INTRODUCTION

1.1 Importance of cooling in gas turbine blades

Gas turbines have become one of the most important prime movers especially in aircraft propulsion, land-based power generation, and industrial applications. The greatest advantage of gas turbines is that it produces comparatively greater energy per unit size and weight. Its compactness, low weight and multiple fuel capability make it a natural choice for power plants for many diverse applications.

The gas turbine entry temperatures (TET) have risen considerably from the beginning of the 1970’s from around 1500 K to over 2000 K for modern turbines (Adami et al. 2003). Nevertheless the need for an increase in thermal efficiency of gas turbine plant, both in industrial and aerospace sectors, still demands higher values of TET without compromising on the structural integrity of the turbine components. Thermal efficiency and power output of gas turbines increase with increasing turbine entry temperature. It is clear from Brayton cycle (Figure 1.1) that the major objective is to increase the turbine pressure ratio which increases the gas turbine thermal efficiency, accompanied by an increase in TET (Horlock et al. 2001).

Fig. 1.1 Brayton Cycle
This calls for a relook in the design of turbine engine and various associated components to achieve the above objective. The current TET level in advanced gas turbines is far above the melting point of the blade material. Further the variation in the temperature within the blade material (which causes thermal stresses) must be limited to achieve reasonable durability goals. Thus it is contingent to cool the turbine blades so that blade metal is within permissible metallurgical limits.

The high pressure gas turbine stage blades have to withstand the most severe combination of temperature, stress, and environment; it is generally considered to be the limiting component in the machine. Therefore, along with high temperature material development, a sophisticated cooling scheme must be developed for continuous safe operation of gas turbines with high performance.

Several cooling techniques have come into use with the aim of reducing the metal temperature to maintain the integrity of the components, for an acceptable engine life. In gas turbine with higher operating temperature, cooling systems need to be designed not only for turbine blades but also to cool end walls, shroud and other components to meet the mechanical limits. There are many types of cooling techniques with regards to turbine blade cooling. The methodologies underlying the turbine blade cooling are briefly described in the following section.

1.2 Broad Concepts of cooling of turbine blades (Yahya, S.M., 2011)

In order to employ high gas temperatures in gas turbine stages it is necessary to cool the casing, nozzles, rotor blades and disc. On account of high rotational speeds and associated stresses, cooling of the rotor blades is more critical. Cooling of these components can be achieved either by internal or external cooling or both.

*Internal cooling* of blades can be achieved by passing cooling air (from the air compressor) through internal cooling passages from the hub towards the blade tips. The
internal cooling passages are distributed inside the blade. The concept of cooling of these blades is by conduction and convection modes as shown in Figure 1.2.

Fig. 1.2 Blade cooling methods

In *external cooling*, the air inside the cooling passages is allowed to flow over the blade surfaces through a number of small orifices inclined to the surfaces. A series of such orifices are provided at various sections of the blades along their lengths. The cooling air thus flowing out of these small orifices forms a thin film over the blade surfaces. The thin film besides cooling the blade surface by convection decreases the heat transfer from hot gases to the blade metal by providing a thermal barrier.

1.3 Turbine blade cooling methodologies (Boyce, M.P., 2002)

1.3.1 Convection cooling

This form of cooling is achieved by designing the cooling air to flow inside the turbine blade or vane, and remove heat through the walls as shown in Figure 1.3. Usually, the air flow is radial, making multiple passes through a serpentine passage from the hub to the blade tip. Convection cooling is most widely used cooling concept in present day gas turbines.

1.3.2 Impingement cooling

In this high intensity form of convection cooling, the cooling air is blasted on the inner surface of the blade by high velocity air jets, permitting an increased amount of heat to be transferred to the cooling air from the metal surface. This cooling method can be
restricted to desired section of the blade to maintain an even temperature over the entire surface.

1.3.3 Transpiration cooling

Cooling by this method requires the cooling air to pass through the porous wall of the blade material. The heat transfer is directly between the coolant and hot gas. Transpiration cooling is effective at very high temperatures, since it covers entire blade with coolant flow.

1.3.4 Film cooling

This type of cooling is an external cooling in which the cooling air forms an insulating layer between the hot gas steam and the blade surface. This type of film cooling protects the blade in the same way as combustor lining does.

1.3.5 Water/steam cooling

Water is passed through a number of tubes embedded in the blade. The water is emitted from the blade tips as steam to provide excellent cooling. This method keeps the
blade temperature below 900 K. In steam cooling, steam is passed through a number of tubes embedded in the nozzle or blades of the turbine. This is a very effective cooling scheme and keeps the blade metal temperature below 1000 K. Liquid or water cooling appears to be more attractive on account of the higher specific heat and possibility of evaporative cooling. However, the problems of leakage, corrosion, scale formation and choking mitigate using this method in gas turbine blade cooling.

1.4 Turbine blade cooling design (Boyce, M.P., 2002)

There are five different blade cooling designs commonly used in modern gas turbine blades.

1.4.1 Convection and impingement cooling/strut insert design

The strut insert design shown in Figure 1.4 has a mid-chord section that is convection-cooled through horizontal fins, and a leading edge that is impingement cooled. The coolant is discharged through a split trailing edge. The air flows up the central cavity formed by the strut insert and through holes at the leading edge. The air then circulates through horizontal fins between the shell and strut, and discharges through the slots in the trailing edge.

Fig. 1.4 Strut insert blade
1.4.2 Film and convection cooling design

![Fig. 1.5 Film and convection-cooled blade](image)

In this type of blade design as shown in Figure 1.5 the midchord region is convection-cooled, and the leading edges are both convection and film-cooled. The cooling air is injected through the blade base into two central and one leading edge cavity. The air then circulates up and down a series of vertical passages. At the leading edge, the air passes through a series of small holes in the wall adjacent to the vertical passages, and then impinges on the inside surface of the leading edge and then passes through the film cooling holes. However the trailing edge is convection-cooled by the air discharging through the slots.

1.4.3 Transpiration cooling design

This design has a strut-supported porous shell. The shell attached to the strut is of a wire made from a porous material as shown in Figure 1.6. Cooling air flows up the central plenum of the strut, which is a hollow structure with various-size metered holes on the strut surface. The metered air then passes through the porous shell. The shell material is cooled by a combination of convection and film cooling. This process is effective due to an infinite number of pores on the blade surface.
1.4.4 Multiple small-hole design

With this particular design, primary cooling is achieved by film cooling with cold air injected through a series of small holes over the blade surface. These holes are considerably larger than the holes formed with porous mesh for transpiration cooling. Also, because of their larger size, they are less susceptible to clogging by oxidation. The shell is supported by the cross ribs and is capable of supporting itself without a strut, under engine operating conditions (Figure 1.7)

1.4.5 Water-cooled turbine blades

This design has a number of tubes embedded inside the turbine blade to provide channels for water as shown in Figure 1.8. In most cases, these tubes are constructed from
copper for good heat transfer conditions. The water, which is converted to steam by the
time it reaches the blade tips, is then injected into the flow stream. The cooling occurs due
to the phase change (evaporative cooling).

![Water cooled turbine blades](image)

**Fig. 1.8 Water cooled turbine blades**

1.4.6 Steam-cooled turbine blades

This design has a number of tubes embedded inside the turbine blade to provide
canals for steam. In most cases these tubes are constructed from copper for good heat
transfer conditions. Steam injection is becoming the prime source of cooling for gas
turbines in combined cycle application. The steam, which is extracted from the exit of HP
turbine, is sent through the nozzle blades, where the steam is heated, and the blade metal
temperature decreases.