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DESIGN, CFD AND VIBRATIONAL ANALYSIS OF GAS TURBINE BLADE WITH COOLING

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Abstract: *Gas turbines are generally utilized in power age, aviation, and modern applications. By giving inside Cooling in the gas turbine edge, in this way, the hotness move rate improves. The cooling air is passed into the rib-upgraded serpentine sections into the sharp edges to accomplish entomb cooling. To achieve maximum efficiency, the internal Cooling path to be optimized so currently existing design of the gas turbine blade is replaced with the new design. In this thesis a turbine blade (with cooling) is modeled and drafted in Creo 2.0 software. The materials used for the Gas turbine blade are Titanium, Nickel and Inconel 625. The CFD Simulation is done and output parameters are pressure distribution, velocity and temperature distribution for the Reynolds numbers 9x10^5, 10x10^5, 11x10^5 and 12x10^5. The pressure is imported to static structural to estimate the deformation, strain, stress distribution and frequencies of the gas turbine blade.*

Keywords- Gas turbine blade; internal cooling; CFD; Reynolds number

1. Introduction

A turbine is a rotational motor that separates vitality from a fluid stream and changes over it into helpful work. The least complex turbines make them move section, a rotor get together, which is a pole or drum with sharp edges connected. Moving liquid follows up on the cutting edges, or the sharp edges respond to the stream, with the goal that they move and give rotational vitality to the rotor. Gas, steam, and water turbines for the most part have a packaging around the sharp edges that contains and controls the working liquid.

A working liquid contains likely vitality (pressure head) and motor vitality (speed head). The liquid might be compressible or in compressible. A few physical standards are utilized by turbines to gather this vitality.

1.1 TYPES OF TURBINES

1. Gas Turbine
2. Steam Turbine
3. Shrouded Turbine
4. Shrouded-Less Turbine

1.2 THEORY OF OPERATION

A working fluid contains potential energy (pressure head) and kinetic energy (velocity head). The fluid may be compressible or incompressible. Several physical principles are employed by turbines to collect this energy

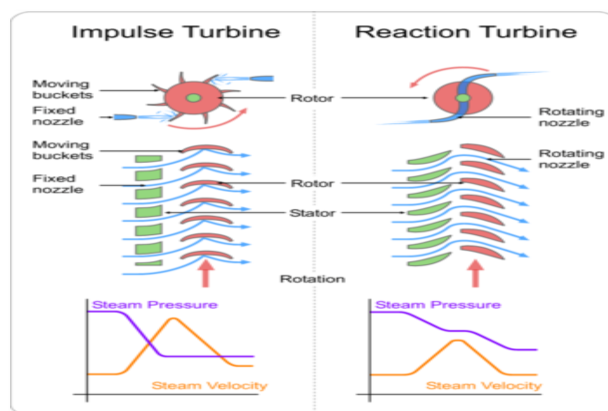

Fig1: Impulse and reaction Turbines

impulse turbines alter the course of stream of a high-speed liquid or gas fly. The subsequent motivation turns the turbine and leaves the liquid stream with decreased active vitality. There is no weight change of the liquid or gas in the turbine edges (the moving cutting edges), as on account of a steam or gas turbine; all the weight drop happens in the fixed sharp edges (the spouts). Prior to arriving at the turbine, the liquid's weight head is changed to speed head by quickening the liquid with a spout. Pelton haggles Laval turbines utilize this procedure solely. Drive turbines don't require a weight casement around the rotor since the liquid stream is made by the spout preceding arriving at the blading on the rotor.

Newton's subsequent law portrays the exchange of vitality for motivation turbines.

Reaction turbines create force by responding to the gas or liquid's weight or mass. The weight of the gas or liquid changes as it goes through the turbine rotor edges. A weight casement is expected to contain the working liquid as it follows up on the turbine stage(s) or the turbine must be completely drenched in the liquid stream, (for example, with wind turbines). The packaging contains and coordinates the working fluid and, for water turbines, keeps up the attractions conferred by the draft tube. Francis turbines and most steam turbines utilize this idea. For compressible working liquids, various turbine stages are typically used to bridle the growing gas effectively. Newton's third law depicts the exchange of vitality for Reaction turbines.

1.3 PERFORMANCE AND EFFICIENCY

The sort of activity for which the motor is structured directs the presentation necessity of a gas turbine motor. The exhibition prerequisite is for the most part dictated by the measure of shaft torque (s.h.p.) the motor creates for a given arrangement of conditions. Most of airplane gas turbine motors are appraised at standard day states of 59 0F and 29.92 inches Hg. This gives a pattern to which gas turbine motors of numerous kinds can be thought about.

The requirement for high productivity in the motor turns out to be increasingly significant as powers become all the more expensive. Motor effectiveness is principally characterized by the particular fuel utilization (s.f.c.) of the motor at a given arrangement of conditions

1.4 INTRODUCTION TO TURBINE BLADE

A turbine blade is the individual segment which makes up the turbine segment of a gas turbine. The sharp edges are answerable for separating vitality from the high temperature, high weight gas delivered by the combustor. The turbine cutting edges are regularly the constraining segment of gas turbines. To make due in this troublesome condition, turbine cutting edges regularly utilize extraordinary materials like superalloys and a wide range of techniques for cooling, for example, inside air channels, limit layer cooling, and warm obstruction coatings.

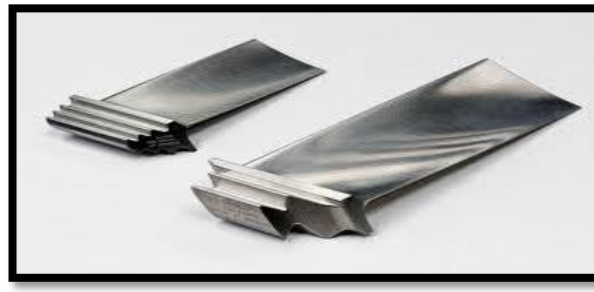

Fig 2: Turbine Blades

1.5 TURBINE BLADE COOLING

Another strategy to improving turbine blades and increasing their operating temperature, aside from better materials, is to cool the blades. There are three main types of cooling used in gas turbine blades; convection, film, and transpiration cooling. While all three methods have their differences, they all work by using cooler air (often bleed from the compressor) to remove heat from the turbine blades.

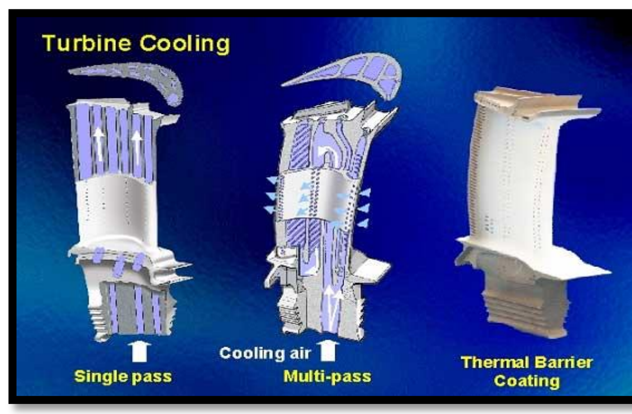

Fig 3: Turbine cooling

1.6 Convection cooling

Convection cooling works by going cooling air through entries inward to the edge. Warmth is moved by conduction through the edge, and afterward by convection into the air streaming within the edge. A huge inward surface region is alluring for this strategy, so the cooling ways will in general be serpentine and brimming with little balances.

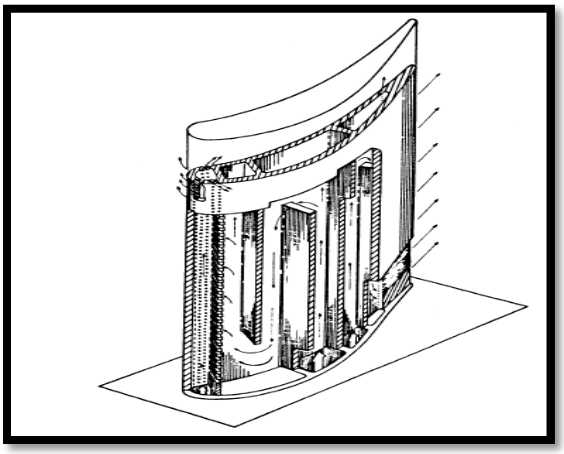

Fig 4: Film and Convection cooled.

2. LITERATURE SURVEY

In this paper by Omid Askari [1], Cooling of Turbine Blade Surface With Extended Exit Holes. The turbine sharp edge surface is cooled by stream from expanded exit holes (EEH). Cooling viability is characterized as temperature difference (TD) between the hot gas stream and the cutting edge surface as a small amount of temperature distinction between the hot gas stream and the coolant move through EEH. Computational exploration utilizing a business code has been done to foresee the presentation of EEH for an alternate structure and working conditions. Viability has been resolved over the sharp edge surface when geometric conditions, for example, the point among EEH and edge surface, area of EEH on the cutting edge surface and exit-to-throat region proportion of EEH. Anticipated viability dispersions concur well with accessible exploratory outcomes, affirming value and preferred position of a computational way to deal with enhancing turbine sharp edge cooling with EEH. In this paper by Fariborz Forghan[2], Film Cooling of Turbine Blade Surface With Extended Exit Holes. The fundamental objective of gas turbine configuration is the powerful utilization of vitality. Ordinarily, the proficient high temperature first and second stage turbine sharp edge surface is cooled by a stream of coolant stream from expanded leave openings (EEH). Against the predominant hot gas stream, the move through EEH must be intended to frame a film of cool air over the sharp edge. Computational examinations are performed to analyze the cooling viability of stream from EEH over the attractions side of a sharp edge by illuminating preservation conditions (mass, force and vitality) and the perfect gas condition of state for the three-dimensional, tempestuous, compressible stream. A separating move through EEH is normally gagged at its throat, bringing about a supersonic stream, a stun and afterward a subsonic stream downstream. The area of the stun comparative with the high-temperature gas stream over the cutting edge decides the temperature dissemination along the edge surface; which is dissected in detail when the coolant stream rate is fluctuated.

3D MODELING OF GAS TURBINE BLADE

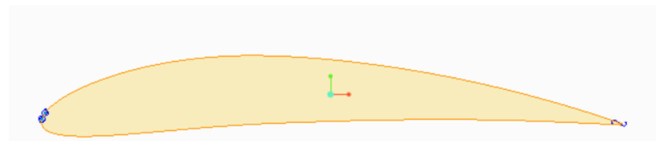

Fig 5: NACA 2D profile

Based on the NACA 6412 coordinate points, a free smooth curve is drawn which indicated the closed loop profile

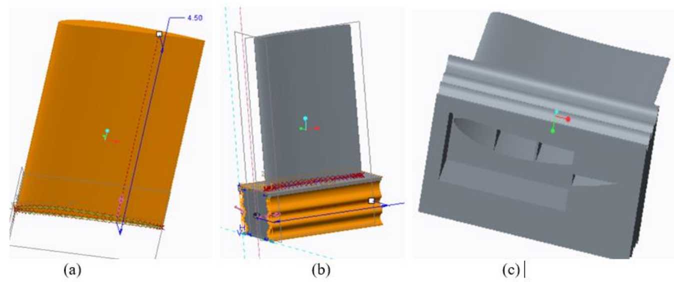

Figure 6: (a) height of the gas turbine blade (b) complete 3D model of the original gas turbine blade (c) cooling ribs to the blade.

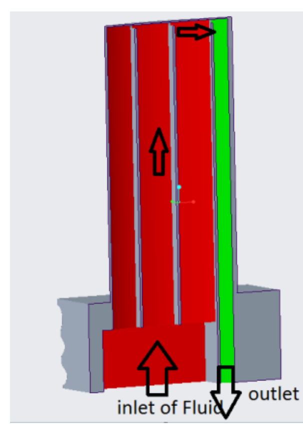

Fig 7: Crossectional view

CFD Simulation

The gas turbine blade is developed in 3D modelling software and then converted into igs format. This format is imported to CFD and then applied Pressure 32364 kPa, Temperature 1500 °C for the outer surface of the blade and 653 °K for cooling fluid. The Material properties (Titanium, Nickel alloy, Inconel 625) are taken consider for the current study. Fig 8, Represents the imported model from the igs format. The part is meshed with tetra with fine and obtained that 102351 nodes and 168523 elements.

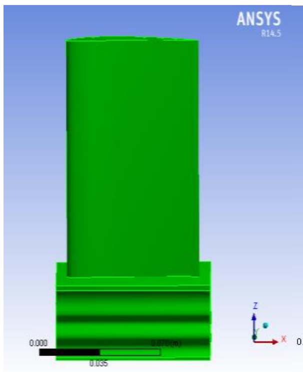

Fig 8: Imported model

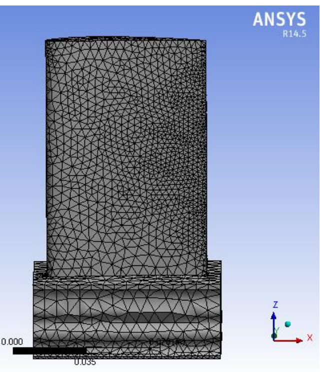

Fig 9: Meshed model

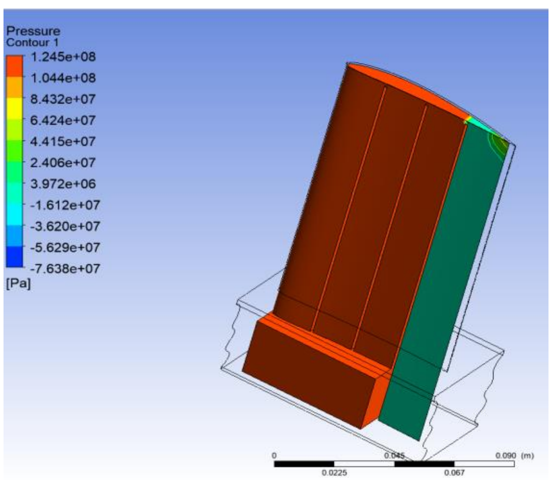

Fig 10: Pressure Contour

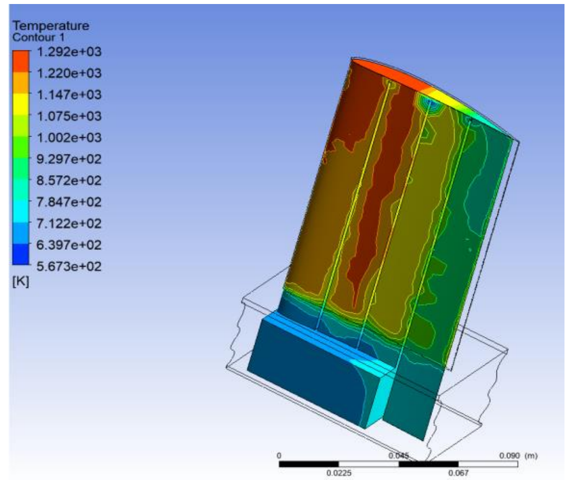

Fig 11: Temperature

From above figure10, it is stated that, maximum pressure is 1.245e+8 Pa obtained at entry of the fluid. while leaving, with effect of cooling and surface friction the pressure is reduced to 3.972e+6 Pa. From above figure 11, it is represented the temperature. The low temperature of the fluid is entering into the turbine blade and it takes maximum temperature at entry level and leaves the with less temperature is 567K

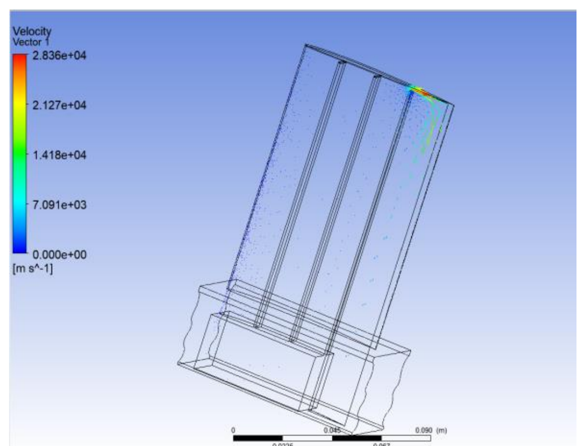

Fig 12: Velocity Vector

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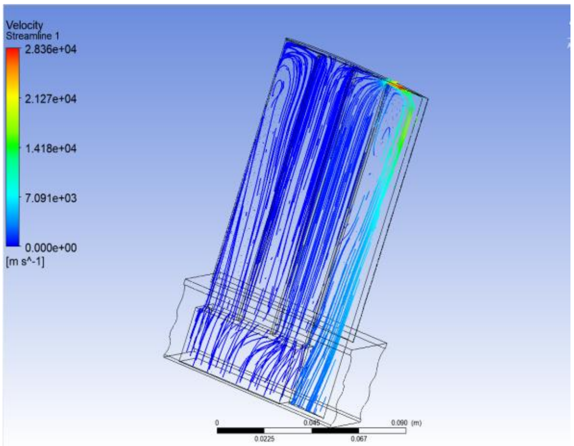


Fig 13: Velocity Streamline

The velocity (fig 12), vector is represented based on the Reynolds number. From above figure 2.836e+4 m/sec velocity of the fluid is identified. The velocity streamline (Fig 13), is represented based on the Reynolds number. From above figure 2.836e+4 m/sec velocity of the fluid is identified.

Static Structural and Modal Analysis

The pressure at different Reynolds numbers from the CFD simulation is noted and imported to the same model to estimate the deformation, stress, strain and frequency of the gas turbine blade by using FSI Technique.

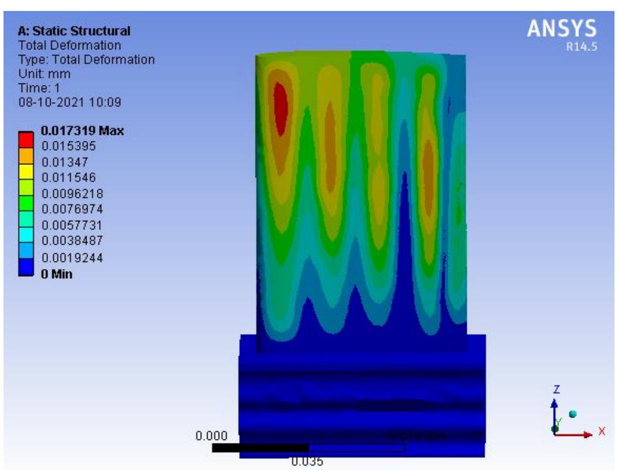


Fig 14: Deformation

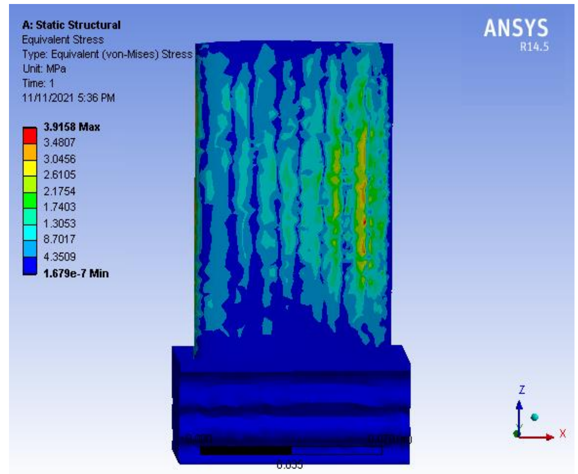


Fig 15: Stress

From above figure14, it was observed that deformation is occurred at the cooling sections due to lack of material. The maximum deformation 0.017319mm is obtained at first passage section and minimum 0mm is at holding portion of the blade. From the figure 15, Maximum stresses are produced at the internal passage of the blade because of weak material zone. The maximum stress is 3.91MPa at fluid passage and minimum is 1.679e-7 MPa at holding portion of the blade.

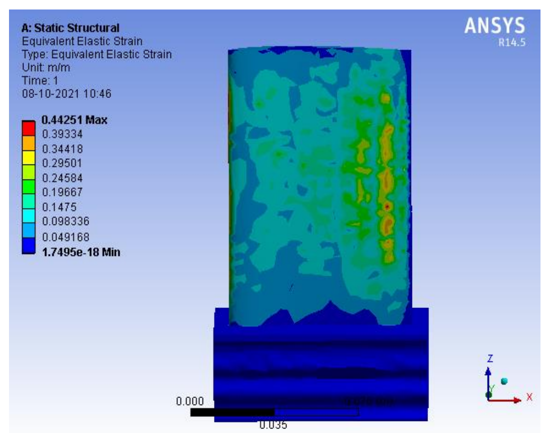


Fig 16: Strain

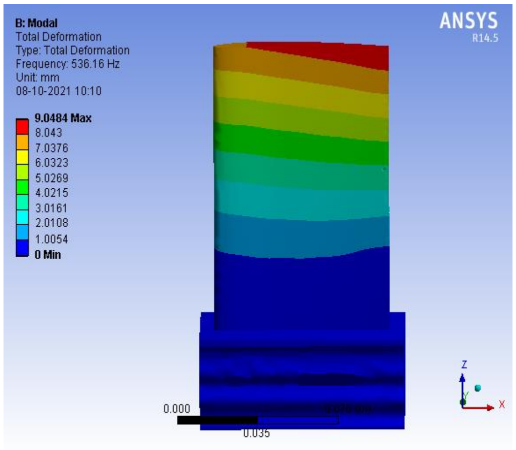


Fig 17: Mode1

From the figure 16, Stain is defined as change in length to original length. The maximum strain is 0.44251 obtained at the exit path of the fluid and minimum at holding portion of the blade. From the figure 17, In modal analysis, at different mode shapes different deformation and frequencies will obtain. In mode 1, the frequency is 536.16Hz with maximum deformation is 9.0484mm and minimum is 0mm

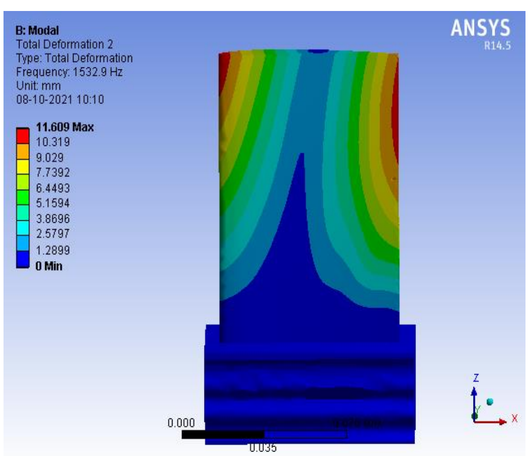


Fig 18: Mode 2

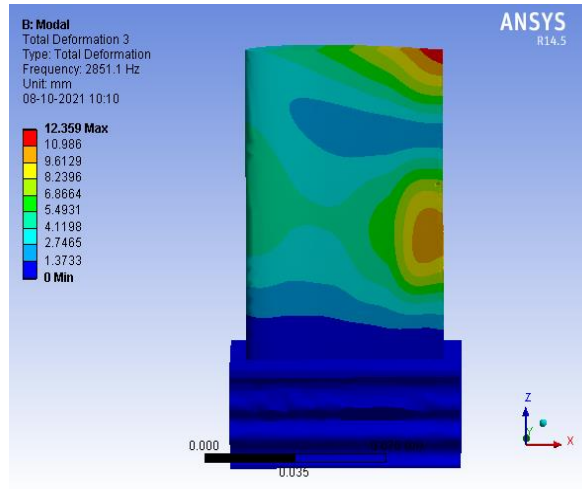
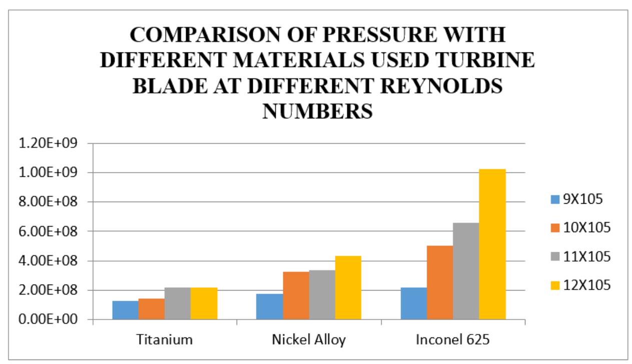
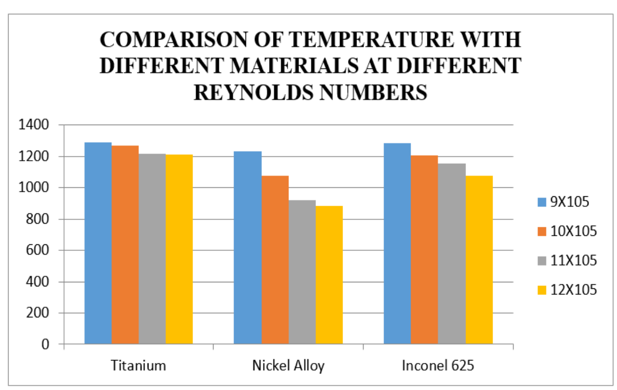


Fig 19: Mode 3

In mode 2 (fig 18), the frequency is 1532.9Hz with maximum deformation is 11.609mm and minimum is 0mm. In mode 3 (Fig 19), the frequency is 2851.1Hz with maximum deformation is 12.359mm and minimum is 0mm

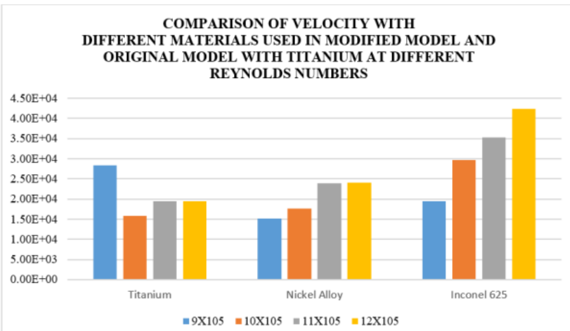
Result and discussions

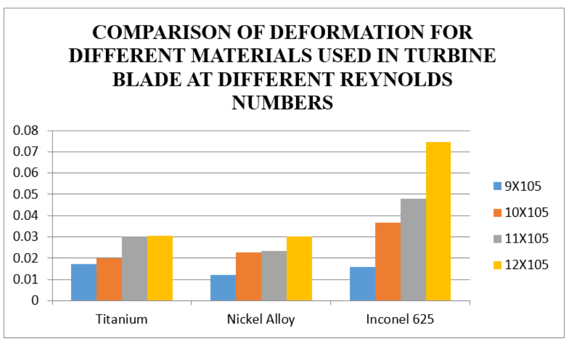




Graph – Comparison of (a) Pressure and (b) Temperature with different materials at different Reynolds numbers.

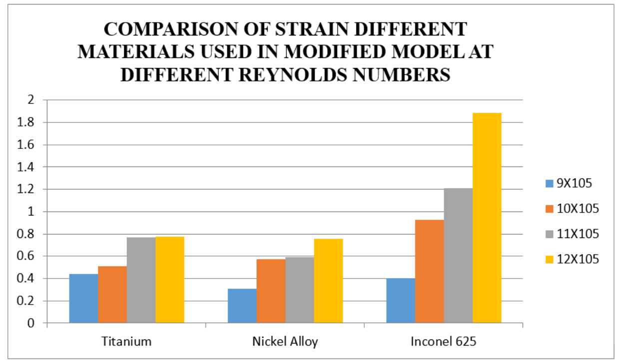
From the above graph(a), it is observed that the Pressure value is increased for 12X10⁵ Reynolds number for Inconel 625 material and Decreasing for titanium because of its mechanical properties. From the above graph(b), it is observed that the Temperature value is increasing at 12X10⁵ Reynolds number for titanium material and decreasing at 9X10⁵ Reynolds number for nickel alloy material.

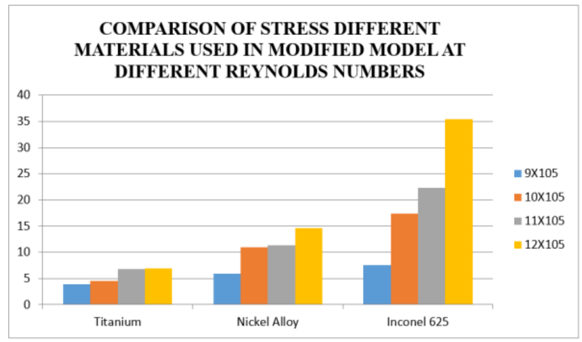




Graph – Comparison of (c) Velocity (d) deformation with different materials used in turbine blade at different Reynolds numbers.

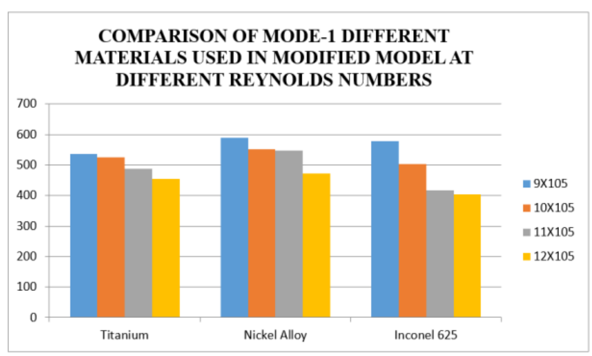
From the above graph(c), it is observed that the Velocity value is increasing at 12X10⁵ and 9X10⁵ Reynolds number for Inconel 625, Titanium materials. From the above graph (d), it is observed that the deformation (mm) value is increasing from 9 to 12X10⁵ Reynolds number for Inconel 625 and Decreasing at all Reynolds number for Titanium material of blade.

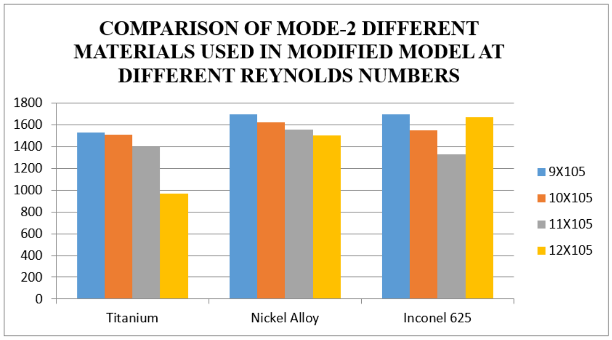




Graph – comparison of (e) strain and (f)stress for different materials used in turbine blade at different Reynolds numbers

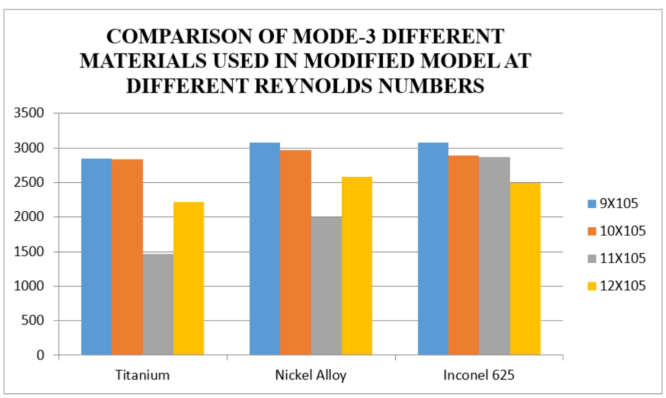
From the above graph(e), it is observed that the strain value is increasing for 12X10⁵ Reynolds number for Inconel 625 and Decreasing at all Reynolds number for Titanium material of blade. From the above graph(f), it is observed that the stress value is increasing for 12X10⁵ Reynolds number for Inconel 625 and Decreasing at all Reynolds number for Titanium material of blade.





Graph – comparison of mode-1 (g) and mode -2 (h) frequency for different materials used in turbine blade at different Reynolds numbers

From the above graph(g), it is observed that the mode 1 is increasing for $9X10^5$ Reynolds number for Inconel 625 and Decreasing at all Reynolds number $12X10^5$ for Inconel material of blade. From the above graph (h), it is observed that the mode 2 is increasing for $9X10^5$ Reynolds number for Inconel 625 and Decreasing at all Reynolds number $12X10^5$ for titanium material of blade.



Graph i: comparison of mode-3 frequency for different materials used in turbine blade at different Reynolds numbers

From the above graph it is observed that the mode 3 is increasing for $9X10^5$ Reynolds number for Inconel 625 and Decreasing at all Reynolds number $12X10^5$ for titanium material of blade.

CONCLUSION

In this work a turbine blade is designed and modelled in Creo 2.0 software. The materials of turbine blade are Titanium, Nickel and Inconel 625. CFD analysis is done to determine the pressure distribution, velocity, temperature distribution, deformation, strain, stress and frequency by applying the Reynolds numbers $9x10^5$,$10x10^5$,$11x10^5$ and $12x10^5$.

From the simulation, the following results are predicted.

- The Pressure, velocity and temperature value is increasing at 12X105 Reynolds number for Inconel 625 material and reduced for titanium material.
- Overall results of static and vibrational analysis, the Deformation, stress, strain and vibrations are less for Titanium material while compared with other materials

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