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Improvisation of Turbine Blade Cooling Effectiveness by Increasing Holes

R. Mousia[1], S. Aravind[2], D. MathalanVivedha[3], R. Nathiya[4]

[1,3,4]B.E., (Aero) – Park College of Technology, Coimbatore, India.
[2]M.E., (Aero) – Park College of Technology, Coimbatore, India

Abstract: Cooling technologies are a major issue in gas turbine devices. Certain parts of them undergo high variations of temperature and, by a consequence, need to be efficiently cooled in order to avoid serious damages. This paper film cooling techniques are used to make a turbine blades more efficient. By increasing complex holes the model has been developed by using software CATIA V5R17 and the pressure and stress distribution over a turbine blade is analyzed by ANSYS 12. Results have been discussed and finally we found that increasing the number of complex holes reduces the temperature distribution throughout the turbine blade. From the analysis we conclude that it is possible to extension the life of turbine blades.

Keywords: Gas turbine, Temperature, Turbine blade, CATIA V5R17, ANSYS 12, Cooling effectiveness.

1. INTRODUCTION

Gas turbines play an important role in aviation, marine, Gas pumping, Blast furnace and industrial applications. There is a growing tendency to use higher temperatures at the inlet of the turbine to improve the efficiency of the gas turbine engine. Consequently, the heat load on the turbine components increases, especially in the high pressure turbine section. This heat load is caused by the exposure to an enormous heat flux of the burnt gas from the combustion chamber. As a result, the lifetime expectancy of a blade can be reduced significantly. In order to comply with modern safety standards, the blades in gas turbines need to be cooled. Gas turbine blades are cooled internally and externally; this paper focuses on turbine blade internal cooling. In this type cooler air is bled from the compressor stage and then passing through internal passages incorporated into blade designs for cooling purpose.

2. COOLING TECHNOLOGY

Graphically explains how the turbine blades are subjected to very strenuous environments inside a gas turbine. They face high temperatures, high stresses, and a potentially high vibration environment. All three of these factors can lead to blade failures, which can destroy the engine, and turbine blades are carefully designed to resist those conditions. In these three problems, high temperatures will cause 80% of failures to the turbine blades, high vibrations will cause 10% of failures to the turbine blades and high stresses will cause 10% of failures of turbine blades. As a result the turbine blades failures are mostly caused by high temperatures so this paper is focus on turbine blades cooling system.

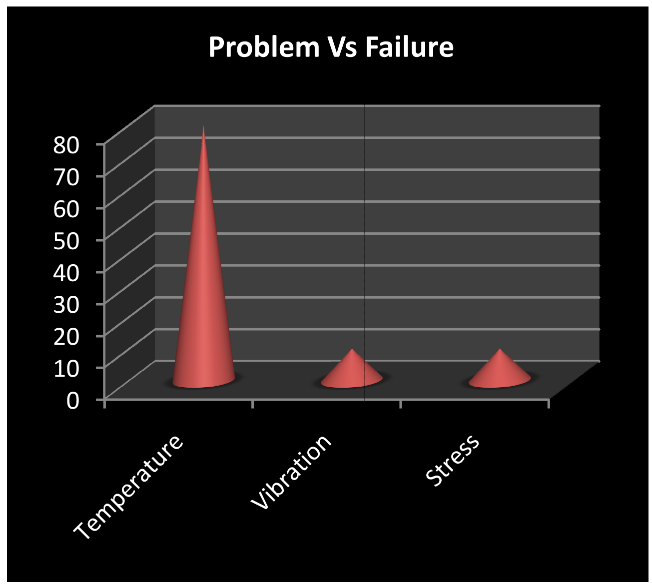


Fig 1: problem Vs failure in turbine blade

Cooling of components can be achieved by air or liquid cooling. Liquid cooling seems to be more attractive because of high specific heat capacity and chances of evaporative cooling but there can be problem of leakage, corrosion, choking, etc. which works against this method. On the other hand air cooling allows discharging air into main flow without any problem. Quantity of air required for this purpose is 1-3% of main flow and blade temperature can be reduced by 200-300°C. There are many types of cooling used in gas turbine blades; convection, film, transpiration cooling, cooling effusion, pin fin cooling etc. which fall under the categories of internal and external cooling. While all methods have their differences, they all work by using cooler air (often bled from the compressor) to remove heat from the turbine blades.

3. METHODS OF COOLING

3.1 Internal cooling

3.1.1 Convection cooling

It works by passing cooling air through passages internal to the blade. Heat is transferred by conduction through the blade, and then by convection into the air flowing inside of the blade. A large internal surface area is desirable for this method, so the cooling paths tend to be serpentine and full of small fins. The internal passages in the blade may be circular or elliptical in shape. Cooling is achieved by passing the air through these passages from hub towards the blade tip. This cooling air comes from an air compressor. In case of gas turbine the fluid outside is relatively hot which passes through the cooling passage and mixes with the main stream at the blade tip.

3.1.2 Impingement cooling

A variation of convection cooling, impingement cooling, works by hitting the inner surface of the blade with high velocity air. This allows more heat to be transferred by convection than regular convection cooling does. Impingement cooling is used in the regions of greatest heat loads. In case of turbine blades, the leading edge has maximum temperature and thus heat load. Impingement cooling is also used in mid chord of the vane. Blades are hollow with a core. There are internal cooling passages. Cooling air enters from the leading edge region and turns towards the trailing edge.

3.2 External cooling

3.2.1 Film cooling

Film cooling (also called *thin* film cooling) is a major type of cooling which works by pumping cool air out of the blade through small holes in the blade. This air creates a thin layer (the film) of cool air on the surface of the blade, protecting it from the high temperature air. The air holes can be in many different blade locations, but they are most often along the leading edge. A United State Air Force program in the early 1970s funded the development of a turbine blade that was both film and convection cooled, and that method has become common in modern turbine blades. There are orifices on the surface through which the cool air flows on the surface and makes a film on the surface which acts as a barrier to heating and provides effective cooling. Besides cooling blade surface it decreases heat transfer from metal surface to the hot fluid. One consideration with film cooling is that injecting the cooler bleed into the flow reduces turbine efficiency. That drop in efficiency also increases as the amount of cooling flow increases. The drop in efficiency, however, is usually mitigated by the increase in overall performance produced by the higher turbine temperature.

3.2.2 Cooling effusion

Blade surface is made of porous material which means having a large number of small orifices on the surface. Cooling air is forced through these porous holes which form a film or cooler boundary layer. Besides this uniform cooling is caused by effusion of the coolant over the entire blade surface.

3.2.3 Pin fin cooling

In the narrow trailing edge film cooling is used to enhance heat transfer from the blade. There is an array of pin fins on the blade surface. Heat transfer takes place from this array and through the side walls. As the coolant flows across the fins with high velocity, the flow separates and wakes are formed. Many factors contribute towards heat transfer rate among which the type of pin fin and the spacing between fins are the most significant.

3.2.4Transpiration cooling

It is similar to film cooling in that it creates a thin film of cooling air on the blade, but it is different in that air is "leaked" through a porous shell rather than injected through holes. This type of cooling is effective at high temperatures as it uniformly covers the entire blade with cool air. Transpiration-cooled blades generally consist of a rigid strut with a porous shell. Air flows through internal channels of the strut and then passes through the porous shell to cool the blade. As with film cooling, increased cooling air decreases turbine efficiency, therefore that decrease has to be balanced with improved temperature performance.

4. FINITE ELEMENT METHOD

The FEM has become a major tool to solve complicated engineering problems. The advance in computer technology and high-speed electronic computers enables complex problems to model easily. This makes to test in computers before the first prototype is built. In these method of analyze, a complex continuum is defined into simple geometric shapes called FEM. The material properties and governing relationship are considered over these elements and expressed in term of unknown values at elemental corners. An assembly of this simple geometry shapes considering load and constraints, a set of equations are obtained.

Steps involved in FEM

- Select the continuum of the body.
- Select the discretization of structure.
- Numbering of Nodes and Elements.
- Selection of a Displacement Function or Interpolation Function.

- Define the material behavior by Strain-Displacement and Stress-Strain Relationships.
- Derivation of element stiffness matrix and global load factor.
- Applying boundary conditions.
- Solution for the unknown displacements.
- Faster automatic calculations, which are repetitive in nature, simultaneous display of modifications & post processing results.
- Accurate prediction with adequate details for identifying critical areas of interest like highly stressed regions.

5. FINITE ELEMENT ANALYSIS OF GAS TURBINES BLADE

Finite element analysis can play a vital role by simplifying the analysis. In this work the turbine blade is analyzed for its thermal as well as structural performance due to the loading condition.

Seven different models having different number of holes where analyzed in this paper to find out the optimum number of holes for good performance.

Table 1: Dimensions of the blade

Parameter	Values
Blade Span	120mm
Blade axial Chord Length	130mm
Cooling passage diameter	2mm

Table 2: Material properties of Titanium-Aluminium Alloy

Strength	Values
Modulus of Elasticity	118Gpa
Poisson's Ratio	0.3
Yield Stress	1050Mpa
Density	4507kg/m3
Coefficient of Thermal Expansion	7.7e-6/ºc
Thermal Conductivity	7W/m/ºc
Melting Point	1300ºc

6. MODELING OF GAS TURBINE BLADE

3D model of turbine blade with hub was done in two stages. First for creating the 3D model of the turbine blade, key points were created along the profile in the working plane. The points were joined by drawing B Spline curves to obtain a smooth contour. This contour was then converted into area and then volume was generated by extrusion. Then working plane was rotated by 90o to generate the hub part in the same way as the blade. These two volumes were then combined to make a single volume using union Boolean operation. Holes were then generated along the blade axially by using subtract Boolean operation. The finite element model was created by meshing the 3D model. Since the turbine blade analyses is unique in a way such that two different element types were involved during thermal and structural analyses respectively.

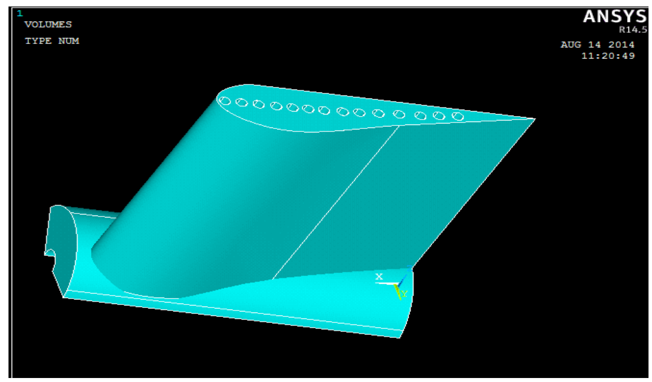


Fig 2: Modeling of turbine blades

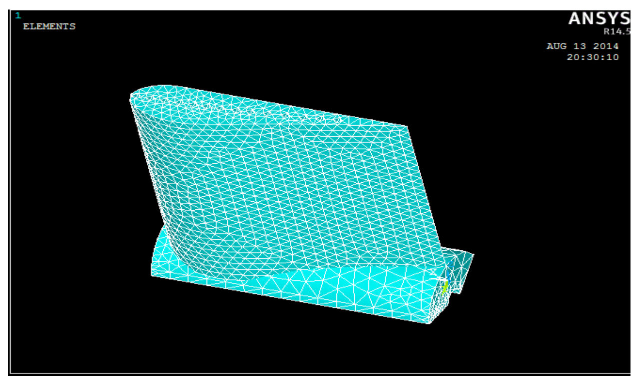


Fig 3 Finite element model of blade

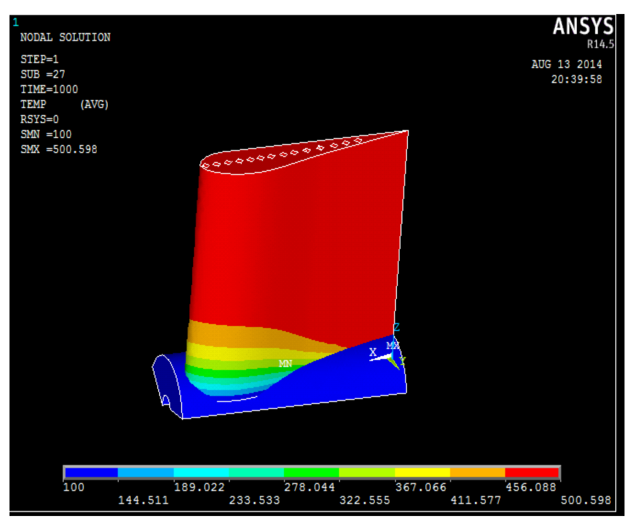
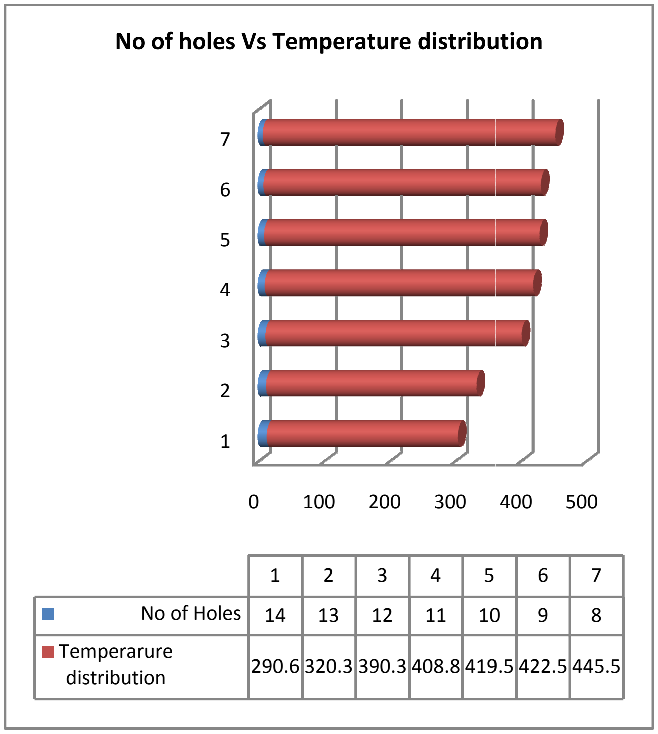


Fig 4 Temperature distribution on 14 holes

7. GRAPHICALLY ANALYSIS OF TURBINE BLADES COOLING SYSTEM

7.1 Graph: No of Holes Vs Temperature Distribution



Graphically the temperature is obtained on analysis with turbine blades with 1370ºc. While increasing number of holes the performance of turbine blades will be decreased. But we analyzed the turbine blades with different holes (14, 13, 12, 11, 10, 9, and 8). We get better cooling technology and performance in 10 holes while compare to 14 holes.

8. RESULTS AND DISCUSSIONS

The thermal-structural finite element analysis was performed for the turbine blades with different number of holes i.e., 14, 13, 12, 11, 10, 9, 8 number of holes by specifying thermal and structural loads with an objective of finding optimum number of holes for the best performance. First the existing blade design with 14 holes was analyzed by specifying 300 C as coolant temperature. Then by specifying 1000 C as coolant temperature, the thermal analysis and structural analysis was performed on all the seven different blade models and thermal and stress distributions were obtained. The temperature distribution on existing design of turbine blade (with 14 holes) when analyzed with coolant temperature of 200o C is much less than that of same blade when analyzed with coolant temperature 300oC. When the coolant temperature of 200oC is intended to be used, it leads to over cooling and affects the performance since an average temperature of 500C is the required allowance blade temperature for the maximum performance of the blade.

The temperature distributions for different holes are shown in table 3.

No of Holes	Temperature distribution
14	290.6
13	320.3
12	390.3
11	408.8
10	419.5
9	422.5
8	445.5

9. CONCLUSION

In this paper, using finite element analysis as a tool, the structural and thermal analyses were carried out sequentially. The blade with different no. of holes (i.e.,) 8, 9, 10, 11, 12, 13 and 14 were used for analysis. From the results obtained, it was found that the blade with 8 holes has got the best temperature distribution when compared other configurations of the blade when the coolant temperature was 1000C. Also, the temperature distribution for the blade with eight holes, matches closely with prescribed temperature of 500C for the better performance of the turbine. The bending stress, obtained from finite element analysis shows lower stress level for the blade with 8 holes. This shows the effectiveness of the finite element analysis. These results indicate that the blade with eight holes will have optimum performance for the prescribed loading conditions.

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