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Optimazation and performance analysis of gas turbine blade by implimenting cooling techniques

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Abstract

Gas turbine are extensively used for aircraft propulsion, land-based power generation, thermal efficiency and power output of gas turbine increase with increasing turbine rotor inlet temperature (RIT) the current RIT level in advanced gas turbine is far above the melting point of the blade material. Therefore, along with high temperature material developed a sophisticated cooling scheme must be developed for continuous safe operation of gas turbine with high performance ,gas turbine blades are cooled internally and externally for increase the life of blade turbine. This paper is focused on internal cooling of blade and vanes on gas turbine, internal cooling is achieved by passing the coolant through several enhanced serpentine passages inside the blade and extracting the heat from the outside of the blade. Jet impingement cooling, rib tabulators, dimple and pin fin cooling are all utilized as method of internal cooling, which are presented in this article. Due to the different heat transfer enhancement and pressure drop, they are used in specific part of the blades and vanes on the gas turbine.

Keywords: AISI D2 steel, tool wear, workpiece surface temperature, Taguchi method, regression analysis.

INTRODUCTION

A turbine is rotating device that used the action of a fluid to produce work. In gas turbine, a pressurized, high temp gases the driving force.For Electrical power generation and marine application. It is generally called a power turbine. For aviation purpose, it is usually called a gas generator. One of the reason that gas turbine are widely used to power aircraft is they are light and compact and have a high power -to-weight ratio. Gas turbine is used in all kind of unexpected places such as helicopter and even the M-1 tank. The main component of a gas turbine engine is compressor, combustor and turbine as shown in fig.

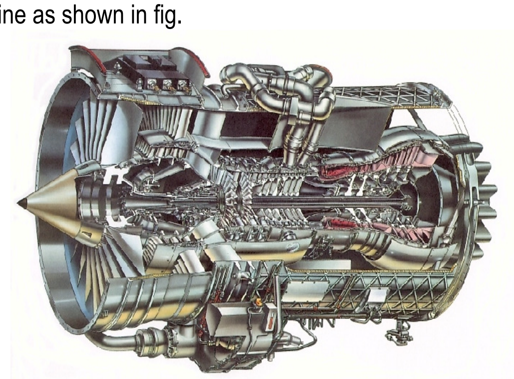

Figure 1 shows the heat flux distribution around an inlet guide vane and a rotor blade. At the leading edge of the vane, the heat transfer coefficient are very high , and as the flow splits and travels along the vane, the heat flux decreases . Along the suction side of the vane, the flow transition from laminar to turbulent, and the heat transfer coefficients increases. As the flow accelerates along the pressure surface, the heat transfer coefficient also increases .the trend are similar for the turbine blade; the heat flux at the leading edge is very high and continues decrease as the flow travel along the blade on the suction surface , the flow transition from laminar to turbulent, and the heat flux sharply increases; the heat transfer on the pressure surface increases as the flow accelerates around the blade

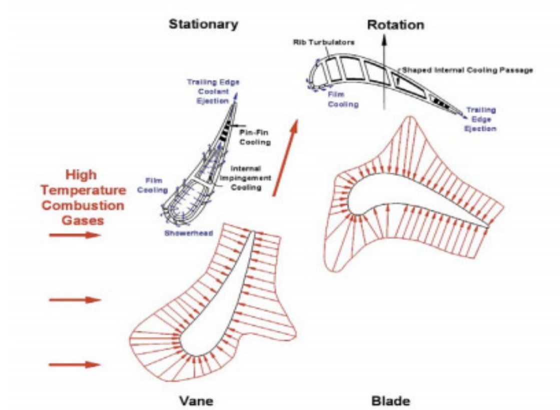

Fig. 1. Cross-Sectional View and Heat Flux Distribution of a Cooled Vane and Blade

Blade geometry

The Taguchi experimental design method is a well-known, The blade geometry design process generally plays an important role in the development and verification of a new turbine or aeroengine.it is inner loop of most design iteration and hence –taking into account the high number of different blade required for turbine.

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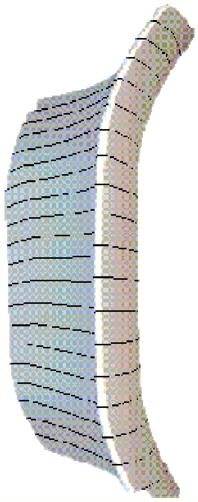

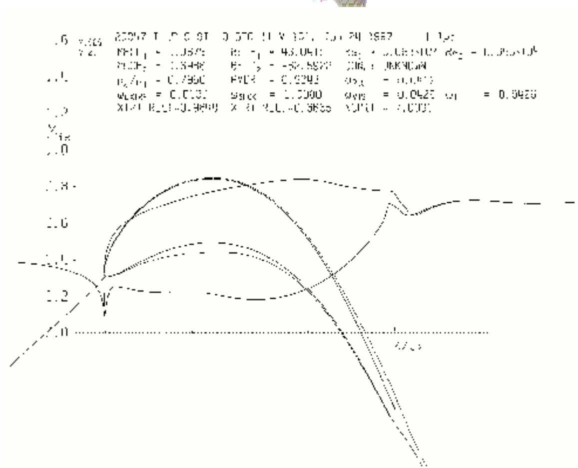

Problem identification

New internal heat transfer data is needed to improve current root blade life performance by cooling technique. And also detailed flow and heat transfer data necessary to understand the flow physical and to improve the current internal cooling designs. Many techniques have been developed to enhance the heat transfer in these passages. The cooling passages located in the middle of the airfoils are often lined with rib tabulator. Near the leading edge of the blade, jet impingement (coupled with film cooling) is commonly used .jet impingement is also used throughout the cross- section of the stator vanes. Pin fins and dimples can be used in the trailing edge portion of the vanes and blades. These techniques have also been combined to further increase the heat transfer from the airfoil walls.

EXPERIMENTAL DETAILS
Rib turbulalated cooling

Rib tabulator is the most frequently used method to enhance the heat transfer in the internal serpentine cooling passages. The rib turbulence promoters are typically cast on two opposite walls of the culling passages. Heat that conducts from the pressure and suction surface through the blade walls is transferred to the coolant passing internally through the blade. The heat transfer performance of the ribbed channel depends on the channel aspect ratio, the rib configuration, and the Reynolds number of the coolant flow. Many fundamental studies have been conducted to understand the coolant flow through a stationary ribbed channel [5, 6, 7, and 8]. The studies show as the coolant passes over a rib oriented 90^0 to the mainstream flow, the flow near the channel wall separates. Reattachment follows the separation, and the boundary layer result in increased heat transfer coefficient in the ribbed channel. This rib induced secondary flow is shown in fig.4 if the tabulators are skewed to the mainstream flow direction counter- rotating vortices are created. Figure 4 show in a channel with angled ribs, two counter-rotating vortices are formed in the cross-rotating of the cooling passages. However, if V - shaped rib tabulator are used, four vertices are generated. The additional set of counter rotating vortices are associated with the V shaped ribs result in more heat transfer enhancement in channel with V -shaped ribs than angled ribs. The ribs also create turbulent mixing in the areas of flow separation. With this additional mixing, the heat is more effectively dissipated from the wall and thus additional heat transfer enhancement because only the flow near the wall of the cooling channel is disturbed by the ribs. The pressure drop penalty by ribs affordable.

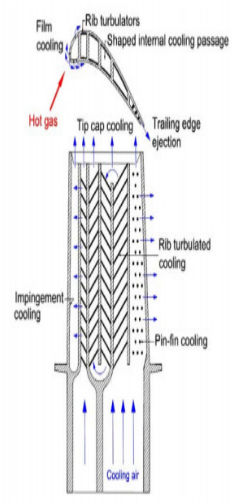

Fig. 6. Schematic of a Modern Gas Turbine Blade with Common Cooling Techniques

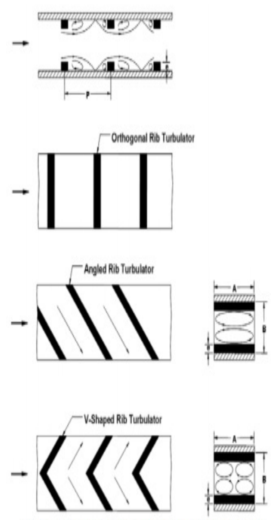

Fig. 7. A Typical Test Model for Turbulated Cooling Studies with Rib Induced Secondary Flow

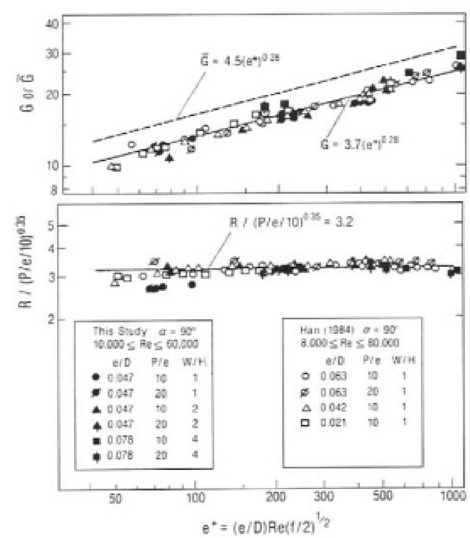

Fig. 8. Friction Factor and Heat Transfer Coefficient Correlations for 90° Ribs

Han and an and park developed correlation for both the pressure penalty and heat transfer enhancement in ribbed channel [7,8] .given the Reynolds number of the coolant flow and the rib geometry ,the average friction factor in a channel with two opposite ribbed walls ,star can be determine from correlation . Fig5 demonstrates the correlation developed for cooling passages with 90^0 ribs. The friction roughness function Reynolds number, e^+, show. Based on the rib spacing (P/E), R can be calculated, and substitute into the following equation to determine f, the four ribbed wall friction factor.

$$R = \left(\frac{2}{f}\right)^{\frac{1}{2}} + 2.5\left(\frac{2e}{D}, \frac{2w}{H+w}\right) + 2.5$$

From f (the friction factor in a channel with rib on all four walls) and the channel geometry (H/W), the average friction factor in a channel with ribs on two wall, f, can be calculated using equation

$$f = \bar{f} + \left(\frac{W}{w}\right)\left(\bar{f} - f_s\right)$$

The friction factor in a channel with smooth walls, fesses, and is known from the existing basis correlation for smooth channel flow. Using the four ribbed wall friction factor, f, the rib height, e/D, and the Reynolds number of the coolant flow, rather roughness Reynolds number, e^+, can be calculated using the definition shown in figure 8. From the e^+ the top figure can be used to obtain G, the heat transfer roughness function, and eon 3 can be used to determine the Stanton number on the ribbed walls, star G=R+The correlation shown in figure 8 is for a print number of 0.703. Because G is inversely proportional to the Stanton number, a low heat transfer roughness function implies high heat transfer from the cooling passage wall.

With the understand that skewed ribs yield higher heat transfer enhancement than orthogonal ribs, these correction were expended to include the effect of the rib angle, fig 6 show the correlation taking into account the rib angle, α, rib spacing (p/e) , and channel aspect ratio (W/H) , the roughness function, R, can be determine. Eqn 1 can used to calculate f, and eon 2 is used to determine the friction factor in a channel with two ribbed walls. Similar to channels with 90^0 ribs, R and e +are then use to determine the Stanton number on the ribbed walls, these correlation can be use over a wide range of channel aspect ratios and rib for specific restrictions of correlations.

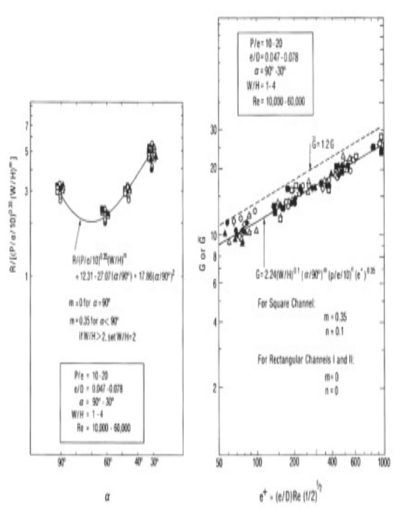

Fig. 9. Friction Factor and Heat Transfer Correlations in Rectangular Ribbed Channels

because ribs are the most common heat transfer enhancement technique for the serpentine cooling passages, many studies have been conducted to study the effects of channel cross-section, rib configuration, and coolant flow Reynolds number. As shown in figure . the aspect ratio of the channels changes from the leading to the trailing edge of the blade , near the leading edge of the blade , the channel may have an aspect ratio around 1/4 but near the trailing edge, much broader channels are present ration around 4

Multiple studies have shown that by skewing the ribs, so they are angled into the mainstream flow, the heat transfer coefficients can be further enhanced. Placing the ribs with an attack angle between 30^0 and 60^0 result in increased heat transfer and reduces the pressure penalty. Most study focused on Reynolds number ranging from 10,000 to80, 000 ,but for today's advanced gas turbine the coolant in the channel can have a Reynolds number gas turbine the coolant in the channel can have a Reynolds number up to 50,000 . the height of the ribs is spacing - to-height ratio varies from 5 to 15 .in addition, a limited number of studies have focused on the more closely spaced ribs with much larger blockage ratio.

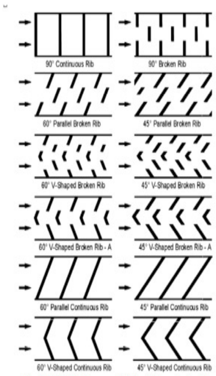

Fig. 10. High Performance Rib Turbulators for Turbine Blade Internal Cooling

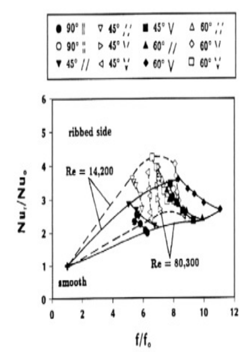

Fig. 11. Comparison of Heat Transfer Performance for Broken and Non-Broken Rib Configurations

With angle ribs performance superior to orthogonal ribs, many researchers have extended their studies to include a wide variety of rib confutations. Han etal. Showed that V -shaped ribs figure out form the angle ribs; for given pressure drop, the V - shaped ribs give more heat transfer enhancement [9] numerous other studies have shown the same conclusion that V-shaped ribs perform better than the traditional angle ribs in a variety of channel and flow condition [10] .in an effort to father increase the heat transfer performance of the rib tabulator, discrete rib confutation were introduced. Above Figure show discrete ribs are similar to the traditional ribs, but they are broken in one or more location, so the rib is not continuous. in the majority of cooling channel, discrete ribs were shown to outperform the continues angled or V - shaped ribs and chow et al. [11] as shown in this figure, the broken 45^0 angled ribs create more heat transfer enhancement than the continues 45^0 angled ribs at a given friction factor ratio, and this conclusion can be extended to other broken versus continuous rib configuration

Impligment cooling

Impingement cooling is commonly used near the leading edge of the airfoil, where the heat loads are greatest. With the cooling jets striking the blade wall, the leading edge is well suited for impingement can also be used near the mid- chord of the vane. Fig shows jet implement located through the cross section of an inlet guide vane. Several aspects must be considered when developing efficient cooling design . the effect of jet -hole size and distribution , cooling channel cross-section ,and target surface shape all have significant effects on the heat transfer coefficient distribution. Jet impingement near the mid- chord of the blade is very similar to impingement on a flute plate. How're, the sharp curvature at the leading edge of the vane must be considered when utilizing impingement in this region.

As shown in fig, many jets are used to increase the heat transfer from the vane wall. It has been shown by Metzger et al. that multiple jets perform very differently from a single jet striking a target surface [12] they concluded that for multiple jet, the mussel number is strongly dependent on the Reynolds number, while there is no significant dependence on the jet-to-target plate spacing.

The different is due to the jet cross - flow from the spent jets. Studies by florschuetz et al. and Koopmans and sparrow showed that the mass from one jet moves in the cross-jet flow direction, and this flow can alter the performance of neighboring jets. The cross - flow attempt to deflect a jet away from its impinging location on the target plate. They determine that cross flow enhancement convective heat transfer, but the enhancement from the jets decreases, as the jets are deflected. Because the enhancement from the impingement jets is much greater than the convective enhancement, the overall mussel numbers decrease in the presence of cross - flow.

A typical test model used by florschuetz et al. is the shown in fig 9 . as shown in this fig, the coolant jets impinge on the target surface from the jet plate in an inline array. As the coolant travels along the test surface, the spent air from the upstream jets effects the heat transfer coefficient distribution of the down stream jets, and this effect increase as more spent air accumulates on the target surface.

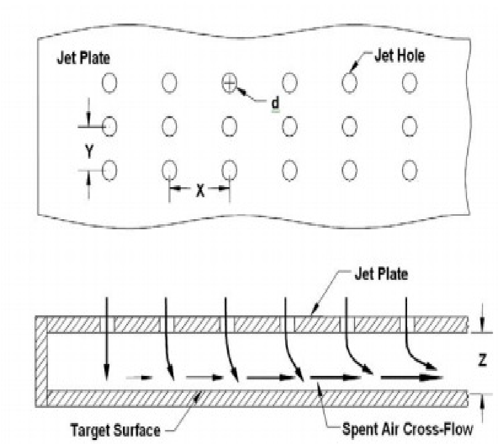

Fig. 3. A Typical Test Model for Impingement Cooling Studies

Pin -fin cooling

Due to manufacturing constraints in the very narrow trailing edge of the blade, pin fin cooling is suitable used to enhance the heat transfer from the blade wall in this region. The pins typically have a height - to-diameter ratio between ½ and 4 in a pin fin array heat is transferred from both the smooth channel end -wall and the numerous pins. Flow around the pins in the array is comparable to flow around a single cylinder .as the coolant flows past the pin, they flow separates and wakes are shed downstream of the pin. In addition to this walk formation, a horseshoe vortex forms just upstream of the base of thepin, and the vortex wrap around the pins. This horseshoe vortex create additional mixing, and thus enhanced heat transfer. Many factors must be considered when investigation pin fin cooling. The type of pin fin cooling array and the spacing of the pining the array affect the heat transfer distribution in the channel .the pin size and shape also have a profound impact on the heat transfer in the cooling passages. Because pinyin are commensally coupled with trailing edge ejection the effect of this coolant extraction must also be considered. There are two commonly used one is inline array second is staggered array.fig shown the test model with a staggered array of pin fins

Dimple cooling

In recent years, dimple cooling have been considered as an alternative to pin fin cooling, dimple cooling is a very desirable alternative due to the relative low pressure loss penalty and moderate heat transfer enhancement.

A typical test section for dimple cooling studies is shown in fig.11 this fig also shown the dimple induced secondary flow. These concave dimples induce flow separation and reattachment with pair of vortices. The area of high heat transfer includes the area of flow reattachment on the flat surface immediately downstream of the dimple. The heat surface in the dimple channel is typically 2 to 2.5 times greater than the heat transfer in a smooth channel with a pressure loss penalty of 2 to 4times that of a smooth channel. this value show the little penalty of Reynolds number and channel aspect ratio .dimple have also be investigated in acicular channel and similar level of heat transfer enhancement and frictional losses were measured [30] from the study it was show that the surface curvature significantly influences the heat transfer enhancement on a surface that is concavely shaped, how're, a convexly curved surface with a dimple decreases the level of heat transfer enhancement

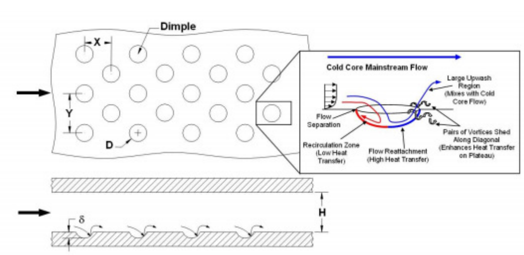

Fig. 5. A Typical Test Model for Dimple Cooling Studies with a Conceptual View of Dimple Induced Secondary Flow

Characteristics of best sollution

Several internal heat transfer enhancement techniques are disused in previous sections. Most common methods of heat transfer augmentation in gas turbine airfoils are ribs, pins, and jet impingement. It is shown that these enhancement techniques increase heat transfer coefficient, but can combine these technique increases the heat transfer coefficient .

Impingment on ribbed, pinned, and dimpled walls

Because the dimple and pins are circular depression and protrusions, respectively, these two target surface offer an interesting comparison of the heat transfer enhancement. At lower Reynolds number the pinned surface performer better than the dimple surface. At the higher Reynolds number, the dimple surface perform better than the pinned surface for a certain flow orientation. Taslim et al reported a significant increase in the heat transfer enhancement on a curved target surface roughened with cooling holes, similar to the showerhead – type film cooling on the leading edge .they concluded that the pressure of leading edge extraction also significantly increases the heat transfer on the target surface.

Combined effect of swirl and impigement

A new jet impingement and swirl technique was investigated by glazer. A preliminary test showed significant improvement in the heat transfer performance. Based on that study, anew airfoil has been designed with swirling impingement in the leading edge. This new air foil is tested in ahoy cascade test section. Result indicate that screw shaped swirl cooling can significantly improve the heat transfer coefficient over a smooth channel and this improvement is not significant dependent on the temp ratio and rotational forces.

Combined effect of swirl flow and ribs

Kieda experiment investigated the single phase water flow and heat transfer in a rectangular cross sectioned twisted channel. Several aspect ratio and twist pitches ewe used. results indicate that in a cooling application, this twisted channel perform similar to a ribbed pipe .zhang used different type of inserts to study the combined rib and twisted tape inserts in square ducts . Four test configuration were used, hemi-circular wavy tape, and hemi -triangle wavy tape. The performance of hemi triangular performance over the twisted tape plus interrupted ribs. Hemi - circular wavy tapes show the lowest heat transfer performance in this group.

New cooling concept-(Phase 2 work)

Heat pipes have very high effective thermal performance 13 therefore; they can transfer heat from high temp to the low temp region. This concept may be used in the airfoil cooling .heat is removed from the initial stage stator airfoil and the heat is delivered at a later stage to heat up the main flow. This way the heat extracted can be recycled to the main flow. In a concept developed by yama waki the heat is conducted away from the hot airfoil to the fin assembly 14 this passive heat extraction reduces the required cooling air. Most heat pipe application design for the stator airfoils, where it is easier to mount the connecting pipes or fins. Commonly a closed loop steam cooled nozzle with thermal barrier coating is used in order to reduce the hot gas temp drop through the first stage nozzle.

CONCLUSIONS

1. The experimental results showed that the Taguchi parameter design is an effective way of determining the optimal cutting parameters for achieving low tool wear and low workpiece surface temperature.
2. The percent contributions of depth of cut (60.85%) and cutting speed (33.24%) in affecting the variation of tool wear are significantly larger as compared to the contribution of the feed (5.70%).
3. The significant parameters for workpiece surface temperature were cutting speed and depth of cut with contribution of 41.17% and 34.45% respectively. Although not statistically significant, the feed has a physical influence explaining 21.58% of the total variation.
4. The predicted optimal range of tool wear is $0.21 \le \mu_{TW} \le 0.31$ and for workpiece surface temperature is $37.51 \le \mu_{T} \le 43.21$.
5. The relationship between cutting parameters (cutting speed, depth of cut, feed) and the performance measures (tool wear and workpiece surface temperature) are expressed by multiple regression equation which can be used to estimate the expressed values of the performance level for any parameter levels.

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