INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING
WWW.IJRAME.COM
ISSN (ONLINE): 2321-3051

Vol.5 Issue.5,
May 2017
Pg: -101-105

Turbine blade cooling techniques

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Abstract

The demands for a modern gas turbine engines are focused on reducing the specific fuel consumption while simultaneously increasing the overall performance of the engine. One method of achieving this is to increase the temperature of the gas entering the turbine. Many modern gas turbine engines can experience temperatures as high as up to 1500K. This temperature far exceeds the melting point of the materials used in turbine blades. Also, operating at this temperature reduces the lifetime of the turbine blades and vanes. Therefore, it is imperative that the blades and the vanes be cooled to an optimum temperature. Due to the advancement of turbine cooling systems, the turbine entry temperature (TET) has been almost doubled over the past 60 years. The present summary will examine specific cooling techniques which bring down the temperature of the turbine blade and vane to the desired level.

***Keywords**:* Convection; turbine cooling; film cooling;

1. Introduction

This paper deals with the technology of gas turbine cooling. Cooling of gas turbine especially in aero engines has evolved over 50 years now. Axial flow turbines in the early era were without cooling-technology. However, for nearly 50 years now various kinds of cooling technology have been used. We would discuss some of the technologies. All these kinds of cooling techniques are still in use today because some of those cooling technologies even today are used in a simple gas turbine engine whereas more ambitious high-performance gas turbine engines may require a more advanced cooling system. So, if we are creating a normal gas turbine engine, an old fashion cooling technique would still be useful and hence those technologies are still in use in some form or the other, many gas turbine engines especially in aero engines even today. The science of blade cooling is primarily based on the field of heat transfer. The idea of cooling actually came from the gas turbine thermodynamic cycle analysis which shows that if the turbine entry temperature could be increased, it would result in substantial benefit in terms of work done by the cycle, which in case of gas turbine engine means more work done by the turbine, more work available, either for creation of thrust for aero engines or for running a propeller which creates thrust or for land-based applications, it would simply mean that more power output can be extracted out of the single gas turbine engine. All this fundamental science of thermodynamic emphasizes on one fact, that the need to have to cool because material science has not been able to go beyond a certain level to provide material or metal alloys that could withstand temperature beyond a certain limit which is roughly of the order of 1000K. Beyond it, the ordinary material technology is not going to really be helpful and in such case, additional techniques are required. For the turbine entry temperature to go even higher and that is when the cooling technology stepped in, and the entire field of heat transfer had to be utilized. Most modern-day engines have turbine entry temperatures close to 1900 to 2000K in commercial applications.

If the time history of turbine blade cooling was looked upon, during the 1950's: uncooled blades were used and temperatures developed were around 1000-1100K. Over the next decade, (the 1960's) internal one or two pass cooling technique was used and temperatures up to 1200-1400K were measured. During 1970’s distributed internal convection cooling was in tradition and resulted in developing higher TET of around 1300-1500K. over next three decades’ engineers resorted to a more complex form of cooling i.e., film cooling in addition to internal cooling and in subsequent years being replaced by film cooling in addition with impingement cooling. This technology has helped in generating even higher TET of the order of 1600-1900K.

Turbine blade temperatures may vary along the blade surface from leading edge to trailing edge by 200 to 300K. Blade temperatures may also vary from the root to the tip of a rotor. Maximum blade temperature can be witnessed at the leading edge of the first stator as the flow arrives from the combustion chamber. The high-pressure turbine blades have maximum temperature and maximum temperature gradients across both rotor and the stator. The blades are thermally loaded in cycles of operation, to illustrate the operating envelope of the aircraft from the time of take-off where the extreme temperatures are felt by the turbine blades to the cruise time when the engine is not operating at its maximum power and thus temperature felt by the blades is significantly lower. And then later when the aircraft lands and the engine are shut off the temperatures drop to atmospheric temperatures. And usually, the turbine failure occurs mostly in creep (thermal fatigue). In a typical case of turbine blades, the flow at the hub is laminar and experiences highest temperatures. As we move towards the trailing edge of the blade the flow transitions from being laminar to turbulent downstream.

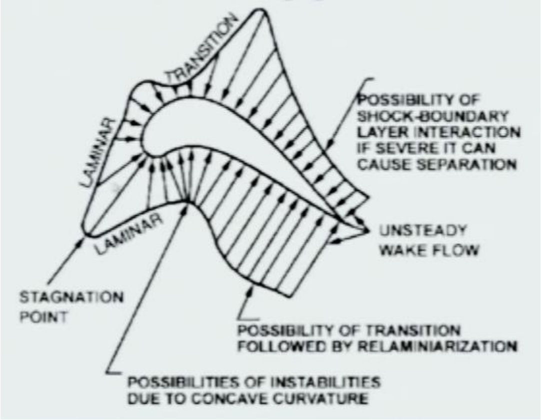

Fig1: Transition of flow across turbine blades from laminar to turbulent

2. Internal Blade Cooling

This technology of cooling gas turbine components, especially the turbine blades has developed over the years involving complex geometries and fluid-surface interactions. The main aim of this technology is to obtain the highest cooling possible without affecting the performance of the gas turbine engine. In internal blade cooling, the heat is removed by a combination of convection and impingement cooling techniques. It involves high-velocity air hitting the blade and the vane surfaces from inside.

2.1 Convection cooling

Cooling of components can be achieved by air or liquid cooling. Liquid cooling looks to be the more viable option because of high specific heat capacity but there are chances of leakage, corrosion, choking, sloshing, etc. On the other hand, cooling by air involves fewer complexities. It works by passing air at a lower temperature than the turbine blade through passages inside the blade. Heat is transferred via conduction and then through convection from blade material to the air. The rate of heat transfer will be higher if a large surface area is available. To this effect, the cooling paths tend to be circular or elliptical and consist of small fins.

2.2 Impingement cooling

Impingement cooling is a variation of convection cooling. It involved hitting the inner surfaces of the blade with high-velocity air. This is a very aggressive technique which allows effective removal of heat from the aerofoil walls. It more heat to be transferred than normal convection. This method is commonly used in areas with the highest heat loads. In turbine blades, the leading edge happens to be at the highest temperature, hence the highest heat loads. This method can also be used near the mid-chord of the vane
After impinging on the walls of the aerofoil, the coolant exits the vane and acts like a protective film on its external surface.

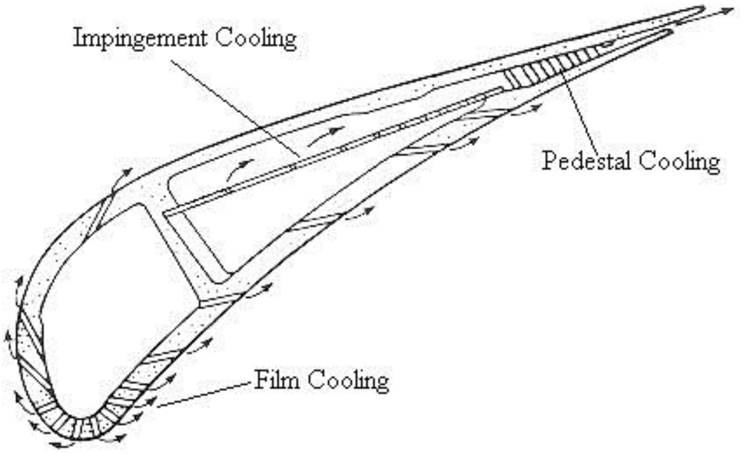

Fig2: Different types of cooling methods

3. Film Cooling

In film cooling, cold air is bled from the compressor stages and is channeled to the internal chambers of turbine blades, and is then released through small holes in the blade wall. Thus, forming an insulating blanket over the external surface of the turbine blades.

Fig3: Typical turbine blade

3.1 Discrete Film Cooling

This is a much more explicit and active cooling system. The cooling air is brought out through holes and is used to push out the air and create a film on the blade surface. On the blade, a film of cool air surrounds within the boundary layer which provides a cold film i.e., it submerges in the boundary layer on the outside of the blade surface. So, a cold boundary layer is seen on the blade surface.

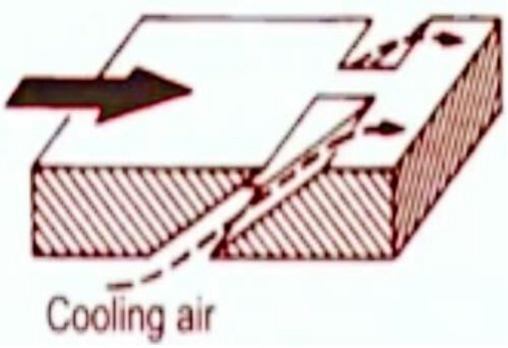

Fig4: Discrete film cooling

3.2 Full Blade Film Cooling

Distributed holes are present on the blade surface, so through various holes, the internal cold air is brought out and is injected onto the surface to create films of cold air on a continuous basis over the entire surface of the blade. In this case, continuous holes on the blade have a flowing cold boundary layer on the surface. The flow ejecting out like a jet is not feasible in this case. That would interfere with the turbine operation and adversely affect the turbine working. The cold film moves into the turbulent boundary layer over the blade and get subsumed inside it and act as an insulation over the blades.

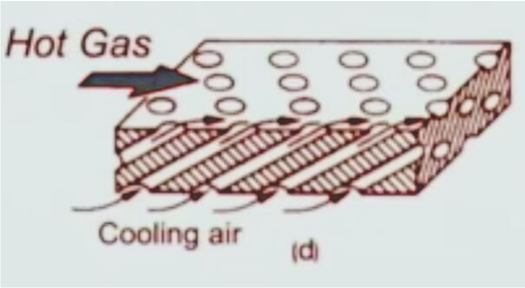

Fig5: Full blade film cooling

4. Conclusion

With modern gas turbines operating at extremely high temperatures, it is necessary to implement various cooling methods, so the turbine blades and vanes survive in the path of the hot gases. Simply passing coolant air through the aerofoils does not provide adequate cooling; therefore, it is necessary to implement techniques that will further enhance the heat transfer from the aerofoil walls. The internal heat transfer can be enhanced with jet impingement. External cooling techniques are more effective and increase the lifespan of the blade.

As the blade design is constrained by the material used, cooling of turbine blades and vanes is of prime importance for the overall performance of the engine. However, these methods are by no means an exhaustive or comprehensive summary. Many other variations and combinations of these techniques are anticipated as manufacturing advances become a reality. Further improvements and new techniques may become feasible as materials, systems integration and controls also advance.

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A Brief Author Biography

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