Structural and Thermal Analysis of Gas Turbine Blade for In-Line and Zig-Zag Arrangement of Cooling Holes by FEM

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Abstract— Force or Pressure is applied to a material, the material deforms and the effect of Pressure is transmitted all over the material. The external induced pressure and reactions to compose the material into a state of equilibrium. In this project work by using Finite element analysis, Static structural and Steady state thermal analysis will be done for two different arrangement of radial cooling holes one is In-Line and another is Zig-Zag, with different pitches of 7, 8, 9, & 10 numbers models were designed, in Static structural analysis calculates Total Deformation and Equivalent (Von-Mises) Stress, and In Steady State Thermal analysis calculates Temperature Distribution and Total Heat Flux, From the results it is observed that Total deformation of the gas turbine blade is minimum 5.5865E-2 in Zig-Zag arrangement of cooling holes and is maximum 5.6386E-2 in In-Line arrangement and Equivalent (Von-Mises) stress of the gas turbine blade is minimum 1.2504E10 in Zig-Zag arrangement of cooling holes and is maximum 1.3022E10 in In-Line arrangement of cooling holes, Temperature distribution is minimum 934.120C in In-Line arrangement of cooling holes and is maximum 955.990C in Zig-Zag arrangement of cooling holes, and Total heat flux or energy transfer is minimum 1.1418E5 in In-Line arrangement of cooling holes and is maximum 1.2742E5 in Zig-Zag arrangement of cooling holes. From the above results the blade with Zig-Zag arrangement of radial cooling holes has given optimum performance than the In-Line arrangement of cooling holes.

Key words: Gas Turbine Blade, FEM

I. INTRODUCTION

Generation of power is the most important relevance in these days to the modern industry. Turbine is the individual key sources for the generation of power using either of the external sources as an input. Turbo machines are the devices in which occurs a continuous energy transfer between a rigid body (Rotor) and a deformable media (Fluid). A large number of machinery is characterized by this energy transfer process. Turbo machines are wide group of equipment (water turbines, steam turbines and gas turbines etc.) their characteristics feature is a rotor with blades on its perimeter, which is usually called an impeller which is a shaft by means of blades are attached. Moving fluid acts on the blades so that they are in motion and impart rotating energy of the rotor. An operational fluid contains pressure energy and kinetic energy. The fluid can be compressible or incompressible. On its definition turbo machine is a device which converts hydraulic energy in to useful mechanical energy and then this Mechanical energy convert in to Electrical energy.

A. Gas Turbines

Gas turbine or rotary engine could be a class of internal combustion device. It has an upstream revolving compressor attached to an area, called a combustor. The fundamental process of the gas turbine is similar to that of the steam power plant apart from that the operational fluid is air as a substitute of water. Clean atm air flows to a compressor so as to bring it to advanced pressure. Power is then extra by spraying liquid natural gas as a fuel into the compressed air and ignites as a result ignition generates a high temperature and pressure. This high temperature & pressure gas enters a turbine, where it expands down to the exhaust pressure, producing shaft work manufacture in the process, the turbine shaft work is utilize to make the compressor & other components such the same as an electric generator that may be attached to the shaft, & thus the power generates through the gas turbine.

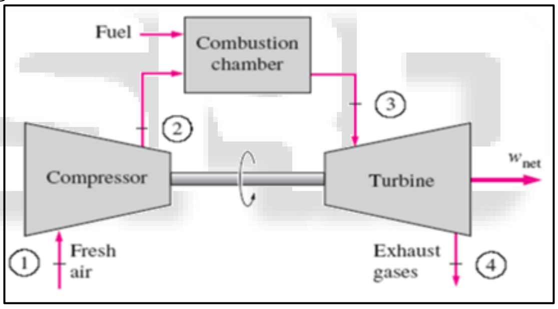

Fig. 1.1: Open Cycle Gas Turbine Engine

B. Introduction to Ansys

Ansys is an Engineering replication software provider founded by software Engineer Mr. John Swanson. He develops it general purpose for FEA and CFD analysis. While Ansys has developed a sort of (CAE) products, it is possibly most excellent known for its Ansys Mechanical & Multiple physics products. Ansys Mechanical & Multiple physics software are non-exportable analysis equipment incorporating geometry creation, mesh generation called pre-processing solver and post processing modules in a graphical consumer interface. These are common function finite element modelling packages for numerically solving mechanical problems, including static structural analysis heat transfer and fluid problems. Ansys Mechanical information incorporates in cooperation structural and objects non-linearity. Ansys Multi physics software includes solvers intended for static structural & Steady State thermal, Electromagnetic, Acoustics & occasionally combines these part physics in concert in direct to deal with multidisciplinary applications. Ansys software is able to study in Civil, Electrical Engineering, physics and chemistry.

C. Ansys Workbench

Ansys workbench is a new invention key, Ansys workbench provides correct method for interacting with the Ansys solver functionally. This background provides a unique combination with CAD, CAM, and design process enabling the best CAE results.

D. Finite Element Analysis

Finite Element Analysis is a computer based of simulating the performance of engineering structures and components under variety of conditions. It is an advanced engineering tool is used in design and to replace experimental testing and for predicting how a product reacts to real world forces or pressure, vibration, heat, fluid flow and other physical effects. Finite Element Analysis shows weather a product will work the way it was designed or not.

Particulars	Nickel Inconel 718	Unit
Melting temperature	1260^{0}c-1336^{0}c	0c
Density	8220kg/m3	Kg/m3
Young's Modulus	200Gpa	GPa
Shear modulus	77.2Gpa	GPa
Poisson's ratio	0.294	
Thermal conductivity	11.4 W/mK	w/m-k
Specific heat	435 J/kg-k	J/kg-k

Table 1.1: Typical Properties of Nickel Inconel 718 at Room Temperature

II. MESHING

Creating the most suitable mesh is the base of engineering simulations. ANSYS meshing is conscious of the type of solutions that will be used to in the project and has the suitable criteria to produce the most excellent suited mesh. ANSYS meshing is automatically incorporated with each solver within the ANSYS work bench setting. ANSYS meshing chooses the most suitable options based on the analysis nature and the geometry of the model.

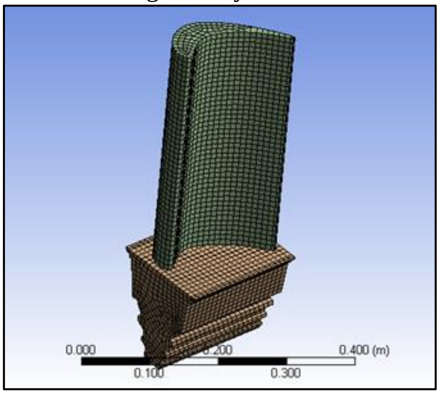

Fig. 2.1: Assembly Level Meshing in Ansys Design Model

Assembly level meshing refers to meshing a complete model as a unit mesh process, in which mesh occurs at the individual part/ Body level respectively. These operations include a combination of volume filling & intersection, and volume combination operations that generate a conformal mesh among all solids, fluids, and virtual bodies in the analysis.

A. Static Pressure Load

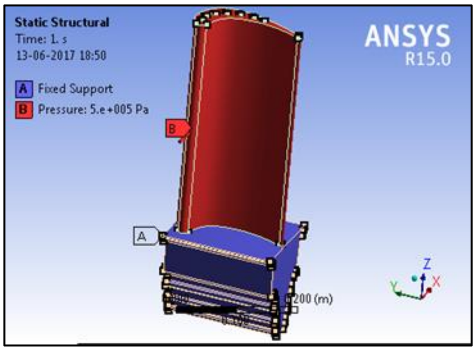

Fig. 2.2: Static Pressure Load Applied on Gas Turbine Blade

The static pressure load acting on the gas turbine blade, Part A is the stem (Fixed part) in ansys workbench and part B is the blade that actual load or pressure acting minimum of 0.5Mpa and maximum of 10.2Mpa.

B. Steady State Thermal Load

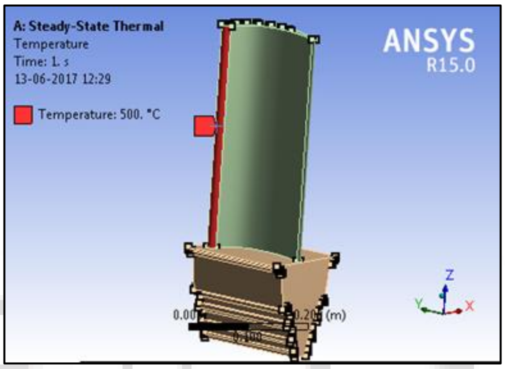

Fig. 2.3: Steady State Thermal Load Applied on Gas Turbine Blade

The steady state thermal load acting on the leading edge of the gas turbine blade minimum of 5000C and maximum of 11000C.

C. Forced Convection

Convection is the process of heat transfer through a fluid in the existence of extent fluid movement. Convection is classify as natural or free and forced convection depending on how the fluid movement is initiated, in natural convection, fluid movement is caused by natural means such as the buoyancy result, i.e. the increase of hot fluid and decrease the cold fluid.

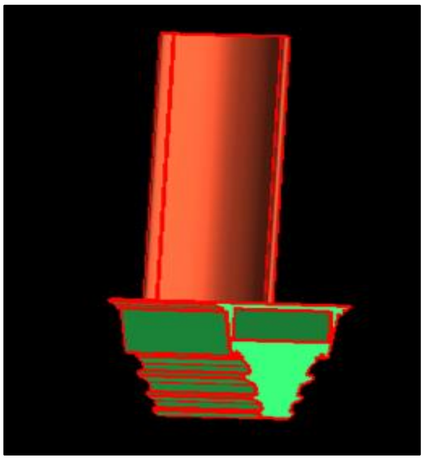

Fig. 2.4: Cold Air Jet Impingement

Where as in forced convection, the fluid is forced to flow over a surface or in a turbine by external means such as pump or fan.

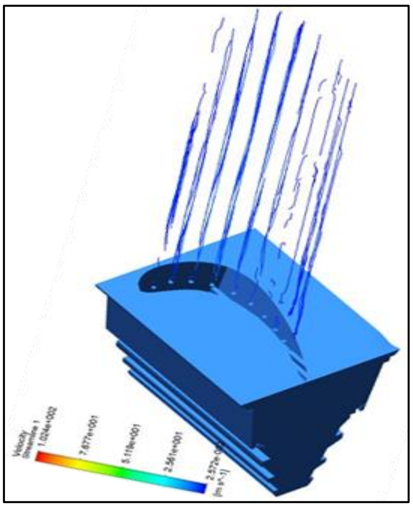

Fig. 2.5: Forced Convection in the Gas Turbine Blade

Jet impingement and forced convection are advanced cooling technology and extensively used in gas turbine blades. Convective heat transfer from impinging jets is identified by area averaged heat transfer coefficients. Impingement jets are of particular concern in the cooling of gas turbine apparatus where advancement relies on the skill to disperse enormously huge heat loads.

D. Arrangement of Radial Cooling Holes

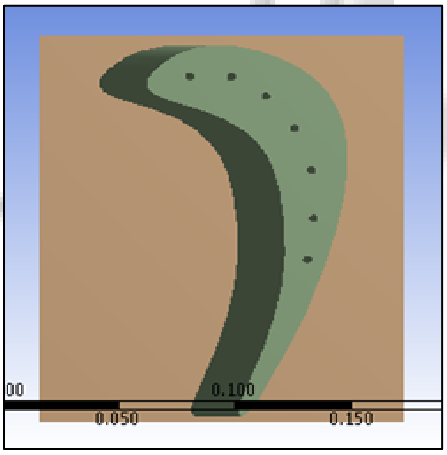

Fig. 2.6: Cooling Holes Arranged in In-Line

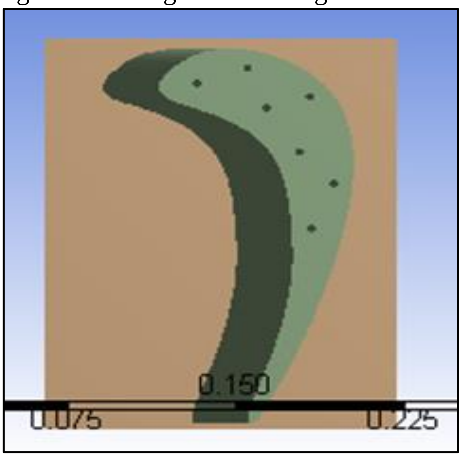

Fig. 2.7: Cooling Holes Arranged in Zig-Zag

III. Results and Discussion

A. Static Structural Analysis

When Force or Pressure is applied to a material the material deforms and the effect of Pressure is transmitted all over the material. The external induced pressure and reactions to compose the material into a state of equilibrium. In this project work in static structural analysis calculates Total Deformation, Equivalent (Von-Mises) Stress.

B. Steady State Thermal Analysis

Change in temperature can make considerable deformation in a body. In this Steady State Thermal analysis, temperature 5000C-11000C applied and Temperature Distribution and Total Heat Flux is going to be calculated.

1) Total Deformation:

The total deformation of the gas turbine blade with In-Line and Zig-Zag arrangement of cooling holes are shown, deformation is disseminated in an ascending manner from the bottom of the hub to the tip of the blade. The blue colour indicates minimum deformation 0.0024588 mts at 0.5 Mpa and maximum deformation of 0.05016 mts at 10.2 Mpa. Maximum deformation occurs, since gas enters at the leading edge and leaving from the trailing edge of the blade with high pressure and temperature, The strength of the hub is high since it is rigidly fixed to stem and it can withstand maximum pressure than the tip of the blade as a result maximum total deformation occurs at the Tip and Minimum at hub of the blade.

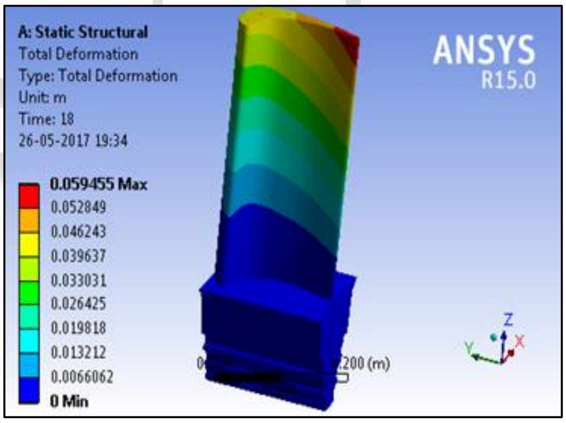

Fig. 3.1: Total Deformation of the Gas Turbine Blade with 7 Cooling Holes In-line

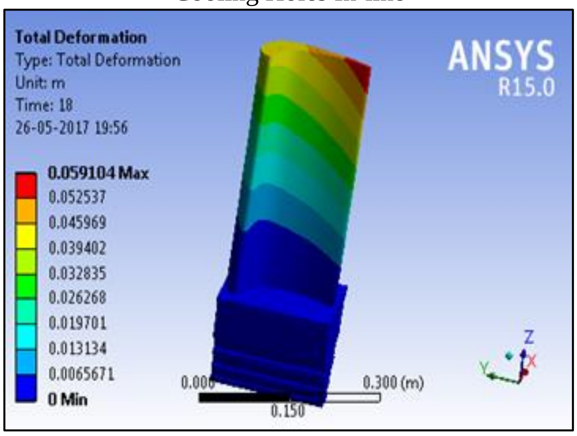

Fig. 3.2: Total Deformation of the Gas Turbine Blade with 7 Cooling Holes Zig-Zag

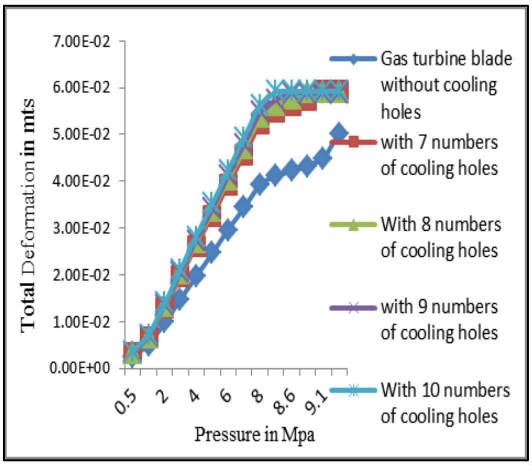

Fig. 3.3: Total Deformation V/S Pressure with Different Cooling Holes In-Line to Without Cooling Holes

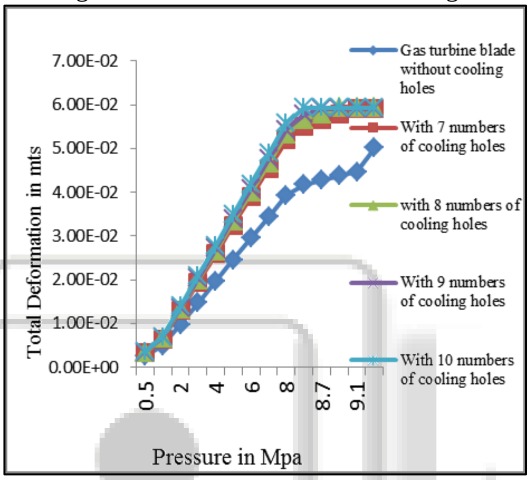

Fig. 3.4: Total Deformation V/S Pressure with Different Cooling Holes Zig-Zag to without Cooling Holes

2) *Equivalent (von-Mises) stress:*

The Equivalent (von-mises) stress is used to resolve the yielding of materials under different loading condition. The stress is almost equally distributed along the blade & they are extremely concentrated on the bottom portion of the hub. Since pressure is directly proportional to stress, hence when pressure increases the stress on the blade increases at the hub i.e. fixed portion of the blade, and at the free end stress is minimum 0 Pa

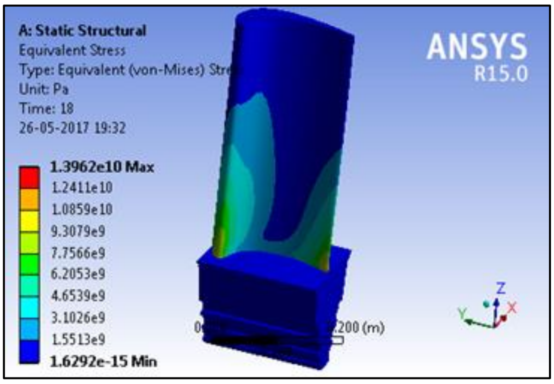

Fig. 3.5: Equivalent (von-Mises) Stress of the Gas Turbine Blade with 7 Cooling Holes in-Line

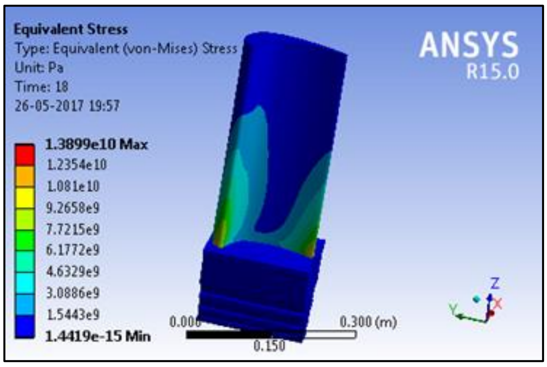

Fig. 3.6: Equivalent (von-Mises) Stress of the Gas Turbine Blade with 7 Cooling Holes Zig-Zag

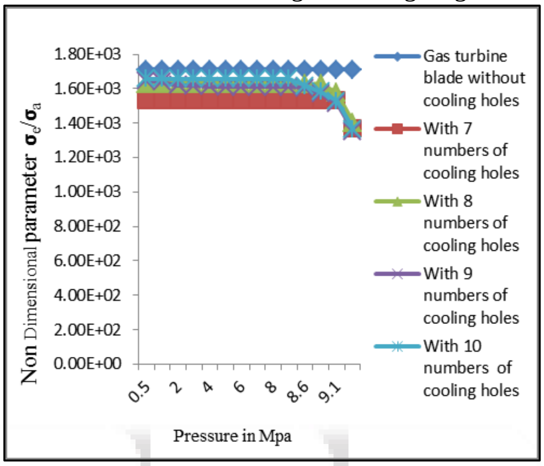

Fig. 3.7: Equivalent (Von-Mises) Stress v/s Pressure with Different Number of Cooling Holes In-Line to without Cooling Holes

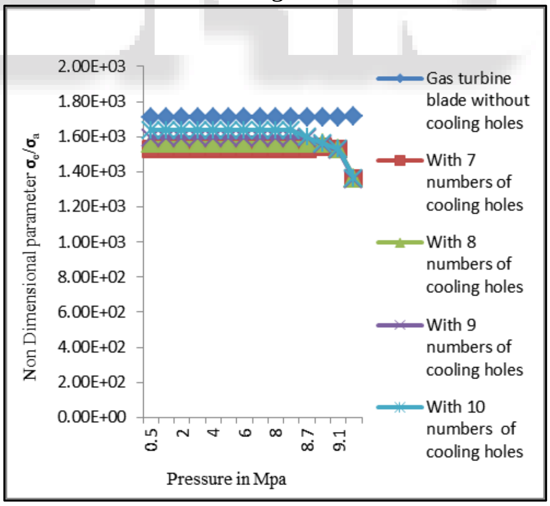

Fig. 3.8: Equivalent (Von-Mises) Stress v/s Pressure with Different Number of Cooling Holes Zig-Zag to without Cooling Holes

3) *Temperature Distribution:*

Temperature Distribution of the gas turbine blade with In-Line & Zig-Zag arrangement of cooling holes is shown. Maximum temperature distribution is found on the leading edge of the blade and minimum on trailing edge. The gas with high temperature strikes on the leading edge of the blade and it decreases when glides over the surface of the blade. High velocity cooling air will be passing from the cooling holes causing forced convection heat transfer from cooling air to the blade & reduce the temperature of the blade.

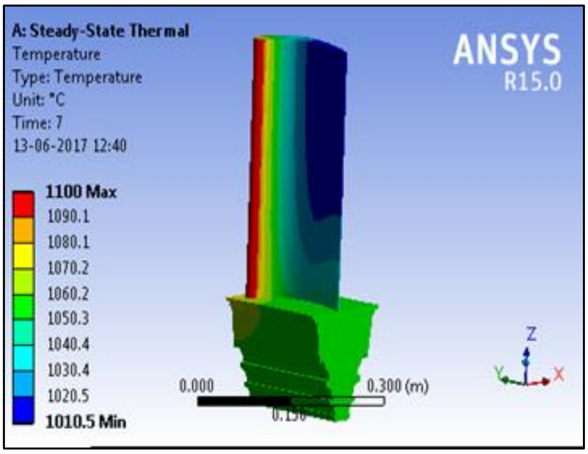

Fig. 3.9: Temperature Distribution of the Gas Turbine Blade with 7 Cooling Holes In-Line

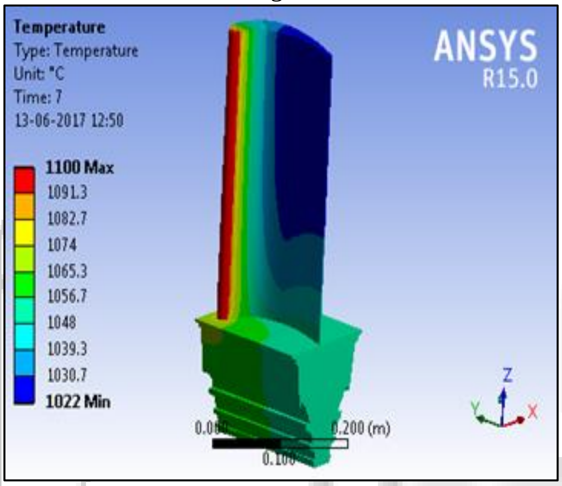

Fig. 3.10: Temperature Distribution of the Gas Turbine Blade with 7 Cooling Holes Zig-Zag

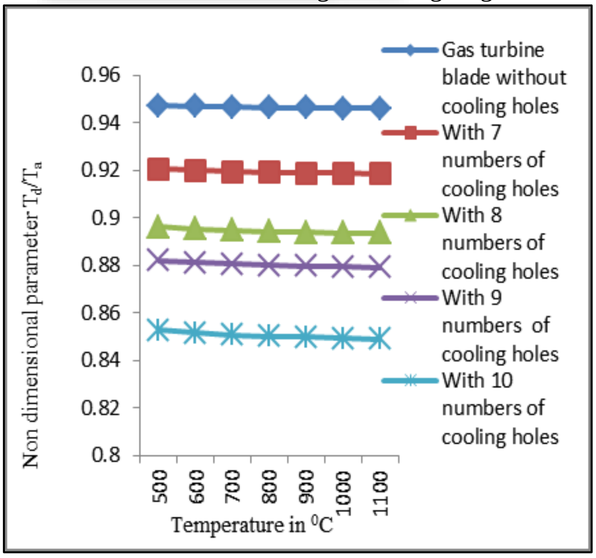

Fig. 3.11: Applied Temperature v/s Non dimensional Parameter (Td/Ta) with Different Number of Cooling Holes (In-line) to without Cooling Holes

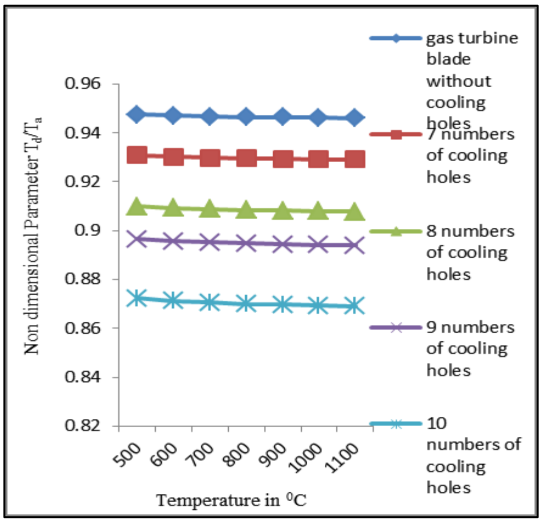

Fig. 3.12: Temperature v/s Non Dimensional Parameter (Td/Ta) with Different Number of Cooling Holes (Zig-Zag) to without Cooling Holes

4) Total Heat Flux:

The rate of energy transmits through a given surface per unit time is called Heat flux or thermal flux. Fig shows the gas turbine blade with In-Line & Zig-Zag arrangement of cooling holes. High velocity cooling air will be passing through the cooling holes. The reduction in temperature of the blade is within allowable limits due to forced convection heat transfer from the cooling air to the blade. Therefore it transmit maximum of 77520 W/m2 heat to the surrounding and minimum of 0.030895 W/m2.

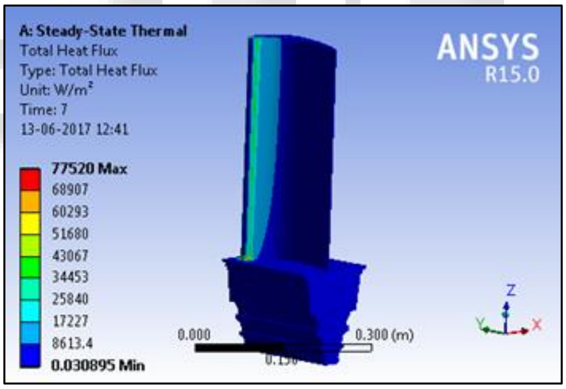

Fig. 3.13: Heat Flux of the Gas Turbine Blade with 7 Cooling Holes In-Line

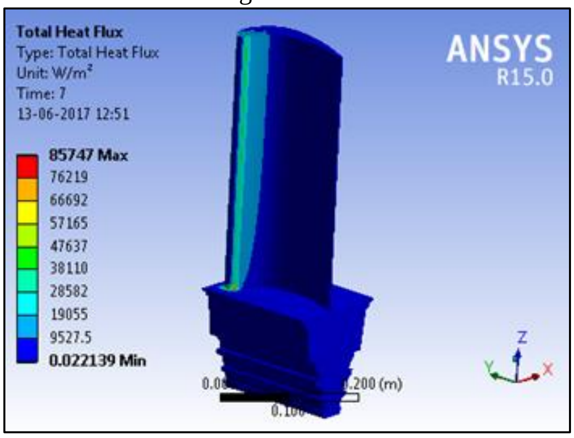

Fig. 3.14: Heat flux of the Gas Turbine Blade with 7 Cooling Holes Zig-Zag

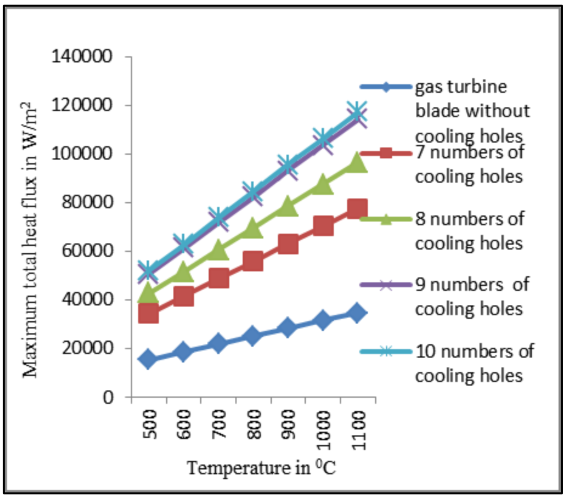

Fig. 3.15: Maximum Heat flux v/s Temperature with Different Number of Cooling Holes (In-Line) to without Cooling Holes

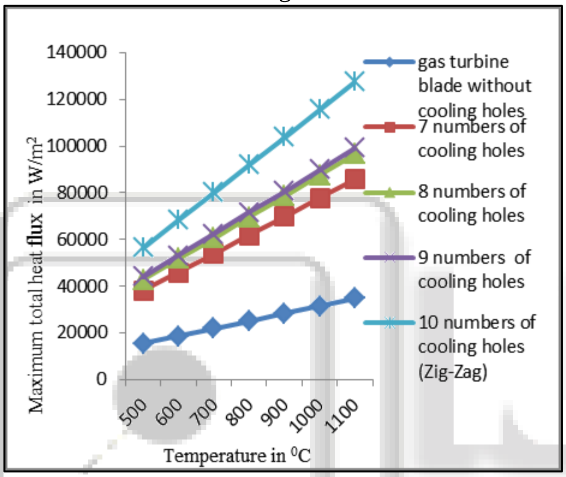

Fig. 3.16: Maximum Heat Flux V/S Temperature with Different Number of Cooling Holes (Zig-Zag) to without Cooling Holes

IV. CONCLUSION

The following conclusions are drawn.

- Total deformation of the gas turbine blade is minimum 5.5865E-2 in Zig-Zag arrangement of cooling holes and is maximum 5.6386E-2 in In-Line arrangement, from the above results it is observed that the total deformation 1% less in Zig Zag arrangement of cooling holes compared with In-Line arrangement.
- Equivalent (Von-Mises) stress of the gas turbine blade is minimum 1.2504E10 in Zig-Zag arrangement of cooling holes and is maximum 1.3022E10 in In-Line arrangement of cooling holes, from the above results it is observed that the maximum stress is 3.97% more in, In-Line arrangement of cooling holes compare with Zig-Zag arrangement.
- In Thermal analysis Temperature Distribution and Total Heat Flux are founded and values are tabulated and comparison of all the models as shown in Fig.
- Temperature distribution is decreases with increasing the number of cooling holes, it is minimum 934.120C in In-Line arrangement of cooling holes and is maximum 955.990C in Zig-Zag arrangement of cooling holes, from the above results it is observed that temperature distribution is 2.28% more in Zig-Zag arrangement of cooling holes compared to In-Line arrangement.
- The total heat flux or energy transfer per unit area is minimum 1.1418E5 in In-Line arrangement of cooling holes and is maximum 1.2742E5 in Zig-Zag arrangement of cooling holes, from the above results it is observe that 10.39% of heat transfer rate is more in Zig-Zag arrangement of cooling holes compared to In-Line arrangement.
- From the above static structural and steady state thermal analysis it is observe that Zig-Zag arrangement of radial cooling holes give optimum values compare to In-Line arrangement of radial cooling holes.

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