# Stress Analysis of Gas Turbine Multi Stage Rotor Assembly

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**Abstract:** ***Gas turbines are essential in generation of power in the field of aviation etc.; proper design of all the elements of the gas turbine will play a pivotal role in providing an efficient and ergonomic gas turbine. Gas turbine rotor is one of the key elements of gas turbine .Hence analysis of gas turbine rotor is essential. Gas turbine rotor assembly is mainly subjected to centrifugal stresses with high temperature gradients. If these stresses are beyond the threshold limit of the strength of the material of the gas turbine rotor, rotor failure will occur. In the present work, the gas turbine rotor assembly is analyzed for thermal loads, centrifugal forces and natural frequency due to the mass of the rotor assembly. The gas turbine rotor will be analyzed as a segment of the design and modeling of gas turbine. In this work structural and thermal characteristics in gas turbine rotor assembly due to various operating conditions will be analyzed by varying the suitable materials, analysis using FEA software ANSYS workbench-14.5 and results are presented. From the results presented, one can say that the structural and thermal characteristics of the rotor will be reduced to eliminate the use of high level materials.***

**Keywords:** gas turbine, Structural, Modal and Thermal Analysis, Finite Element Analysis

## 1. Introduction

The basic operation of the gas turbine is similar to that of the steam power plant except that air is used instead of water. Fresh atmospheric air flows through a compressor that brings it to higher pressure. Energy is then added by spraying fuel into the air and igniting it so the combustion generates a high-temperature flow. This high-temperature high-pressure gas enters a turbine, where it expands down to the exhaust pressure, producing a shaft work output in the process. The turbine shaft work is used to drive the compressor and other devices such as an electric generator that may be coupled to the shaft. The energy that is not used for shaft work comes out in the exhaust gases, so these have either a high temperature or a high velocity. The purpose of the gas turbine determines the design so that the most desirable energy form is maximized. Gas turbines are used to power aircraft, trains, ships, electrical generators, or even tanks.

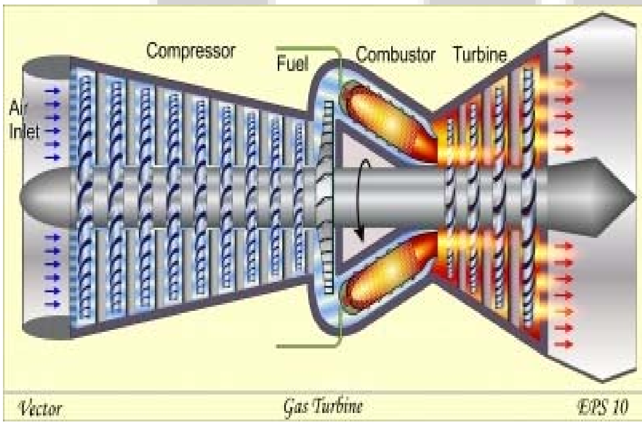


**Figure 1.1:** Basic multi stage gas turbine

## 2. Amateur Gas Turbines

Increasing numbers of gas turbines are being used or even constructed by amateurs. In its most straightforward form, these are commercial turbines acquired through military surplus or scrap yard sales, then operated for display as part of the hobby of engine collecting. In its most extreme form, amateurs have even rebuilt engines beyond professional repair and then used them to compete for the Land Speed Record. The simplest form of self-constructed gas turbine employs an automotive turbocharger as the core component. A combustion chamber is fabricated and plumbed between the compressor and turbine sections. More sophisticated turbojets are also built, where their thrust and light weight are sufficient to power large model aircraft, The Schreckling design constructs the entire engine from raw materials, including the fabrication of a centrifugal compressor wheel from plywood, epoxy and wrapped carbon fiber strands. Several small companies now manufacture small turbines and parts for the amateur. Most turbojet-powered model aircraft are now using these commercial and semi-commercial micro turbines, rather than a Schreckling-like home-build.

### 2.1 Advantages of Gas Turbine Engines

- Very high power-to-weight ratio, compared to reciprocating engines;
- Smaller than most reciprocating engines of the same power rating.
- Moves in one direction only, with far less vibration than a reciprocating engine.
- Fewer moving parts than reciprocating engines
- Low operating pressures.
- High operation speeds.
- Low lubricating oil cost and consumption

### 2.2 Disadvantages of Gas Turbine Engines

- Cost is very high
- Less efficient than reciprocating engines at idle speed
- Longer startup than reciprocating engines
- Less responsive to changes in power demand compared with reciprocating engines
- Characteristic whine can be hard to suppress.

## 3. 3D Modeling and Analysis

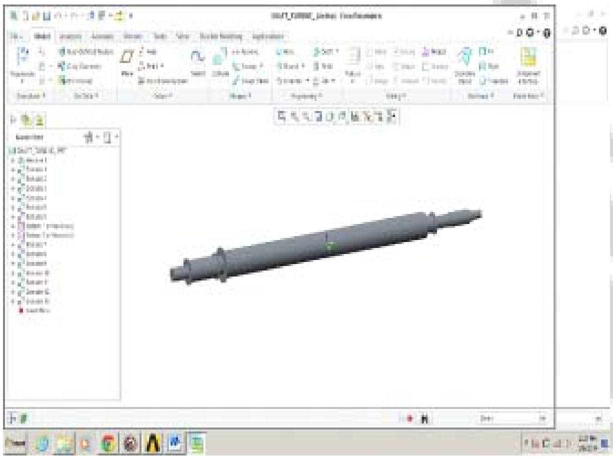

**Figure 3.1:** Pro-E Modeling Gas Turbine Rotor

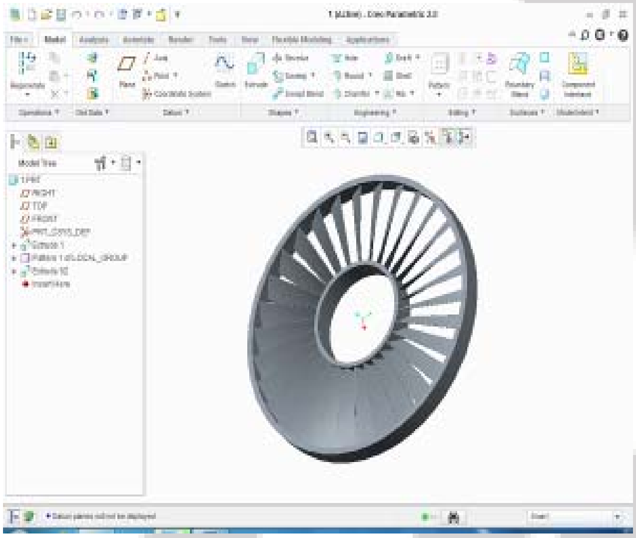

**Figure 3.2:** Gas turbine blade modeling

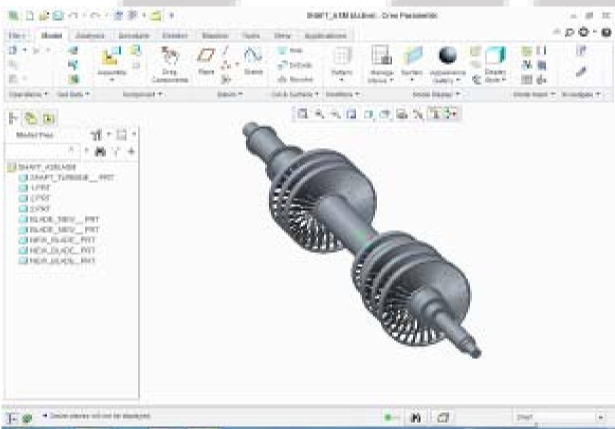

**Figure 3.3:** Gas turbine shaft and blade assembly

**Material 1:**
AISI 4130 Steel (super alloy steel) Material 1
Yield strength: 4.6e+008 N/m^2
Tensile strength: 5.6e+008 N/m^2
Elastic modulus: 2.05e+011 N/m^2
Poisson's ratio: 0.285
Mass density: 7850 kg/m^3
Shear modulus: 8e+010 N/m^2

**Material 2:**
Haynes Hastelloy C-276 alloy
Yield strength: 364.7 N/mm^2
Tensile strength: 601.2 N/mm^2
Elastic modulus: 2.05e+011 N/m^2
Poisson's ratio: 0.22
Mass density: 8890 kg/m^3

**Material 3:**
Special Metals INCONEL® Alloy 718
Yield strength: 1100 N/mm^2
Tensile strength: 1375N/mm^2
Elastic modulus: 2.15e+011 N/m^2
Poisson's ratio: 0.20
Mass density: 819047 kg/m^3

## 4. Over View of Analysis of Gas Turbine

### 4.1 Structural Analysis with Material

Structural analysis is the determination of the effects of loads on physical structures and their components. Structures subject to this type of analysis include all that must withstand loads, such as buildings, bridges, vehicles, machinery, furniture, attire, soil strata, prostheses and biological tissue.. The results of the analysis are used to verify a structure's fitness for use, often saving physical tests. Structural analysis is thus a key part of the engineering design of structures.

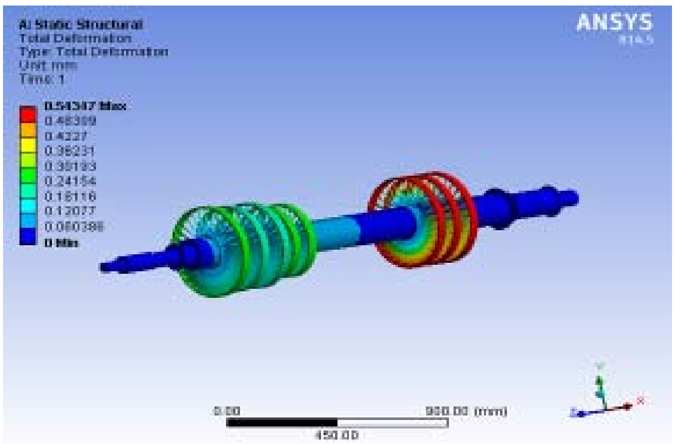


**Figure 4.1:** Deformation of gas turbine

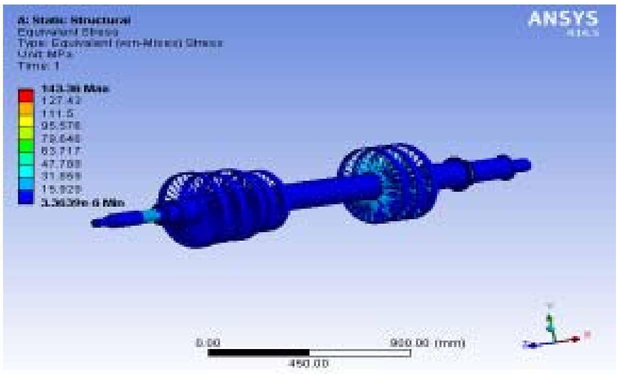


**Figure 4.2:** Stress range at static condition

### 4.2 Thermal Analysis with Material

Thermal analysis is a branch of materials science where the properties of materials are studied as they change with temperature. Several methods are commonly used – these are distinguished from one another by the property which is measured:

Dielectric thermal analysis (DEA): dielectric permittivity and loss factor

Differential thermal analysis (DTA): temperature difference

Differential scanning calorimetry (DSC): heat difference

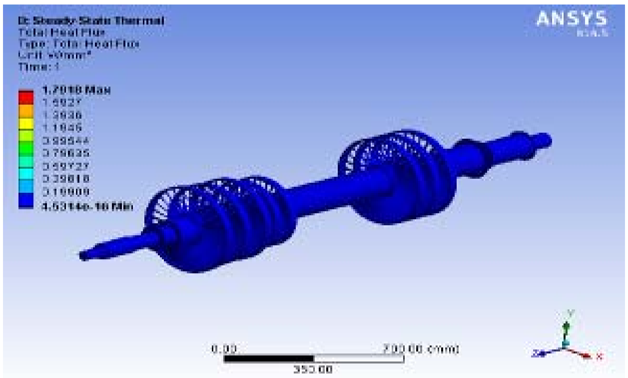


**Figure 4.3:** Heat Flex of Rotor Assembly at Thermal Condition

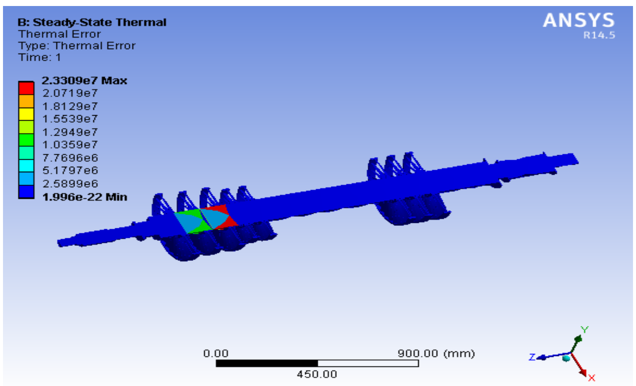


**Figure 4.4:** Thermal Error at Thermal Condition

### 4.3 Coupled Field Analysis with Material

Coupled Field Analysis is the combination of two separate analysis streams like thermal and static analysis. With this analysis we can find the final stress, deflection or strain values with both structural and thermal loads.

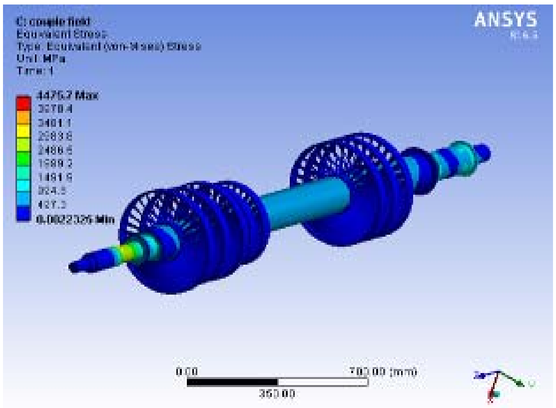


**Figure 4.5:** Stress Range At Couple Field Condition

### 4.4 Fatigue Analysis with Material

In materials science, fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit.

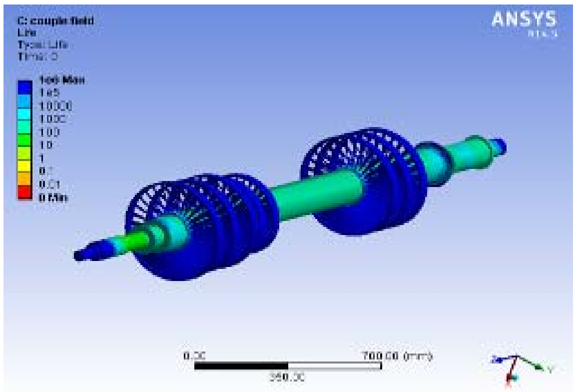


**Figure 4.6:** Life range at couple field condition

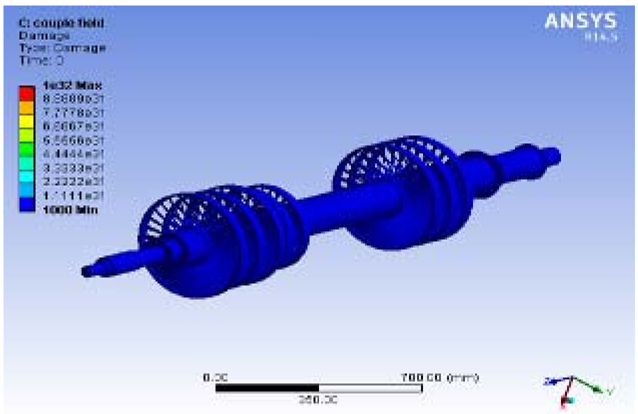


**Figure 4.7:** Damage Range at Couple Field Condition

### 4.5 Analysis of Single Blade

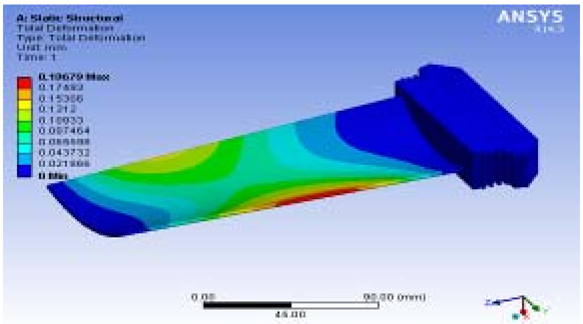


**Figure 4.8:** Single blade deformation at static condition

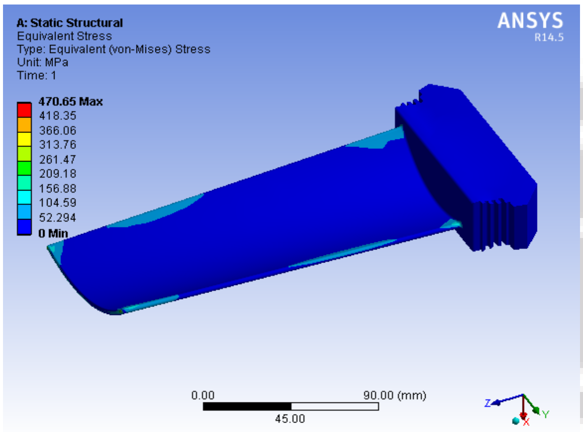


**Figure 4.9: Single blade stress range at static condition**

## 5. Results

### 5.1 Static Analysis of Assembly Rotor

| | *Material 1* | *Material 2* | *Material 3* |
|---|---|---|---|
| Deformation | 0.54347 | 0.51956 | 0.50605 |
| Stress(Mpa) | 143.36 | 145.54 | 146.65 |
| Strain | 0.0013576 | 0.0014366 | 0.001455 |
| Shear stress(Mpa) | 76.39 | 75.431 | 76.282 |
| Shear strain | 0.00099307 | 0.00088362 | 0.00085152 |

### 5.2 Thermal analysis of assembly rotor

| | *Material 1* | *Material 2* | *Material 3* |
|---|---|---|---|
| Heat flux (W/mm2) | 1.791 | 1.7918 | 1.7918 |
| Thermal error | 2.3309e$^{7}$ | 2.3309e$^{7}$ | 2.3309e$^{7}$ |

### 5.3 Coupled field analysis of turbine rotor assembly

| | *Material 1* | *Material 2* | *Material 3* |
|---|---|---|---|
| Deformation | 3.9974 | 3.9974 | 3.2752 |
| Stress(Mpa) | 4475.7 | 4475.7 | 4203.1 |
| Strain | 0.0228 | 0.0228 | 0.0198 |

### 5.4 Factor of Safety

| | *Working stress(MPA)* | *Yield strength(MPA)* | *FOS* |
|---|---|---|---|
| Material1 | 143.36 | 460 | 3.2 |
| Material 2 | 145.54 | 364.7 | 2.5 |
| Material 3 | 146.65 | 1100 | 7.5 |

## 6. Graphs

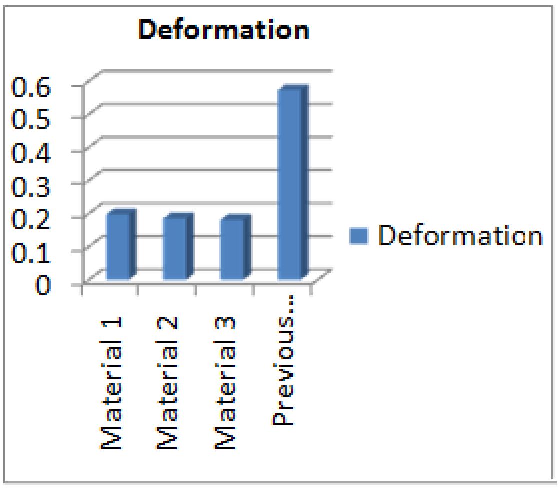


**Figure 5.1:** Single blade analysis deformation

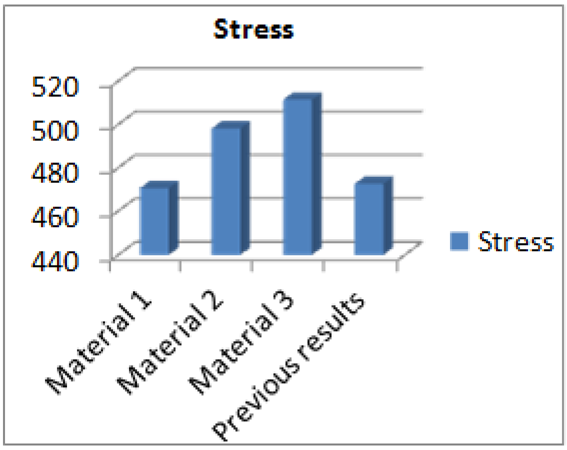


**Figure 5.2:** Single Blade Analysis Stress Range

## 7. Conclusion

This project work deals with "stress analysis of gas turbine multi stage rotor assembly" for suggesting optimum material for the turbine rotor assembly. Initially literature survey and data collection was done to understand the methodology and also used for material selection. Three materials are selected, present material AISI-4130 super alloy steel, Hast alloy c-271(as per previous paper), new material INCONEL alloy-718 for performing analysis. Parametric modeling was done in pro-engineer using parameters collected from the design department of industries. Using the above three materials static, thermal and couple field(combination of static and thermal) analysis was conducted on both turbine rotor assembly and single blade ( for comparison with previous journal results).Results tables and graphs are prepared for the easy comparison and understanding. Couple field analysis provides fully developed analysis using thermal and structural loads as per the coupled field analysis Inconel alloy-718 is showing good characteristics Fatigue analysis was done to find life and damage percentage of turbine rotor assembly, each cycle refers to one year of running time(3600X24X365-in sec), fatigue analysis is directly connected with S-N curve. As per results obtained from analysis 3rd material (INCONEL alloy-718) gives the maximum life to the turbine rotor assembly, due to its good structural properties, low deformation, stress, strain and thermal behaviors.

## 8. Future Scope

Gas turbine rotor assembly is to add more number of blades and change the blade angles to apply different pressure and temperature, it will be evaluate decrease the deformation value and increase the stress value, gas turbine using different materials alloy to increases life time of gas turbine rotor decrease the damages and to avoid the corrosions resistance of the gas turbine rotor apply ceramics materials. After that will do the different analysis like corrosion analysis apply the gas turbine rotor assembly.

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