Indian Journal of Science and Technology, *Vol 9(31), DOI: 10.17485/ijst/2016/v9i31/95978, August 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Effect of Twisted Tape Inserts and Stacks on Internal Cooling of Gas Turbine Blades

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Abstract

Objectives: In gas turbine blades, heat transfer can be enhanced by using twisted tape inserts and stacks. In the present paper, we proposed cooling effect of a gas turbine blade can be improved by using suitable twisted tape inserts and stack configurations. A Comparative study between this type and the twisted tape without stack configurations was performed. **Methods/Statistical Analysis**: Simulations are carried out for different width ratios of twisted tape with and without using stack configurations. Computation results showed that by using twisted tape inserts of width ratio (W) = 0.3 with stack configurations, provides better cooling effect compared to the others. **Findings:** Without using the stack Configurations, blade temperature is decreased by 34% at the leading edge and 21.2% at the trailing edge for W = 0.3. By using stack configurations, the blade temperature is decreased by 50.7% at the leading edge and 48% at the trailing edge for W = 0.3. **Application/Improvements:** All these demonstrated that cooling effect of gas turbine blade especially at the trailing edge can be enhanced with suitable twisted tape and insert and stack configurations.

Keywords: Leading Edge, Numerical Analysis, Stacks, Trailing Edge, Turbine Blade Cooling, Twisted Tape Inserts

1. Introduction

Thermodynamic study of gas turbine shows that plant efficiency and energy output can be enhanced with higher turbine inlet temperatures. Modern gas turbines try to approach these high temperatures (1500°C) to improve performance but are limited by the maximum allowable thermal stresses for the blade material. To enhance fatigue life of gas turbine blade many cooling techniques can be used on the blade exterior such as internal convective cooling and film cooling. One of the toughest regions to cool is the trailing edge as it must be thin to reduce aerodynamic losses. As the trailing edge is thin, cooling of this region is a challenging task as enough coolant can't be guided. Additional constraints due to structural integrity and manufacturing difficulty for internal cooling passage geometry in this thin section also arise. One of the cooling techniques frequently used by turbine designers for the trailing edge is using twisted tape inserts. Among the different heat transfer techniques, twisted tape is widely used due to their simple configuration and easy installation. Several studies have been performed for aerodynamics and film-cooling effectiveness by slot injection on the trailing edge. Telisinghe[1] investigated total pressure losses from a conventional trailing edge and a cutback trailing edge. They were found to be similar. An experimental and numerical investigation for trailing edge slot injection was performed by[2,3] under realistic engine flow conditions. In[4] studied the impact of trailing edge cutback design and concluded that the life capability to resist thermos-mechanical fatigue, creep and aerodynamic performance can be improved with the cut back designs. [5–11]In earlier research work established from CFD analysis that helicoidal cooling duct and buttress shaped grooved configuration provided a significant improvement in turbine blade cooling.

The primary motivation for this paper is to investigate the cooling effect of gas turbine blade at the leading edge

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especially at the trailing edge with the usage of twisted tape inserts. Enhancing cooling effect at the trailing edge is challenging task as the area covered by the trailing edge is less compared to the leading edge and enough coolant can't be channelized at that particular region. Additional constraints due to manufacturing difficulty for internal cooling passage geometry in this thin section also arise. In the present paper, several twisted tape insert and stack configurations are used and heat transfer simulation in gas turbine blade with various insert configurations using CFD tool is done. Stack is one type of insert configuration which is in the form of serrated plates. As these stacks are thin it can be placed at the trailing edge as the area covered by trailing edge is less. Simulation is carried out for different twisted tape insert configuration and comparison of results are also be made with different twisted tape inserts with and without using stack configuration at the trailing edge.

2. Physical Model

CFD preprocessor is powerful design tool to define CFD simulations which can be later exported to CFD solvers and postprocessors like Fluent, Polyflow and Star-Cd for analysis purpose.

2.1 Modeling of Gas Turbine Blade and Stacks

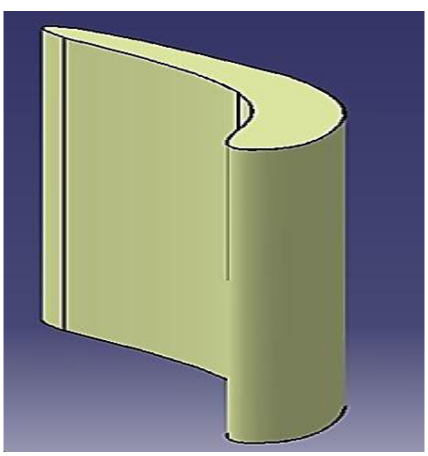


Figure 1. Gas turbine blade.

Modeling of gas turbine blade is carried out by measuring coordinates of gas turbine blade by CMM in Catia software. Figure 1 shows the gas turbine blade model. Stack is one type of insert configuration which is in the form of serrated plates. It can be placed at the trailing edge as the area covered by trailing edge is less. As these stacks are placed in trailing edge of the gas turbine blade, it creates disturbance to the flow and hence heat transfer can be enhanced. Figure 2 shows two different views of the stack configuration.

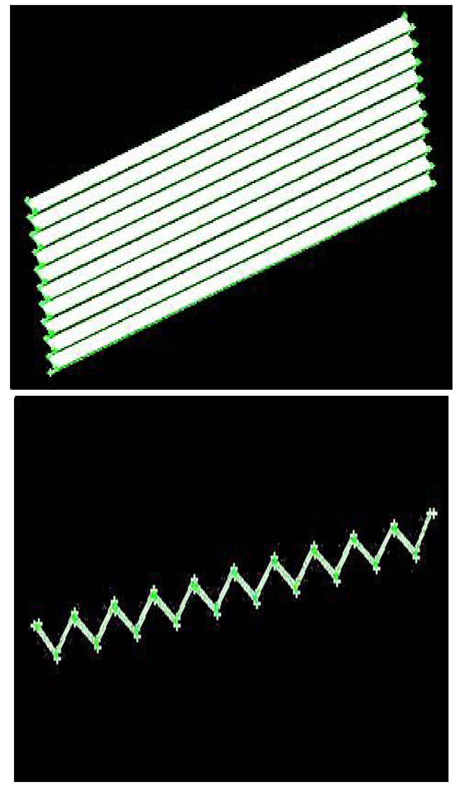


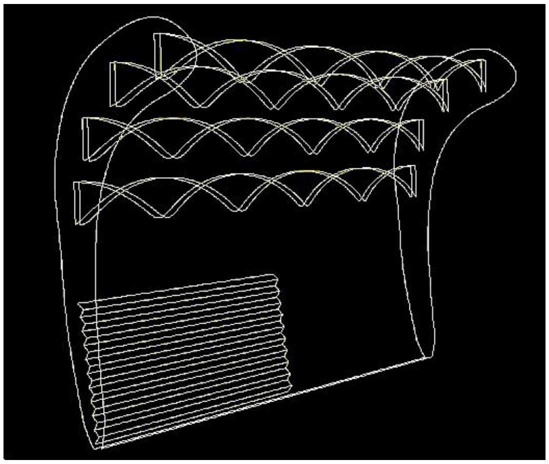
Figure 2. Stack configuration.

2.2 Gas Turbine Blade with various Twisted Tape Inserts and Stack Configuration

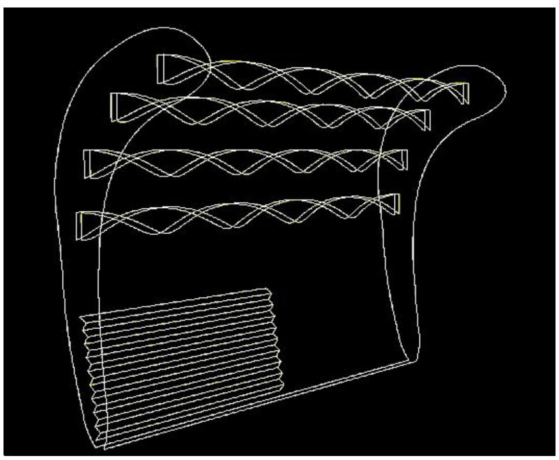
Twisted tape inserts are placed in leading edge and stacks are placed in the trailing edge of the blade as shown in Figure 3. Twisted tape inserts starting from width ratio W = 0.3, 0.25, 0.2 and 0.15 are placed in the top half part of the gas turbine blade.

Due to the space constraints in the gas turbine blade, it is not possible to place twisted tape of width ratio W = 0.9. Stack is used only up to the middle of the gas turbine blade. This is because the number of cells generated by the full length stack is around three million which can't be simulated using CFD software. A small portion of material removed from the trailing edge (called as Cut-back region) and at same region pressure out-let condition is considered for the analysis[12] as shown in Figure 4.

Tetrahedral grid is used for the meshing as depicted in Figure 5.



W = 0.3



W = 0.2

Figure 3. Gas turbine blade with various inserts and stack configuration.

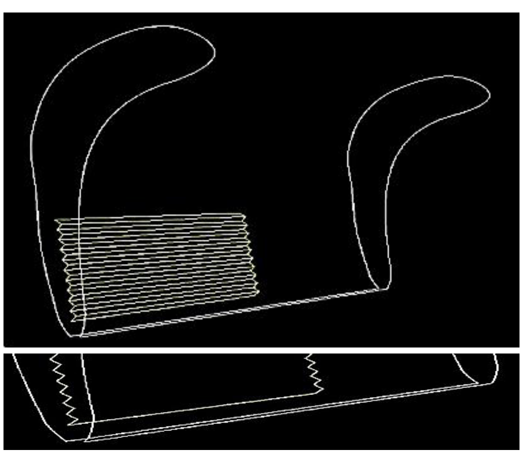


Figure 4. Cut-back at the trailing edge.

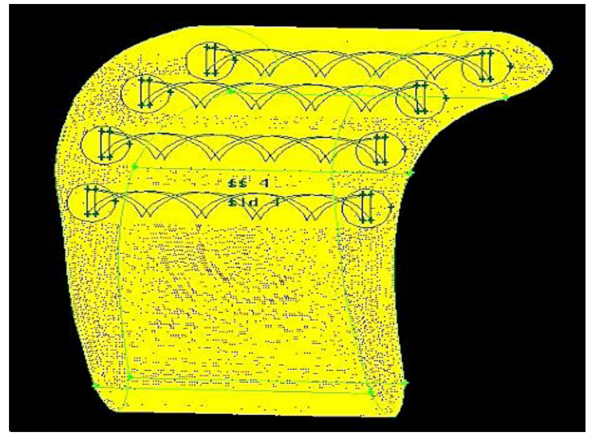


Figure 5. Tetrahedral grid generation.

2.3 Boundary Conditions

Simulation needs to be carried out under high pressure and high temperature conditions to understand the physics of cooling of gas turbine working under real operating environment. The parameters simulating gas turbine operating environment are listed in Table 1. The turbulence model has been explained in[13] and is summarized in Table 1 without further explanations.

Table 1. Boundary condition

Inlet velocity	128 m/s
Temperature at inlet	644 K
Wall temperature	1561 K
Pressure outlet	Gauge pressure
Fluid	Air
Material	Nickel alloy
Viscous Model	Standard k–ε model

3. Results and Discussion

3.1 Results of Gas Turbine Blade with Stack Configuration

Without using any of the twisted tape insert simulation is carried out with only Stacks configurations which are placed in the trailing edge of the blade. Figure 6 shows the variations of temperature for stack configuration. Similar to the twisted tape insert, even stack configuration creates disturbance in the flow and hence increases the rate of cooling effect and therefore large heat transfer is taking place at that particular region rather than in the leading edge.

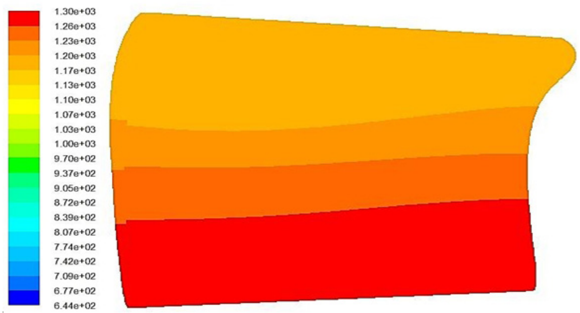


Figure 6. Static temperature contour of W = 0.15.

Results shows that by using stack configurations at the trailing edge (without using twisted tape insert) the blade temperature is decreased by about 13.5% at the leading edge i.e. from 1561 K to approx. 1350 K and about 22% at the trailing edge i.e. from 1561 K to approx. 1220 K.

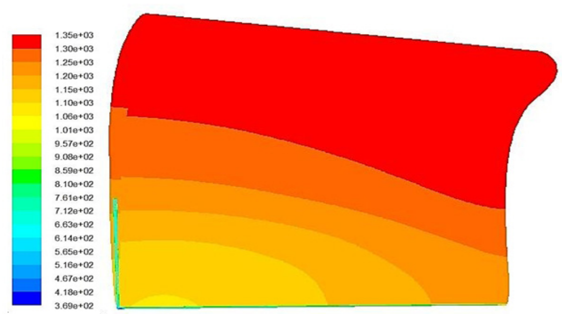


Figure 7. Static temperature contour of gas turbine blade with stack configuration.

3.2 Gas Turbine Blade with various Twisted Tape Insert and Stack Configuration

Previous results showed that by using stack configuration cooling effect of the gas turbine blade can be enhanced. Now both twisted tape inserts and stack configuration are used for the simulation to increase the heat transfer rate. Twisted tape inserts are placed in leading edge region and stack in trailing edge region. From Figures 7 and 8 shows the temperature contour plot for width ratio W = 0.2 and 0.3 with stack configuration.

Results shows that by using twisted tape of W = 0.3 with stack configuration gives better cooling effect compared with the W = 0.2 with stack configurations. By using twisted tape inserts of W = 0.3 with stack configurations, the blade temperature is decreased by about 50.7% at the leading edge i.e. from 1561 K to approx. 770 K and about 48% at the trailing edge i.e. from 1561 K to approx. 811 K.

By using four twisted tape inserts of W = 0.2 with stack configurations, the blade temperature is decreased by about 45.5 % at the leading edge i.e. from 1561 K to approx. 850 K and about 43% at the trailing edge i.e. from 1561 K to approx 890 K.

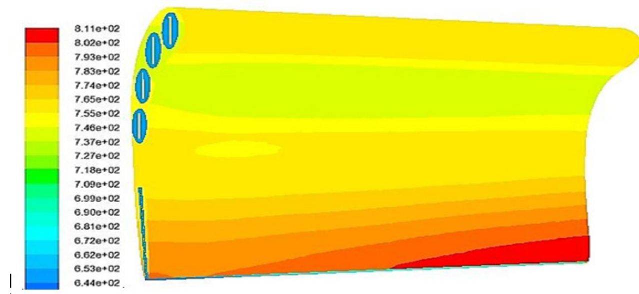


Figure 8. Static temperature contour for W = 0.3 with stack configuration.

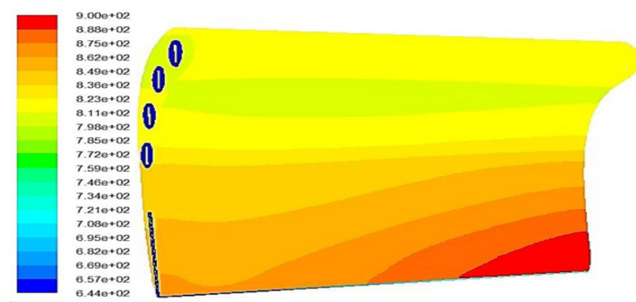


Figure 9. Static temperature contour for W = 0.2 with stack configuration.

Temperature distribution of the blade at three different chord length is taken and are compared with the different width ratio. Figure 9 on hence a great amount of heat transfer is taking place compared to the other width ratio and hence temperature at both leading and trailing edges is low for W = 0.3 when compared to W = 0.2.

Figure 10, 11 and 12 shows variation of static temperature over the blade surface for various chord length. From Figure 12, for W = 0.3 static temperature at the beginning of the leading edge of the gas turbine blade is higher (around 780 K). As the fluid flows in the gas turbine blade the temperature of blade goes on decreases. Hence it is clear from the figure that by using both twisted tape inserts and stack configuration cooling effect of a gas turbine blade can be increased.

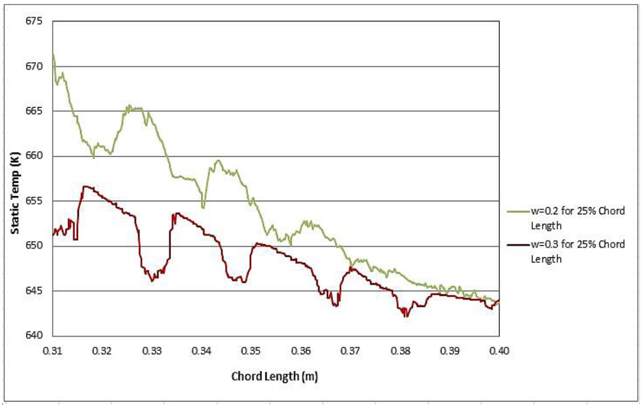


Figure 10. Variation of static temp for 25% of chord length.

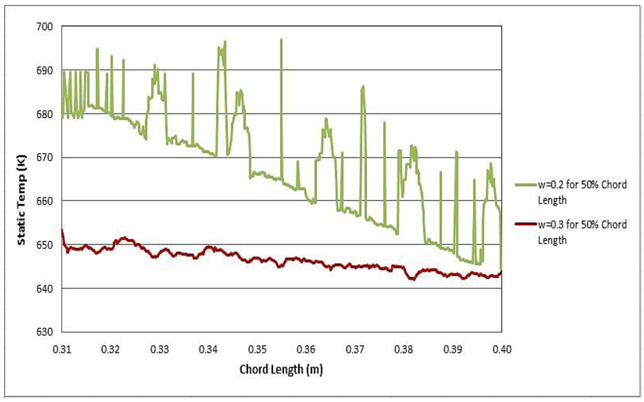


Figure 11. Variation of static temp for 50% of chord length.

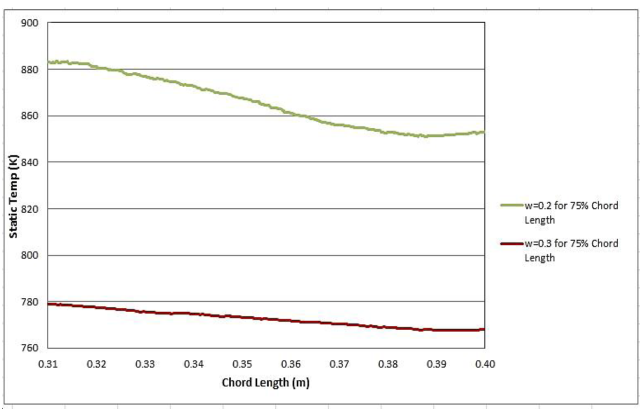


Figure 12. Variation of static temp for 75% of chord length.

4. Conclusions

- Simulation is carried out with suitable insert configurations of width ratio without using stacks and results showed that by using twisted tape insert for width ratio (w) = 0.3 gives better cooling effect compared to the others.
- Simulation of gas turbine with stack configuration is carried out and results showed that by using stack configurations at the trailing edge (without using twisted tape insert) the blade temperature is decreased by about 13.5% at the leading and about 22% at the trailing edge.
- Four twisted tape inserts of W = 0.3 with stack configurations, the blade temperature is decreased by about 50.7% at the leading edge and about 48% at the trailing edge.
- Four twisted tape inserts of W = 0.2 with stack configurations, the blade temperature is decreased by about 45.5% at the leading edge and about 43% at the trailing edge.
- Stack configurations being thin, it can be placed in the trailing edge of the blade. It produces great amount of turbulence and hence cooling effect can be increased.
- Cooling effect can be increased by sensibly increasing the number of insert configurations in the blade.
- Different configurations of stacks can be placed in the trailing edge so that cooling effect can be increased.

Hence it can be concluded that cooling effect of gas turbine blade especially at the trailing edge can be enhanced with suitable insert configurations.

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Nomenclature

H	Twist pitch
δ	Thickness of the twisted plate
W	Width of the twisted plate
y	Twist length
Y	Twist ratio (y / W)
Re	Reynolds number
ρ	Density
$\dot{v}$	Volume
E	Energy
H	Enthalpy
Nu	Nusselt Number
L	Length of the tube
D	The diameter of the tube
w	Width ratio (W/D)
h	Heat transfer coefficient
u	Flow velocity
μ	fluid dynamic viscosity
k	Thermal conductivity of fluid
Δp	pressure drop between tube entry and exit