0.90e-5	/K
Heat capacity	280	J/kg-K
Thermal conductivity	22	W/m-K
Allowable temperature	2100	°K

TABLE III
Material properties of Nickel

Material Properties	Value	Units
Density	8500	kg/m^3
Modulus of elasticity	790	GPa
Poisson's ratio	0.31	-
Thermal expansion coefficient	1.70e-5	/K
Heat capacity	360	J/kg-K
Thermal conductivity	90	W/m-K
Allowable temperature	2050	°K

B. Modelling

Figure 4 shows the first stage gas turbine rotor blade profile. Gas turbine have used this profiles which is specified by air foil terminology. With the dimensional parameters of the gas turbine rotor blade is modeled by using the Cosmo software.

Fig4. First stage turbine rotor blade profile

TABLE IV
RESULTS OF TURBINE FIRST STAGE ROTOR BLADE PROFILE

Symbol	Value	Units
U_{m1}	343.8615	m/sec
α_{2r}	65.5731	deg
β_{2r}	45.2708	deg
α_{2t}	63.5179	deg
β_{2t}	34.9727	deg
α_{3r}	39.3237	deg
β_{3r}	63.3089	deg
α_{3t}	35.7720	deg
β_{3t}	64.0034	deg
θ_{2r}	40.2708	deg
θ_{2t}	44.9727	deg
h_{S1}	0.0595	m
h_{R1}	0.0826	m
n_{S1}	124	blades
n_{R1}	92	blades
w_{R1}	0.0275	m
t_{R1}	0.0129	m

C. Evaluation of total thermal heat fluxes

The gas turbine rotor blade is analysed for the temperature distributions and total thermal heat fluxes.

Turbine rotor blade inlet temperature is 1895°K and turbine rotor blade outlet temperature is 1751°K. When the turbine rotor blade is subjected to heat flux and so the Nusselt number is given by,

$$Nu = 0.664Re^{0.5}Pr^{1/3}$$

Reynlods number is less than 5×105. Prandtl number for gas is between 0.7 and 1. Conduction heat flux is governed by Fourier's Law,

$$q''_x = -k\frac{\partial T}{\partial x}$$

Convection heat flux is defined by film coefficient h, and the difference between the surface temperature Ts and ambient temperature Tα.

$$q''_{conv} = h(T_\alpha - T_s)$$

Therefore, the total heat flux for the gas turbine rotor blade is defined by the combination of conduction heat flux and convection heat flux.

$$q''_t = q''_{cond} + q''_{conv}$$

TABLE V
RESULTS OF TOTAL THERMAL HEAT FLUXES

Type of material	Parameter	Symbol	Value	Units
Copper	Total thermal heat flux	q_t''	2.6453	MW/m^2
Titanium	Total thermal heat flux	q_t''	0.9927	MW/m^2
Nickel	Total thermal heat flux	q_t''	1.9559	MW/m^2

III. STEADY STATE THERMAL ANALYSIS

Steady state thermal analysis is used to determine the temperature distribution and total thermal heat fluxes. The finite element analysis for steady state thermal analysis of gas turbine rotor blade is carried out by using ANSYS 14.5 software. Figure 7 shows the meshing of the first stage gas turbine rotor blade profile.

Fig Meshing of first stage rotor blade

The steady state thermal analysis shows that the temperature distributions and the heat fluxes for the gas turbine rotor blade. Figure 8 shows the temperature distribution of gas turbine rotor blade for copper material. In this figure, the maximum temperature is observed at the leading edge surface and minimum temperature is observed at trailing edge surface of the rotor blade.

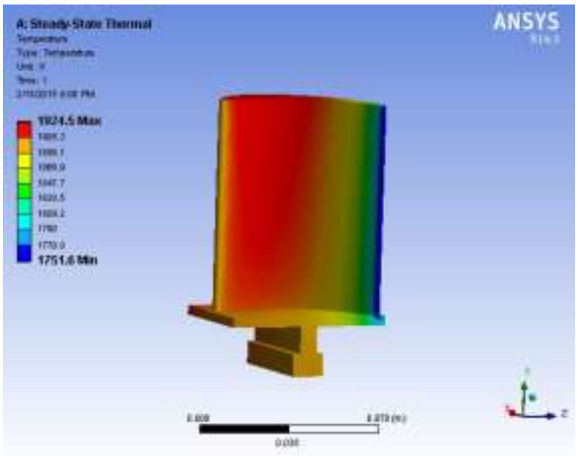

Fig8. Temperature distribution (for copper)

The total thermal heat flux for copper material is shown in Figure 9. In this figure, the maximum total thermal heat flux is along at the trailing edge surface and minimum total thermal heat flux is seen at the leading edge surface of the rotor blade.

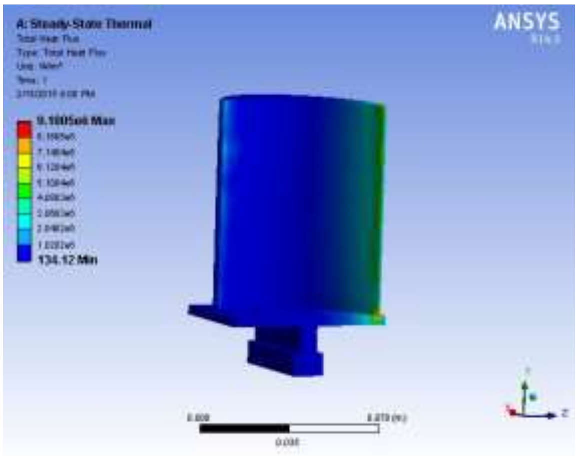

Fig9. Total thermal heat flux (for copper)

For titanium material, the temperature distribution is shown in Figure 10 and total thermal heat flux is shown in Figure 11. In Figure 10, the highest temperature value is seen near at the leading edge surface and the lowest temperature value is seen at the trailing edge surface of the rotor blade.

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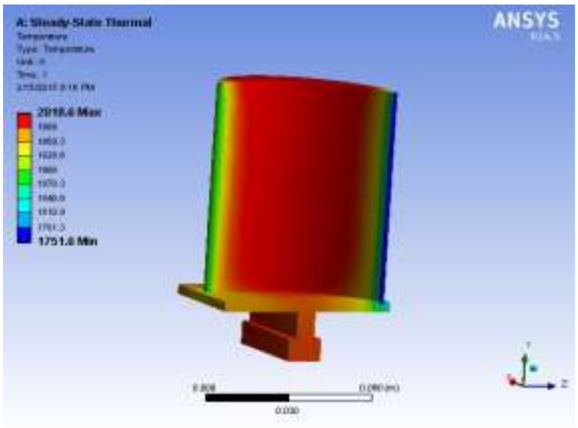

Fig10. Temperature distribution (for titanium)

In Figure 11, the maximum total thermal heat flux is along at the trailing edge surface and minimum total thermal heat flux is seen at the leading edge surface of the rotor blade.

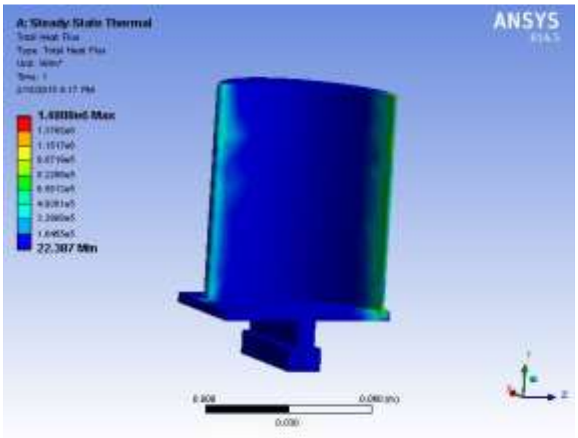

Fig11. Total thermal heat flux (for titanium)

Figure 12 shows the temperature distribution for nickel material. The maximum temperature is observed at the leading edge surface and minimum temperature is observed at trailing edge surface of the rotor blade.

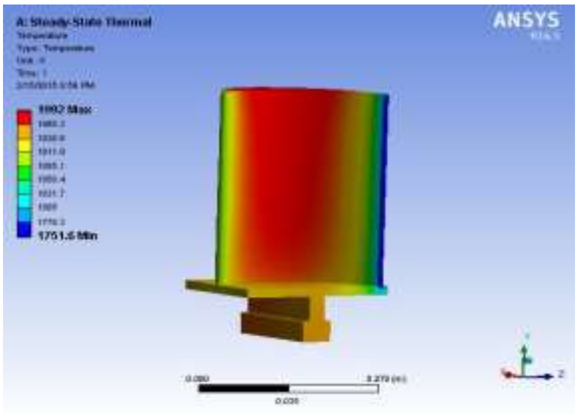

Fig12. Temperature distribution (for nickel)

The total thermal heat flux for nickel material is shown in Figure 13. The maximum total thermal heat flux is along at the trailing edge surface and minimum total thermal heat flux is seen at the leading edge surface of the rotor blade.

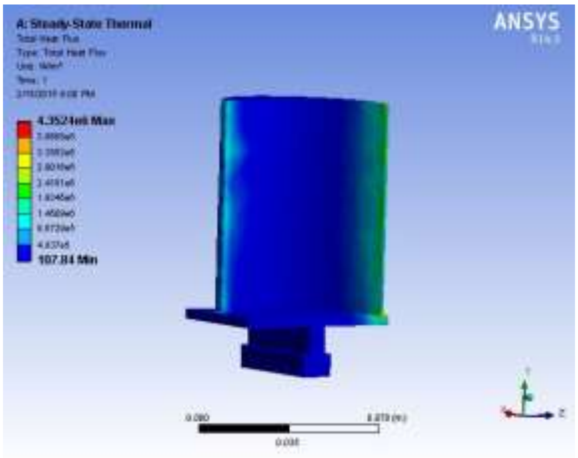

Fig13. Total thermal heat flux (for nickel)

TABLE VI
COMPARISON OF THEORETICAL AND SIMULATION RESULTS

Symbols	Theoretical results	Simulation results	Deviation
q_t (for copper)	2.6453 MW/m²	3.0060 MW/m²	11..99%
q_t (for titanium)	0.9927 MW/m²	1.1503 MW/m²	13.01%
q_t (for nickel)	1.9559 MW/m²	2.1810 MW/m²	10.32%

IV. RESULTS AND DISCUSSION

The finite element analysis for steady state thermal analysis of gas turbine rotor blade is carried out using ANSYS 14.5 software. The temperature has a significant effect on the overall turbine blades. The temperature distribution is analyzed for three different materials. The titanium material shows high withstanding in temperature 2018.6°K. And also by comparing the other two materials the temperature for copper material is 1924.5°K and for nickel material is 1992°K. The analysis results of the temperature distribution of the three materials are not exceeded their allowable temperatures. The values of total thermal heat fluxes for materials are depend upon the thermal conductivity and convection heat transfer coefficient of the material. In this steady state thermal analysis result, the total thermal heat flux for titanium is the least value. So titanium material gives better result than the two other materials.

V. NOMENCLATURE

E	Young's Modulus
N	Speed of Turbine in RPM
U_{m1}	Blade speed
h_{S1}	Stator blade height
h_{R1}	Rotor blade height
D_{t1}	Rotor blade tip diameter
r_{t1}	Rotor blade tip radius
n_{S1}	Number of stator blades
n_{R1}	Number of rotor blades
w_{R1}	Rotor blade width
t_{R1}	Rotor blade thickness
ρ_b	Rotor blade density
ω	Angular velocity
A_t	Rotor blade tip area
A_r	Rotor blade root area
r_r	Rotor blade root radius
r_t	Rotor blade tip radius
z	Section modulus
Nu	Nusselt number
Pr	Prandtl number

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