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# A Review on Air Film Cooling Technique

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Abstract

One of the widely used technique is air- film cooling comparing previous models relevant to air-film cooling technique and also proposed a model for the estimation of blade coolant mass fraction which is considering heat transfer from hot combustion gases to turbine blade surface. cycle performance have been evaluated based on two models in order to compare coolant flow mass fraction ,turbine plant specific work. This paper also shows the effect of air-film cooling on aerodynamic performance of turbine blades.

Keywords: Gas turbine, air-film cooling, aerodynamic performance

## I. Introduction

Performance of gas turbine cycle evaluated based on two models so as to compare the flow mass fraction of coolant and turbine plant specific work which is a function of compressor-pressure ratio and inlet temperature. According to the International energy agency report of over 1.6% increment have been forecast in the global energy demand For the development and increasing standard of living of our country consumption of energy id the main factor which is to be focus . As population are increasing and also the demand for the energy consumption so we need to find the efficient energy producing technology on the field of gas turbine.gas turbine are being considered as one of the most important energy utility as it the efficient power producing technology .Gas turbine is one of the most important features as it has high efficiency conversion and low cost power production. Thus to achieve a high thermal efficiency we need to increase the inlet temperature which also result in a high power output. But inlet temperature can be increased only to a limit amount as it restricted to material. Increase in inlet temperature can lead to a destruction of hot gas path due to thermal stress and creep. Thus because of this we need to find some mean to cool the turbine blade this can be done by means of blowing air through the internal serpentine path inside having a hollow blades which is the most widely used practiced method .Two gas turbine BGT and IcGT features of this two cycles are compared thermodynamically .A code has been developed by using various governing equations and models so as to obtained the results for the power utility and operating parameters .As the demand for the power output and thermal efficiency are being increasing and thus to meet this demand gas turbine has to be operated at a temperature higher than the usual. Thus it becomes challenging job for the components of the hot path to work at a higher temperature .In order to meet this demand we used film cooling which acts as a protection for the components being damaged .cool air are being extracted from the compressor and is being injected into main flow from various holes on the surfaces of the blades and thus it from the layers which separates the hot gas and the blades .As we know now a days there is more desire for the high thermal efficiency of turbine this can be achieve by increasing the inlet temperature . now a days gas turbine are being working at a temperature more than 1600 C and for this the turbine to work at such a high temperature we need to provide the thermal barrier coatings and the most advanced cooling system techniques. Due to the high temperature the gas temperature growth also exceeds continuously.

## II. Literature Review

In order to increase the performance of turbine blades operating temperature must be increased .The test model consist of 4 rows having a holes located on suction side of about 5%, 10%, 15% and 50% of chord length. By varying the location of angle of attack, mainstream velocity performance is measured. Reynold number is $1.2\times10^5$ which is based on airfoil chord. The effect of blowing ratio is measured by pressure measurement and particle image velocimetry. Thus the result obtain as blowing ratio increases from 0 to 0.48 film cooling increases and as blowing ratio increases from 0.64 to 1.91 film cooling decreases. Gas turbine specific work is found to be around 417.39kJ/kg at compressor –pressure ratio =22 and TIT=1650K for the cooling model and thus the thermal efficiency is found to be 41.25% at compressor-pressure ratio=22 and TIT=1550K.From the blade cooling model it is obtained that the important source of exergy destruction is approx.29% and the gas rational efficiency =35.28% at compressor pressure ratio =22 and TIT=1750K.The air which is ejected increases the mixing of about 40% with reference to the baseline and the highest losses is found to be between y=-4mm to y=-7mm.The aerodynamic losses are found to be lower for the BR=0.96.Thus it is found that the effect of BR is same for all different angles of attack and mainstream velocity. The outcomes get from the pressure measurement and PIV have good impact between the techniques. Ejection of the coolant at higher BR delays he separation importantly during high angle of attack and thus increases the pressure recovery. Due to this reason BR can be used as a design parameter for the use of increasing the blade loading. We should also taken into consideration for determining the overall strategy of a turbine the effect of blade loading, Film cooling etc.BGT has more impact than IcGT both in terms of energy as well as exergetic efficiency. As there are many development have been done now a days the modern blades are being used are twist blades in modern gas turbine .Rotation of the twist is in annular cascade during working condition .Further it is simplified to linear cascade by using straight blades in order to study the influence of blades on film cooling performance. Many investigation have been done on the influence of this three simplification as rotation vs. non-rotation, linear vs. annular cascade, straight vs. twist blades. Thus it is found that the simplification which has been done from twist to straight has great effect on film cooling. It is also found that the simplification of blades from twist to straight may lead to some errors. Twist to straight simplification of blades lead to most effect on film cooling effectiveness and the influence is mostly found near the hub and the leading edge. And thus the coolant distribution from the leading edge is being affected by the rotation. First stage turbine blade cooling efficiency are being estimated for various different parameters. Two types of parameters are being used for comparison. They are air and water vapor. The criteria are being chosen for cooling efficiency are the wall heat transfer coefficient and the average volume temperature of the blades. By studying for different temperature it is found that the coolant which is most efficient is steam than the air for same temperature and pressure. Thus it is found that when steam is used the blade temperature is lower to about 20-30 C. from the cooling channel to coolant the heat transfer coefficient for the steam is more for about 10-30% as compared to air.

## III. Configuration of system

Atmospheric air enters into the axial-flow compressor and the compressor compress as per the compressor pressure ratio to the required pressure level. From the compressor the air enters into the combustion chamber and in the combustion chamber where the natural gas is burnt so as to raise the temperature of the gas in the presence of excess air. Due to this the energy of the working fluid increases. Thus as a result high temperature and pressure are developed this high temperature and pressure in the turbine are expands from where the work are being extracted and thus the energy level of the fluid decreases after the expansion process in order to cool the turbine blade coolant required is bled from compressor whose pressure from the main gas flow pressure is slightly more.

## IV. Governing equations and their modeling

The following section shows the mathematical modeling of components like compressor, combustion chamber turbine etc. fluid and their physical properties i.e gas as well as air.

### Properties of air and gas

As well all know that specific heat of gas is a function of temperature and pressure and thus the variation of it can be considered as most important at high pressure. But now it is considered as only a function of temperature only which can also be represented as a polynomial form.

For range of temperature 250-599K

$$C_{p,a}=1.023204-1.76021\times10^{-4}T+4.0205\times10^{-7}T^2-4.87272\times10^{-11}T^3$$

The turbine and the compressor process i.e expansion and the compression are considered as a polytropic and thus the energy and the mass balance of each component are being modeled.

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## V. Compressor

The thermodynamic losses which is taking place in compressor has to be compensate in order to compensate this we need to considered the polytropic efficiency. In order to find the temperature at any point of the compressor which is considered as function of pressure is given by the formula:

$$dT/T = (R/(\eta\ c, p\ Cp, a))\ \ dp/p$$

## VI. Combustion Chamber

There are various activity takes place inside the combustion chamber some of the activity are losses and the requirement of fuel so as to attain the exit temperature. The losses takes place in combustion chamber are the incomplete combustion and the pressure drop. All this losses can be considered by simply taking the concept of combustion. efficiency ($\boldsymbol{\eta}_{comb}$) as well as the pressure drop of the inlet.

## VII. Model of the cooled gas turbine

Gas turbine consists of hollow blades and form the compressor coolant air being bled which is at an appropriate pressure this coolant air are then injected to the blades via the blade roots. This coolant air is then flown via the serpentine path which is at inside the blades. In this process coolant cools the blades internally. After this the coolant air which is spent is flown out through the leading edge in order to form a layer which consists of coolant air. This coolant air further acts as a thermal barrier for the hot gas and the blade surface. Thus further it will get mix with the gas and then finally it expands in the turbine. The following diagram shows the gas turbine which consist of air-film cooling.

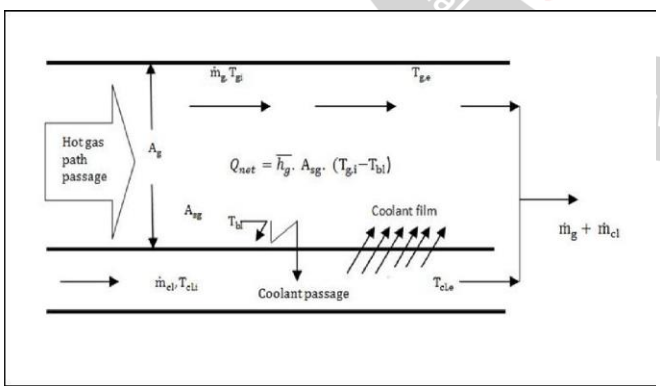


Fig 1. Air-film cooled blade cooling arrangement

## VIII. Scheme of the air-film blade cooling

From the compressor the cooling air which bled this air goes into the main stream with a temperature of $T_{cl,e}$ . This air flows through the holes of the leading edge of the blade surface so as to form a cooling film. The function of the film is to protect the surface of the blade coming in contact directly with the hot gases. The formula which gives the heat transfer is:

$$Q_{net} = h_g.A_{sg}.(T_{g,i}-T_{bl})$$

The graph shows for different blade cooling models with the variation in coolant mass fraction for air-film blade gas turbine. From the graph it can be seen that coolant mass fraction increases with the increase in the compression ratio. Thus from this we can say that as compression ratio increases coolant temperature of the blade increases.

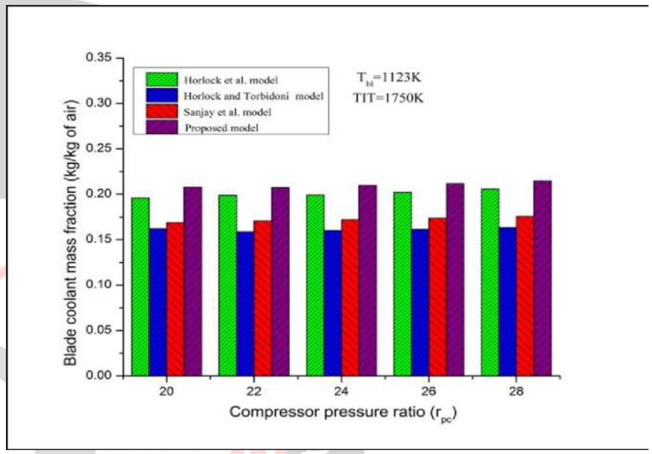


Fig 2. Coolant mass fraction with compressor pressure ratio ($r_{pc}$)

The graph shows the as the changes done in the inlet temperature the changes also obtained in the mass coolant fraction. From the graph it is seen that as we increases the inlet temperature the coolant mass fraction also increases. Also form the graph it can be seen that at high temperature high coolant mass fraction is found.

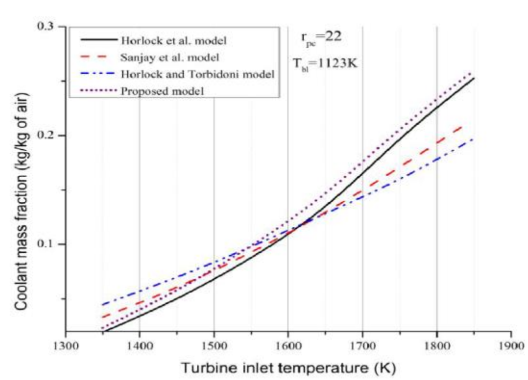


Fig 3. Coolant mass fraction with turbine inlet temperature variation (TIT)

## IX. Schematic view of turbine blade

From the figure it can be seen that turbine blades consist of coolant plenum, cooling holes and the flow passage. On the pressure side there is one row of holes is made which is named as PS and from this there is a three rows from the leading edge which is named as SH1, SH2, SH3 and the other two rows are being arrange on the other side of the suction which is names as SS1, SS2. It can also be seen that the holes are round with a diameter of 0.6mm.

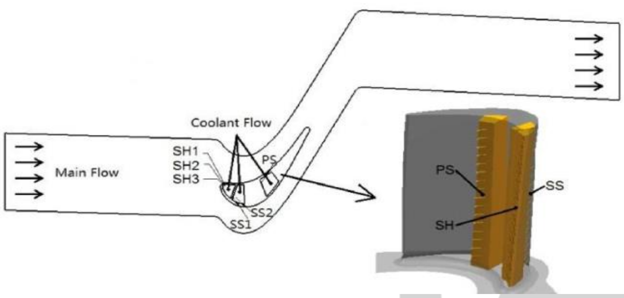


Fig 4. Turbine blades with film holes

This is the twist model and from this we came to know that the profile is along the radial direction. Thus from the twist model the straight model can be made by extruding the mid-span profile. The following figures show the twist and the straight models.

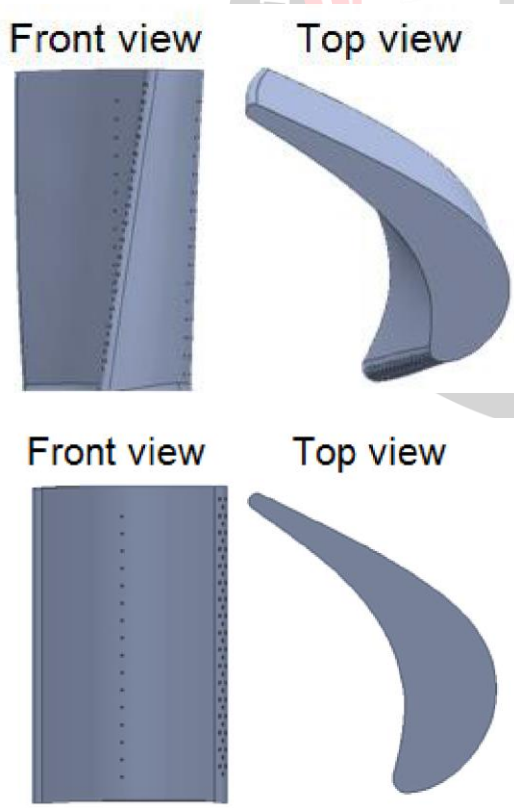


Fig 5. Twist blades and straight blades sketch

## X. Conclusions

As now a days power utility developers are demanding more efficiency and high power output with low power producing cost. Thus it becomes essential to use turbine which sustain at high temperature and this can be made by incorporating air-film cooling system.

Thermal barrier also plays a very vital role as it is to be introduced between the hot gas and the blade surface so that the high temperature should not come in direct contact with blade surface.

The major impact after simplification of twist blade to straight blade is on cooling effectiveness.

When the steam is used as a coolant than the air the average volume temperature of the blade is lower to about 20-30$^{o}$C.

## XI. Future scope

With the rapid increase in the development of the industrialization as well as in the urbanization which leads to more demand for the higher output as well as high performance gas turbine cycle has to be increase their inlet temperature so as to meet the requirement of the high efficiency. Thus for this blade should have well advance cooling technique to withstand the high temperature and this can be meet by incorporating air-film cooling technique. As this technique helps to get high output with less power producing cost which is well needed for further generation.

## XII. Nomenclature

| | |
|---|---|
| TIT | turbine inlet temperature |
| $r_{pc}$ | cycle pressure ratio |
| GT | Gas turbine |
| I | Inlet |
| T | Temperature |
| Bl | Blade |
| P | Pressure |
| **η** | Efficiency |
| M | Mass flow rate |
| c | compressor |
| cl | coolant |
| g | Gas |

| | |
|---|---|
| e | Exit |
| comb | combustion |
| Sg | Area exposed for heat transfer |
| net | Difference between two value |
| SS1/SS2 | Film holes on the suction side |
| SH1/SH2/SH3 | Film holes at the leading sides |
| PS | Film holes on the pressure side |
| R | Gas constant |
| IcGT | Intercooled gas turbine ccle |
| BGT | Gas turbine cycle |
| h | Specific enthalpy of the stream |
| $T,T_0$ | Inlet and outlet temperature |
| PIV | Particle image velocimetry |
| a | Air |
| f | Fuel |

## XIII. References

Mithilesh Kumar Sahu*, Sanjay (2018), Journal of Cleaner Production, *Thermoeconomic investigation of basic and intercooled gas turbine based power utilities incorporating air-film blade cooling.*

A.B. Moskalenko, A.I. Kozhevnikov, (2016), International Conference on Industrial Engineering, ICIE 2016, *Estimation of gas turbine blades cooling efficiency.*

Xueying Li, Jing Ren, Hongde Jiang, (2016), International Journal of Heat and Mass Transfer, Influence of different film cooling arrangements on endwall cooling.

Francesco Lanzillotta, Andrea Sciacchitano, Arvind gangoli Rao, (2017), International journal of heat and fluid flow, *Effect of film cooling on the aerodynamic performance of an airfoil.*

Lingyu Zeng, Pingting Chen, Xueying Li, Jing Ren, Hongde Jiang, (2017), Applied Thermal Engineering, *Influence of Simplifications of Blade in Gas Turbine on Film Cooling Performance.*

S. Mishra, Sanjay (2017), Applied Thermal Engineering, *Energy and Exergy Analysis of Air-Film Cooled Gas Turbine Cycle: Effect of Radiative Heat Transfer on Blade Coolant Requirement*