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Design and Analysis of Gas Turbine

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ABSTRACT: In the present work the first stage rotor blade of a two-stage gas turbine has been analyzed for structural, thermal using ANSYS 12 which is powerful Finite Element Software. In the process of getting the thermal stresses, the temperature distribution in the rotor blade has been evaluated using this software. From different materials titanium alloy, stainless steel alloy and Aluminum2024 alloy that has been considered for the purpose analysis. . The turbine blade along with the groove is considered for the static, thermal, modal analysis. The blade is modeled with the 3D-Solid Brick element. The geometric model of the blade profile is generated with splines and extruded to get a solid model. It is observed that the Maximum temperatures are observed at the blade tip section are linearly decreasing from the tip of the blade to the root of the blade section.

KEYWORDS: Gas Turbine, Structural Analysis, Thermal Analysis, Modal, Finite Element Analysis

I. INTRODUCTION

General

The purpose of turbine technology are to extract the maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency by means of a plant having maximum reliability, minimum cost, minimum supervision and minimum starting time. The gas turbine obtains its power by utilizing the energy of burnt gases and the air which is at high temperature and pressure by expanding through the several rings of fixed and moving blades. To get a high pressure of order 4 to 10 bar of working fluid where fuel is continuously burnt with compressed air to produce a steam of hot, fast moving gasas shown in figure 1[1].

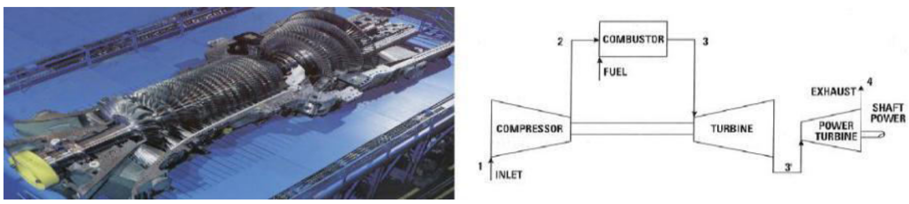

Figure 1: Gas Turbine Simple Open Cycle

This gas stream is used to power the compressor that supplies the air to the engine as well as providing excess energy that may be used to do other work, which is essential for expansion a compressor, is required. The quantity of the working fluid and speed required are more so generally a centrifugal or an axial compressor is required. The turbine drives the compressor so it is coupled to the turbine shaft. If after compression the working fluid were to be expanded in a turbine, then assuming that there were no losses in either component, the power developed by the turbine can be increased by increasing the volume of working fluid at constant pressure or alternatively increasing the pressure at constant volume.

Either of these may be done by adding heat so that the temperature of the working fluid is increased after compression. To get a higher temperature of the working fluid a combustion chamber is required where combustion of air and fuel takes place giving temperature rise to the working fluid. Gas turbines have been constructed to work on the following: - oil, natural gas, coal gas, producer gas, blast furnace and pulverized coal.

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The engine consists of three main parts.

- The Compressor section
- The Combustion section (the combustor).
- The turbine (and exhaust) section.

The Turbine compressor usually sits at the front of the engine. There are two main types of compressor, the centrifugal compressor and the axial compressor. The compressor will draw in air and compress it before it is fed into the combustion chamber. In both types, the compressor rotates and it is driven by a shaft that passes through the middle of the engine and is attached to the turbine as shown below in figure 2 [1], [2].

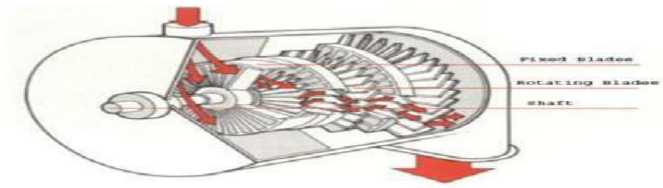

Figure 2: Turbine Blade Coupled to Centrifugal Compressor

Types of Gas Turbine

There are four main types of gas turbine: The turbojet, turbofan, turboprop and turbo shaft**[2].**

Fuel for Gas Turbine Power Plants

Gas turbine fuel systems are similar for all Turbines. For the most common fuels, which are natural gas, LNG (liquid natural gas), and light diesel, the fuel system consists:

A fuel delivery system,Fuel nozzles,Fuel additives (to deal with vanadium), Fuel washing (to deal with sodium and potassium Salts) and Modifications to the fuel delivery system[3].

Natural Gas

Natural gas comprises over 80% methane with minor amounts of ethane, propane, butane, and heavier hydrocarbons. It may also include carbon dioxide, nitrogen, and hydrogen. There are a plethora of blends of natural gas available worldwide[3].

Applications of Gas Turbine

The following are the applications of gas turbine as shown in figure 3.

- **Land Applications:** Central power stations, Industrial and Industrial.
- **Space Applications:** Turbo jet and Turbo prop.

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Figure 3: Some Examples of Application Gas Turbine

Turbine Blade

The rotor blades of the turbo machine are very critical components and reliable operation of the turbo machine as a whole depends on their repayable operation. The major cause of break down in turbo machine is the failure of rotor blade. The failure of the rotor blade may lead to catastrophic consequences both physically and economically. Hence, the proper design of the turbo machine blade plays a vital role in the proper functioning of the turbo machine as shown in figure 4[1].

Figure 4: Turbine Blade

A good design of the turbo machine rotor blading involves the following:

- Determination of geometric characteristics from gas dynamic analysis.
- Determination of steady loads acting on the blade and stressing due to them.
- Determination of natural frequencies and mode shapes.
- Determination of unsteady forces due to stage flow interaction.
- Determination of dynamic forces and life estimation based on the cumulative damage fatigue theories[3].

Production of Blades

Blades may be considered to be the heart of turbine and all other member exist for the sake of the blades. Without blade there would be no power and the slightest fault in blade would mean a reduction in efficiency and costly repairs. The following are some of the methods adopted for production of blades.

- **Rolling:** Sections are rolled to the finished size and used in conjunction with packing pieces. Blades manufactured by this method do not fail under combined bending and centrifugal force.

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- **Machining:** Blades are also machined from rectangular bars. This method has more or less has the same advantage as that of first. Impulse blade is manufactured by this technique.

- **Forging:** Blade and vane sections having airfoil sections are manufactured by specialist techniques.

Turbine Blade Cooling

Unlike steam turbine bladings, gas turbine bladings need cooling. The objective of the blade cooling is to keep the metal temperature at a safe level to ensure a long creep life and low oxidation rates. Although it is possible to cool the blades by liquid using thermosyphon and heat pipe principal, but the universal method of blade cooling is by cool air or working fluid flowing through internal passage in the blades. The mean rotor blade temperature is about 350^{0}C below the prevailing gas temperature after efficient blade cooling as shown below in figure 5.

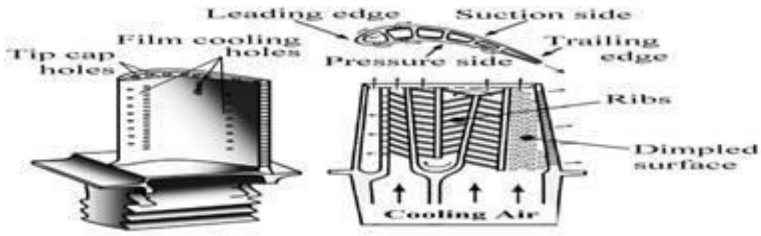

Figure 5: Turbine Blades Cooling

Due to corrosion and corrosion deposits turbine blades fail. To protect it from corrosion, the uses of pack-aluminized coatings are used. The main elements used are aluminum, nickel, and chromium[1], [5].

II. ASSUMPTION SYSTEM AND SIMULATIONS

Turbine Blade Materials

Advancements made in the field of materials have contributed in a major way in building gas turbine engines with higher power ratings and efficiency levels. Improvements in design of the gas turbine engines over the years have importantly been due to development of materials with enhanced performance levels. Gas turbines have been widely utilized in aircraft engines as well as for land based applications importantly for power generation. Advancements in gas turbine materials have always played a prime role – higher the capability of the materials to withstand elevated temperature service, more the engine efficiency; materials with high elevated temperature strength to weight ratio help in weight reduction. A wide spectrum of high performance materials - special steels, titanium alloys and super alloys - is used for construction of gas turbines [4].The material available limits the turbine entry temperature (TET).the properties required are as follows (a) tensile strength (b) resistance to high frequency vibration fatigue stresses(c) low frequency thermal fatigue stresses (d) resistance to erosion and corrosion [1].

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III. RESULTS AND DISCUSSIONS

Structural Analysis

Case1: Von Mises Stress Of Titanium, Aluminum2024 and Stainless Steel Alloys

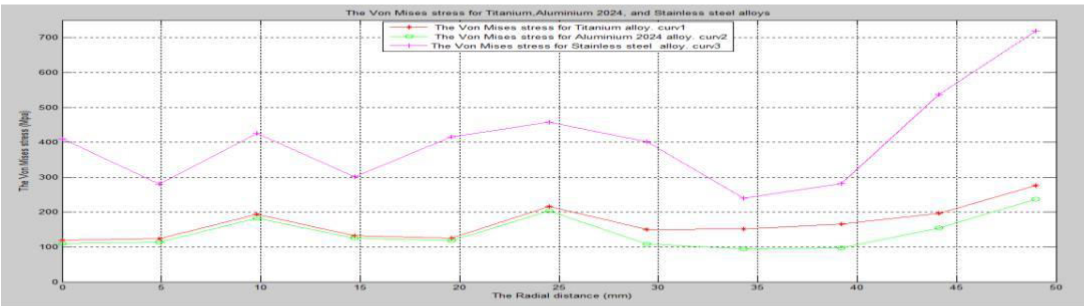

Figure 20: The Von Mises Stresses (MPa) of Titanium, Stainless Steel and Aluminum 2024 Alloys

Figure 20 shows that variation of stresses along the radial distance. It is observed that the stress is varying as the radial distance increases. The maximum stresses are observed to be719.075 MPa for stainless steel alloy at a distance of 49

mm and the minimum stresses are observed to be 94.8706MPa for Aluminum 2024 Alloy at a distance of 34.3 mm as shown in figure 24, 25 and 26.

Case2: Resultant Deformation of Titanium, Aluminium 2024 and Stainless Steel Alloys

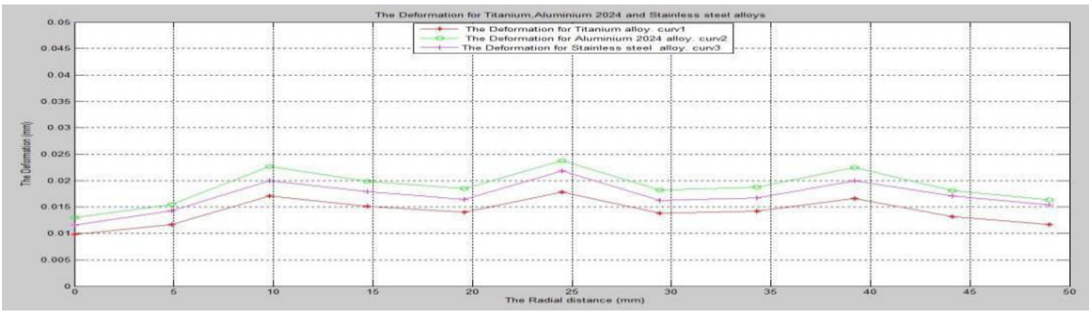

Figure 21: Deformation Variations (mm) of Titanium, Stainless Steel and Aluminum 2024 Alloys

Figure 21 shows the variation of deformation along the radial distance .It is observed that the deformation is varying as the radial distance increases and maximum is 0.023821mm for the Aluminum 2024 Alloys and minimum is 0.00978284 mm for the Titanium alloys as shown in figure 27, 28 and 29.

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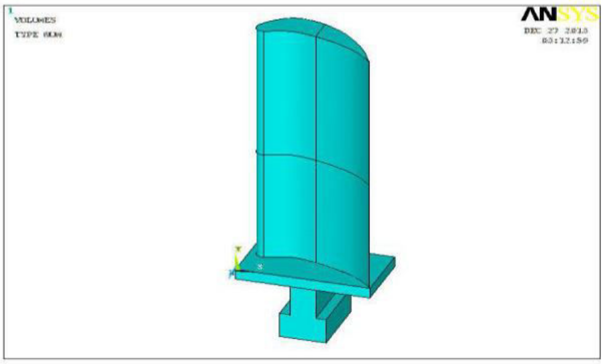

Figure 22: Solid Modal of Gas Turbine Blade

Figure 23: Finite Element Modal Free Mesh

IV. CONCLUSIONS

The finite element analysis of gas turbine rotor blade is carried out using 8 nodded brick element. The static and thermal analysis is carried out. The temperature has a significant effect on the overall stresses in the turbine blades.Maximum temperatures are observed at the blade tip section and minimum temperature variations at the root of the blade.Temperature distribution is almost uniform at the maximum curvature region along blade profile.Temperature is linearly decreasing from the tip of the blade to the root of the blade section.For all the materials the temperature maximum observed is varying between 794^0C to 812^0C.Maximum stress induced is within safe limits for all the materials except aluminum.The modal analysis reveals that the fundamental frequency of titanium alloy is highest (35Hz) as compared all other materials. Hence resonance delay for this hence dynamically more stable.

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