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Review of Passive Cooling Techniques in Gas Turbine Blades to Enhance the Heat Transfer Rate

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ABSTRACT

In recent years the gas turbines have become an important part of power generating industries. As the demand of power is increasing day by day, the generation of additional power requires a gas turbine to produce more amount of energy per day. In order to achieve this more shaft power needs to be generated per unit time. This means the turbines should operate at higher temperatures of the gas at the inlet (Turbine Inlet Temperature or TiT) to increase the power as well as to enhance the efficiency of the gas turbines. But if the temperature is increased beyond a specific value it may cause the turbine blades to melt and ultimately damage it. In order to prevent this melting and damage, cooling techniques are employed in the gas turbines. There are mainly two types of cooling techniques-Active cooling and Passive cooling. Active cooling relies on external cooling devices which may result in increased power consumption, although it will work effectively in some cases. Passive cooling techniques directly use geometrical modifications to the surfaces of the turbine blades like pin-fins, dimples, passages and so on. In this article we are going to review the passive cooling techniques employed in a gas turbine blade.

Keywords: Turbine inlet temperature; Active cooling; Passive cooling; Geometrical modifications

INTRODUCTION

A gas turbine is a device used to generate mechanical work by absorbing the kinetic energy of hot impinging gases. The gas turbines operate on Brayton cycle. Analysis of the Brayton cycle reveals that the thermal efficiency of a gas turbine can be increased by increasing the inlet temperature of the hot gases entering into the turbine. Recent advancements in the gas turbines have made it possible to operate the gas turbines at inlet gas temperature beyond 1400 °C. But although the inlet temperature of the gases increases the efficiency of the gas turbines, the temperature of the inlet gas cannot be extended beyond 1500 °C as will because the thermal stresses generated, to damage the blades of the turbine and ultimately the gas turbines. In order to prevent these stresses to cause damage to the turbine blades, cooling techniques have been employed. Passive cooling techniques are one of the cost efficient ways to avoid this damage to the gas turbine blades. Also the power consumed by this type of cooling is low as compared to active cooling techniques. It is also going to enhance the thermal efficiency of the turbine blades. In this article we are going to specifically see a few of the efficient passive cooling techniques employed for gas turbine cooling.

LITERATURE REVIEW

Rib cooling

This paper has discussed the effects of rib turbulatedcooling [1]. The rib turbulated cooling is mostly employed to the central portion of the gas turbine blades as maximum are is available here. For the leading edge and trailing edge, film cooling and pin fin cooling is employed due to relatively smaller area available. The ribs are mostly modeled as short, square and rectangular channels with different aspect ratios depending upon the size of the gas turbine blades and the space available. They have discussed that the heat transfer enhancement using these ribs depend upon a variety of factors such as rib size, shape, distribution, flow attack angleand Reynolds number. It was observed that the shorter rib height is more efficient than the larger height of the ribs for heat transfer augmentation but it may cause the pressure drop penalty to increase with Reynolds Number. Also closer or wider rib spacing has reduced the heat transfer augmentation but provided it enough and reduced the pressure drop penalty (Figure 1).

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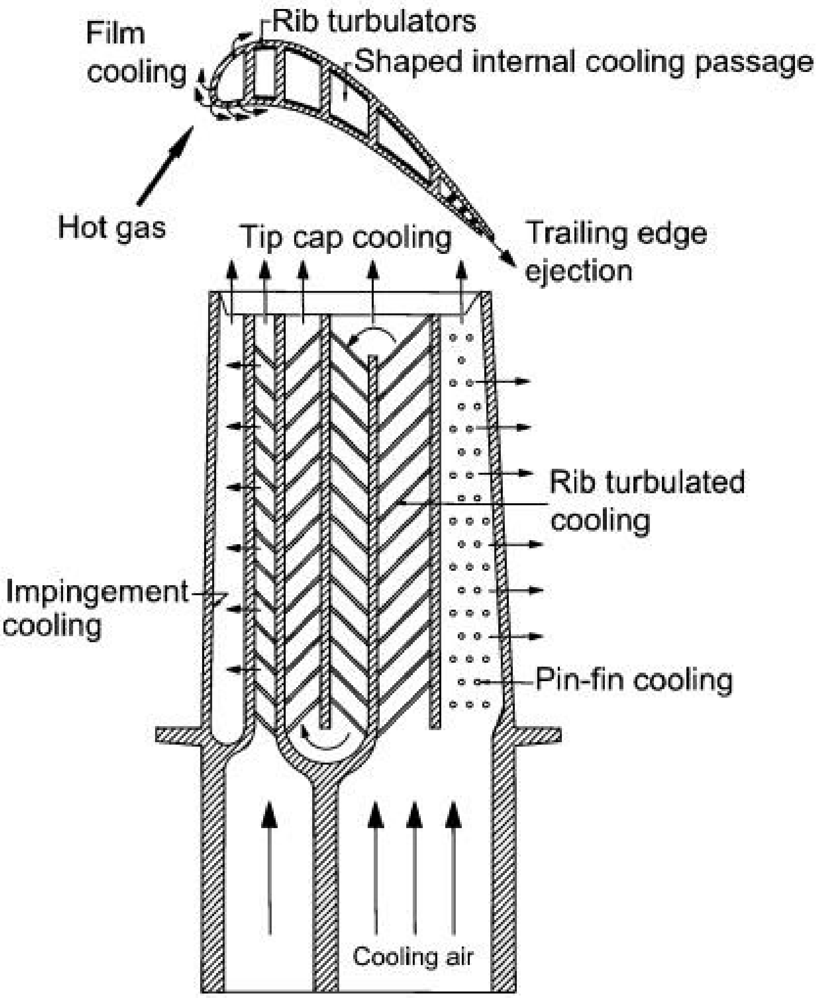

Figure 1: Typical internal cooling in a gas turbine.

So this can be used wherever the pressure drop penalty is a concern more than the heat transfer augmentation. The Numerical simulations of fluid flow and heat transfer in square ribbed channel [2]. Transverse and 45° inclined rib arrays were set in inline and staggered arrangements on two opposite heated walls as shown in (Figure 2).

The Reynolds number based on the inlet velocity and inlet hydraulic diameter is ranging from 2 × 104 to 4 × 104. The overall performance of the simulated channels is evaluated and compared. It was found that the ribbed wall area-averaged Nusselt number is almost the same for inline and staggered rib arrangements. It was also observed in their simulations that the channel with transverse ribs can reveal 2.8 times higher heat transfer than that of a channel without ribs. The inclined ribs generate secondary flow consisting of two counter-rotating vortices thereby improving the turbulent mixing of the approaching cold fluid and hot fluid near the walls. The presence of 45° inclined ribs can provide 50% higher heat transfer than that of the transverse ribs however; they exhibit the lowest heat transfer zone at the vicinity of rib upstream near rear sidewall. It was suggested that the lowest heat transfer zone of inline ribs can be improved by increasing the Reynolds number. The staggered inclined ribs show no significant enhancement of local Nusselt number at the rear sidewall with the Reynolds number.

Pin fin cooling

As discussed earlier pin fin cooling is used in a narrow cross sectional area of the turbine blades where there is least space available to accommodate rib turbulators. The training edge of the gas turbine blades is the place where smallest area is available. At such places it is not possible to use cooling methods like rib turbulators. Hence to enhance the cooling effect at the trailing edge of the gas turbine blades, pin-fin cooling is employed.

Performance of a numerical investigation of pin-fin cooling on the gas turbine blade trailing edge [3]. The study was carried out in two steps–first being the validation of simulated results from an existing training edge cutback cooling with staggered pin-fin arrays inside the cooling passages against the experimental measurements and second to investigate the pin fin cooling performance with different blowing ratios. Both the simulated data and test data were found to be well in agreement of each other. The author observed that the averaged heat transfer coefficient at the surface of the pin-fin array is more noticeable in the region near the slot exit in line with the increase in Reynolds number. The pin- fin array plays an important role in the turbulence flow motions inside the cooling passage. The turbulence intensity is found to be more pronounced due to the existence of the pin-fin, in which it is associated with the coolant fluid inside the wedge-shaped duct. The effect of boot-shaped rib heat transfer characteristics of internal cooling turbine blades [4]. In their investigation the authors have changed the design parameters by taking higher air flow momentum and ultimately relatively removing the minor vortex at the front rib (Figure 3).

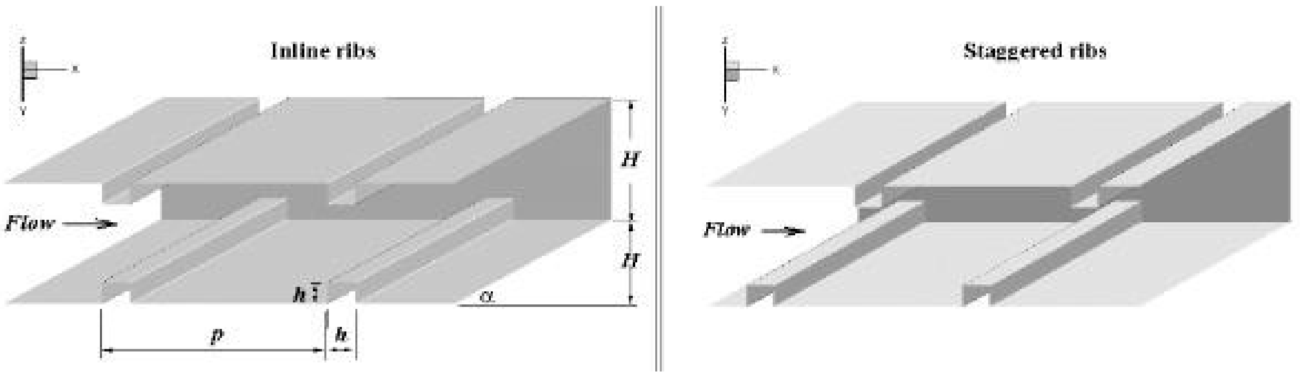

Figure 2: Transverse and 45ºC inclined rib arrays.

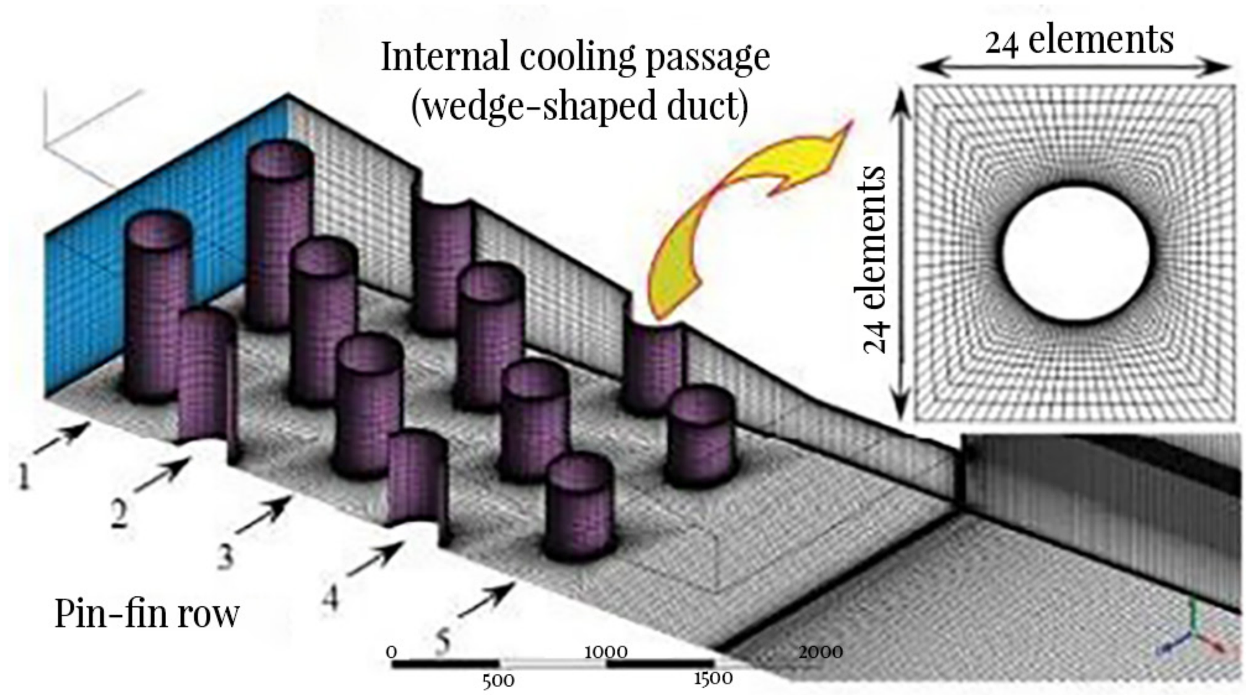

Figure 3: Transverse the 3D structured mesh of a wedge- shaped duct.

Impingement cooling

Their research has studied the effect of separators used at the leading edge of the gas turbine blade internal passages, on the heat transfer augmentation of the blades [5]. Two models were used, one with separators and other without the separators. Numerical strategy including RNG k-ε turbulence model was validated by the experimental data. It was observed after the investigation that when the jet Reynolds number, mass flow ratio and temperature ratio are matched to the real conditions, the Nusselt numbers predicted by low temperature conditions can be generally matched with an exclusion of the forepart of the internal surface at the blade leading edge. But the error of overall cooling effectiveness on the blade external surface is not neglected.

DISCUSSION

The application of separators can prevent the heat transfer deterioration caused by cross flow with extending the heat exchange area, thus the leading edge with separators can be further cooled over 30 K compared to the traditional design. Under the real operating conditions of gas turbine, two new correlations between the surface averaged Nusselt number with jet Reynolds number and temperature ratio were suggested. The area averaged heat transfer increases with decreasing jet diameter and this is attributed to the higher jet velocities involved when smaller nozzles are used. For the air jets, secondary peaks were present at low jet-to-target spacing's and high Reynolds numbers. The peaks became more pronounced with decreasing H/d and increasing Reynolds number. The water jets also exhibit secondary peaks, however these have only been observed at a low Reynolds number of 10000 and a low H/d of 1.

CONCLUSION

It has been found that if cost is a concern then passive cooling techniques will always be a better option for the cooling of turbine blades. Also with passive cooling methods a variety of configurations can be studies and simulated for the augmentation of heat transfer. Mainly the passive cooling methods include rib turbulated cooling for the middle portion of the gas turbine blade, jet impingement cooling for the leading edge of the gas turbine blade and pin-fin cooling for the smallest cross sectional area i.e. the trailing edge of the gas turbine blades. Although simulations can help us understand the behavior of various configurations inside the turbine blades, readings taken on the actual experimental test set up should be used for validation.

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