Heat Transfer Analysis of Turbine Blade Cooling using Ribbed Passages through CFD Simulations

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***Abstract* - Gas turbines convert from Thermal energy into Mechanical energy. It is a type of internal combustion engine, generally used in ships, power aircraft, trains, generators, and tanks. The equipment consists of an upstream compressor coupled with a turbine at the rear end, with a combustor in between. Atmospheric air flowing into the compressor is brought at a higher pressure. The addition of Heat energy to the high-pressure air by spraying it with fuel in the combustor section, thus igniting it and producing a high-temperature flow. The thermal efficiency of the gas turbine is directly proportional to the turbine inlet temperature. Today the combustion and turbine technology has improved to such an extent that the operating temperature at the turbine inlet is higher than the melting temperature of the turbine material. Different techniques are used to cope with this problem. One of the most commonly used methods is internal cooling of turbine blades. Conventionally air from the compressor is used for this purpose but due to higher heat capacity, steam can be used as coolant. This increases the possibility to increase the gas temperature. In case of a combined cycle power plant, the availability of steam provides a good opportunity to be used as coolant. This thesis presents computational fluid dynamics based numerical work concentrated on the flow and heat transfer on two pass rectangular channels with and without rib tabulators. The effect of variation in the Aspect ratio was studied for these channels. Their effect on heat transfer was studied for smooth as well as ribbed channels. The result show that for a smooth channel the reduction in width of the inlet pass does not affect the heat transfer enhancement at the inlet and outlet pass regions. In case of ribbed channels, heat transfer decreases at the tip and bend bottom with decrease in width of the inlet pass.**

INTRODUCTION

The primary goal in the design of gas turbines is the improvement of the cooling efficiency in internal cooling passages. For higher turbine inlet temperature, Higher cooling efficiency is required and also increased specific power and higher overall thermal efficiency. It is then clear that a better understanding of heat transfer processes in internal cooling channels is beneficial in the improvement of cooling designs

The purpose of the current study is to investigate the effects of rib tabulators and 180 deg bends in cooling channels with differing divider to tip wall distance. Actual blade geometries often employ cooling channels with differing divider to tip wall distance dependent on the location of the cooling channels. It is, thus important to understand the effects of changing divider to tip wall distance on heat transfer performance. Gas turbines are used to convert thermal energy into mechanical energy. The thermal efficiency of the gas turbine is directly related to the turbine inlet temperature. The combustion and turbine technology has improved to such an extent that the operating temperature in the turbine inlet is higher than the melting temperature of the turbine material. Different techniques are used to cope with this problem. One of the most commonly used methods is internal cooling of turbine blades. Conventionally air from the compressor is used for this purpose but due to higher heat capacity, steam can be used as coolant. This opens up the possibility to increase the gas temperature. In this case of a combined cycle power plant, its availability provides a good opportunity to be used as coolant. This thesis presents computational fluid dynamics based numerical work concentrated on the flow and heat transfer on two pass rectangular channels with and without rib tabulators. The effect of variation in the divider to tip wall distance was studied for these channels. Their effect on heat transfer was studied for smooth as well as ribbed channels. The result show that for a smooth channel the reduction in width of the inlet pass does not affect the heat transfer enhancement at the inlet and outlet pass regions. In case of ribbed channels, heat transfer decreases at the tip and bend bottom with decrease in width of the inlet pass.

It is thus important to understand the effects of changing divider to tip wall distance on heat transfer performance [1]internal flow applications and applied for the investigation of heat transfer problems in gas Turbine components. [2] prediction method for the blade temperature, based on reverse engineering. [3] newly designed coolant passage shapes such as Four star tip (4ST), Four star smooth(4SS), Five star tip(5ST), Five star smooth(5SS), Hexagon tip(HT), Hexagon smooth(HS). [4] heat transfer ppoblems encountered in the cooling jet engine turbine blades with internal cooling only. [5] The flow and performance quantities predicted using the mean line loss model code and 2/3D Navier-strokes equations adopted in numerical simulation showed reasonable agreement. The results provided by the comparison of flow parameters, such as Mach number and total pressure showed good agreement. This concludes that the 3D CFD results are consistent with mean line analysis used in the conceptual design of the Turbine in study.

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METHODOLOGY

Conventionally Two pass channels are used to model the cooling passages inside a gas turbine blade. ANSYS ICEM_CFD was used to create geometries as well as to generate the unstructured mesh. ANSYS CFX was used to solve the numerical problem. The realizable k-e turbulence model with enhanced wall treatment was applied for turbulence modeling. The Nusselt number is based on the hydraulic diameter at the inlet of the channel. To study the effect of the bend and augmentation devices in the channel, the Dittus-Boelter correlation is been used to normalize the Nusselt number in the current study and is defined as

$$Nu_0 = 0.02Re^{0.8}\,Pr^{0.4}$$

The boundary conditions at the inlet of the channel, the flow condition is assumed to be fully developed. In order to apply a fully developed flow boundary condition, at the inlet of the two pass channel, velocity, temperature and turbulence profiles were mapped from the outlet of a periodic segment to the inlet of two pass channel. This periodic segment ensures that the flow is fully developed. The inlet mass flow rate of the periodic segment corresponds to the Reynolds number of 100000 with the inlet temperature of 310k. Turbulence intensity of 3.8% was used at the inlet. This was calculated by the relationship provided by

$$I = 0.16Re^{-1/8}$$

All walls were kept at a constant temperature of 350k.symmetry was taken at the top, which reduces the computational effort. Ambient conditions were set at the outlet. The flow is considered incompressible, three dimensional, turbulent and steady with constant thermodynamic properties. The working fluid is dry air with prandtl number equal to 0.71

Description of the physical model

1. **Two pass rectangular smooth channel**

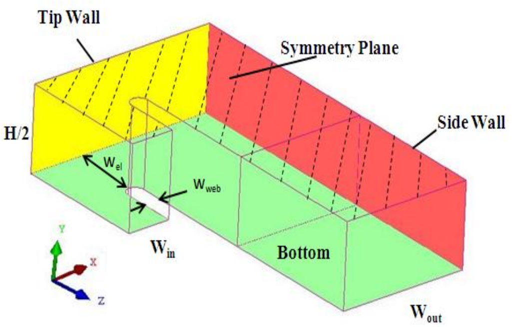

Fig. Rectangular Two Pass Smooth Channel.

A schematic geometrical model of the smooth two pass channel used in the study is as shown in fig. due to symmetry, only half of the plane is simulated. The inlet pass of the model as an aspect ratio (AR_{in} = W_{out}/H) of 1:3.5, while the outlet pass is a square channel having (AR_{in} = W_{out}/H) of 1:1. These two are connected by 180 degree bend. The channel height H= 150mm, while inlet width is W_{in} = 42.857mm. Hydraulic diameter of inlet pass is 66.6667mm. A divider wall thickness Wweb= 20mm and separates the two pass.

Two pass rectangular channel with Rib Tubulators.

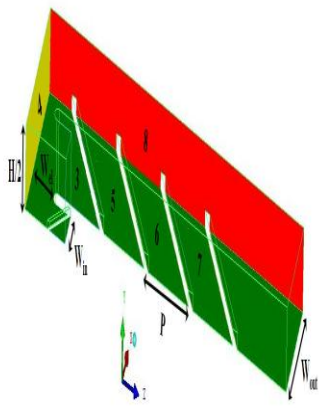

Fig. Rectangular Two Pass Channel with Rib Tubulators.

And for the ribbed model keeping all the parameters same creating the 45 degree ribs of height to hydraulic diameter ratio was kept constant and equal to 0.1 for both inlet and outlet pass. Similarly the pitch to rib height distance (P/e) was kept to 10. The ribs were installed inline arrangement on top and bottom surface and thus allowing half of the channel to be modeled in simulations with the introduction of a symmetry boundary conditions at the upper surface. To avoid back flow effect, the channel was extended to a length equal to hydraulic diameter of the outlet pass.

RESULTS AND DISCUSSION

Case 1. With W_{el}/W_{in} =1.5

i. For Ribbed Channel

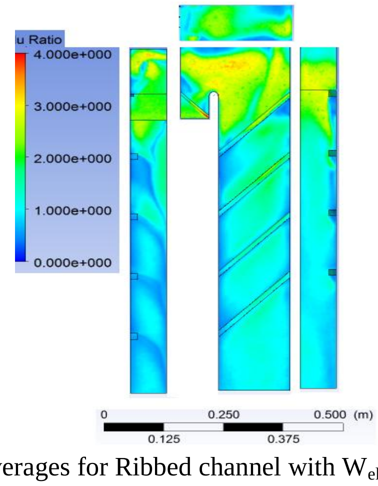

Fig: area averages for Ribbed channel with W_{el}/W_{in} =1.875 normalized by Dittus-Boelter relation

ii. For Smooth Channel

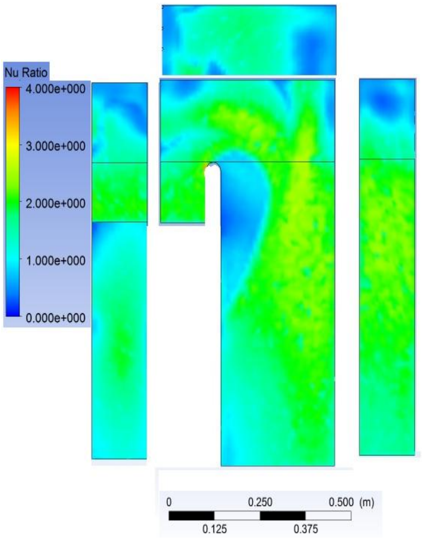

Fig: Area averages for Smooth channel with W_{el}/W_{in} =1.5 normalized by Dittus-Boelter relation

Region	NU/NU0
INLET	1.90
BEND INLET	1.02
BEND BOTTOM	1.59
TIP WALL	1.43
OUTLET BEND	1.04
OUTLET	1.51

REGION	NU/NU0
INLET	1.98
BEND INLET	1.44
BEND BOTTOM	1.60
TIP WALL	1.62
OUTLET BEND	1.52
OUTLET	1.24

Case 2. With W_{el}/W_{in} =1.875

i. For Ribbed Channel

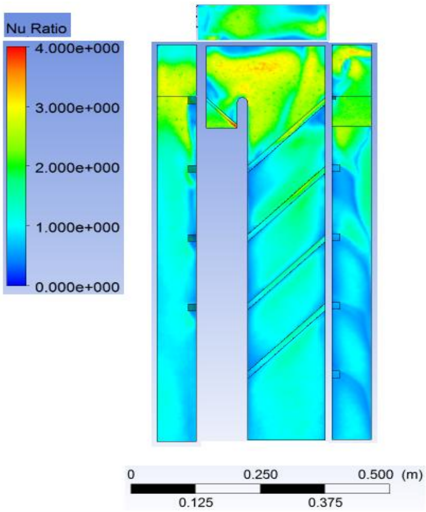

Fig: Area averages for ribbed channel with W_{el}/W_{in} =1.875 normalized by Dittus-Boelter relation

Region	NU/NU0
INLET	2.05
BEND INLET	1.48
BEND BOTTOM	1.37
TIP WALL	1.20
OUTLET BEND	1.38
OUTLET	1.05

ii. For Smooth Channel

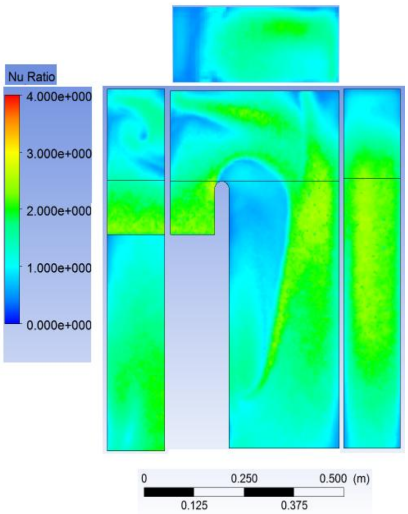

Fig: Area averages for Smooth channel with W_{el}/W_{in} =1.875 normalized by Dittus-Boelter relation

Region	NU/NU0
INLET	2.14
BEND INLET	1.93
BEND BOTTOM	2.19
TIP WALL	1.56
OUTLET BEND	2.09
OUTLET	1.08

The results without ribs showed a strong effect of the bend on heat transfer enhancement and serve as the basis for comparison with ribbed channels. Area averages were carefully selected and were made to illustrate the behavior of the bend and to show the extent to which the inclusion of ribs increases heat transfer in these two-pass channels.

CONCLUSION

The result showed a strong effect on heat transfer enhancement due to introduction of ribs. The increase in heat transfer was almost ten times. Dynamic start at the inlet with maximum heat transfer was seen. Ribs with W_{el}/W_{in}=1.875 showed a better heat transfer rate than the W_{el}/W_{in}=1.5 and can be justified that increase in length increases the heat transfer for the given inlet width. Approximately equal at the inlet bend and bend bottom. Increase at tip wall and bend outlet. And rapid decrease at the outlet.

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