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DESIGN AND STRUCTURAL THERMAL ANALYSIS OF STEAM TURBINE BLADE USING FEM

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Abstract: A steam turbine is mechanical device which converts thermal energy of steam into mechanical work. The steam turbine gives the better thermodynamic efficiency by using compound stages in the expansion of steam. The stages are characterized by the way of energy extraction from them is considered as impulse or reaction turbines.

In the present work the first stage rotor blade of a two-stage Steam turbine has been analyzed for structural, thermal using ANSYS 15, which is a powerful Finite Element Software. In the process of getting the static and thermal stresses, the fatigue life in the rotor blade has been improved using this software

The first stage rotor blade of the Steam turbine has been analyzed for the static and thermal stresses resulting from the tangential, axial and centrifugal forces. The Steam forces namely tangential, axial were determined by constructing velocity triangles at inlet and exist of rotor blades. The rotor blade was then analyzed for the temperature distribution. For obtaining temperature distribution, the convective heat transfer coefficients on the blade surface exposed to the Steam have to feed to the software. After containing the temperature distribution, the rotor blade was then analyzed for the combined mechanical and thermal stresses . The aim of the project is to increase the life steam turbine blade using different materials designwith(2mm,3mm4mm) and with out holes of steam turbine blade using catia software with and without holes and analysis by using ansys software we preferred two types of analysis structural and thermal analysis in structural analysis find out stress and strain and in thermal point of view find out temperature distribution and total heatflux choosing three materials they are Nimonic 80A, haste alloy , inconel 600 taking two designs without holes and with holes finally concluded the suitable design and material of the steam turbine blade based on results.

Keyword : *Steam Turbine, Thermal Energy, Impulse Turbine, Reaction Turbine, Static Analysis, Thermal Analysis*

I TURBINE INTRODUCTION

A turbine (from the Latin turbo, a vortex, related to the Greek τύρβη, tyrbē, meaning "turbulence") is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The work produced by a turbine can be used for generating electrical power when combined with a generator or producing thrust, as in the case of jet engines. A turbine is a turbo machine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. Early turbine examples are windmills and waterwheels Gas, steam, and water turbines have a casing around the blades that contains and controls the working fluid. Credit for invention of the steam turbine is given both to British engineer Sir Charles Parsons (1854–1931) for invention of the reaction turbine, and to Swedish engineer Gustaf de Laval (1845–1913) for invention of the impulse turbine.

FIGUR1TURBINE

1.2 USES OF TURBINES: Almost all electrical power on Earth is generated with a turbine of some type. Very high efficiency steam turbines harness around 40% of the thermal energy, with the rest exhausted as waste heat. Most jet engines rely on turbines to supply mechanical work from their working fluid and fuel as do all nuclear ships and power plants. Turbines are often part of a larger machine. A gas turbine, for example, may refer to an internal combustion machine that contains a turbine, ducts, compressor, combustor, heatexchanger, fan and (in the case of one designed to produce electricity) an alternator. Combustion turbines and steam turbines may be connected to machinery such as pumps and compressors, or may be used for propulsion of ships, usually through an intermediate gearbox to reduce rotary speed. Reciprocating piston engines such as aircraft engines can use a turbine powered by their exhaust to drive an intake-air compressor, a configuration known asa turbocharger (turbine supercharger) or, colloquially, a "turbo". Turbines can have very high power density (i.e. the ratio of power to weight, or power to volume). This is because of their ability to operate at very high speeds. The Space Shuttle main engines used turbo pumps (machines consisting of a pump driven by a turbine engine) to feed the propellants (liquid oxygen and liquid hydrogen) into the engine's combustion chamber. The liquid hydrogen turbo pump is slightly larger than an automobile engine (weighing approximately 700 lb) and produces nearly 70,000 hp (52.2 MW).

1.3:BLADE AND STAGE DESIGN Turbine blades are of two basic types, blades and nozzles. Blades move entirely due to the impact of steam on them and their profiles do not converge. This results in a steam velocity drop and essentially no pressure drop as steam moves through the blades. A turbine composed of blades alternating with fixed nozzles is called an impulse turbine, Curtis turbine, Rateau turbine, or Brown-Curtis turbine. Nozzles appear similar to blades, but their profiles converge near the exit. This results in a steam pressure drop and velocity increase as steam moves through the nozzles. Nozzles move due to both the impact of steam on them and the reaction due to the high-velocity steam at the exit. A turbine composed of moving nozzles alternating with fixed nozzles is called a reaction turbine or Parsons turbine. Except for low-power applications, turbine blades are arranged in multiple stages in series, called compounding, which greatly improves efficiency at low speeds.[16] A reaction stage is a row of fixed nozzles followed by a row of moving nozzles. Multiple reaction stages divide the pressure drop between the steam inlet and exhaust into numerous small drops, resulting in a pressure-compounded turbine. Impulse stages may be either pressure compounded, velocity-compounded, or pressure-velocity compounded.

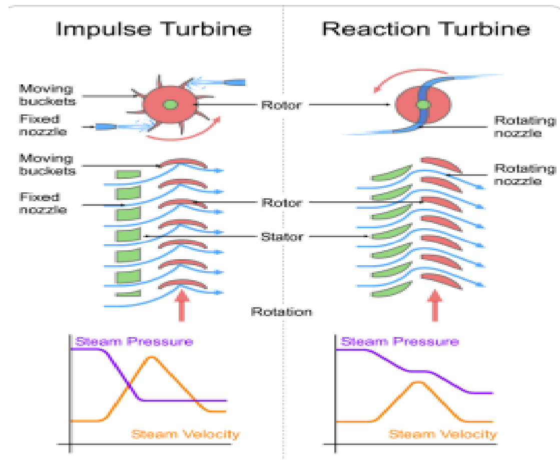

FIG2: TYPESOFSTEAMTURBINE

1.4 PRINCIPLE OF STEAM TURBINE: by The steam energy is converted mechanical work. Expansion takes place through a expansion through the turbine. Series of fixed . In each row fixed blades (nozzles) and moving blades Blade and moving blade are called stage Steam Turbine System:

• Thermodynamic cycle is the “Rankin cycle” that uses a boiler

• Most common types

• Back pressure steam turbine

• Extraction condensing steam turbine

1.4.1: BACK PRESSURE STEAM TURBINE •Steam exits the turbine at a higher pressure that the atmospheric HP Steam Advantages& Disadvantages: Advantages Simple configuration – Low capital cost Boiler Turbine -Low need of cooling water – High total efficiency Fuel Disadvantages: Condensate LP Process Steam – Larger steam turbine

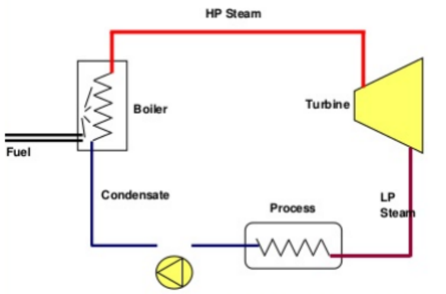

FIGURE3:BACK PRESSURE STEAM TURBINE

II LITERATURE REVIEW

Many investigators have suggested various methods to explain the effect of stress and loading on turbine blade, roter and analysis the various parameters:

John. V, T. Ramakrishna was investigated on design and analysis of Gas turbine blade, CATIA is used for design of solid model and ANSYS software for analysis for F.E. model generated, by applying boundary condition, this paper also includes specific post processing and life assessment of blade. How the program makes effective use of the ANSYS pre-processor to mesh complex geometries of turbine blade and apply boundary conditions. The principal aim of this paper is to get the natural frequencies and mode shape of the turbine blade. In this paper we have analyzed previous designs and generals of turbine blade to do further optimization, Finite element results for free standing blades give a complete picture of structural characteristics, which can utilized for the improvement in the design and optimization of the operating conditions.

Subramanyam Pavuluri, Dr. A. Siva Kumar was investigated on design of high pressure steam turbine blade addresses the issue of steam turbine efficiency. A specific focus on airfoil profile for high-pressure turbine blade, and it evaluates the effectiveness of certain Chromium and Nickel in resisting creep and fracture in turbine blades. The efficiency of the steam turbine is a key factor in both the environmental and economic impact of any coal-fired power station. Based on the research presented modifications to high-pressure steam turbine blades can made to increase turbine efficiency of the turbine. The results and conclusions are presented for a concerning the durability problems experienced with steam turbine blades. The maximum operational Von Mises Stresses are within the yield strength of the material but the deformation is comparatively better for material CA-6 NM (Chromium Nickel). Modified solutions for Steam turbine blade values to machines to maximize their reduce life cycle costs, efficiency, and improve reliability.

Sanjay Kumar was investgated on creep life of turbine blade. Inertia load is the constant load that will cause creep failure. Creep is a rate dependent material nonlinearity in which material continues to deform in nonlinear fashion even under constant load. This phenomenon is predominant in components, which exposed to high temperatures. By studying the creep phenomenon and predicting the creep life of the component, we can estimate its design life. The main objective is to predict the creep life of the simple impulse steam turbine blade, and to give the FEM approach for creep analysis. The analysis of turbine blade for different loads, which shows that the maximum stresses, induced in each case. These stresses are within yield limit of the material and will not undergo plastic deformation during operationresult is found that, creep life decreases as the stress value increases. Hence, by decreasing the stress value in the component we can increase its creep life. This was be achieved by modifying the blade design.

Avinash V. Sarlashkar, MARK L. Redding investigated on the architecture and capabilities of Blade Pro. An ANSYS based turbine blade analysis system with extensive automation for solid model and F.E. model generation, boundary condition application, file handling and job submission tasks for a variety of complex analyses; the program also includes turbo machinery specific postprocessing and life assessment modules. Blade Pro is a cutting-edge example for vertical applications built on the core ANSYS engine using ANSYS APDL. Examples of how the program makes effective use of the ANSYS preprocessor to mesh complex geometries of turbine blade and apply boundary conditions are presented using specific examples.

A real world application is used to demonstrate the pre-processing capabilities, static and dynamic stress analyses results, generation of Campbell and Interference diagrams and life assessment. The principal advantage of Blade Pro is its ability to generate accurate results in a short amount of time, thus reducing the design cycle time. The good correlation achieved is a testament to the accuracy of the ANSYS solvers and validity of the modeling techniques adopted in Blade Pro.

DR.SHANTHARAJA.M, DR. Kumar. K., was work on the large variety of turbo-machinery blade root geometries used in industry prompted the question if an optimum geometry could be found. An optimum blade root was defined, as a root with practical geometry which, when loaded returns the minimum fillet stress concentration factor. The present paper outlines the design modification for fillet stresses and a special attention made on SCF of the blade root (T-root) which fails and to guarantee for safe and reliable operation under all possible service conditions. Finite Element Analysis is used to determine the fillet stresses and Peterson’s Stress Concentration Factor chart is effectively utilized to modify the blade root. The root modified due to the difficulty in manufacturing the butting surface of the tang that grips the blade to the disk crowns A Review on Analysis of Low Pressure Stage of Steam Turbine Blade with FEA (ANSYS Software) (IJSRD/Vol. 1/Issue 10/2013/0003) All rights reserved by www.ijsrd.com 2060 having small contact area. Verify the same using Finite Element Analysis for two cases with and without the tang in the blade. Firstly, to study the fillet stresses with tang and then Petersons chart is used to reduce the peak stresses with the modification to the butting area and reducing the fillet radius. To conduct the sensitivity analysis for the fillet stresses in blade and disk using FEA.

Zachary Stuckl addresses steam turbine efficiency by discussing the overall design of steam turbine blades with a specific focus on blade aerodynamics, Nimonic (Ni20 Cr20 Co0.4 Fe6 Mo2.1 Ti0.4 Al0.06 C) Nickel-base super alloy NIMONIC® alloy 80A) is a wrought, age-hardenable nickel-chromium composite, reinforced by increases of titanium, aluminium and carbon, produced for administration at temperatures up to 815°C (1500°F). It is delivered by high-recurrence materials are used in the manufacture of steam turbine blades, and the factors that cause turbine blade failure and therefore the failure of the turbine itself. This paper enumerates and describes the currently available technologies that enhance the overall efficiency of the generator and prevent turbine failure due to blade erosion and blade cracking. The stresses developed in the blade as a result of steam pressure, steam temperature, and the centrifugal forces due to rotational movement are delineated; current designs calculated to counter the fatigue caused by these stresses are existing. The aerodynamic designs of impulse and reaction turbine blades are compared and contrasted, the effect of those designs have on turbine efficiency are debated. Based on the research unfilled herein, this paper presents a complete summary of what modifications to existing steam turbine generator blades can be made to increase turbine efficiency.

TK Ghosh et.al states that the limited primary energy sources and awareness of environmental pollution has led to ever increasing end over to develop new steam turbine power plants with the highest possible efficiency. Considering their output, even small step increase in efficiency can result in major saving for the customers. As overall cycle efficiency is strongly dependent on steam turbine performance, Continuous improvement are sought to increase the turbine efficiency. These effectors are directly primarily towards improvements are blading as the key component of the turbine. This paper presents the BHEL realness to meet the requirement of higher efficiency by adapting newer balding, which can substantially improve stages efficiency and hence overall performance of the turbine. Also contains the new developments in the area of shrouds and sealing of flow of the part art manufacturing facilities establish at BHEL, Haridwar for manufacturing advance class blading.

Kenji Nakamura et.al response to global environmental issues, higher efficiency and improved operational reliability are increasingly being requested for steam turbines, essential equipment for thermal power generation.

III TERMINOLOGY OF STEAM TURBINE BLADE AND BASIC DEFINITIONS

3.1STEAM TURBINE BLADE TERMINOLOGY: It is necessary to define the parameters used in describing blade shapes and configurations of blade. Blade profiles are usually of airfoil shape for optimum performance, although cost is more important than the ultimate in efficiency, simple geometrical shapes composed of circular areas and straight line are of ten used. Journal of Engineering and Development, Vol. 11, No. 3, December (2007) ISSN 1813-7822 85 The spacing or pitch of the blade is the distance between corresponding points of adjacent blade and is expressed either by the pitch-chord ratio or alternatively the solidity. When the blades are evenly spaced around a rotor, the pitch is the circumference at any radius divided by the number of blades.

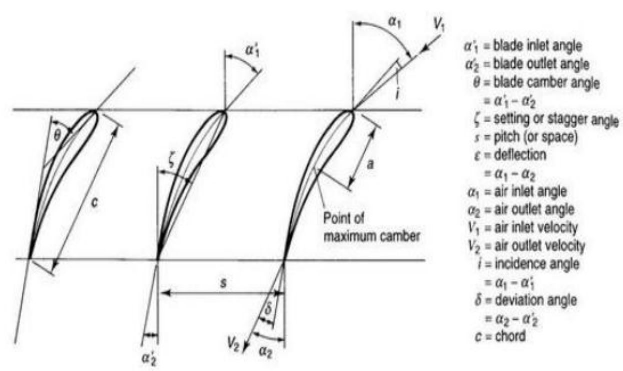

FIGURE4: STEAM TURBINE BLADE NOMENCLATURE

3.2NOMINCLATURE OF BLADE

Ar = Cross section area of blade root.

Am = Cross section area of blade middle.

At = Cross section area of blade tip.

A = Is the area of blade at radius R.

Fcf = Centrifugal force.

R = Raduis.

Rr = Radius from shaft center at root blade.

Rm = Radius from shaft center at middle blade.

Rt = Radius from shaft center at tip blade.

m = Mass of blade.

Lb = Blade height. Mv,

Mu = Bending moment about the axes

v,u. ω = Speed in radians.

ρ = Density of blade material.

cf2.cf3 = Axial velocity of inlet and outlet.

Vw2, Vw3 = Whirl velocity of inlet and outlet.

Cr = Relative velocity.

Nb = Number of blades.

p2, p3 = Pressure inlet and outlet of moving blade.

s = Spacing or pitch from two moving blade.

ρf = Density of steam.

σcf = Centrifugal stress.

σt = Total stresses (tension and bending)

3.4OBJECTIVE

The objective of this project is to make a Steam turbine blade different 3D models of the steam turbine blade with holes and without holes we are taking Four different holes radius (without holes,2mm 3mm,4mm) and study the static - thermal behaviour of the steam turbine blade with different materials by performing the finite element analysis.3D modelling software (catia v5) was used for designing and analysis software (ANSYS) was used for analysis.

3.5METHODOLOGY

THE METHODOLOGY FOLLOWED IN THE PROJECT IS AS FOLLOWS:

1. Create a 3d model of the different turbine blades,consider different designs 10 holes with different radius (2mm,3mm,4mm) using parametric software catia v5.

2. Convert the surface model into its and import the model into ansys to do analysis.

3. Perform static thermal analysis on the steam turbine blade.

4. Finally it was concluded which material is the suitable for steam turbine blade on these materials Nimonic 80A, haste alloy, Inconel 600.

3.6SCOPE OF THE PROJECT:

1. To generate 3-dimensional geometry model in Catia workbench of the steam turbine blade

2. To perform structural analysis on the model to determine the stress, strain, temperature distribution and heat flux of the component under the thermal load conditions.

3. To compare analysis between two different designs and three materials Nimonic 80a, haste alloy , Inconel of steam turbine blade.

4. Finally concluded the suitable design and material of the steam turbine blade

IV INTRODUCTION TO SOFTWARES

CATIA SOFTWARE: Welcome to CATIA (Computer Aided Three Dimensional Interactive Application). As a new user of this software package, you will join hands with thousands of users of this highend CAD/CAM/CAE tool worldwide. If you are already familiar with the previous releases, you can upgrade your designing skills with the tremendous improvement in this latest release. CATIA V5, developed by Dasssault Systems, France, is a completely re-engineered, Nextgeneration family of CAD/CAM/CAE software solutions for Product Lifecycle Management. Through its exceptionally easy-to-use and state-of-the-art user interface, CATIA V5 delivers innovative technologies for maximum productivity and creativity, from the inception concept to the final product. CATIA V5 reduces the learning curve, as it allows the flexibility of using feature-based and parametric designs. CATIA V5 provides three basic platforms: P1, P2, and P3. P1 is for small and medium-sized process-oriented companies that wish to grow toward the large scale digitized product definition.

P2 is for the advanced design engineering companies that require product, process, and resource modeling. P3 is for the high-end design applications and is basically for Automotive and Aerospace Industry, where high quality surfacing or Class-A surfacing is used. The subject of interpretability offered by CATIA V5 includes receiving legacy data from the other CAD systems and even between its own product data management modules. The real benefit t is that the links remain associative. As a result, any change made to this external data gets notified and the model can be updated quickly.

V RESULTS AND ANALYSIS

This analysis is performed to find Structural and thermal parameters such as Stresses, Deformation, heatflux, temperature distribution with and without holes of steam turbine blade using three materials namely Nimonic 80A, haste alloy, Inconel 600 finally observed results as shown below figures NIMONIC 80A

5.1 WITH OUT HOLES OF NIMONIC 80 A MATERIAL:

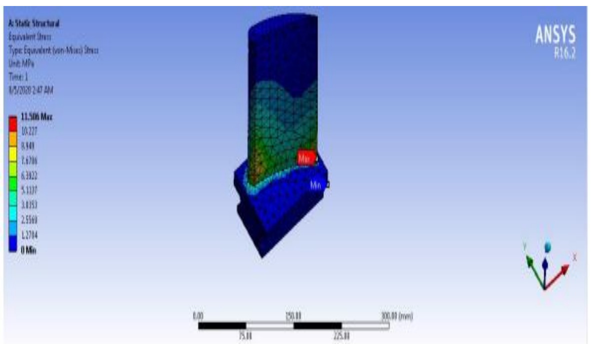

FIGURE 5 VON-MISES STRESS OF NIMONIC 80A WITHOUT HOLES

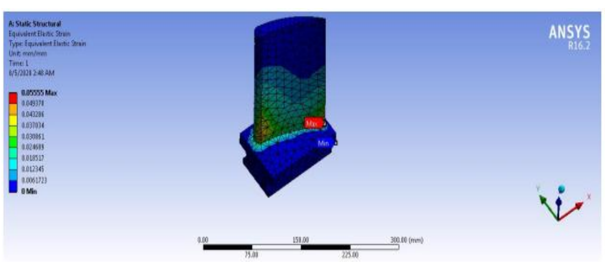

FIGURE6:STRAINOFNIMONIC80AWITHOUT HOLES

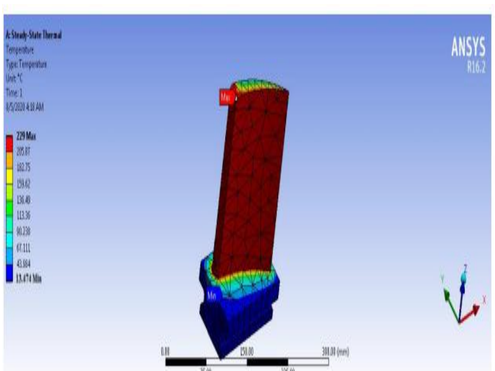

FIGURE 7:TEMPERATURE DISTRIBUTION OF NIMONIC 80A WITHOUT HOLES

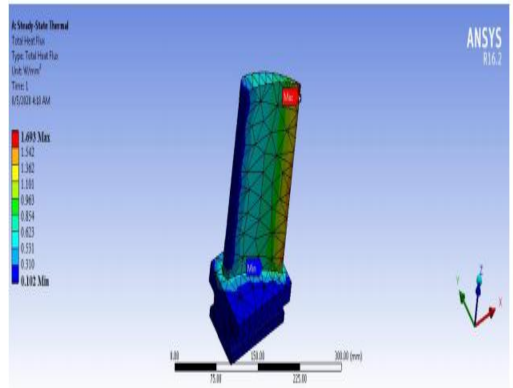

FIGURE 8:TOTAL HEATFLUX OF NIMONIC 80A WITHOUT HOLES

5.2: 2MM WITH HOLES OF NIMONIC 80 A MATERIAL:

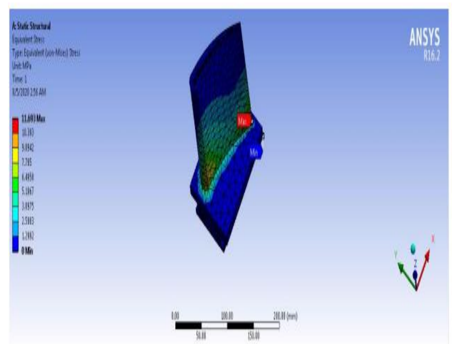

FIGURE 9:VON-MISES STRESS OF NIMONIC 80A WITH 2MMHOLES

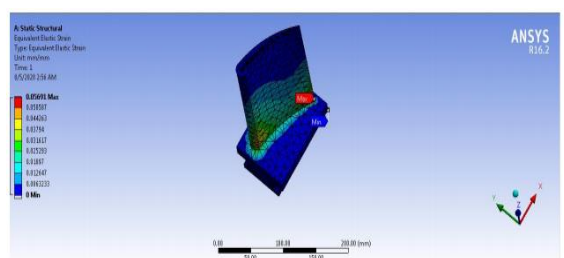

FIGURE 10 :STRAIN OF NIMONIC 80A WITH 2MM HOLES

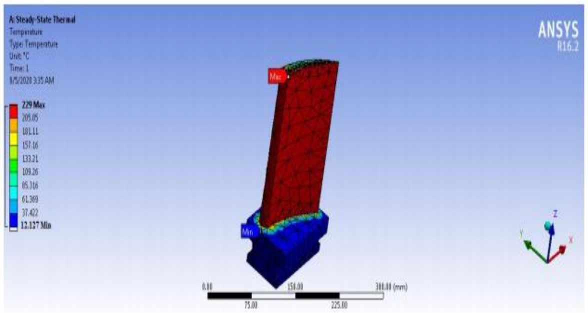

FIGURE 11 :TEMPERATURE DISTRIBUTION OF NIMONIC 80A WITH 2MM HOLES

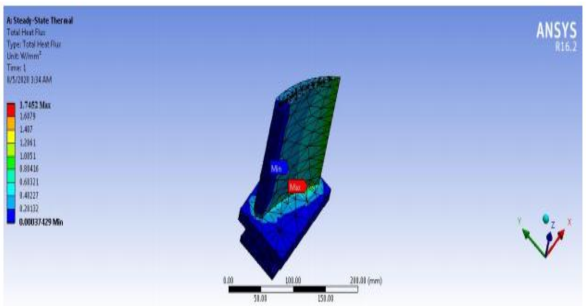

FIGURE 12:TOTAL HEAT FLUX OF NIMONIC 80A WITH 2MMHOLES

5.3 3MM WITH HOLES OF NIMONIC 80 A MATERIAL:

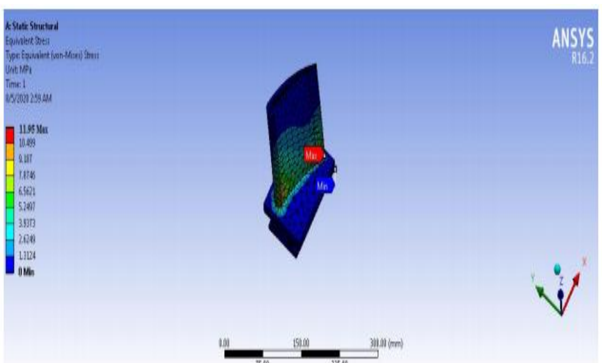

FIGURE 13:VON-MISES STRESS OF NIMONIC 80A WITH 3MMHOLES

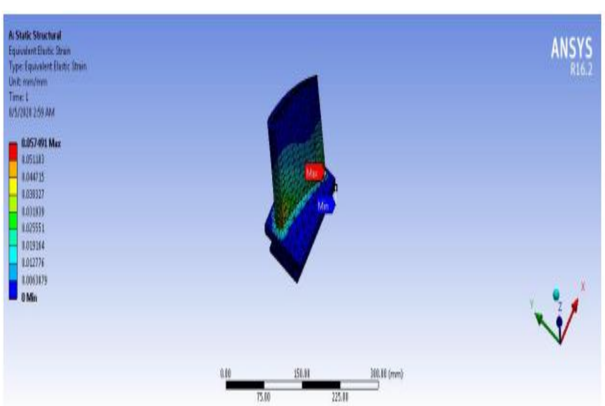

FIGURE 14:STRAIN OF NIMONIC 80A WITH 3MM HOLES

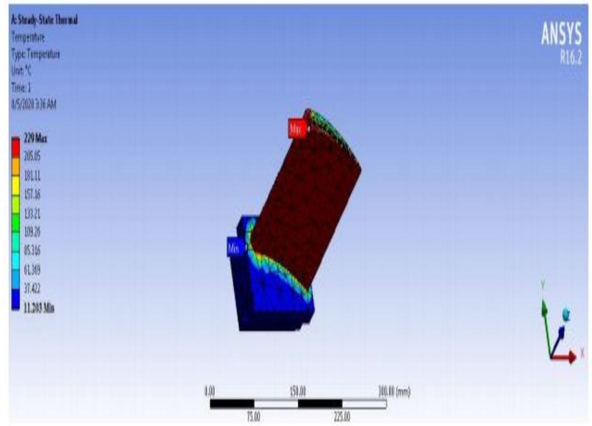

FIGURE 15:TEMPERATURE DISTRIBUTION OF NIMONIC 80AWITH3MMHOLES

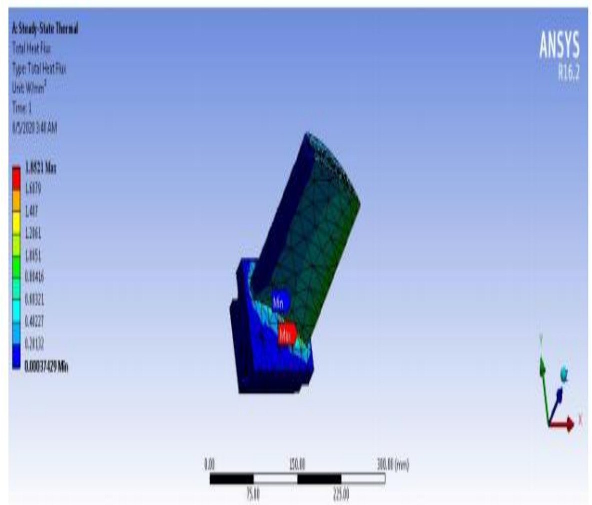

FIGURE16: TOTAL HEAT FLUX OF NIMONIC 80A WITH 3MMHOLES

5.4 4MM WITH HOLES OF NIMONIC 80 A MATERIAL:

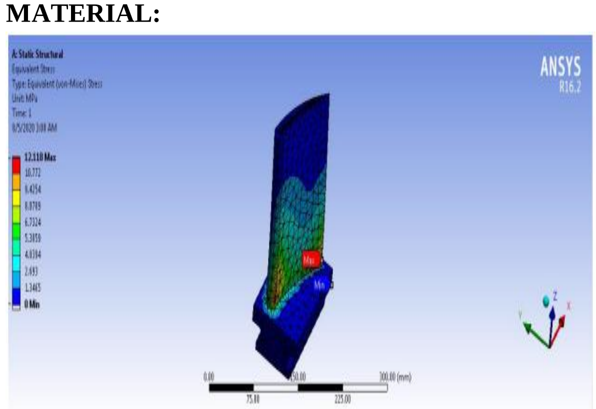

FIGURE 17VON-MISES STRESS OF NIMONIC 80A WITH 4MMHOLES

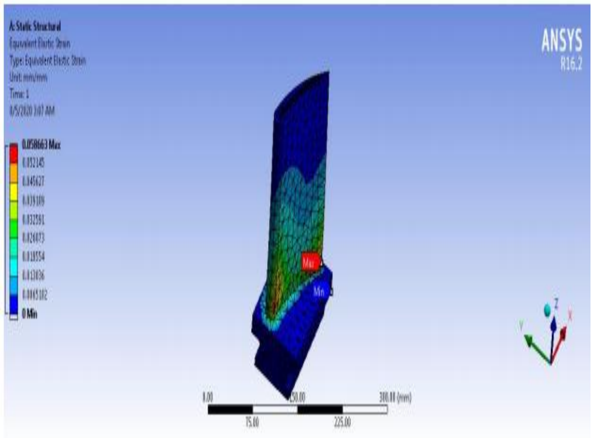

FIGURE18 STRAIN OF NIMONIC 80A WITH 4MM HOLES

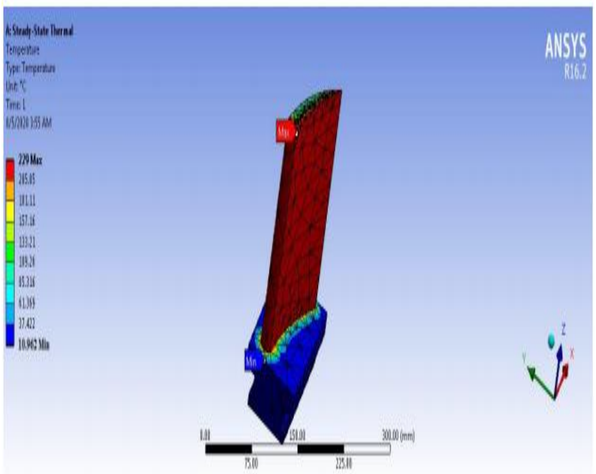

FIGURE 19TEMPERATURE DISTRIBUTION OF NIMONIC 80A WITH 4MM HOLES

5.5VON-MISES STRESS GRAPH The below graph shows that with Variation of stresses 4 different designs with(2mm,3mm,4mm) and without holes and 3 different materials Inconel 600, Nimonic 80A, haste alloy finally Nimonic 80 A Material has least Vonmisses stress as shown below figure graph

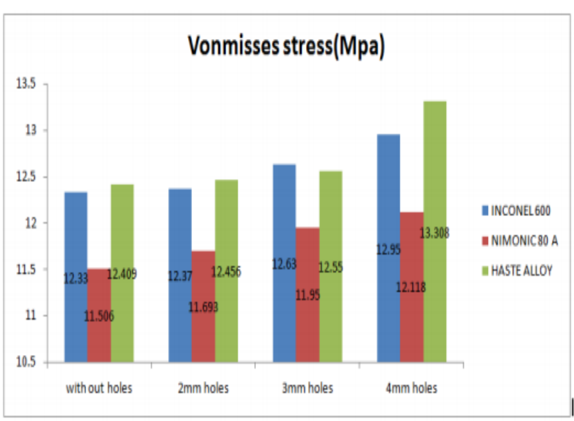

FIGURE 20VONMISSES STRESSS GRAPH

5.6 STRAIN GRAPH :

The below graph shows that with Variation of strain 4 different designs with (2mm,3mm,4mm) and without holes and 3 different materials Inconel 600, Nimonic 80A, haste alloy finally Nimonic 80 A Material has least strain as shown below figure graph

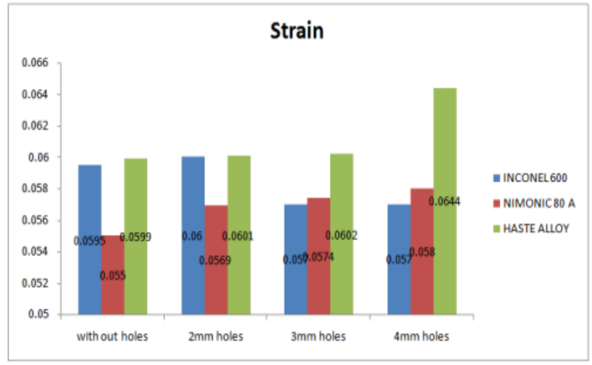

FIGURE21: STRAINGRAPH

5.7TEMPERATURE DISTRIBUTION GRAPH : The below graph shows that with Variation of Temperature distribution 4 different designs with(2mm,3mm,4mm) and without holes and 3 different materials Inconel 600, Nimonic 80A, haste alloy finally Nimonic 80 A Material has reached very fastly as shown below figure graph

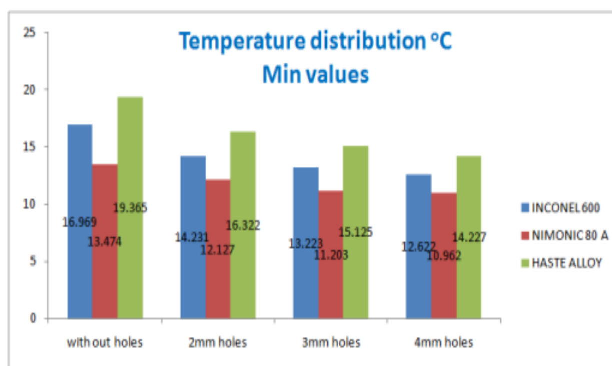

FIGURE 22: TEMPERATURE DISTRIBUTION GRAPH

VI CONCLUSION

Modeling of steam turbine blades with (2mm,3mm,4mm) and without holes is done by using CATIAV5 Software and then the model is imported into ANSYS Software for Structural analysis and thermal analysis on the steam turbine blade to check the quality of materials such as Nimonic 80A, haste alloy ,inconel 600. Vonmisses Stress obtained for the steam turbine blade with 2mm Nimonic 80A is 11.693Mpa this is best material compared to remaining materials. Equavalent strain also concluded the nimonic 80 A material with 2mm holes obtained value is 0.056, In temperature distribution point of view Nimonic 80 A is the better temperature distribution obtained value is 1.127, finally Total heat flux also nimonic 80 A Material is rate of heat transfer also high obtained value is 1.7452 in all conditions satisfied this material this corrosion resistance of Nimonic 80A in oxidising atmospheres is excellent - this includes heating and cooling conditions. This protection is due to the chromium oxide film formed on the surface of the alloy, which also offers resistance at elevated temperatures.

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