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ANALYSING THE INTERNAL COOLING SYSTEM OF INDUSTRIAL GAS TURBINE USING ANSYS

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Abstract - *The function of the turbine inlet temperature is critical to the overall output of the turbine. The temperature of the turbine inlet rises, resulting in a boost in average turbine performance. Gas turbines run at extremely high temperatures, up to 1400-1500°C, resulting in the melting of the turbine blade and the possibility of the turbine failing. As a result, a sophisticated cooling system for turbine blades is required. The inlet temperature of the turbine blade should be increased to boost overall turbine efficiency, however heat will have a direct effect on turbine blades. There are numerous technologies to cooling turbine blades, one of which is blade cooling technology with different cooling hole layouts. This procedure is used to improve the turbine's performance by lowering the temperature of the turbine blades. The blades are built of superalloys, which can withstand high temperatures. Various software programmes are used to detect the ability to perform in severe temperatures without failing. For the analysis of turbine blades, ANSYS and CFD software are commonly utilised.*

The temperature of turbine blades is frequently reduced by using various cooling systems. The system of cooling primarily uses air as a coolant that impinges on turbine blades, resulting in significantly lower turbine blade temperatures.

Blade geometry with staggered holes is set on the surface of the blade in this work, and STATIC and CFD calculations with boundary conditions are performed, with comparable results. When compared to blades without holes, the analysis shows that the uniformity of the temperature distribution over the blade surface is higher in staggered holes and that the peak temperature over the blade surface is lower.

***Key Words*: Computational Fluid Dynamics (CFD), Static Analysis, Turbine Cooling, Staggered Holes Cooling.**

1. INTRODUCTION

Gas turbines are primarily utilised for power production and propulsion applications and play an essential role in meeting a variety of power needs. Turbine engine performance and efficiency are heavily influenced by turbine rotor inlet temperatures, which are normally higher the hotter.

The heat transmission qualities of the turbine blades limit the combustion temperature and fuel efficiency in gas turbines.

The use of effective cooling solutions is crucial in pushing the limits of hot gas temperatures while preventing the melting of blade components in high-pressure turbines.

As the temperature of the turbine inlet rises, so does the amount of heat transferred to the turbine blade, and the operating temperature may rise much above the permitted metal temperature. In such instances, inadequate turbine blade cooling causes excessive thermal stress on the blades, resulting in early blade failure. This could jeopardise the engine's safe operation.

The goal of turbine technology is to collect as much energy as possible from the working fluid and turn it into meaningful work as efficiently as possible using a plant with maximum reliability, least cost, little monitoring, and minimal start-up time.

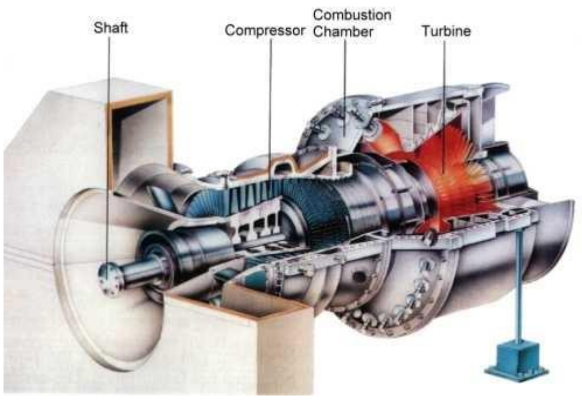


Fig -1: ABBILDUNG 3 the Dressed BR715 Engine

The figure [1] shows the structure of Gas turbine of BR715 engine with exploded view showing various parts. The three main sections of gas turbine are compressor, combustor, and power turbine which work on the principle of Brayton cycle under constant pressure conditions. The turbine generates power by exploiting the energy of burnt gases as well as air at severe temperatures and pressures, which expands through numerous rings of fixed and moving blades to create a high pressure of 4 to 10 bar in the working fluid, which is critical.

A compressor is necessary for expansion. Because the amount of working fluid and the needed speed are greater, a centrifugal or axial compressor is usually required. The compressor is connected to the turbine shaft as shown in Fig [1] that is driven by the turbine.

If the working fluid in a turbine is expanded after compression, the power output by the turbine is often enhanced by increasing the quantity of working fluid at constant pressure or raising the pressure at constant volume, assuming no losses in either component. Either of these could be accomplished by increasing the temperature of the working fluid after compression by introducing heat. to raise the temperature of the working fluid, a combustion chamber is necessary, where air and fuel are burned to raise the temperature of the working fluid. The exhaust gas provides energy to the turbine. Turbines are typically centrifugal or axial, similar to compressors. The turbine is rotated by fast-moving exhaust gas in either case; but, because the turbine is attached to the same shaft as the compressor at the front of the engine and consequently revolves together, it can only extract enough energy to turn the compressor. Extra turbine stage energy could also be employed to turn additional shafts to power other machinery such as a helicopter's rotor, a ship's propellers, or electrical generators in power plants, as in a pure jet engine.

1.1 Turbine Blade

The turbine blades are critical components that rely on the overall performance of the turbo system. The rotor blade failure is the most common cause of turbo failure. The loss of the rotor blade could have disastrous physical and financial consequences. As can be seen in the Fig [2], the correct configuration is critical for the turbo blade, to the proper operation of the turbo system.

Fig -2: Turbine Blade

A successful configuration of the turbo bladder requires the following:

- Determination of geometric gas dynamic research properties.
- Evaluating regular pressures and pressures on the weapon.
- Normal frequency and mode forms determination.
- Determination of unpredictable powers due to interaction of the stage movement.
- Determination of complex powers and average exhaustion estimates for life.

1.2 Limitations on Turbine Inlet Temperature (TIT)

Because of the architecture of its functioning, the power produced by a gas turbine rises with a rise in the temperature of the gas entering known as the "turbine intake temperature." Increased performance is aided by increased power production. Due to the constraints imposed by the temperature at which the blade material melts, the temperature of the input turbine cannot be rapidly increased. While some advances in material technology have resulted in the production of modern alloys with high melting points that can withstand activity at such high temperatures without fail, they are extremely expensive and difficult to fabricate.

2. INTRODUCTION ABOUT CONVECTION BLADE COOLING

Over time, various types of internal cooling have been developed. There is no one-size-fits-all method of cooling that is suited for all applications. The cooling scheme must also be chosen in accordance with the application's working circumstances and standards.

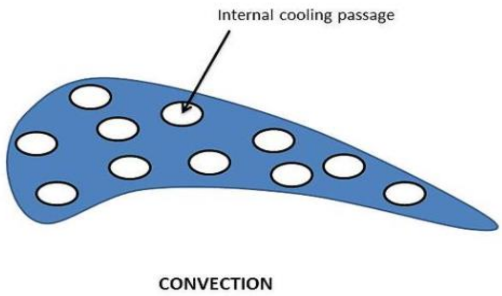


Fig-3: Turbine Blade with Convection cooling

The cooling of the turbine blade using convection method is shown in Fig [3]. It operates by circulating cool air through the blade's interior passageways. Heat is delivered through the blade via conduction and convection into the air moving within it. Because this technology requires a high interior surface area, the cooling pathways are serpentine and packed with tiny fins as shown in the Fig [3]. The blade's internal channels can be round or elliptical. Cooling is performed by passing air via these tubes from the hub to the blade tip. The cooling air is supplied by a compressor. Because the fluid outside a gas turbine is quite hot, it passes through the cooling tunnel and blends with the majority of the stream flow at the blade tip.

3. OBJECTIVE OF STUDY

In the gas turbine Blade design, a finite element analysis and alteration of the cooling route was performed. With the help of the air let, CATIA V5 is utilised to design the solid model of the turbine blade (holes in blade). By applying boundary conditions to the finite element model obtained by blade meshing, ANSYS 19.2 Workbench software is used to analyse it. The superior material for the first stage turbine blade is determined by the analysis results. The cooling tube of the turbine blade is then converted into a model and holes utilising superior material qualities and the following parameter are studied in this study.

1. Static liner structural analysis of industrial gas turbine blade interior cooling system.
2. With and without hole comparison of industrial gas turbine blade interior cooling system.
3. CFD analysis of industrial gas turbine blade interior cooling system.

4. METHODOLOGY

This chapter explains about the step-by-step methods which are carried out to accomplish this study.
Using CATIA V5 solid model of internal cooling system of industrial gas turbine were developed by taking the dimensions from analytical design. Developed internal cooling systems of industrial gas turbine model were imported to ANSYS 19.2. In ANSYS turbine blade model were meshed and by applying suitable boundary conditions, Static analyses of internal cooling system of industrial gas turbine are carried out to check whether structure is safe or not. Later 3D model of the turbine blade are analysed under Computational Fluid Dynamics (CFD) analysis. Once the results of the analysis are obtained, it is validated and design optimization is carried out for the best results.

4.1 Material properties

The selection of material is the first step in the design of any engineering component. Deformation and heat flow will differ depending on the substance. Chrome steel was chosen as the material for the turbine blade construction because of its comparatively high strength, strong corrosion resistance, substantial internal friction or damping capacity, and other features such as durability and fatigue resistance.
The following table [1] gives complete information on the physical properties for the chrome steel material used for designing turbine blade and disc, which is given as input to ANSYS software.

Table.1 Material Properties of chrome steel

PROPERTY	VALUES
Mass Density	$7.85x10^{-9}$ kg/mm^3
Poisson's Ratio	0.3
%Reduction in Area	40
Young's Modulus (E)	$2.1x10^5$ MPa
Yield Strength	550 MPa
Ultimate Tensile Strength	784.8 MPa
Mean Co-efficient of thermal expansion	$11.7x10^{-6}$ 1/ ^{0}C

4.2 2D-Geometry of gas turbine blade

Using CATIA V5 software, a two dimensional-geometric model is generated based on the calculated turbine blade dimensions obtained in the preceding step. The below figures [4] show various views of the CAD model that were built, which are helpful in understanding all the aspects of the turbine blade.

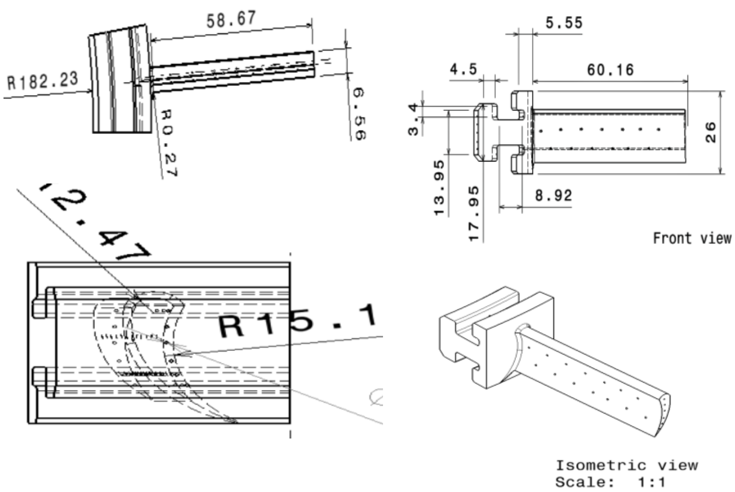


Fig-4: 2-Dimentinal CAD views of the turbine blade

4.3 Geometric model

Geometric model is created according the calculated dimensions of turbine blade obtained in the previous section using CATIA V5 software. Different views of 3D model created are shown in the Fig [5] they are helpful to understand all the features of turbine blades. The Fig [5] shows the isometric view and top view of turbine blade with staggered holes (14nos) on the surface of the blade

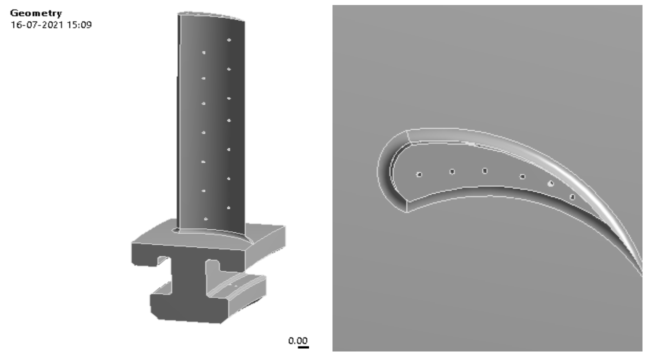


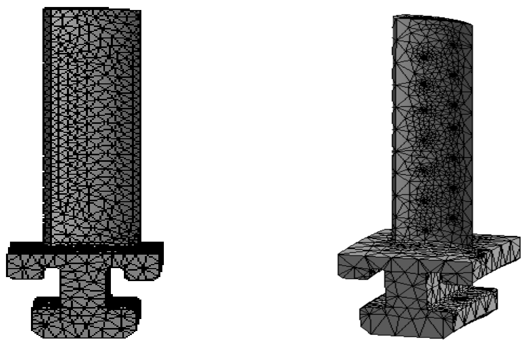
Fig -5: Industrial Gas Turbine Blade With Staggered Holes

The Isometric view of industrial gas turbine blade without staggered holes on the surface of the blade is shown in the Fig [6]. The surface of the blade is plain and does not contain any holes for the air to pass in order to cool the turbine blade.

Fig -6: Isometric Industrial Gas Turbine Blade Without Holes

4.4 Meshing of Geometric model

The term meshing refers to the process of discretizing a domain into a finite element model.The geometric model is first imported into ANSYS, and then the geometry for finite element modelling is extracted. ANSYS is used to create a finite element mesh from the extracted structure. The method of meshing is used to discretize the entire model into small elements, resulting in a finite element model. Nodes and elements make up the mesh model. Several types of elements can be used to mesh the continuum. The following features of the final mesh are generated in this work. Fig [7] shows a finite element mesh model of a turbine blade Tetra elements are utilised here, with a general element size of 10 for the model. There will be a total of 102057 nodes and 65389 elements in the meshed model of turbine blade.



(a) Plain blade (b) Blade with staggered holes

Fig–7: Meshing Model of Industrial Gas Turbine Blade

4.5 Boundary condition

Loads and boundary conditions are established when the finite element model of the turbine blade is prepared. A boundary condition is “a condition that must be fulfilled at all or part of an area in which a set of distinct stipulations must be solved” and is defined as “a condition that must be satisfied at all or part of a territory in which a set of distinctive requirements must be solved.” The mathematical solutions to physical issues are known using boundary conditions. Loads and restrictions are crucial for understanding the model's behaviour or characteristics given the material and qualities specified. The following are the boundary conditions employed in this project:

- Applying a load of 120 Newton force on the face of turbine blade.
- Applying a fixed support in base of gas turbine blade.

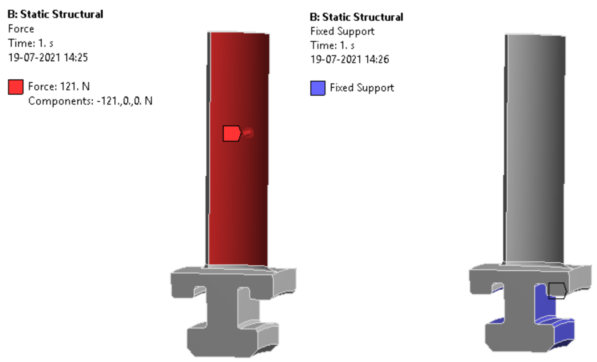


Fig-8: Boundary Conditions of Industrial Gas Turbine Blade without Holes

The finite element model of turbine blade without holes is shown in the Fig [8] with applied boundary conditions. The force of 120N is imposed on the face of the turbine plain blade without holes by fixing the base of the turbine blade as shown in the above Fig [8] and analysis are carried out for the plain turbine blade with applied boundary conditions.

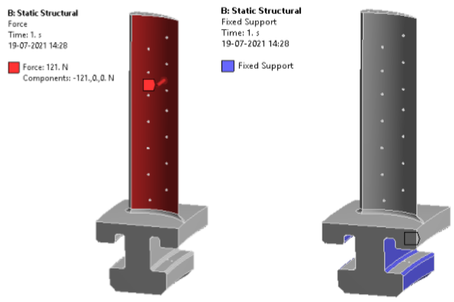


Fig-9: Boundary Conditions of Industrial Gas Turbine Blade with Staggered Holes

The above Fig [9] shows a finite element model of a turbine blade (with holes) with boundary conditions imposed. As indicated in the above Fig [9], a load of 120N is applied to the face of the turbine blade with staggered holes and a fixed support is provided at the base of the gas turbine blade. In the finite element model of the turbine blade different analyses are carried out with these boundary conditions, and the results are discussed in the next chapter.

4.6 FE- Static analysis results of turbine blade with staggered holes

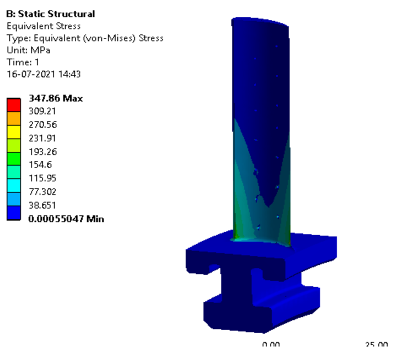


Fig-10 Linear Von-Mises stress is 347.68 MPa

Fig [10]: linear Von-mises stress in blade, suction side .From the fig it is observed that at the suction side of the blade the Von-mises stress is found to be maximum at the fillet region of t-root region and is equal to 347.68 MPa.

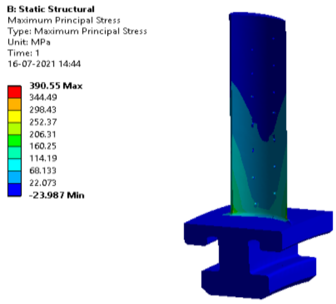
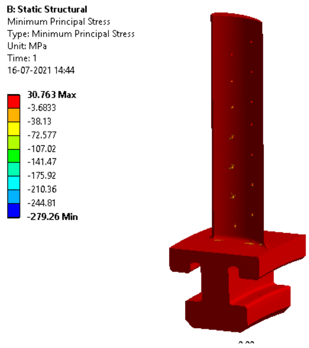


Fig-11: Maximum Principal Stress Is 390.55 MPa

Fig [11] shows maximum principal stress for FEA results of turbine blade with staggered holes. Due to the load and its boundary conditions, the maximum principal stress found at the fillet region is 390.55 MPa.



Fig,-12: Minimum Principal Stress Is 30.763 MPa

Fig [12] shows minimum principal stress for FEA results of turbine blade with staggered holes. Due to the load and its boundary conditions, the minimum principal stress found at the fillet region is 30.763 MPa.

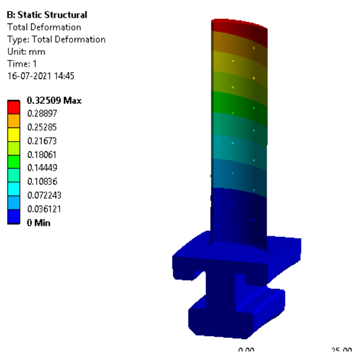
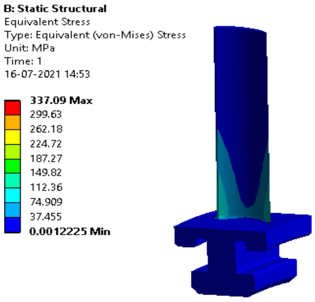


Fig-13: shows the total deformation along x-axis

Fig [13] demonstrate total deformation for the effects of the FEA on turbine blade (with staggered holes) design. In view of its load and boundary conditions, the overall deformation was 0.325 mm.

4.7 FE- Static analysis results of turbine blade without holes



Fig,-14 Linear Von-Mises stress is 337.09 MPa for the applied load condition

Fig [14]: Linear Von-Mises stress in blade, suction side from the fig it is observed that at the suction side of the blade the von-misses stress is found to be maximum at the fillet region of t-root region and is equal to 337.09 MPa

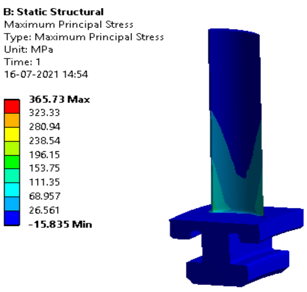


Fig-15: Maximum Principal Stress Is 365.73 MPa

Fig [15] shows maximum principal stress for FEA results of turbine blade without holes. Due to the load and its boundary conditions, the maximum principal stress found at the fillet region is 365.73 MPa.

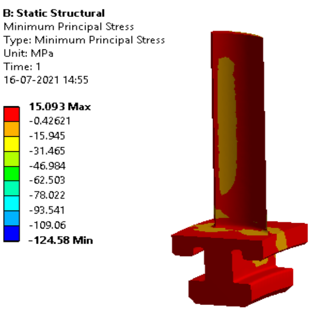


Fig-16: Minimum Principal Stresses Is 15.093 MPa

Fig [16] shows minimum principal stress for FEA results of turbine blade without holes. Due to the load and its boundary conditions, the minimum principal stress found at the fillet region is 15.093 MPa.

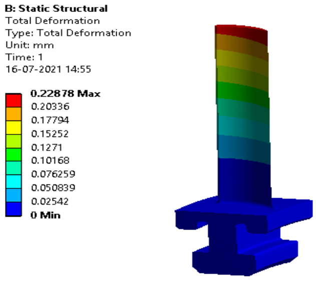
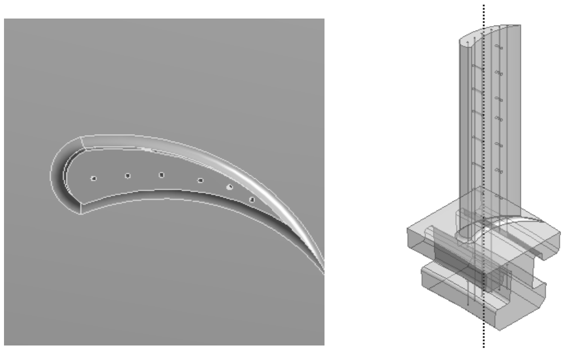


Fig -17: It Shows the Total Deformation of the turbine blade Along X-Axis

Fig [17] demonstrate total deformation for the effects of the FEA on turbine blade (without holes) design. In view of its load and boundary conditions, the overall deformation was 0.2287 mm

4.8 COMPUTATIONAL FLUID DYNAMICS ANALYSES FOR THE BLADE WITH STAGGERED HOLES AND WITHOUT HOLES

- **Geometry:**



(a)Top view (b) Isometic View

Fig-18 : Turbine Blade With Staggered Holes

The isometric perspective of a turbine blade with staggered perforations is shown in Fig [18]. ANSYS-19.2. Design Modeler programming was used to create the blade profile. The edge's cross-section was created by importing 374 points and then creating a spline using those points. The spline was then extruded to a length of 140 mm, with holes measuring 1 mm in diameter and 8 mm between holes.

- **Meshing:**

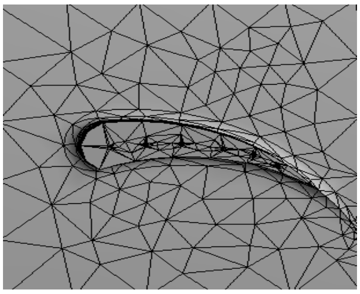


Fig-19: Top View Of Meshed Model Of Gas Turbine Blade With Staggered Holes

The meshed model for turbine blade with staggered holes is shown in Fig [19]. The 3D model is imported from Catia v5 and is meshed in ANSYS. The Tetra elements are utilised here, with a general element size of 10 for the model. There will be a total of 102057 nodes and 65389 elements in the meshed model of turbine blade.

4.9 Boundary condition

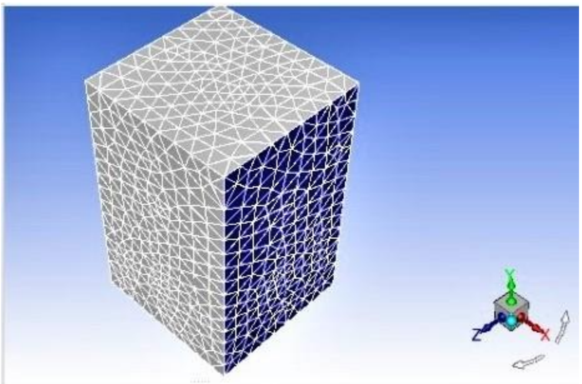


Fig-20: CFD- Boundary Conditions of Industrial Gas Turbine Blade

The above Fig [20] shows a finite element model of a turbine blade with boundary conditions imposed for computational fluid dynamics analysis. The following are the boundary conditions employed in this project:

Velocity Inlet

Velocity specification method: Magnitude, Normal to boundary

Reference frame: Absolute

Velocity magnitude (m/s):1 (Constant)

Turbulence

Specification method: Intensity and Viscosity Ratio

Turbulent intensity (%): 5%

Turbulent viscosity ratio: 10

Thermal- Temperature T1: 200 °C (Constant)

4.9 CFD analysis results of turbine blade

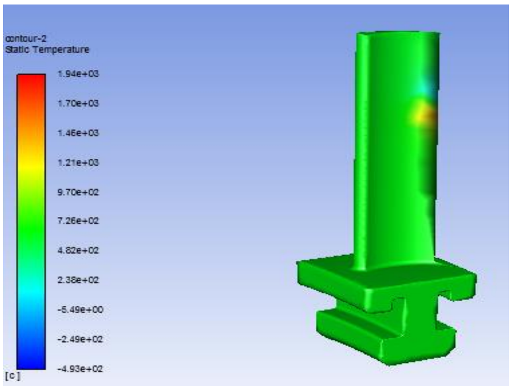


Fig-21: Without Hole Blade Computational Fluid Dynamics Temperature is 200 °C

Computational fluid dynamics analysis for the turbine blade without holes is shown in the Fig [21], the new temperature of 200 °C is found for the applied boundary conditions by using finite volume method.

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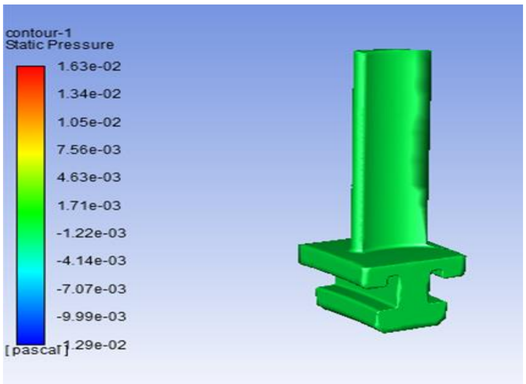

Fig-22: Staggered Hole Blade CFD Temperature is 195 °C

Computational fluid dynamics analysis for the turbine blade with 14 staggered holes on the surface of the blade is shown in the Fig [22], the new temperature of 195 °C is found for the applied boundary conditions by using finite volume method.

5. RESULTS AND DISCUSSIONS

5.1 Static Analysis:

CASE1: When loads are applied to the body of a turbine blade, the body deforms and the load effect is conveyed throughout the blade. Internal forces and reactions are induced by external loads, bringing the body into stability. Static analysis is carried out for the blade with staggered holes and static analysis calculates displacement, maximum stress, minimum stress and equilibrium stress and the readings are tabulated in the table [2]

Table.2. Results of Static Analysis

FE- Static Analysis Result of Blade With Staggered Holes		
1	Linear Von-Misses Stress	347.68MPA
2	Maximum Principal Stress	390.55MPA
3	Minimum Principal Stress	30.763MPA
4	Total deformation along 'x'-axis	0.325MM

CASE2: The structural analysis was performed for turbine blade (without holes), the results obtained are tabulated in the table [3]. Based on the results it is observed that the stress and deflection values are within the permissible limits and meets requirement of the specification.

Table.3. Results of Static Analysis

FE-Static Analysis Result of Turbine Blade Without Holes		
1	Linear Von-Misses Stress	337.09MPA
2	Maximum Principal Stress	365.73MPA
3	Minimum Principal Stress	15.093MPA
4	Total deformation along 'x'-axis	0.2287MM

6.1 CFD Analysis:

Temperature changes can cause significant deformation, strain, and stress. Thermal stress analysis is a static analysis that takes temperature into consideration. The CFD analysis is carried out for both plain blades and staggered holes blade and results are tabulated in the below table [4]

Table.4.CFD Analyses Results

CFD Analysis Results of Turbine Blade			
1	Blade Without Holes	Computational Fluid Dynamics Temperature	200 °C
2	Staggered Hole Blade	Computational Fluid Dynamics Temperature	195 °C

- Blade structure of industrial gas turbine was analyzed using FEM technique to verify structural strength.
- In both case 1 and case 2 (with holes and without holes) of the turbine blade the stress, and deformation are investigated by applying load conditions and results are tabulated in the above tables [2] and [3]
- It is observed from FEM analysis, that the stress and deflection values are within the permissible limits and meets requirement of the specification.
- CFD analysis is conducted for the turbine blades(case1 and case2) and results are tabulated in the above table [4]
- It is observed from CFD analysis, that the temperature is less in staggered hole blade compared with blade without holes.

7. CONCLUSIONS

- Numerical analyses are performed on gas turbine blade internal cooling by arranging holes in staggered manner on suction of the turbine blade (Chrome Steel) and results are compared between case 1 and case 2.
- Static structural analysis conducted for case 1 and case 2 (without hole and with hole) structural is safe which is less then yield stress.
- CFD analysis conducted there is temperature difference between case 1 and case 2, there is less temperature observed in the blade with holes.

- In case of staggered holes arrangement the maximum temperature region is less when compared with the blade without holes.
- The uniform temperature distribution over the blade surface is better in case of staggered holes condition when compared with blade without holes.

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