Simulation of Gas Turbine Blades with Cooling Holes

Sambhav Jain[1] Devendra Singh Sikarwar[2]
[1]Research Scholar [2]Associate Professor & Head of the Department
[1,2]Department of Mechanical Engineering
[1,2]Patel College of Science and Technology, Indore, India

Abstract— Gas turbines are commonly used turbo-machine basically used in the power cycles which is operated by the gaseous fluid as a working medium. The gas turbine consists of impeller, casing, inlet and outlet duct, and nozzle also. The impeller is the rotating member of the gas turbine and blades are mounted on the periphery of the impeller. During the continuous flow of working medium on the blades, friction is generated and as a result of which blades are heated. Due to this heating action, the blades get deformed so, to avoid this deformation continuous cooling of the blades are mandatory. There are different techniques of cooling's exists such as by external cooling medium either by air or water. To supply the cooling medium from outside is one of the tedious task to overcome this difficulty the cooling holes can be provided inside the blades at different locations, this cooling hole provides better heat transfer as well as good temperature distribution throughout the blade and it will be helpful to overcome the structural deformation of the blades up to a certain level. This, in turn, increases the blade life and enhances the performance of the blade. In present work, we will focus on the different designs of the blades with providing holes at different locations as well as the same is to be optimized for different blade material and provide a better choice for selecting a proper blade for a variety of applications.

Keywords: Gas Turbine, Impeller, Blade, Optimization, Blade with Holes, Temperature Distribution, Heat Transfer

I. Introduction

In turbines the heat transfer is mainly through surface convection, conduction and then internally mainly by forced convection. The radiation heat transfer is neglected. The tip of the blade or the leading edge is called as its stagnation point. At this stagnation point the flow comes to a halt and at this point the total temperature is equal to the static temperature. So, the stagnation point is indeed the hottest spot on the blade surface.

There are varieties of turbine blades are used in the gas turbine few of them are listed below

1) forward curved blades
2) backward curved blades
3) adial blades
4) airfoil blades

II. Literature review

Brahmaiah K. H. et al. [1] carried out the heat transfer analysis of the gas turbine blade with different models, which consist of a blade without holes and a blade with a different number of cooling holes. Schlobohm J. et al. [2] presents four complementary non-destructive measurement techniques for material characterization and damage detection of turbine blades. The techniques are macroscopic fringe projection with inverse fringe projection algorithms, robot. Liu, J. H. et al. [3] In this work, a spoon with end wall film cooling, shower head film cooling and pressure / suction film cooling was used to model the cascade flow and the film cooling flow. Bario F. et al. [4] investigated the aerodynamic behaviour of cold discrete jets in a cold secondary flow. Zhou, W et al. [5] conducted an experimental investigation to investigate a new film cooling design using the Barchan-Dune-Shaped-Ramp (BDSR) concept to increase the efficiency of film cooling injection from discrete holes. Andrews G. E. et al. [6] examined the mixture of the cooling air with the main gases using the temperature of the boundary layer and the CO2 profiles. It was shown that the entrainment of hot flame gases between the injection holes resulted in a very low cooling efficiency of the adiabatic film. Wadia A. R. et al. [7] conducted the experiments in a wind tunnel on several stainless steel test specimens in which flow and heat transfer parameters were measured over the simulated airfoil leading edge surfaces. Based on the experiments, an engineering design model is proposed that treats the gas-to-surface heat transfer coefficient with film cooling in a manner suggested by a recent Purdue-NASA investigation and includes the important contribution of upstream (coolant inlet face) heat transfer.

III. Working principle

Gas turbine engines derive their power from burning fuel in a combustion chamber and using the fast flowing combustion gases to drive a turbine in much the same way as the high pressure steam drives a steam turbine. A simple gas turbine is comprised of three main sections a compressor, a combustor, and a power turbine. The gas-turbine operates on the principle of the Brayton cycle, where compressed air is mixed with fuel, and burned under constant pressure conditions. The resulting hot gas is allowed to expand through a turbine to perform work.

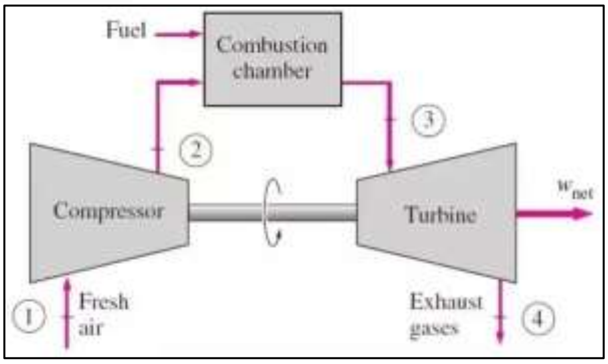

Fig. 1: Working of Gas turbine

IV. Geometric Modeling

The following table represents the dimensions of the part taken for modeling.

Sr. No.	Name of section	Dimensions taken
1	Total Width of the I section	150 mm
2	Total Depth of I Section	100 mm
3	Total Height of I section	150 mm
4	Width top, bottom & centre solid I section	50 mm
5	Total height of blade	300 mm
6	Total width of blade	150 mm
7	Type of air foil used	NACA 2424
8	Number of equidistance holes	06
9	Width of outer shell of air foil blade	1.5 mm

Table 4.2: Blade turbine dimensions

Once the model is successfully made the next task is to modify the same model using hollow blade model to analyse and compare the two models in some analysis software. The following model represents the top viw of the wireframe model of the blade turbine profile with cooling holes.

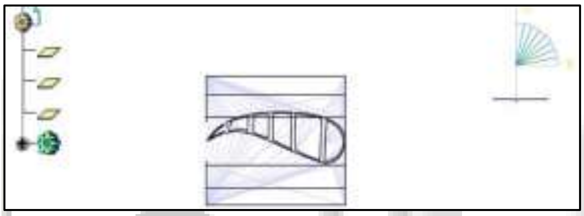

Fig. 2: Top view of NACA 2424 Air foil blade profile with holes

Then the three dimension model is made using pad tool in CATIA to get the 3D shape of the blade. The following figure represents the same model design.

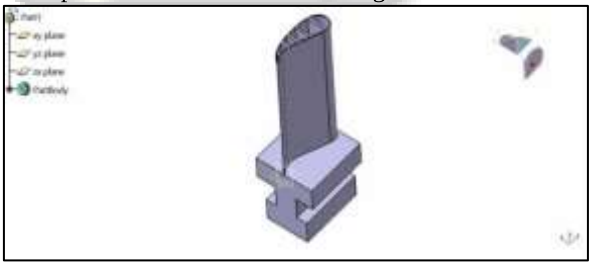

Fig. 3: Model of gas turbine blade

In assembly workbench we have to call the different parts by using the existing component tool bar and then browsing all the three parts from the location in computer where the components are previously saved this will bring all the parts together in a single product file. Now our task is only to position the components irrespective the exact location to match the design in our imagination. The manipulate tool is used in which we can move the different part within 3D. environment to get approximate location for giving further offset constraint successfully and with ease.

Modelling work has been completed at this stage. Now assembly model is ready to export in the analysis workbench.

V. Thermodynamics Behind Temperature on Turbine Blade Surface

$$T = \frac{T_{01}+T_{02}}{2} - \frac{U_{mean}^2}{2C_{P-gas}}$$

Where Dr = Rx

Heat transfer coefficient =

$$\frac{\text{Quantity of heat transferred}}{\text{Surface area} \times t \times \Delta T \text{ between hot gas and the surface}}$$

Where,

t = time

ΔT = Temperature difference

$$N_u \propto F_1(R_e) \times F_2(P_r)$$

N_u = Nusselt No.

R_e = Reynolds No.

P_r = Prandtl No.

$$N_u = 0.0296. R_e^{0.8} \times P_r^{\frac{1}{3}}$$

When it comes to turbine cooling the first thing that comes to our mind is water cooling. Turbines are subjected to gas at high temperature and at high pressure but the blade feel a temperature that is not same as turbine entry temperature. Let the turbine entry temperature is $T01$ and the blade exit temperature is $T02$. What the blade feels is the average of two minus the rotating kinetic head. Which is represented mathematically in above stated equation.

Quite often the heat transfer is done in terms of Nusselt number which is proportional to product of Reynolds number and Prandtl number and that's too for simple systems through some constant terms which are used to create this semi empirical relationship. Now, this is the kind of science or technology that one would need to bring forth in the turbine cooling business.

VI. Analysis and Simulation

The three dimensional model once made in CATIA is imported in ANSYS workbench using suitable data exchange format. Here the IGES data exchange format is used which is readable in both CATIA and ANSYS workbench. The following figure 5.1 shows the imported model of the same in ANSYS workbench.

In present work the steady state thermal analysis module is used as per the discussion in introduction and literature part as our aim is to see the high heating zones and the effect of providing holes in the blade of gas turbine. Here a single blade is analysed for both without cooling holes and with cooling-hole model.

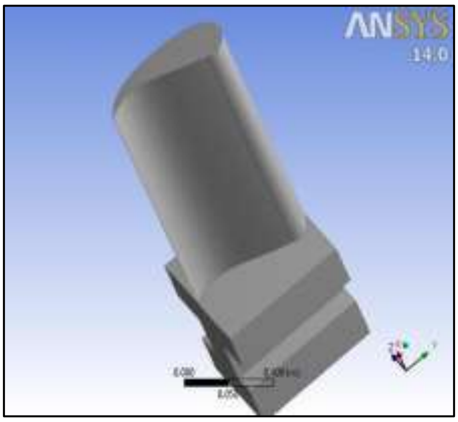

Fig. 4: Gas turbine blade model as imported in ANSYS 14.0

Figure 5 represents the blade model with cooling holes. The model is modelled using CATIA V5R12 and the same is imported in ANSYS 14.0 using IGES data exchange format. The tool used for making holes is pocket tool in CATIA 3D workbench module.

Figure 6 and figure 7 represents the meshed model of the turbine blade for which ANSYS meshing module is used the size of the mesh is taken as the superfine mesh as it will provide the more promising results as far as the thermal FEA analysis is considered. Secondly the mesh element type used is tetrahedron element because the body is curvy in shape for which block type of elements will mesh with a comparatively great amount of errors. The tetrahedron is a type of 3D element in which a pyramid type of 3D element is considered having 4 equilateral triangular faces including 6 edges and 4 vertices. Each edge is considered having equal element size and each vertex is called as nodes of the elements. Here in present element type the 5 nodes are considered in each element as there are 5 vertexes in each tetrahedral element.

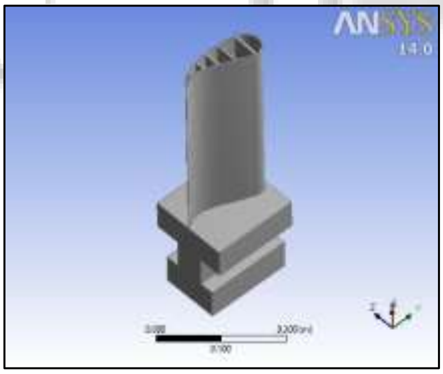

Fig. 5: Gas turbine blade model with cooling holes as imported in ANSYS 14.0

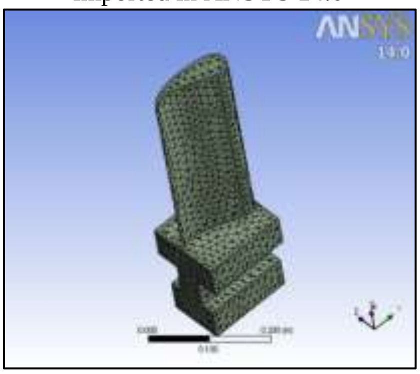

Fig. 6: Mesh model of Gas turbine blade

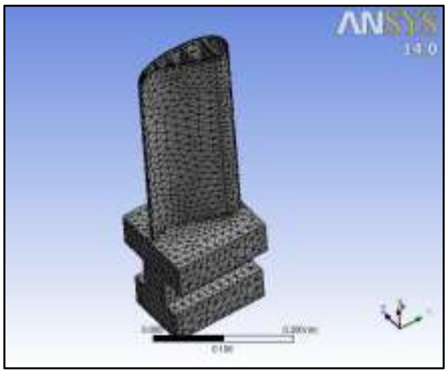

Fig. 7: Mesh model of Gas turbine blade with cooling holes

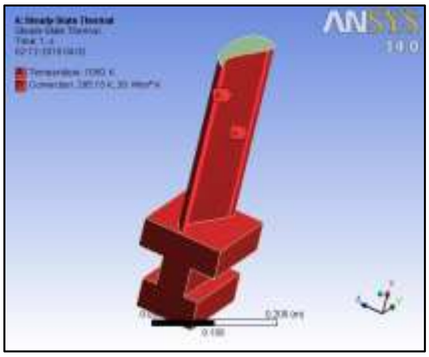

Fig. 8: Boundary Conditions

Figure 8 and 9 shows the boundary conditions of the gas turbine blade with and without cooling holes as the temperature zones are created at the leading and the trailing edges of the blade profile and the temperature range provided is 1050 Kelvin. Whereas the base temperature is taken as 295.15 kelvin the second important constraint is the convection coefficient which is given as 30 W/m^2K

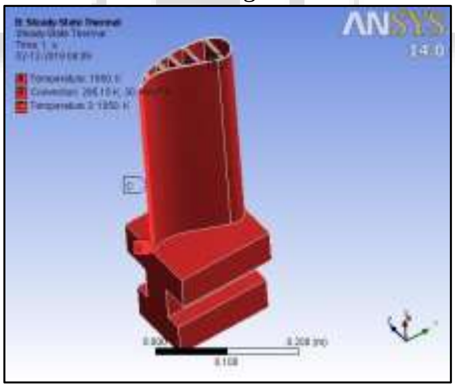

Fig. 9: Boundary conditions of Gas turbine blade with cooling holes

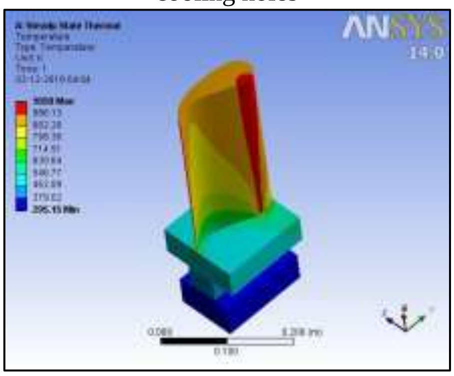

Fig. 10: Temperature distribution of Gas turbine blade

Figure 10 and figure 11 represent the temperature distribution of the gas turbine blade without and with cooling holes. The temperature contours shows that what are the major zones where its effects are maximum and where we need to enhance the cooling performances of the turbine blade.

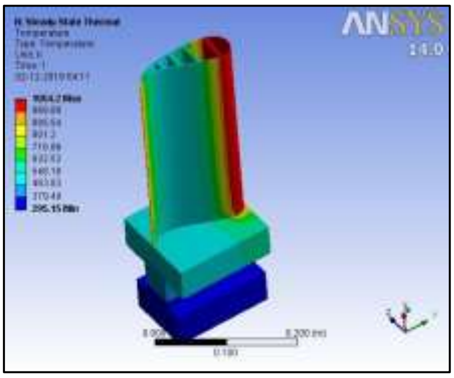

Fig. 11: Temperature distribution of Gas turbine blade with cooling holes

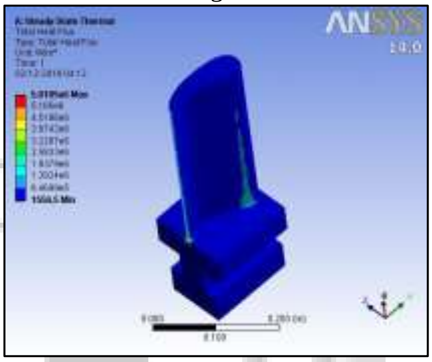

Fig. 12: Temperature distribution of Gas turbine blade

Figure 12 and figure 13 represent the heat flux distribution of the blade without and with cooling holes it can be clearly seen that there is a drastic change in cooling performance of the blade with cooling holes. As the heat flux increases the effect of cooling also increases as it is the rate of heat dissipation per unit area of the blade surface

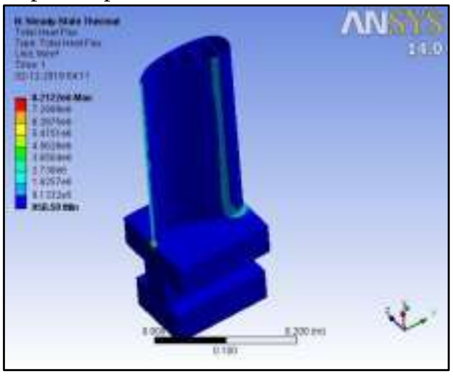

Fig. 13: Heat flux distribution in gas turbine blade with cooling holes

VII. Results:

After the computer aided modelling and finite element analysis work the following results are obtained with and without cooling holes of gas turbine blade which is represented in table 6.1.

Sr. No.	Blade Geometry	Max. Temperature	Max. Heat Flux
1	Without Cooling holes	1050	5.8105e6
2	With Cooling Holes	1054.2	8.2122e6
3	%Deviation	0.398%	29.2%

Table 6.1 Result table for Gas turbine blade with and without cooling holes

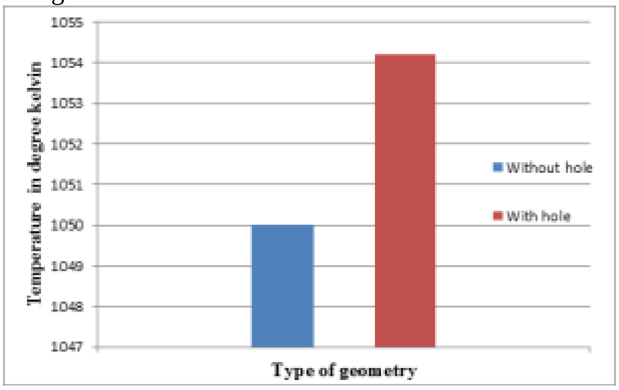

Fig. 14: Temperature distribution for two types of geometry.

VIII. Discussions

From the aforementioned results we can say the following points:

1) On the basis of presented work we can say that the temperature maximum did not vary much by modifying the blade geometry by embossing holes inside it.
2) The heat flux distribution is highly affected by imposing holes and that too of the order of 29.24% which is a much significant change as compared to blade without holes profile.
3) As the heat flux is directly related to rate of cooling so the modified geometry must be preferred over the traditional blade without holes.
4) The ANSYS simulation software is proved to solve such kind of thermal analysis problems which can be complex to solve numerically.
5) It can be observed that the by providing holes the temperature on the topmost part of the blade at the centre is also decreased to great level and hence can optimize the blade performance in other way

IX. Conclusion

1) The gas turbine blade with holes profile gives much better results in terms of heat dissipation rates and should be implemented in practices where high performance is required.
2) By changing the blade geometry the temperature does not affected much and hence it can be implemented in gas turbine applications.
3) FEA analysis can be used to solve such kind of thermal nonlinear analysis problems.
4) As the temperature difference is increased up to 4 degree and heat flux increases up to 29% using same material of turbine blade so, the heat transfer coefficient of the system is increased in modified geometry blade.

In future instead of structural steel some more kind of materials can also be used to solve the same problem.

Some other FEA solver like Hyper-mesh, Abacus etc. can be used to compare results obtained for the same problem.

1) The meshing size and mesh type can be changed to see their impact in FE analysis.
2) Instead of using steady state thermal analysis only one can change switch to transient thermal analysis to observe the blade performance in dynamic time dependent situation.
3) The boundary conditions such as temperature and convection can be varied in future and can be analysed.

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