FILM COOLING OF TURBINE BLADE SURFACE WITH EXTENDED EXIT HOLES

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ABSTRACT

Gas turbines are extensively used for air craft propulsion, land based power generation and industrial applications. The current rotor inlet temperature in advanced gas turbine is for above the melting point of blade material. A sophisticated cooling scheme must be developed for continuous safe operation of gas turbines with high performance. The techniques that involve to cool the blades and vanes by using cooling methods is to have radial holes to pass high velocity cooling air along the blade span. The turbine blade is designed with no holes, 5 holes, 9 holes, 13 holes. CFD analysis is done to determine the pressure distribution, velocity, temperature distribution and heat transfer rate by applying the inlet velocities. Thermal analysis is done to determine the heat transfer rates of the blade. The present used material for blade is chromium steel. In this thesis, it is replaced with Inconel 718. The better material for blade is analyzed.

Key words: Materials, Turbine blades, Chromium steel, INCONEL-718, Blades with 5,8,13 holes, Pressure, Velocity, Heat transfer.

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1. INTRODUCTION

A turbine blade is the individual component which makes up the turbine section of a gas turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings.

Turbines components must operate under a variety of stress, temperature, and corrosion conditions. Compressor blades operate relatively low temperatures but are highly stressed. The combustor operates at a relatively high temperature and low-stress conditions. The turbine blades operate under extreme conditions of stress, temperature, and corrosion.

The extreme conditions of stress, temperature and corrosion make the gas turbine blade a material challenge. In the 1980s, IN 738 blades were widely used. IN-738, was the acknowledged corrosion standard for the industry. New alloys, such as GTD-111 possesses about a 35°F (20°C) improvement in rupture strength as compared to IN-738. GTD-111 is also superior to IN-738 in low-cycle fatigue strength.

The design of this alloy was unique in that it utilized phase stability and other predictive techniques to balance the levels of critical elements (Cr, Mo, Co, Al, W and Ta), thereby maintaining the hot corrosion resistance of IN-738 at higher strength levels without compromising phase stability.

Convection cooling works by passing cooling air through passages internal to the blade. Heat is transferred by conduction through the blade, and then by convection into the air flowing inside of the blade. A large internal surface area is desirable for this method, so the cooling paths tend to be serpentine and full of small fins.

The second major type of cooling is film cooling (also called thin film cooling). This type of cooling works by pumping cool air out of the blade through small holes in the blade. This air creates a thin layer (the film) of cool air on the surface of the blade, protecting it from the high temperature air. The air holes can be in many different blade locations, but they are most often along the leading edge.

2. 3D MODELING OF GAS TURBINE BLADES

3D MODELING OF GAS TURBINE BLADES

Figure 1 Without Holes

Figure 2 With 5 Holes

Figure 3 Drafting of 5 holes

Figure 4 With 9 Holes

Figure 5 Drafting of 9 holes

Figure 6 With 13 Holes

Figure 7 Drafting of 13 holes

2.1 Analysis of Film Cooling of Turbine Blade Surface with Extended Exit Holes

Material properties are taken from the matweb.com

Table 1 Materials values

Sl.No	Materials	Thermal conductivity (w/m-k)	Temperature (K)
01	Chromium Steel	11.2	$619.15^{\circ}\text{C} + 273 = 892.15\text{k}$
02	Inconel 718	24.90	892.15k

CFD ANALYSIS

Boundary Conditions

For CFD analysis input Parameters are

Velocity = 277.16 m/s

Temperature = 300 K

2.2. Without Holes

Figure 8 : Imported Model

Figure 9 : Mesh Model

SPECIFYING BOUNDARIES FOR INLET AND OUTLET

Figure 10 Inlet

Figure 11 outlet

Figure 12 Graph of velocities

Figure 13 Pressure

Figure 14 Velocity

Figure 15 Temperature

Figure 16 Heat Transfer Coefficient

Total Heat Transfer Rate (w)

inlet	63215.273
outlet	-63444.215
wall-_trm_srf	0
Net	-228.94141

2.3 5 HOLES

Figure 17 Imported Model

Figure 18 Meshed model

Figure 19 Inlet

Figure 20 Outlet

Figure 21 Pressure

Figure 22 Velocity

Figure 23 Temperature

Figure 24 Heat Transfer Coefficient

Total Heat Transfer Rate (w)	

inlet	63215.273
outlet	-63168.352
wall-_trm_srf	0

Net	46.921875

2.4 9 HOLES

Figure 25 Imported Model

Figure 26 Meshed model

Figure 27 Inlet

Figure 28 Outlet

Figure 29 Pressure

Figure 30 Velocity

Figure 31 Temperature

Figure 32 Heat Transfer Coefficient

Total Heat Transfer Rate	(w)
inlet	63215.273
outlet	-63220.566
wall-_trm_srf	0
Net	-5.2929688

2.5 13 HOLES

Figure 33 Imported Model

Figure 34 : Meshed model

Figure 35 Inlet

Figure 36 Outlet

Figure 37 Pressure

Figure 38 Velocity

Figure 39 Temperature

Figure 40 Heat Transfer Coefficient

Total Heat Transfer Rate (w)

inlet	63215.273
outlet	-63220.566
wall-_trm_srf	0
Net	-5.2929688

3. THERMAL ANALYSIS

3.1. Without Holes

MATERIAL - CHROMIUM STEEL

Figure 41 Imported

Figure 42 Mesh

Figure 43 Temperature

Figure 44 Convection

Figure 45 Temperature

Figure 46: Heat flux

INCONEL 718

Figure 47 Temperature

Figure 48 Heat flux

3.2. With 5 Holes

Chromium Steel

Figure 49 Imported

Figure 50 Meshed Model

Figure 51 Temperature

Figure 52 Convection

Figure 53 Temperature

Figure 54 Heat flux

INCONEL 718

Figure 55 Temperature

Figure 56 Heat flux

3.3. With 9 Holes

Chromium Steel

Figure 57 Imported

Figure 58 Meshed Model

Figure 59 Temperature

Figure 60 Convection

Figure 61 Temperature

Figure 62 Heat flux

INCONEL 718

Figure 63 Temperature

Figure 64 Heat flux

3.4. With 13 holes

Chromium steel

Figure 65 Imported

Figure 66 Meshed Model

Figure 67 Temperature

Figure 68 Convection

Figure 69 Temperature

Figure 70 Heat flux

INCONEL 718

Figure 71 Temperature

Figure 72 Heat flux

RESULTS TABLE

CFD ANALYSIS

Table 1.1 CFD analysis results for blade with no holes, 5, 9, 13 holes

	Pressure (Pa)	Velocity (m/s)	Temperature (K)	Heat Transfer Coefficient (W/m ² -K)	Total Heat Transfer Rate(W)
Without holes	7.93e+04	5.79e+02	3.00e+02	2.50e+03	228.94141
With 5 holes	1.17e+05	5.94e+02	3.00e+02	2.61e+02	46.921875
With 9 holes	1.15e+05	5.85e+02	3.00e+02	2.64e+02	5.2929688
With 13 holes	1.15e+05	5.85e+02	3.00e+02	2.64e+02	5.2929688

GRAPHS

Figure 73 Comparison of pressure values for all models

Figure 74 Comparison of velocity values for all models

Figure 75 Comparison of temperature values for all models

Figure 76 Comparison of heat transfer coefficient values for all models

Figure 77 Comparison of total heat transfer rate values for all models

THERMAL ANALYSIS

Table 1.2 Thermal analysis results for blade with no holes, 5, 9, 13 holes

	Temperature min (K)		Heat Flux (W/mm ²)	
	Inconel 718	Chromium Steel	Inconel 718	Chromium Steel
Without holes	892.15	892.15	6.6267	12.979
With 5 holes	892.15	892.15	5.4545	10.744
With 9 holes	892.15	892.15	5.6263	11.171
With 13 holes	892.15	892.15	6.1293	12.122

GRAPHS

Figure 78 Comparison of temperature values of different materials for all models

Figure 79 Comparison of heat flux values of different materials for all models

4. CONCLUSION

The turbine blades are designed using cooling holes. The turbine blade is designed with no holes, 5 holes, 9 holes, 13 holes.

CFD analysis is done to determine the pressure distribution, velocity, temperature distribution and heat transfer rate by applying the inlet velocities.

By observing the CFD analysis results, the temperature and velocity are less for 8 holes and pressure is more.

Thermal analysis is done to determine the heat transfer rates of the blade. The present used material for blade is chromium steel. In this thesis, it is replaced with Inconel 718. The better material for blade is analyzed.

By observing the thermal analysis results, the heat transfer rate is more for Rene 77 and by using 8 holes.

So from the above two analysis it can be concluded that providing 8 holes for Rene 77 is better.

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