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Finite Element Simulation and Stress Analysis of Gas Turbine Blade Due to Centrifugal Force

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Abstract – Gas turbine always consider one of the most important system in the modern engineering applications, because it has continuous ability to generate electric power. In gas turbines the major portion of performance dependency lies upon turbine blade design ,the blades are considered one of the important and expensive parts in the gas turbines , where the blades of first stage from failure . Most studies indicate that 50% of failure and breakage accidents cannot be accurately determined due to the large number of variables .The blades of the gas turbine suffer from tensile stresses due to centrifugal forces resulting from the high rotational speed and because of the loading of dense gasses at a high temperature and speed ,as the centrifugal force is one of the problems that the designer of the turbine blades faces , as the designer aims to reduce stresses within the permissible limit . The current work is concerns with study and analysis of the stresses at the first stage blades in Al Mosul power station at Mosul city, AUTOCAD which is computer program has been an efficient software to draw and specify blade dimensions at the exact measurement, as well as the ANSYS 21 software program was also used as an effective tool in determining the stresses and deformation under the influence of centrifugal force. As the blade was considered root bound in all direction (X, Y and Z) and adding the special mechanical properties of (INCONEL738 alloy), After conducting a stress analysis in the program, it was found that the stress values of the posterior and anterior edge of the blade root region were high and these results were validated with the results carried out by some studies that dealing with study and analysis of the blades at the first stages in turbine stations. The static and modal analysis of the turbine blade is being considered. To analyze these aspects, the blade is represented using the 3D-Solid Brick element. The blade's geometric model is created by generating and then extruding them to form a solid model. An analytical approach is utilized to estimate the centrifugal forces. The objective of this presented work is to investigate the impact of mechanical analysis on the structure of gas turbine blades. The findings indicate lower levels of mechanical stress.

Keywords – Finite Element, Gas Turbine, Centrifugal Effect, Turbine Blade, Stress Analysis

I. INTRODUCTION

Accurate estimation of the operational lifespan of industrial turbine blades is crucial due to the demanding duty cycles they experience in utility combined-cycle plants. These duty cycles involve frequent startups, shutdowns, and extended periods of operation. As the turbine blades are constructed from expensive super alloys and require costly manufacturing procedures, their replacement costs are significant. Therefore, it becomes imperative to obtain precise assessments of their durability to avoid unnecessary expenses. The gas turbine can be defined as a power plant to extract a large amount of mechanical power from the working fluid with maximum efficiency .Gas turbine has a great role in the electric power generation, and by increasing the demand for power, the thermal efficiency of gas turbine and output power will be increased .a gas turbine is an engine that uses air as the working fluid and the fuel is continuously burnt with compressed air to produce a fast hot moving gas. Blades of gas turbine are the most important components, because they are subjected to high centrifugal tangential and axial forces during extracting energy from the high temperature and high pressure gases [1]. Gas turbines play a major role in the power generating units. The main function of the blades in gas turbines is imparting energy to, or extracting it, from a fluid stream. We will mainly deal with the modeling and analysis of gas turbine blades. The design data for a turbine blade is obtained using Reverse Engineering technique. Using the data so obtained, a model of the turbine blade is created in finite element analysis by means of ANSYS [2]. Turbine axis is horizontally connected with the axis of the compressor directly on the one side and on other with the mechanical load to be rotated and through the gearbox the speed can be reduced, because the turbine rotation speed is high (5100 r.p.m.) the gases produced by combustion enter the turbine and hit the blades and then into the exhaust chimney. The gas turbine at the Al-Mosul gas station consists of two stages, the first stage consists of 120 blades, and the second stage consists of 90 blades [3]. Many researchers presented various studies of the effective force on these blades and analyzed the stresses and reasons for the failure of gas turbine blades in various power plants. The researcher (A.Thakker et al. 2001) analyzes the stresses of two types of stresses resulting from the centrifugal force and the aerodynamic force resulting from the flow of burning gases for two types of gas turbine blade designs .the first hollow and the other solid ,at two values of angular velocity ,the first (36.65 rads)and the second at (194 rads)by the finite element method using ansys program and compared with the values of van Mises stresses and the values of the highest main strain of the two types of gas turbine blades. [4]

Gopinath Chintalaa, She used a reverse engineering (RE) technique to make a solid gas turbine blade sample and then resolve this sample in ANSYS finite element analysis. Five various materials were applied. It was found that Ti is the bestead material for gas turbine blades to withstand centrifugal forces and it was taken into account in this study because it takes possession of prominent properties in structural constancy when exposure to differ temperatures and stress loads, and it also takes possession of maximum strength at rising temperatures [5].

The researchers (A.Patil,others) (2009) studied the failure of the second stage turbine blade ,it was studied by mechanical and metallic examination of the failed blade, and the blade is made of (Inconel738lc) alloy , where the turbine engines were in service for about (73500 hr) [6] and [7].the blade failed ,the blade failure caused damage to these motors. The examinations showed that the cracking that occurred was on the blade surfaces, and there was evidence in degrees of fatigue on the fractured surface, and that the subtle structural changes were not critical as a result of the blade working at high temperatures [8], [9] and 10]. Low cross sectional area is completed by fracture, and has an analytical calculation using the finite element method was used to determine the static stress due to high centrifugal force , then the dynamic properties of the turbine blades were evaluated by the finite element method using the ANSYS program and numerical analysis [6]. In the current work, the analysis if stresses were examined and characterised numerically by means of simulating part to explain the variation of that stresses affected by the influence of centrifugal force.

II. SET UP OF FINITE ELEMENT METHOD

The finite element method (FEM) has presently turn out a very substantial factor of engineering analysis. The FEM configured the turbine blade model for analysis using a compound system of points or nodes linked into a lattice known as mesh. The nodes were coordinated at a specific density throughout the model. The geometry of the gas turbine blade is modeled in AUTOCAD and then imported into ANSYS for meshing. The airfoil profile of the rotor blade was produced on the XZ plane with the help of key points defined by the coordinates. Then a number of splines were fitted through the key points, creating the 2D airfoil shape. The geometry of the blade was meshed with the element type used for Tetrahedron. It has 3 degrees of freedom per node, that is, clarification in three direction X,Y and Z were used. the gas turbine blade geometrical models created in ANSYS 21 and meshed modal of gas Turbine blade using simulating program itself. The steps employed in the course of the analysis are as follows;

- Creating a three dimensional model in AUTOCAD software 2010.
- Import the AUTOCAD model in ANSYS21 R1software .
- Mesh the imported model in ANSYS (264938) nodes and (160413) elements.
- Apply boundary conditions.
- Solve the system equations to find out the unknowns.
- Validation of solutions obtained with the operating conditions.

The dimensions of the blade turbine and the mechanical properties of its material were depicted below as in Table 1 and Table 2 respectively.

Table 1: Dimensions of the Blade

Total Length of Blade	Length of Root	Length of Airfoil	Length of Hollow
157 mm	62 mm	95 mm	52 mm

Table 2: Material Properties for Turbine Blade Analysis Inconel738 Alloy

Young' Modulus (Gpa)	Density (kg/m^3)	Poisson's Ratio	Therm. Conduct	Yield strength (Mpa)
175	8110	0.3	$11.6*10^{-6}$	980

The and mechanical stress analyses were conducted using the versatile finite element software ANSYS 21. The blade's finite element models were created using 8-noded and 20-noded brick elements. The geometry, fixing boundary condition and the type of applying mesh technique for the completed blade design was illustrated in Figure 1. To simulate the rotor's operation at a speed up to 5100 revolutions per minute, centrifugal forces were implemented as body forces.

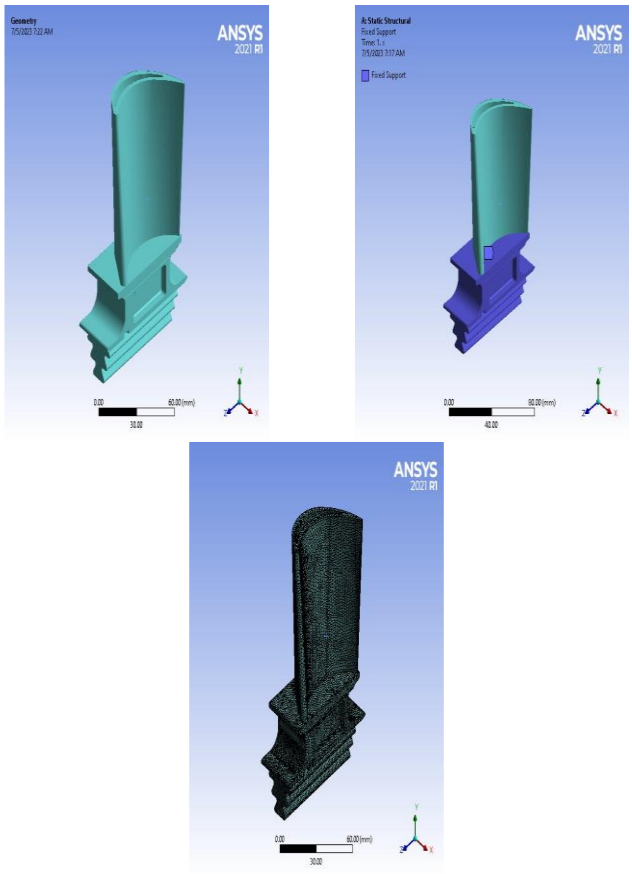
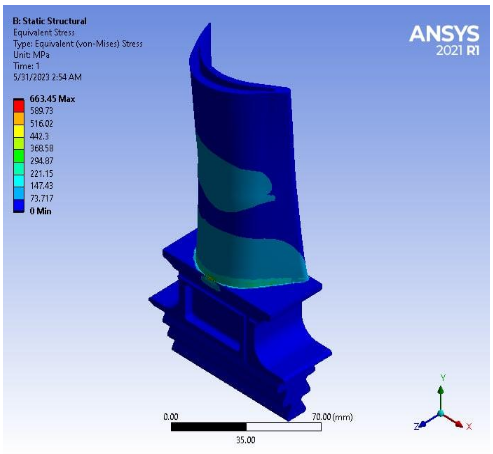


Figure1 Geometry of Blade, Fixed Support and the mesh technique of gas turbine rotor

The pressure distribution, derived from an analysis of the turbine's aerodynamics, varied between 0.1 to 1.5 MPa at different positions on the pressure side of the blade. In Figure 2, the distribution of the maximum principal stress component in the airfoil, resulting from the combined effects of centrifugal and pressure loadings, is illustrated. It is evident that the highest tensile stress occurs near the root of the airfoil's suction side. However, when considering mechanical stresses, the location of the maximum tensile stress shifts to the corner of an internal rib. Additionally, the modeling was focused on a critical area near the root of the leading edge, despite the relatively lower tensile stresses in that particular region. Figure 3 and Figure 4 were depictd the results of simulation for both shear stress and maximum principle stress respectively. The maximum stress for gas turbine blades type Inconel 738 alloy under the angular velocity 5100 rpm was 663.45 Mpa as shown in figure3.In addition, further tests were carried out on examining the values of normal stress Figure 5, total deformation Figure 6 and equivalent elastic strain Figure 7, as these properties have significant effect on the stress distribution along the blade turbine profile. The discussion of these analyses confirms that the change in stresses due to centrifugal force has direct influential effect on the structural properties of turbine blades through operating conditions.



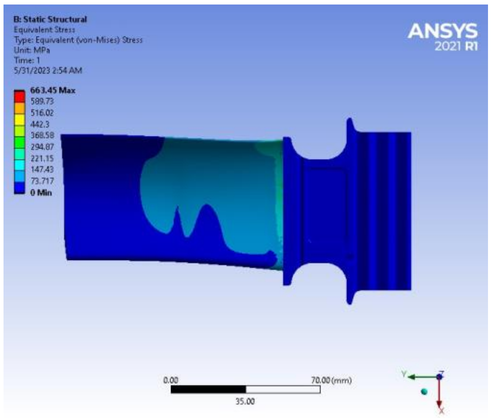


Figure 2 Equivalent Stress of the gas turbine blade

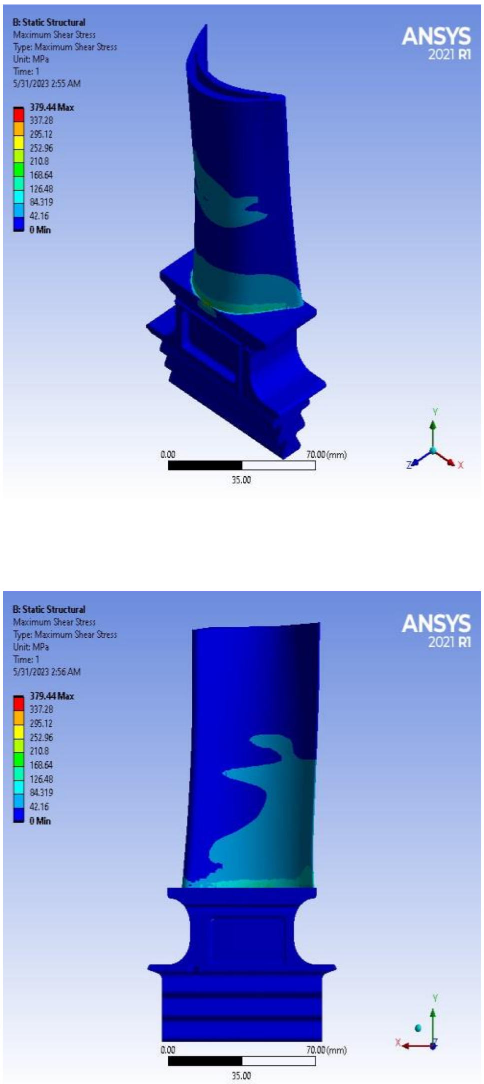


Figure 3 Variation of maximum Shear Stress along the gas turbine blade

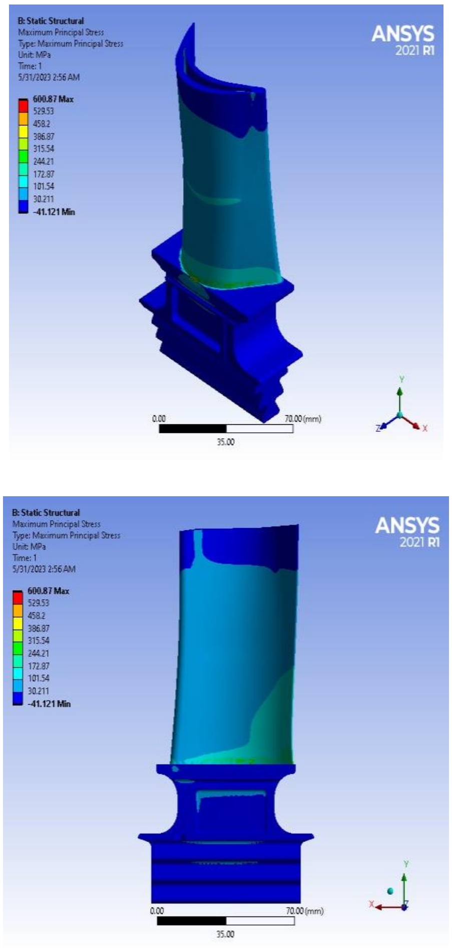


Figure 4 Variation of maximum principle Stress along the gas turbine blade

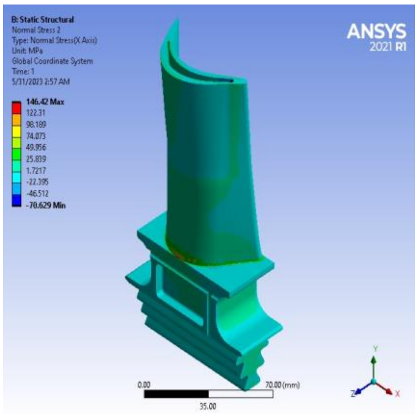


Figure 5 Normal stress of the gas turbine blade

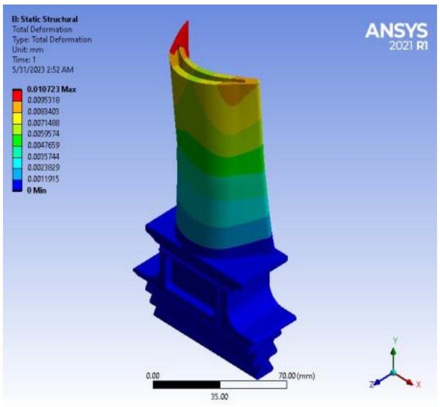


Figure 6 Total deformation of the gas turbine blade

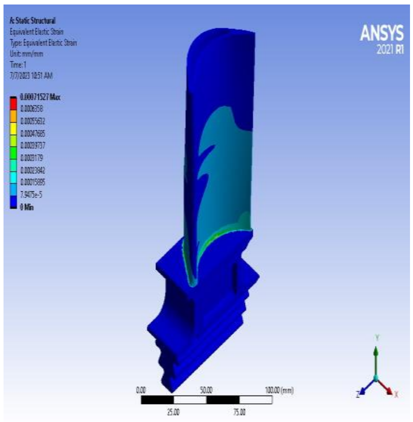


Figure 7 Equivalent elastic strain of the gas turbine blade

The maximum total deformation of gas turbine rotor blades made of Inconel 738 Alloy under the angular velocity 5100 rpm was 0.010723 mm as shown in figure 6, while The maximum strain for gas turbine blades under the same loading conditions was 0.000715 mm\mm as seen in Figure7.

III. CONCLUSION

In this presented work, a numerical analysis of gas turbine blades was conducted to gain insights into their response to external centrifugal force. The simulation of the gas turbine blades was performed using ANSYS 21, the findings demonstrated that as the load values were increased, and there was a corresponding increase in stress, strain, and total deformation of the blades. According to the results it is concludes that after conducting a stress analysis in the program ,it was found that the stress values of the posterior and anterior edge of the feather root region were high and these results are coincided with the results made by some researchers that are presented under the same loading conditions. The findings of this research indicate that good matching between process parameters leads to lower level of mechanical stress.

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