Static and Thermal Analysis of Turbine Blade of Turbocharger

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Abstract—This paper borders around analysis of turbine blade. The blade is a rotating part which converts kinetic energy into mechanical energy. Turbine blade is critical part of turbocharger which has shown increasing growth of failure damaging turbine disk. It deals with Static and thermal analysis of turbine blade which is made up of INCONEL 718 to estimate its performance. The causes of failure for turbine blade have also been found out. The investigation has been done using SoildWorks 2012 and ANSYS 10.0 software. SolidWorks 2012 is used for modeling of turbine blade and analysis has been done by ANSYS 10.0 software. An attempt has been made to investigate the effect of induced stresses, pressure and temperature on the turbine blade. A structural analysis has been carried out to investigate the stresses and displacements of the turbine blade. A thermal analysis has been carried out to investigate the thermal gradient and thermal stress.

***Index Terms*—ANSYS, FEA, INCONEL 718, Turbine blade, SolidWorks**

I. INTRODUCTION

A turbocharger is a turbine driven forced induction device used to allow more power to be produced by an engine of a given size. A turbocharger increases mass of air entering the engine cylinder enabling more fuel burning in engine cylinder to produce more power. Performance is improved as energy is recovered from exhaust waste. In exhaust gas turbocharging exhaust gas energy is used to drive turbine. The turbine is coupled to compressor, which draws in combustion air, compresses it and then is supplied to engine inlet.

The turbocharger was invented by Swiss engineer Alfred Buchi (1879-1959), who received a patent in 1905 for using a compressor driven by exhaust gasses to force air into an internal combustion engine to increase power output but it took another 20 years for the idea to come to fulfillment. Alfred Buchi stated in his 1905 patent that internal combustion engines have very low efficiency because two-thirds of the energy is lost through exhaust heat. He wanted to capture that heat and use it to improve the engine.

The main component in turbocharger is central housing assembly of which turbine is main component. The break down and failures of turbo machineries have been influencing such as consequential damages, hazards to public life and most importantly the cost to repairs .To avoid these, it is obvious that the blading of turbo machinery must be made structurally stronger.

II. FINITE ELEMENT ANALYSIS OVERVIEW

Finite element analysis (FEA) involves solution of engineering problems using computers. Engineering structures that have complex geometry and loads, are either very difficult to analyze or have no theoretical solution. However, in FEA, a structure of this type can be easily analyzed. Commercial FEA programs, written so that a user can solve a complex engineering problems without knowing the governing equations or the mathematics, the user is required only to know the geometry of the structure and its boundary conditions. FEA software provides a complete solution including deflections, stresses and reactions.

FEA is divided in 3 steps

- **Pre-processing**
  Using a CAD program the structure is modeled. A model consists of several elements that collectively represent the entire structure. The geometry of the structure, the constraints, loads and mechanical properties of the structure are defined. Thus, in pre-processing, the entire structure is completely defined by the geometric model. The structure represented by nodes and elements is called mesh.
- **Solution**
  This phase can be performed in the Model Solution task of the simulation application, or in an equivalent external finite element solver. Model Solution can solve for linear and nonlinear static, dynamics, buckling, heat transfer, and potential flow analysis problems.
- **Post-processing**
  CAD program is utilized to manipulate the data for generating deflected shape of the structure, creating stress plots, animation. Graphical representation of the results is useful in understanding behavior of the structure.

Modeling and meshing of turbine blade.

Modelling by using SolidWorks 2012

The geometry of turbine is drafted based on the dimensions of geometric parameters. SOLIDWORKS 2012 software is used for modeling of turbine blade. Solid modeling of axial turbine with 64 numbers of rotor blades with hub and shaft is shown in fig. 1. A single rotor blade geometry is modeled in SOLIDWORKS 2012 and is saved in IGES format as it will be used for analysis purpose is shown in fig. 2.

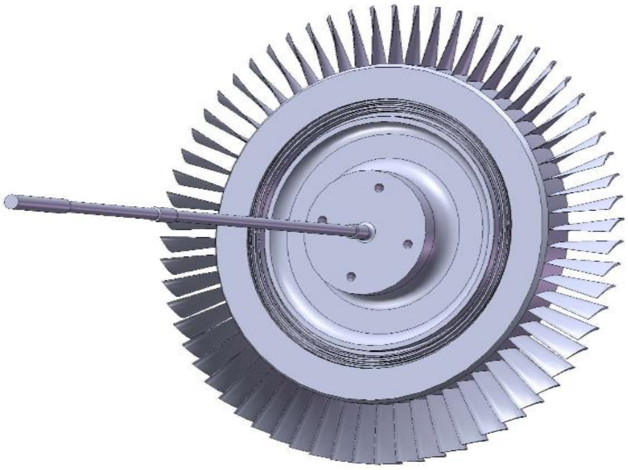

Fig. 1 Turbine blade of rotor assembly

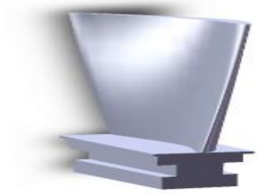

Fig. 2 Single turbine blade

Meshing in ANSYS 10.0

Turbine blade model is imported in ANSYS, and is meshed properly in Mechanical APDL ANSYS to divide it into elements and nodes. Tetramesh is used for turbine blade, and element size length is 1 mm. Quality checks and mesh optimization for elements were also performed taking into consideration of aspect ratio, distortion, stretch.

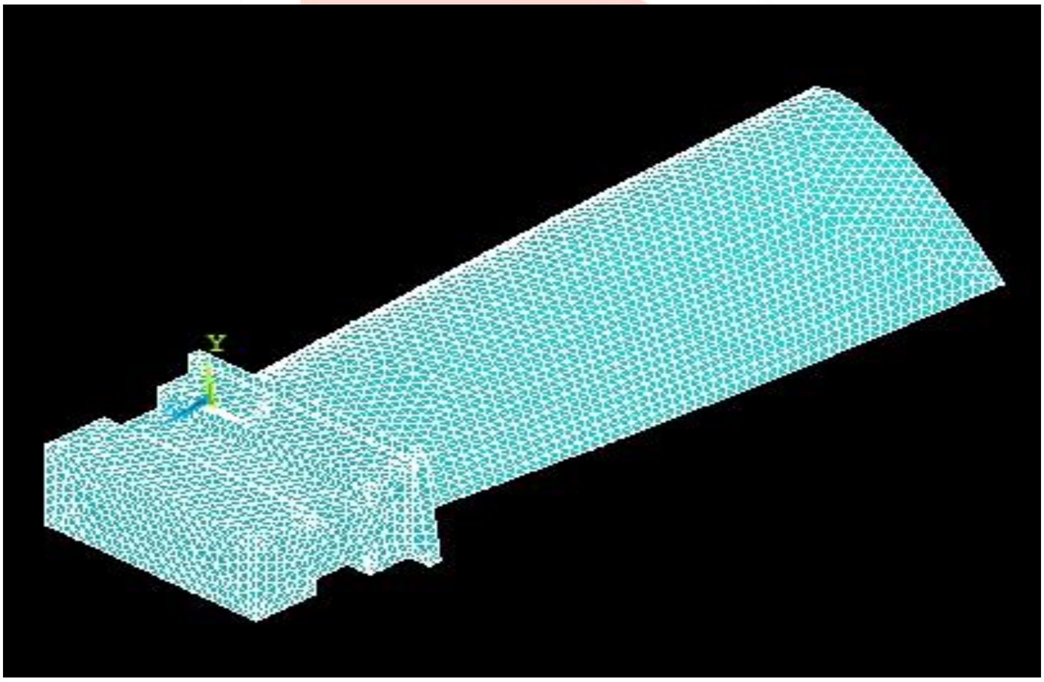

Fig. 3 Meshed model of turbine blade

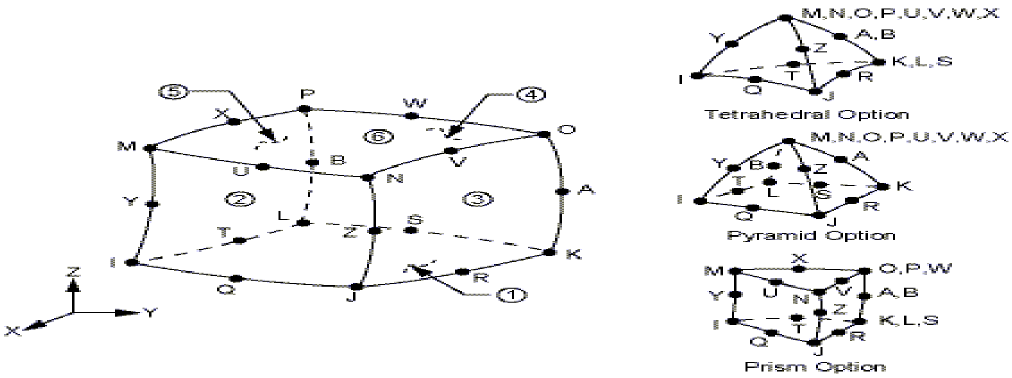

Fig. 4 Solid 186 3D-node element

SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior as shown in Fig. 4 is used as element. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities.
Nodes: I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z, A, B.
Degrees of Freedom: UX, UY, UZ.
Material Properties: EX, EY, EZ, ALPX, ALPY, ALPZ, PRXY, PRYZ, PRXZ, DENS, GXY, GYZ, GXZ, DAMP.
Surface Loads: Pressures.
Body Loads: Temperatures.

Table 1 Inconel 718 Properties

Properties	**Inconel 718**
Tensile strength (MPa)	1407
Yield strength (MPa)	1172
Density (kg/m^3)	8200
Poisson's ratio	0.29
Modulus of elasticity (GPa)	249
Thermal conductivity (W/m-k)	11.40
Coefficient of expansion (µm/m-˚C)	13

III. RESULTS AND DISCUSSION

Static analysis has been carried out to predict stress and displacement. Figure 5-10 shows result for von mises stress, stress in x-direction, stress in y-direction, stress in z-direction, displacement vector sum and displacement in y- direction.
Thermal analysis has been carried out to predict results. Figure 11-12 shows result for thermal gradient and thermal stress. Figure 13 shows the distribution of temperature on surface of turbine blade.

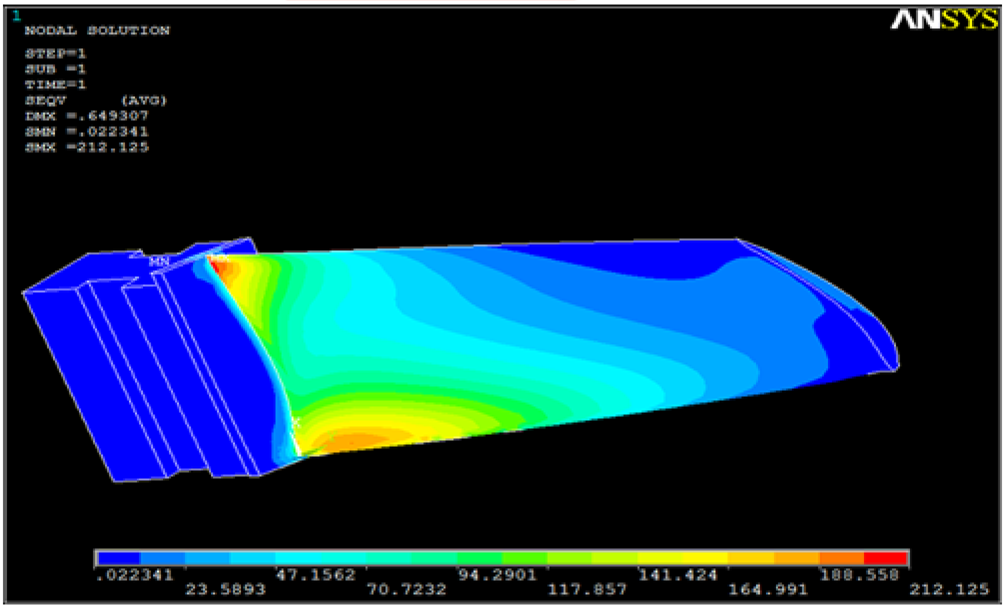

Fig. 5 Von mises stress

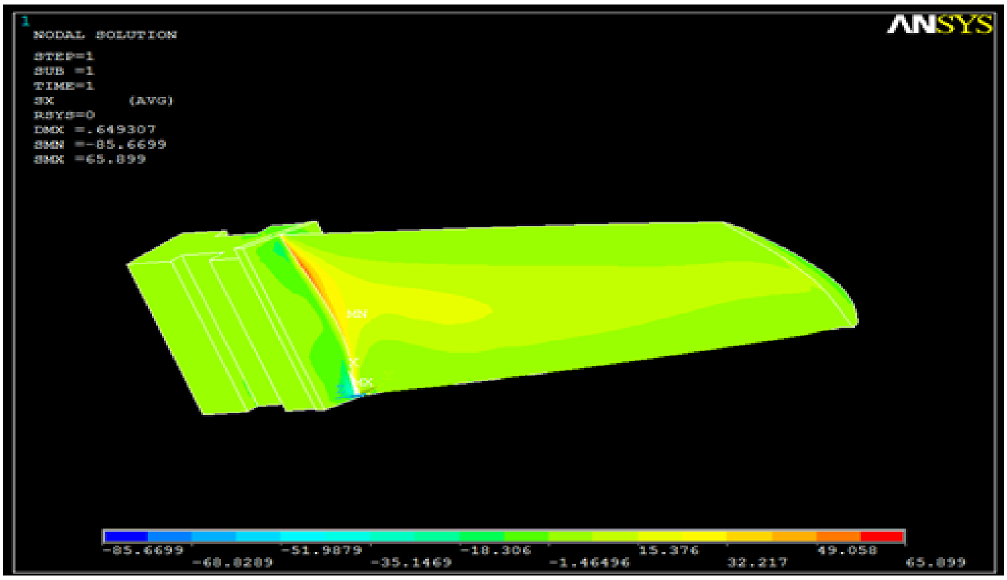

Fig. 6 Stress in X-direction

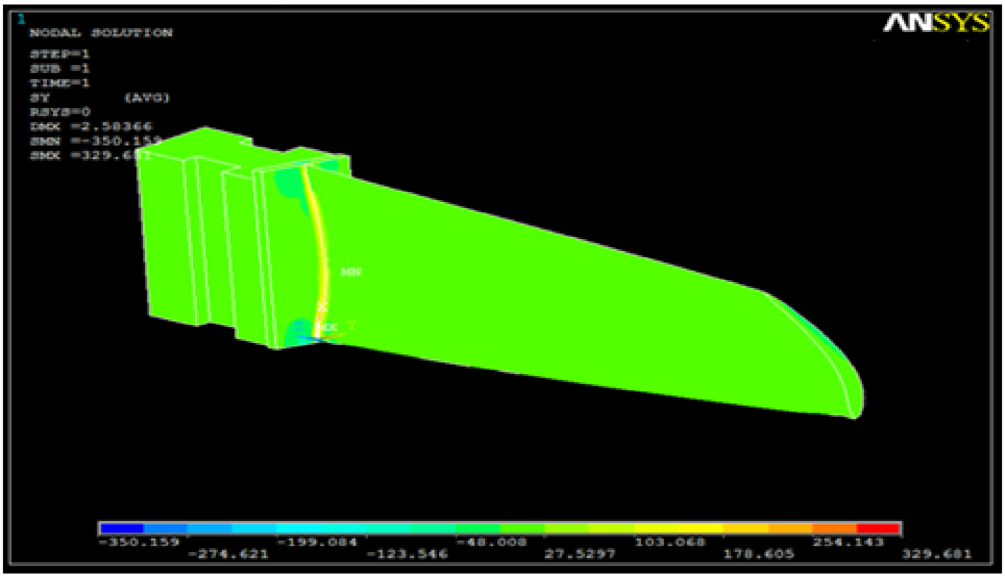

Fig.7 Stress in Y-Direction

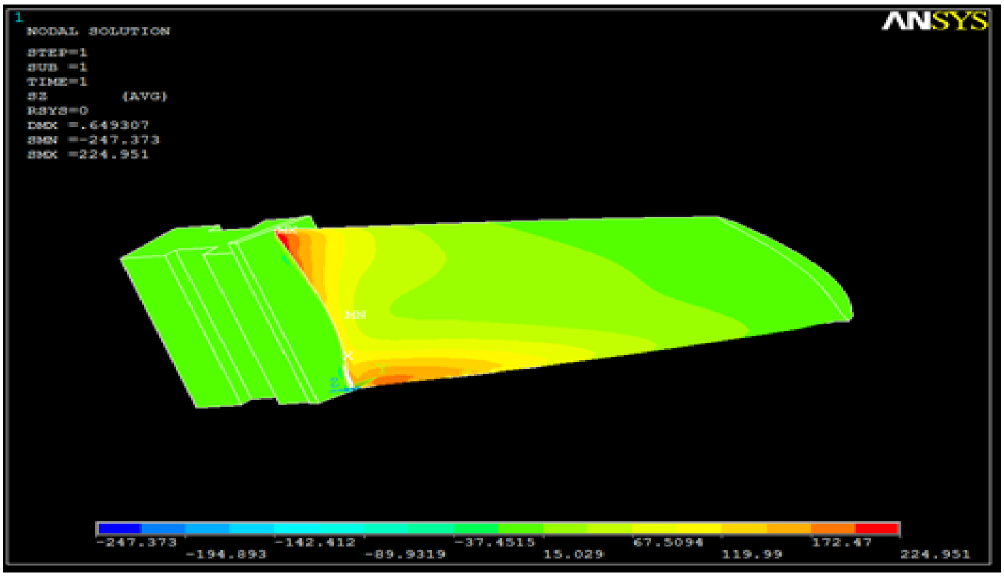

Fig. 8 Stress in Z-Direction

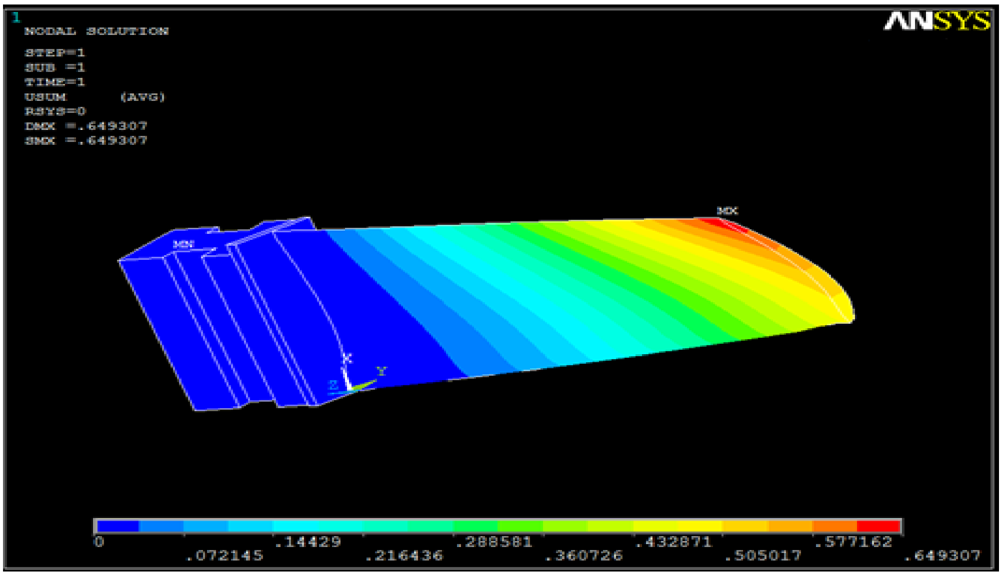

Fig. 9 Vector sum displacement

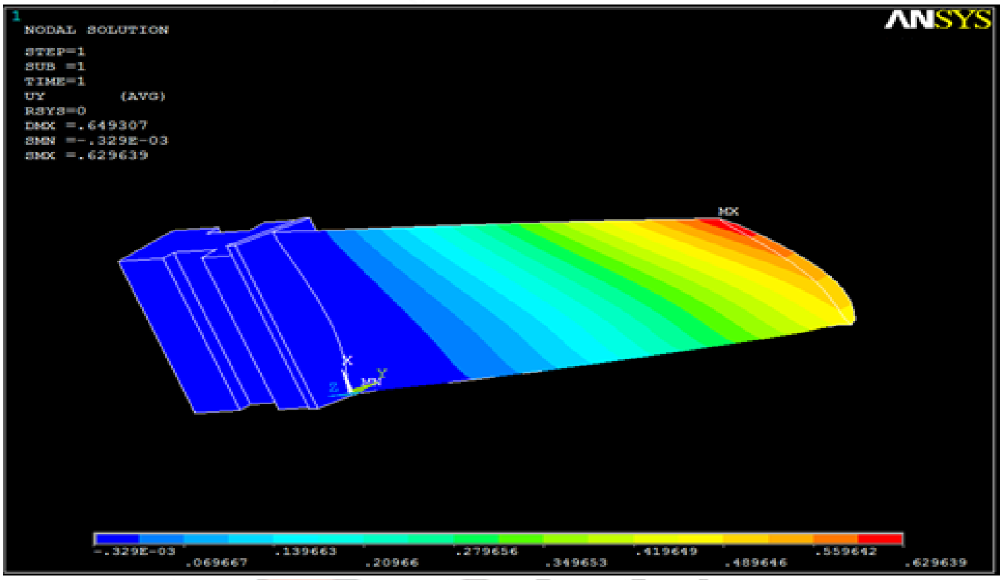

Fig. 10 Y-component displacement

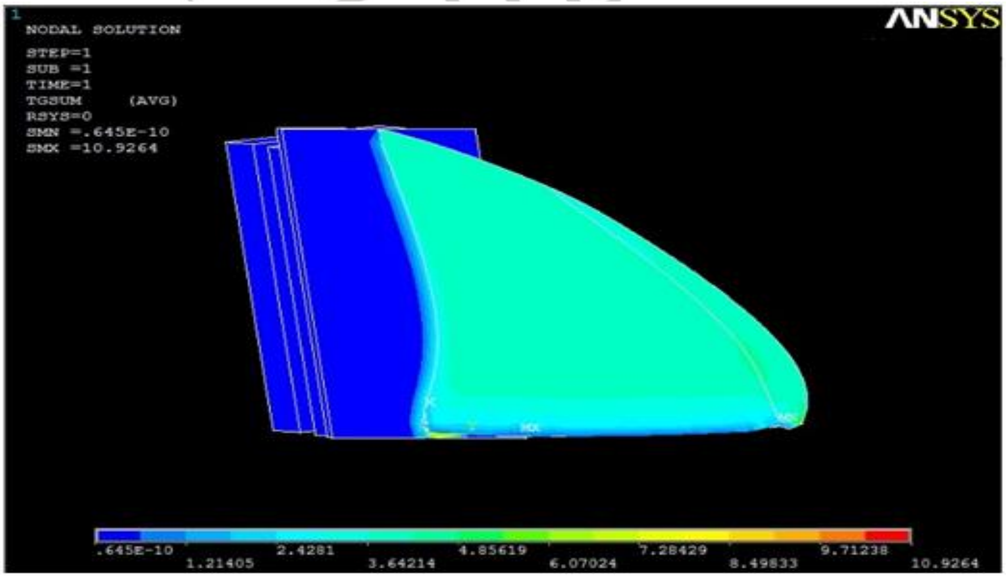

Fig. 11 Thermal gradient

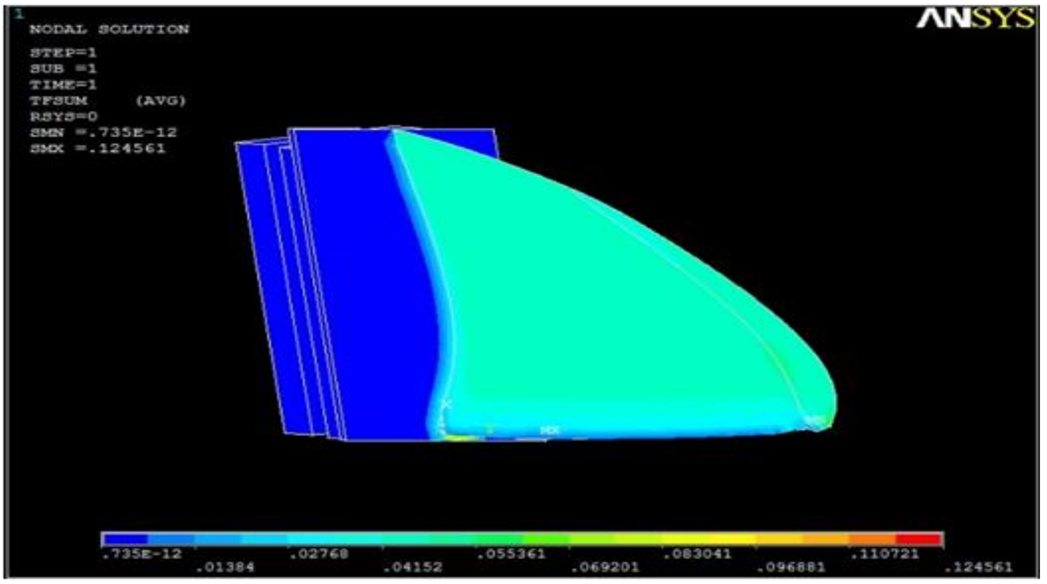

Fig. 12 Thermal flux

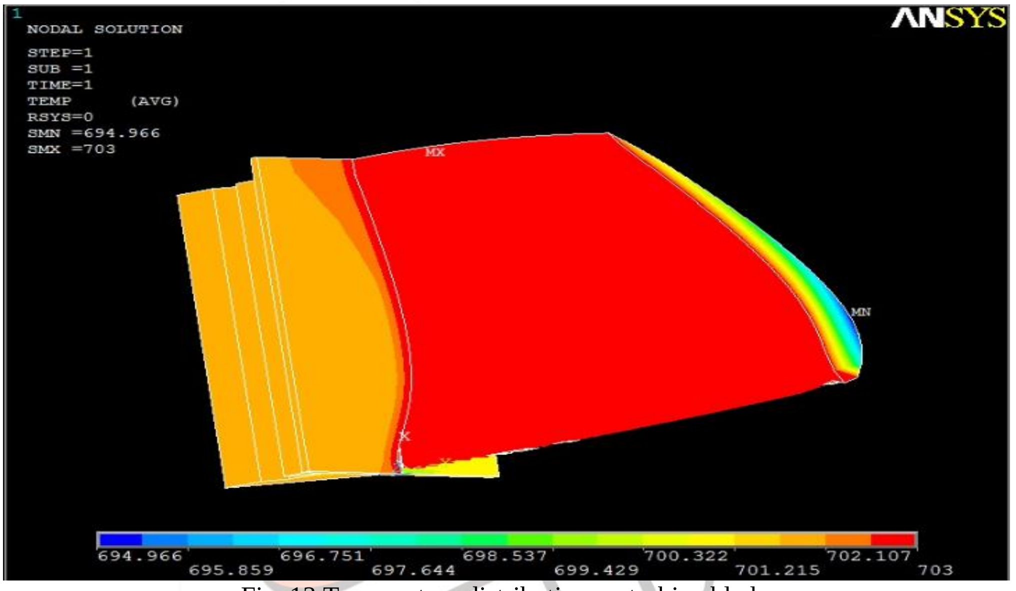

Fig. 13 Temperature distribution on turbine blade

Table 2 Analysis results

Properties	**Inconel 718**
Von mises stress (MPa)	212.125
Stress in X- Direction (MPa)	65.899
Stress in Y- Direction (MPa)	82.1361
Stress in Z- Direction (MPa)	224.951
Displacement vector sum (mm)	0.649307
Displacement in Y-Direction (mm)	0.629639
Thermal gradient(K/m)	10.9264
Thermal stress (W/m^2)	0.124561

IV. REASONS FOR FAILURE OF TURBINE BLADE

High thermal stresses are aggravated by improper maintenance of injectors, insufficient cleaning of after coolers, incorrect phasing of the fuel injection pumps, and low booster pressure due to other turbocharger defects or leaks in the system. Vibration over period of time can create fatigue failures. Vibrations at bearings supporting the rotor are caused due to altering the distribution of mass in rotor body. Balance is shifted when rotor rotates about inclined axis. The rotor assembly is revolving at very high rpm is susceptible to fail due to mechanical stresses. Centrifugal force is important contributing factor for tensile stress and bending stresses. Engine exhaust gas force being the driving force, exerts loads on the blade due to gas pressure from the pressure side of the blade profile resulting in bending stresses. Turbine blade works under high temperature conditions resulting in high thermal load, making it susceptible to failure.

V. CONCLUSION

- Turbine rotor assembly is more vulnerable to failure due to structural and thermal load.
- Distribution of stress along blade was studied by software and it shows that critical region of turbine blade which is between hub and blade requires careful attention.
- Maximum deformation occurs at tip section of blade.
- Periodic maintenance is necessary to satisfy prescribed conditions of turbocharger like clearances, balancing, exhaust gas temperature to avoid vibrations.
- The rotor imbalancing need to look upon critically while carrying out analysis because change in thickness of blade seriously imbalance rotor causing rpm of rotor to be fluctuating and whirling of shaft.
- Structural and thermal analysis is carried out and maximum stress induced is within safe limit.

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