Computational Fluid Dynamics and Couple Field Analysis of Gas Turbine Blade by using Super Alloy Inconel-718

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Abstract – A turbine blade is the individual component which makes up the turbine section of a gas turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings. In this project, a turbine blade is designed and modeled in 3D modeling software Pro/Engineer. The design is modified by changing the base of the blade to increase the cooling efficiency. Since the design of turbo machinery is complex, and efficiency is directly related to material performance, material selection is of prime importance. In this project, two materials are considered for turbine blade titanium alloy and nickel alloy. Optimization is done by varying the materials Titanium alloy and Super Alloy by performing coupled field analysis on the turbine blade for both the designs. In this project, CFD technique is employed to investigate the flow the fluid over the turbine blade. Analysis is done in Ansys 14.5 Version.

Index Terms – Modelling, CFD, Turbines

1. CHAPTER-I

1.1. Introduction to Turbine

The word "turbine" was coined in 1822 by the French mining engineer Claude Burdin from the Latin turbo, or vortex, in a memoir, "Des turbines hydrauliques ou machines rotatoires à grande vitesse" (Hydraulic turbines or high-speed rotary machines), which he submitted to the Académie royale des sciences in Paris. Benoit Fourneyron, a former student of Claude Burdin, built the first practical water turbine.

A turbine is a rotary element which is used to convert fluid flow energy into useful work..

Gas, steam, and water turbines usually have a casing around the blades that contains and controls the working fluid.

1.1 TYPES OF TURBINES

1.1.1 STEAM TURBINE

A Steam turbine is a device that extracts thermal energy from pressurized steam and uses it in to mechanical work on a rotating output shaft. Its modern manifestation was invented by sir Charles Parsons in 1884.

The simplest turbines have one moving part, a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades, or the blades react to the flow, so that they move and impart rotational energy to the rotor.

Fig: 1 Steam Turbine

1.1.2 GAS TURBINE

A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber in-between.

Gas turbines are sometimes referred to as turbine engines. Such engines usually feature an inlet, fan, compressor, combustor and nozzle (possibly other assemblies) in addition to one or more turbines

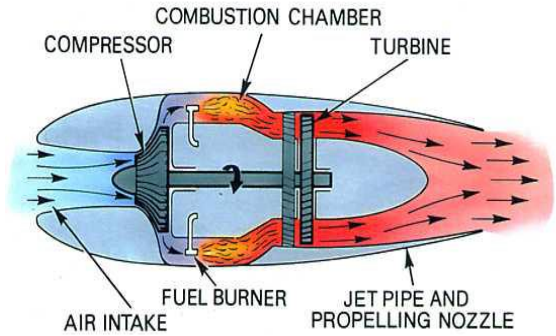


Fig: 2 Gas Turbine

1.1.3 SHROUDED TURBINE

Shrouded turbine, many turbine rotor blades have shrouding at the top, which interlocks with that of adjacent blades, to increase damping and thereby reduce blade flutter. In large land-based electricity generation steam turbines, the shrouding is often complemented, especially in the long blades of a low-pressure turbine, with lacing wires. These wires pass through holes drilled in the blades at suitable distances from the blade root and are usually brazed to the blades at the point where they pass through. Lacing wires reduce blade flutter in the central part of the blades. The introduction of lacing wires substantially reduces the instances of blade failure in large or low-pressure turbines.

1.1.4 SHROUDED-LESS TURBINE

Shroud less turbine, Modern practice is, wherever possible, to eliminate the rotor shrouding, thus reducing the centrifugal load on the blade and the cooling requirements.

2. CHAPTER-II

2.1. Introduction to Turbine Blade

A turbine blade is the individual component which makes up the turbine section of a gas turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings.

Fig: 3 Turbine Blade

2.1 MATERIALS

Since the design of turbo machinery is complex, and efficiency is directly related to material performance, material selection is of prime importance. Gas and steam turbines exhibits similar problem areas, but these problems areas are of different magnitudes. Turbines components must operate under a variety of stress, temperature, and corrosion conditions. Compressor blades operate relatively low temperatures but are highly stressed. The combustor operates at a relatively high temperature and low-stress conditions. The turbine blades operate under extreme conditions of stress, temperature, and corrosion. These conditions are more extreme in gas turbine than in steam turbine applications. As a result, the material selection for individual components is based on varying criteria in both gas and steam turbines.

2.2 GAS TURBINE BLADE MATERIALS

In the 1980s, IN 738 blades were widely used. IN-738, was the acknowledged corrosion standard for the industry. New alloys, such as GTD-111 possesses about a 35ºF (20ºC) improvement in rupture strength as compared to IN-738. GTD-111 is also superior to IN-738 in low-cycle fatigue strength.

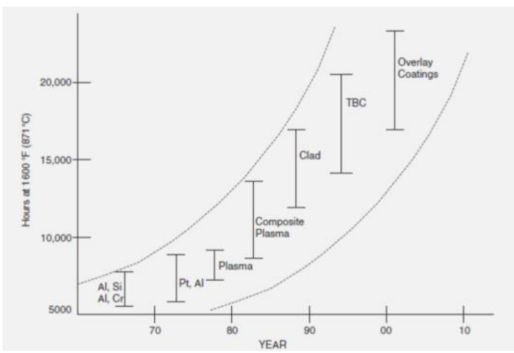
The design of this alloy was unique in that it utilized phase stability and other predictive techniques to balance the levels of critical elements (Cr, Mo, Co, Al, Wand Ta), thereby maintaining the hot corrosion resistance of IN-738 at higher strength levels without compromising phase stability.

A superalloy, or high-performance alloy, is an alloy that exhibits excellent mechanical strength and creep (tendency for solids to slowly move or deform under stress) resistance at high temperatures, good surface stability, and corrosion and oxidation resistance. Super alloys typically have a matrix with an austenitic face-centered cubic crystal structure. A super alloy's base alloying element is usually nickel, cobalt, or nickel-iron.

2.3 TURBINE BLADE COATING

Blade coatings were originally developed by aircraft engine industry for aircraft gas turbines. Metal temperatures in heavy-duty gas turbines are lower than those in aircraft engines. However, heavy-duty gas turbines generally subjected to excessive contamination or accelerated attack known as hot corrosion.

Blade coatings are required to protect the blade from corrosion, oxidation, and mechanical property degradation. As super alloys have become more complex, it has been increasingly difficult to obtain both the higher strength levels that are required and a satisfactory level of corrosion and oxidation resistance without the use of coatings. Thus, the trend toward higher firing temperatures increases the need for coatings. The function of all coating is to provide a reservoir of elements that will form very protective and adherent oxide layers, thus protecting the underlying base material from oxidation and corrosion attack and degradation.



3. CHAPTER-III

3.1. Introduction to Cad & Ansys

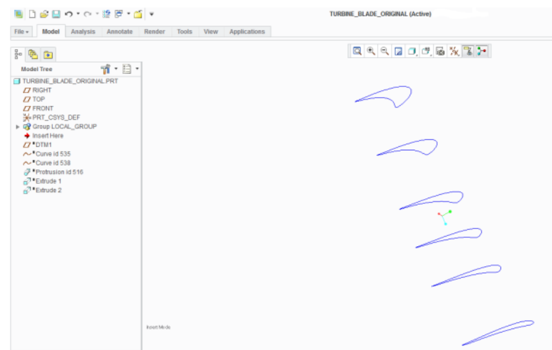
Computer-aided design (CAD), also known as computer-aided design and drafting (CADD), is the use of computer technology for the process of design and design-documentation. Computer Aided Drafting describes the process of drafting with a computer. CADD software, or environments, provide the user with input-tools for the purpose of streamlining design processes; drafting, documentation, and manufacturing processes. CADD output is often in the form of electronic files for print or machining operations. The development of CADD-based software is in direct correlation with the processes it seeks to economize; industry-based software (construction, manufacturing, etc.) typically uses vector-based (linear) environments whereas graphic-based software utilizes raster-based (pixelated) environments.

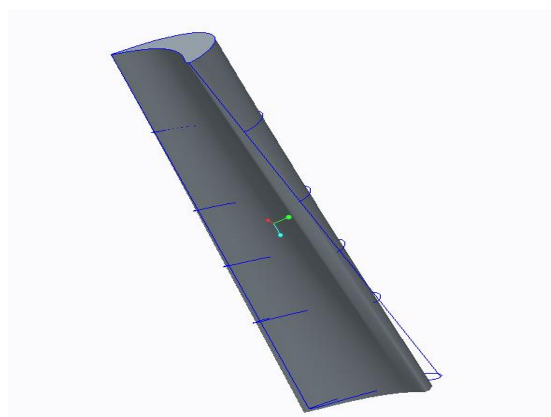
CADD environments often involve more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions.

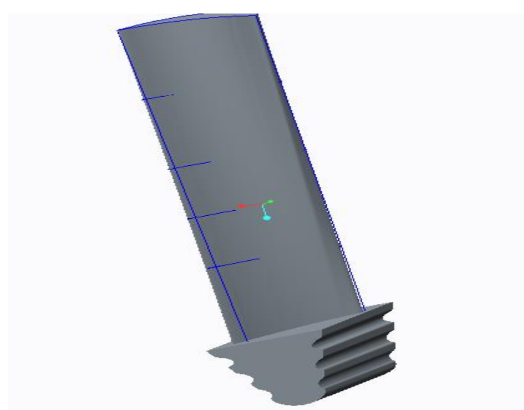
CAD may be used to design curves and figures in two-dimensional (2D) space; or curves, surfaces, and solids in three-dimensional (3D) objects.

CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals. The modern ubiquity and power of computers means that even perfume bottles and shampoo dispensers are designed using techniques unheard of by engineers of the 1960s. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry.

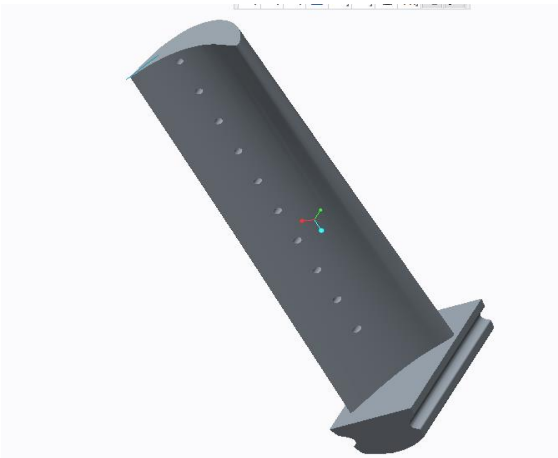
MODEL OF TURBINE BLADE







MODIFIED MODEL – FOR COOLING



INTRODUCTION TO FEA

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variational calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Topp established a broader definition of numerical analysis. The paper centered on the "stiffness and deflection of complex structures".

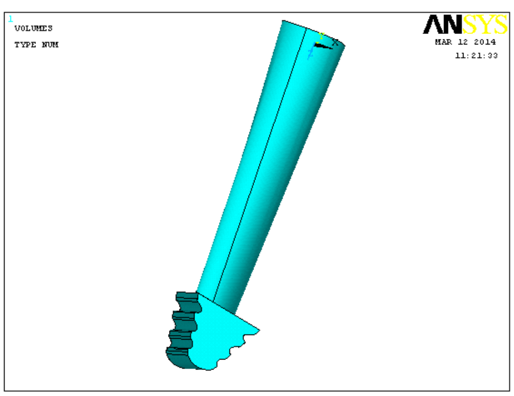
FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement.

COUPLED FIELD ANALYSIS OF TURBINE BLADE

ORIGINAL MODEL

TITANIUM ALLOY

Imported Model from Pro/Engineer



Thermal Properties

Element Type: Solid 20 node 90

Material Properties: Thermal Conductivity – 0.0067W/mmK

Specific Heat – 526.3J/Kg K

Density – 0.00000443 Kg/mm^3

Meshed Model

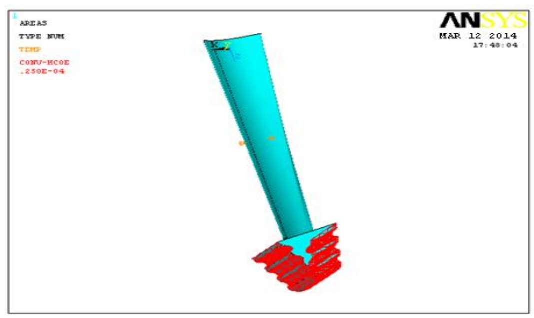
Temperature Loads

Temperature – 923K

Loads – define Loads – Apply – Thermal – Convection – on areas

Bulk Temperature – 600 K

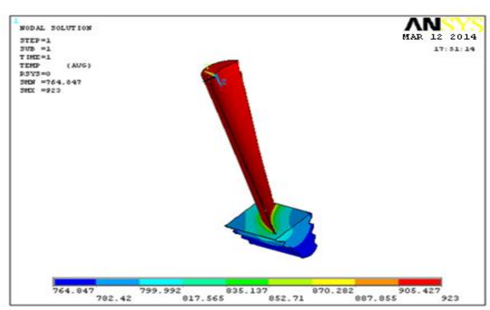
Film Coefficient – 0.00068W/mm^2 K



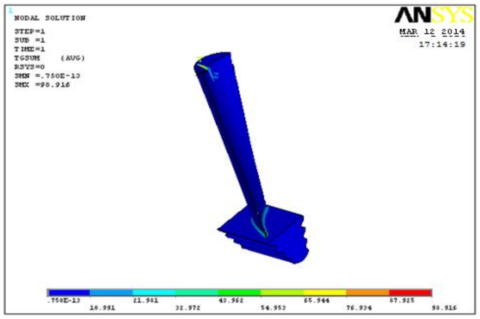
Solution

Solution – Solve – Current LS – ok

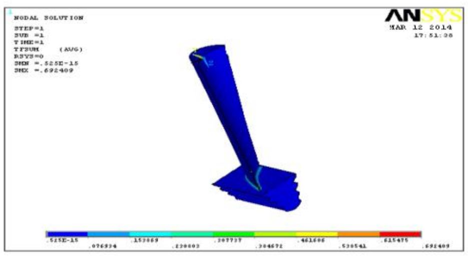
Nodal Temperature



Thermal gradient



Thermal flux



NEW ANALYSIS

Structural Properties

Element Type: Solid 20 node 95

Material Properties:

Density – 0.00000443Kg/mm^3

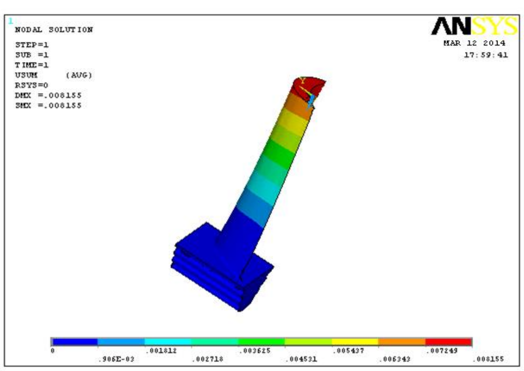
Young’s Modulus – 113800Mpa

Poisson’s ratio - 0.342

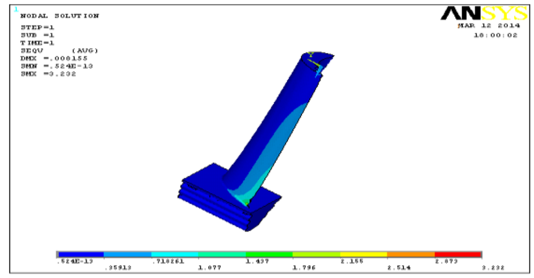
Pressure – 0.29

Post Processor

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Displacement Vector Sum



General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress



NICKEL BASED ALLOY – INCONEL 918

Thermal Properties

Element Type: Solid 20 node 90

Material Properties:

Thermal Conductivity – 0.0114W/mmK

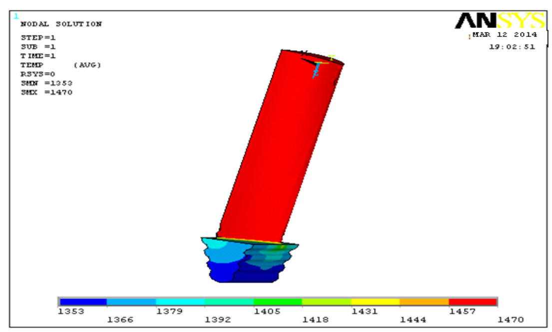
Specific Heat – 435J/Kg K

Density – 0.00000819 Kg/mm^3

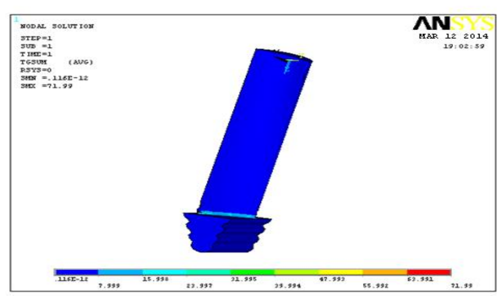
Solution

Solution – Solve – Current LS – ok

Nodal Temperature



Thermal gradient



Thermal flux

NEW ANALYSIS

Structural Properties

Element Type: Solid 20 node 95

Material Properties:

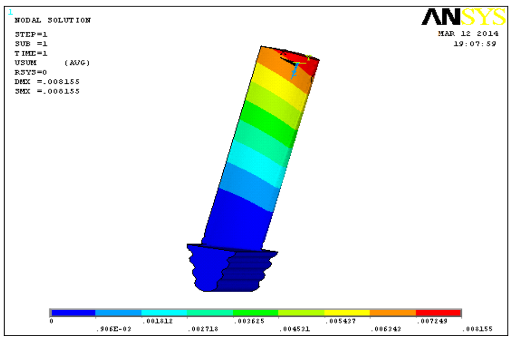
Density – 0.00000822Kg/mm^3

Young's Modulus – 200000Mpa

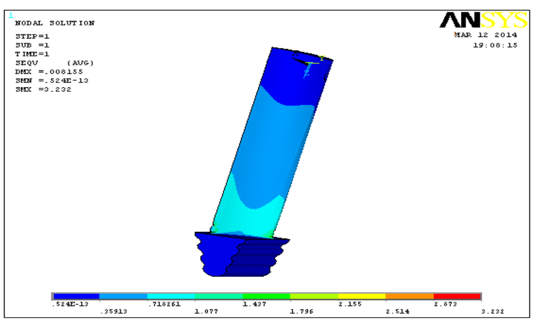
Poisson's ratio - 0.294

Post Processor

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Displacement Vector Sum



General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress



MODIFIED MODEL

TITANIUM ALLOY

Imported Model from Pro/Engineer

Meshed Model

Temperature Loads

Temperature – 923K

Loads – define Loads – Apply – Thermal – Convection – on areas

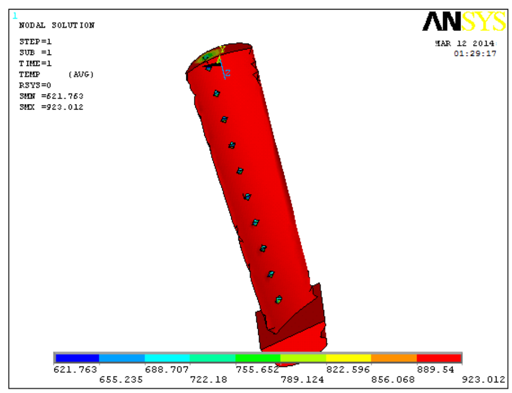
Bulk Temperature – 600 K

Film Coefficient – 0.00068W/mm^2 K

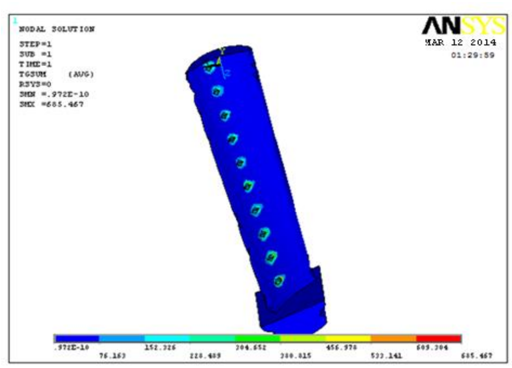
Solution

Solution – Solve – Current LS – ok

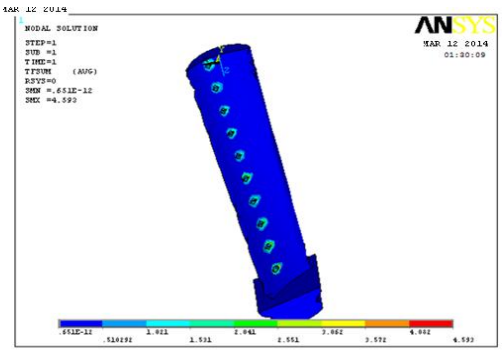
Nodal Temperature



Thermal gradient



Thermal flux

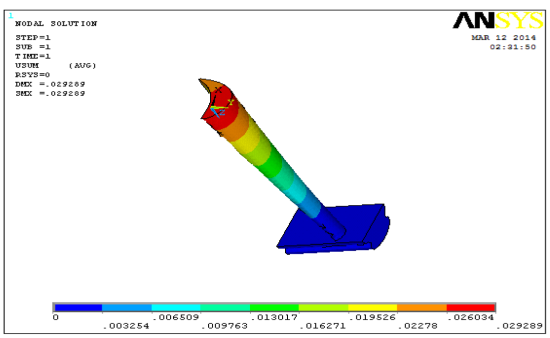


NEW ANALYSIS

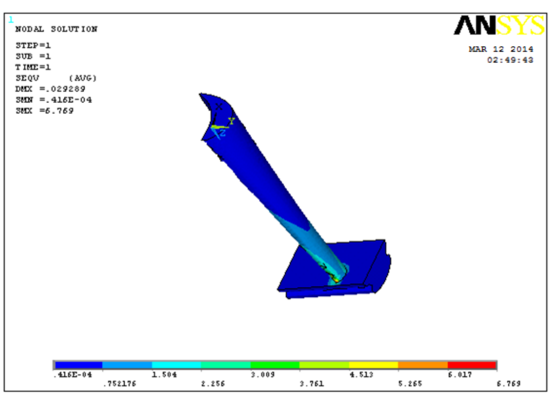
Pressure – 0.29

Post Processor

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Displacement Vector Sum



General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress

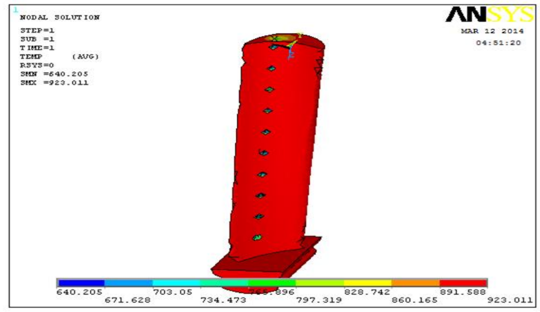


NICKEL BASED ALLOY – INCONEL 718

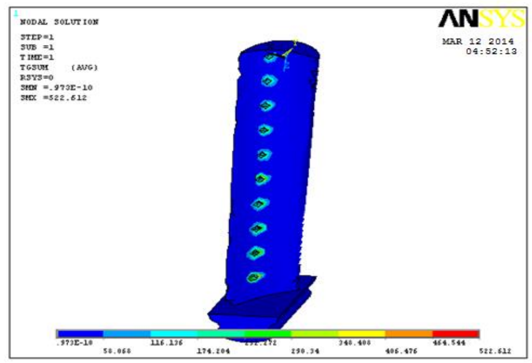
Solution

Solution – Solve – Current LS – ok

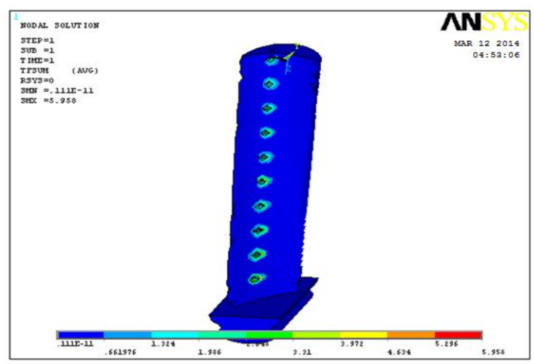
Nodal Temperature



Thermal gradient



Thermal flux



NEW ANALYSIS

Structural Properties

Element Type: Solid 20 node 95

Material Properties:

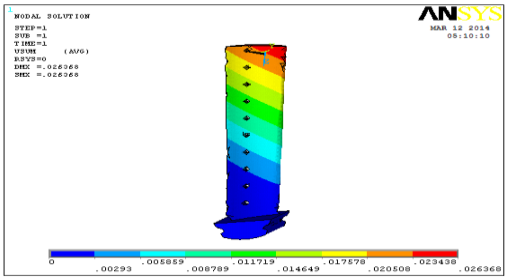
Density – 0.000007612Kg/mm^3

Young's Modulus – 200000Mpa

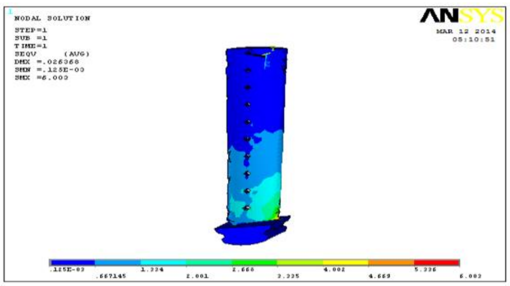
Poisson's ratio - 0.29

Post Processor

General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Displacement Vector Sum



General Post Processor – Plot Results – Contour Plot – Nodal Solution – Stress – Von Mises Stress



4. CHAPTER-IV

RESULTS AND DISCUSSIONS

ORIGINAL MODEL

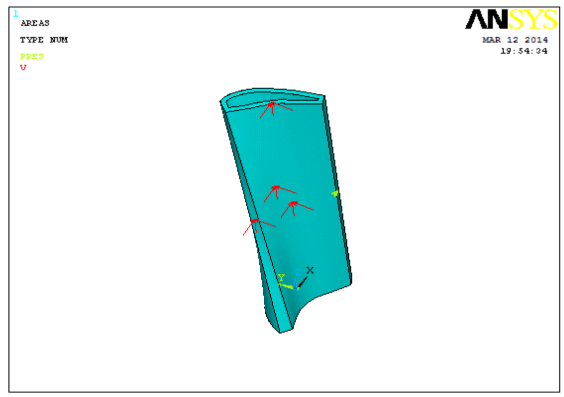
PROPERTIES	**TITANIUM ALLOY**	**INCONEL 718**
Nodal Temperature (K)	923	1470
Thermal Gradient (K/Mm)	98.916	71.99
Nodal Temperature (K)	0.692	2.127
Thermal Gradient (K/Mm)	0.00815	0.00815
Thermal Flux (W/Mm^2)	3.232	3.232

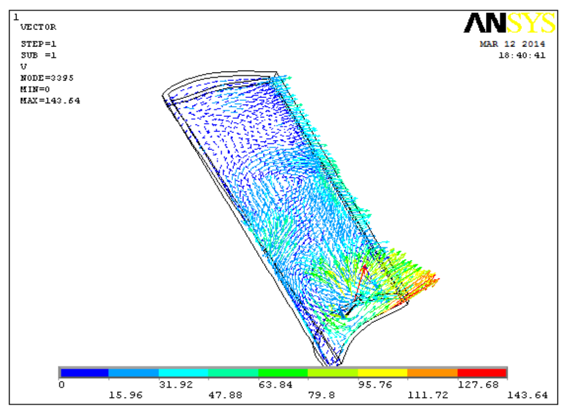
MODIFIED MODEL

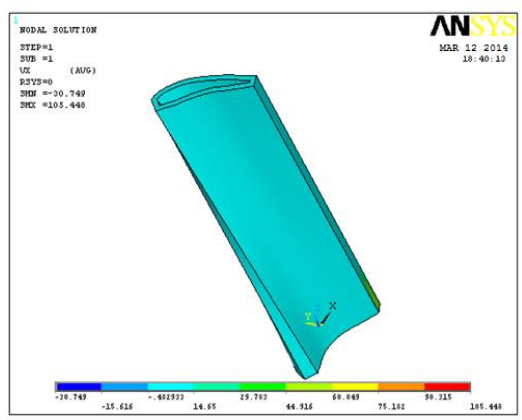
PROPERTIES	**TITANIUM ALLOY**	**INCONEL 718**
Nodal Temperature (K)	923.012	923.011
Thermal Gradient (K/Mm)	685.467	522.612
Thermal Flux (W/Mm^2)	4,593	5.958
Displacement (Mm)	0.0029	0.0026
Stress (N/Mm^2)	6.769	6.003

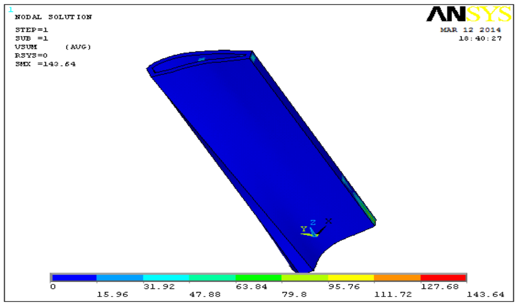
CFD ANALYSIS OF TURBINE BLADE

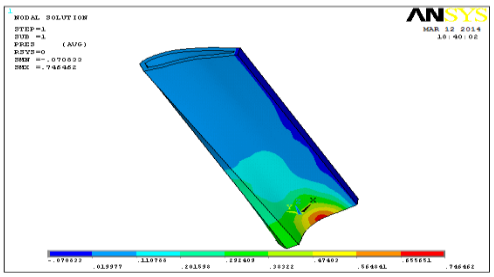
INLET VELOCITY – 620 miles/hr or 277.165m/s











RESULTS TABLE

ORIGINAL MODEL

PROPERTIES	TITANIUM ALLOY	INCONEL 718
nodal temperature (k)	923	1470
thermal gradient (k/mm)	98.916	71.99
thermal flux (W/mm^2)	0.692	2.127
displacement (mm)	0.00815	0.00815
stress (N/mm^2)	3.232	3.232

MODIFIED MODEL

PROPERTIES	TITANIUM ALLOY	INCONEL 718
nodal temperature (k)	923.012	923.011
thermal gradient (K/mm)	685.467	522.612
thermal flux (W/mm^2)	4,593	5.958
displacement (mm)	0.0029	0.0026
stress (N/mm^2)	6.769	6.003
permissible stress (N/mm^2)	880	1100

5. CHAPTER V

CONCLUSION

In our project we have designed a turbine blade used in gas turbines from the point data given by the company and modeled in 3D modeling software Pro/Engineer. We have changed the design by giving cooling channels to the turbine blade so that the heat transfer rate increases. The present used material for the turbine blade is Chromium Steel. We are replacing with titanium alloy and Super alloy Inconel 718 since their strength is more than that of Chromium Steel. The weight of the titanium alloy is less than that of titanium alloy since its density is less that of Chromium Steel and Super alloy Inconel 718. The weight of the super alloy is more than that of Chromium Steel and Titanium alloy but its strength is more than that of other two materials. We have done coupled field analysis on both the models of turbine blades using Titanium alloy and Super alloy Inconel 718. By observing the analysis results, the analyzed stress values are less than their permissible stress values. So using both the materials is safe. By observing the thermal results, thermal flux is more Super alloy than titanium alloy. So using Super alloy is better than Titanium alloy. But the main disadvantage is its weight. By comparing the results for both the models, by modifying the actual design, thermal flux is more for the modified model, so heat transfer rate is increased.

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