Structural and Thermal Analysis of Various Holes Configuration Effect on Gas Turbine Rotor Blade

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Abstract- Gas turbines are used extensively for aircraft propulsion, land-based power generation, and industrial applications. The stress and displacement analysis of the rotor blade of any turbo machine in the field of design played a very important roll. Rotor blade is the very critical component in the field of turbo machines. The major cause of break down is due to different loadings such as fluid or gas forces and centrifugal forces are acting on the rotor blades. In this study, the first stage rotor blade of the gas turbine is created in SolidWorks software. The material of the blade is structural steel. This rotor blade has been analyzed by using ANSYS14.5. The gas forces namely tangential, axial were determined by constructing velocity triangles at inlet and exist of rotor blades. Three different models with different number of holes (5, 9 and 13) were analyzed to find out the optimum number of holes for good performance.
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Index Terms- Gas turbine, rotor blade, structural analysis, thermal analysis, blade holes configuration

I. Introduction

The gas turbine is a power plant, which produces a great amount of energy for its size and weight. The gas turbine has found increasing service in the past 40 years in the power industry both among utilities throughout the world. Its compactness, low weight and multiple fuel application make it a natural power plant.

The gas turbine power plants can be classified into two categories. These are open cycle gas turbine power plant and close cycle gas turbine power plant. The simple open cycle gas turbine is suitable for frame type heavy duty gas turbine. The operation of a gas turbine depends upon the characteristics of its major components such as the compressor, combustor and turbine. The fundamental idea with a turbine is to extract work from the incoming airflow and convert it into mechanical work at a rotating axis. In a gas turbine power plant, a turbine, which is used as a prime mover, converts the kinetic energy of the gases into mechanical energy and drive electric generator that generates the electrical power.

The objective of this study is to analyse the structural for the gas turbine rotor blade and compare with theoretical studies. The specification data for open cycle gas turbine is obtained from 'Ahlone Power Station', Yangon Division in Myanmar. The gas turbine is normally operating in high pressure and its rotor blades are contacting gas with extremely high temperature. Turbine blades are the most important components in a gas turbine power plant. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor.

II. WORKING PRINIPLE OF THE GAS TURBINE

A schematic drawing of a simple gas turbine is shown in Figure 1. The working principle behind the gas turbine is as follows. Ambient air is compressed in the compressor. This compressed air is directed to the combustion chamber. In the combustion chamber the compressed air is mixed with vaporized fuel and burned under constant pressure. This burning process results in a hot gas with high energy content. This hot gas is allowed to expand through the turbine where the energy in the gas is converted to a rotation of the turbine shaft. The turbine shaft powers both the compressor and a generator used to obtain electrical power from the gas turbine.

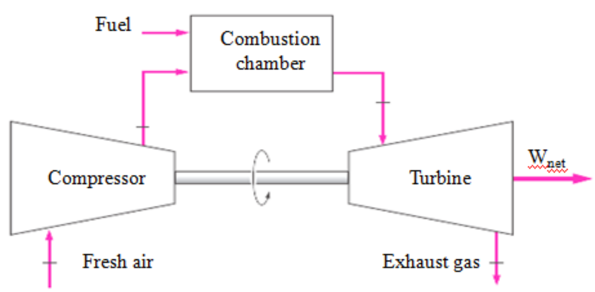

Fig1. Open cycle gas turbine

It's the foremost preliminary step for proceeding with any research work writing. While doing this go through a complete thought process of your Journal subject and research for it's viability by following means:

1) Read already published work in the same field.
2) Goggling on the topic of your research work.
3) Attend conferences, workshops and symposiums on the same fields or on related counterparts.
4) Understand the scientific terms and jargon related to your research work.

III. HOLES CONFIGURATION

Most often, the holes on the blade tip are arranged on the mid camber line of the blade tip section. Turbine first stage axial blade chord length is 64.5mm and cooling passage diameter is 1.4mm. It is shown in Figure 2, the blade consisting of 5 holes, in

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Figure 3, the blade consisting of 9 holes and in Figure 4, the blade consisting of 13 holes.

Fig2. Turbine first stage rotor blade with 5 holes

Fig3. Turbine first stage rotor blade with 9 holes

Fig4. Turbine first stage rotor blade with 13 holes

In this work, the structural and steady state thermal analysis of the gas turbine rotor blade is made of structural steel.
Table 1 shows the properties of structural steel material.

TABLE I
Material properties of Structural Steel

Material Properties	Value	Units
Density	7850	kg/m^3
Modulus of elasticity	200	GPa
Poisson's ratio	0.3	-
Thermal expansion coefficient	2.50e-5	/K
Yield Strength	250	MPa
Thermal conductivity	60.5	W/m-K
Allowable temperature	2173	°K

IV. EVALUATION OF GAS FORCES OF THE ROTOR BLADE

Gas forces acting on the blades of the rotor in general have two components namely tangential (F_t) and axial (F_a). These forces result from the gas momentum changes pressure differences across the blades. These gas forces are evaluated by constructing velocity triangles at inlet and outlet of the rotor blades. Figure 5 shows the velocity triangle for the turbine first stage rotor blade.

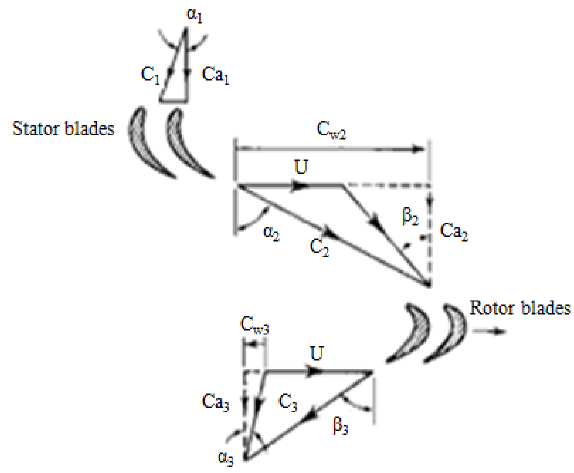

Fig5. Velocity diagram of axial flow turbine first stage

V. FINITE ELEMENT ANALYSIS OF GAS TURBINE ROTOR BLADE

Finite element analysis can play a vital role by simplifying the analysis. The finite element method is a numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Although originally developed to study stresses in structures, it has since been extended and applied to the broad field of continuum mechanics. In this work a turbine blade is analyzed for its thermal as well as structural performance due to the loading condition. Three different models having different number of holes were analyzed in this research to find out the optimum number of holes for good performance.

A. Structural Analysis

Static structural analysis was carried out to know the mechanical stresses experienced by the gas turbine rotor blades, which includes the parameters such as the gas forces are assumed to be distributed evenly, the tangential and axial forces act through the centroid of the blade. The centrifugal force also acts through the centroid of the blade and in the radial direction.

Figure 6 shows the values of von-Mises stresses for turbine first stage rotor blade with five holes.

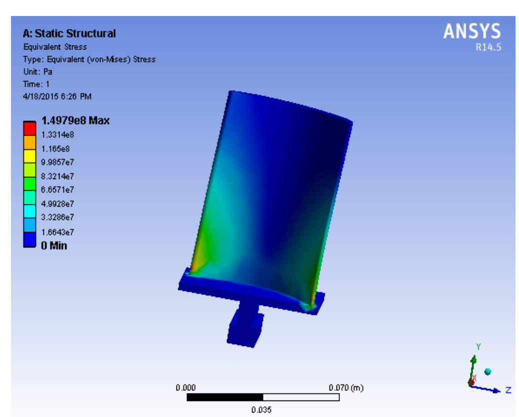

Fig6. Von-Mises stresses for turbine first stage rotor blade with five holes

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In this figure, the maximum von-Mises stress, 103.5860MPa is observed at the root of the rotor blade and minimum von-Mises stress, 16.6430MPa is observed at the tip of the rotor blade.
Figure 7 shows the values of von-Mises stresses for turbine first stage rotor blade with nine holes.

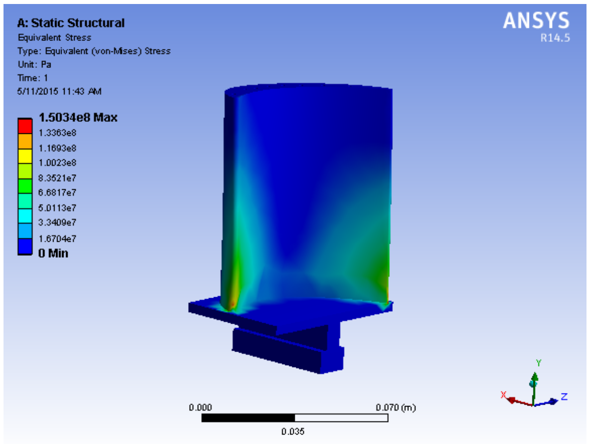

Fig7. Von-Mises stresses for turbine first stage rotor blade with nine holes

In this figure, the maximum von-Mises stress, 104.7786MPa is observed at the root of the rotor blade and minimum von-Mises stress, 17.7030MPa is observed at the tip of the rotor blade.
Figure 8 shows the values of von-Mises stresses for turbine first stage rotor blade with thirteen holes.

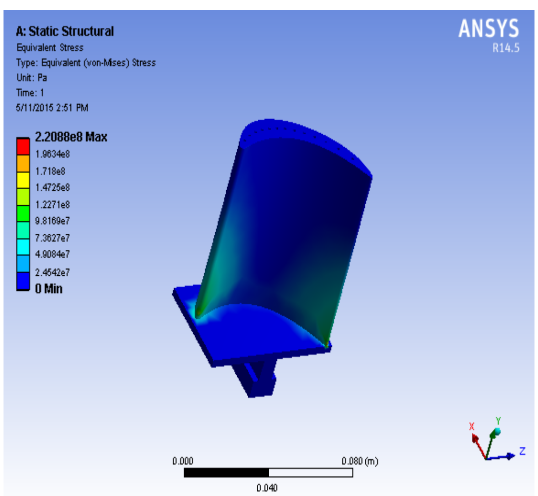

Fig8. Von-Mises stresses for turbine first stage rotor blade with thirteen holes

In this figure, the maximum von-Mises stress, 105.3306MPa is observed at the root of the rotor blade and minimum von-Mises stress, 18.9930MPa is observed at the tip of the rotor blade.

B. Thermal Analysis

Thermal analysis was carried out to know the temperature distribution of the gas turbine rotor blades. Thermal analysis plays an important role in the designing of many components such as heat exchangers, turbines, internal combustion engines and piping systems. The steady state thermal analysis shows that the temperature distributions for the gas turbine rotor blade with three different blade holes configuration.
Figure 9 shows the temperature distribution for the turbine first stage rotor blade with five holes.

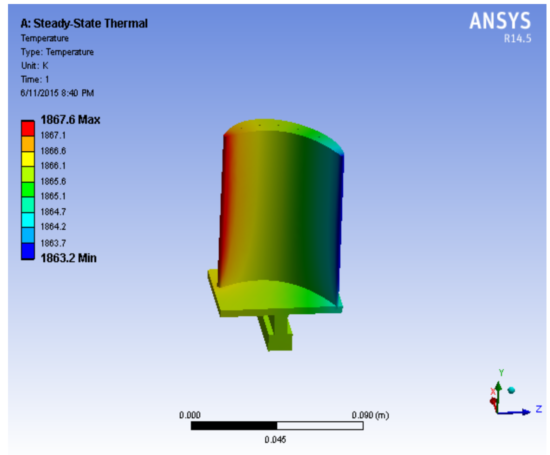

Fig9. Temperature distribution of turbine first stage rotor blade with five holes

In this figure, the maximum temperature, 1867.1°K is observed at the leading edge surface and minimum temperature, 1863.6°K is observed at trailing edge surface of the rotor blade.
Figure 10 shows the temperature distribution for the turbine first stage rotor blade with nine holes.

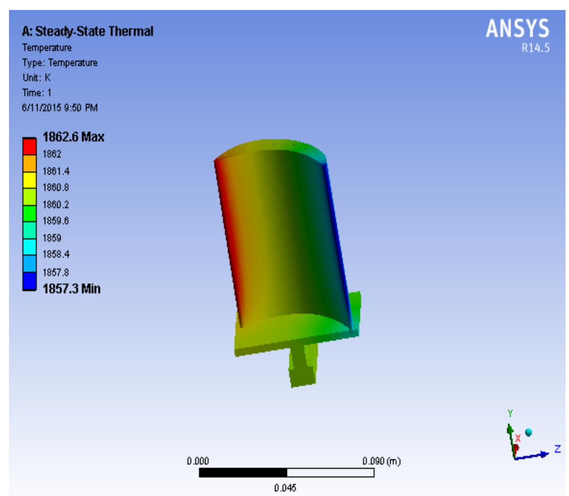

Fig10. Temperature distribution of turbine first stage rotor blade with nine holes

In this figure, the maximum temperature, 1862.1°K is observed at the leading edge surface and minimum temperature, 1857.6°K is observed at trailing edge surface of the rotor blade.
Figure 11 shows the temperature distribution for the turbine first stage rotor blade with thirteen holes.

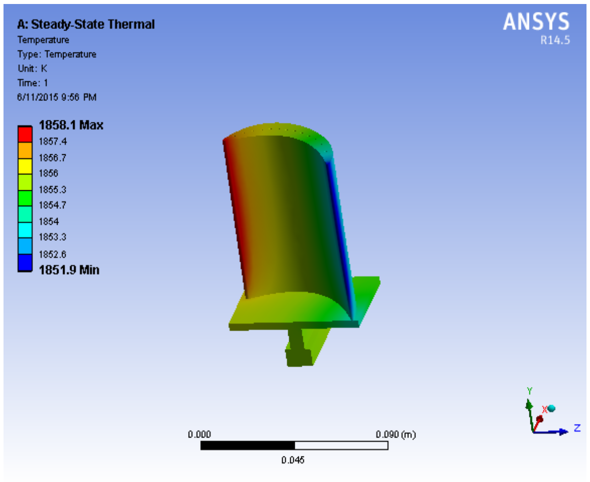

Fig11. Temperature distribution of turbine first stage rotor blade with thirteen holes

VI. CONCLUSION

The structural and thermal analysis were performed for the turbine blade with different number of holes i.e., 5,9,13 number of holes by specifying thermal and structural loads with an objective of finding optimum number of holes for the best performance. Static structural analysis for turbine first stage rotor blade, the highest von-Mises stress value, 105.0031MPa is observed at the rotor blade consisting of 13 holes The least von-Mises stress value, 103.5860MPa is observed at the rotor blade consisting of 5 holes. Static structural analysis for the turbine blade with three different numbers of holes, the turbine blade consisting of 5 holes gives better results than two other results. In steady state thermal analysis, the highest temperature value, 1867.6°K is observed at the rotor blade consisting of 5 holes and the least value, 1851.1°K is observed at the rotor blade consisting of 13 holes. Steady state thermal analysis for the turbine blade with three different numbers of holes, the turbine blade consisting of 13 holes gives better results than two other results.

In structural analysis, the rotor blade with 9 holes is better than the rotor blade with 13 holes. Besides, in the steady state thermal analysis, the rotor blade with 9 holes is better than the rotor blade with 5 holes. According to the structural and thermal analysis of the turbine blade with three different numbers of holes, the turbine rotor blade consisting of 9 holes is very suitable for the turbine first stage rotor blade.

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