Comparative Analysis of Two Alloys (GTD-111 and IN-738) used in Blade of Gas Turbine Model MS9001E at South Baghdad Station

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ABSTRACT. Blades are one of the basic components of a gas turbine and its main function is to rotate the shaft associated with the generator motor. Gas turbine model MS9001E used power plants at south Baghdad station, the blades are subjected to harsh working conditions such as high vibration, temperatures and pressures, thus highlighting the importance of studying the materials used in the manufacture of blades that work under harsh operating conditions. In this research, stress, strain and deformation produced by the centrifugal force that the blade is subjected to be studied, as well as studying the natural frequencies of the blades. Three-dimensional was created through the program solidwork 2018 and then exported to the program ansys 2019 for analyzing. Two alloys of materials (GTD-111) and (IN-738) were analyzed and compared between them, and the results showed that alloy (GTD-11) is the best and is suitable for use in the manufacture of blades.

Keywords: Turbine blade alloy, Modal analysis, blade frequency, static analysis, blade stress.

1. Introduction

Industrial heavy-duty gas turbines started in the market in the early 1950s. These ground-based units have no constraints on weight and space. Their design features included thick-walled casing, sleeve bearings, large-diameter combustion chambers, thick airfoil sections for moving and fixed blades, and large front area [1]. There are three main parts of a gas turbine, namely the compressor and the combustion chamber. And turbines (although from a material point of view, another major component Groups-rotors, casings and additives—are also very important) [2]. Rotate the shaft joined to the generator motor is the basic use of the gas turbine blade. In power plants, gas turbine blades are subject to extraordinary vibration, pressure and temperature, this is order to manufacture material should be able to resist these harsh working conditions [3]. Vibration in rotating machinery is unavoidable, and it is desirable for rotating parts to operate within acceptable levels to prevent a surge in vibration. When the components of the rotating body (such as the gas turbine system) are not aligned with each other or generate excessive noise, vibration is...
likely to occur. If not corrected, the problem may aggravate and eventually lead to failure [4]. Turbine operating temperature (combustion temperature) will also affect the higher the efficiency, the higher the temperature, the higher the efficiency. But the turbo the inlet temperature is limited by the thermal conditions, and the thermal conditions can be Turbine blade metal alloy. The gas temperature at the turbine inlet is between 1200°C and 1600°C, but some injection ports have been added due to unpredictable conditions and overload. Temperatures up to 1600°C and cause blade/disc fatigue and blade Fracture, through finite element analysis to study the properties of the component. It is recommended to use tool kits like ANSYS and reduce the stress on the blade. Protect metallurgy through engineering design of blade coating and cooling system. The components are not damaged by heat [5]. The repeated cyclic load on the rotor blades is the main cause of turbine blade failure in high cycle fatigue (HCF) [6]. Task of turbo technology is to eliminate enough power Convert of working fluid to the most effective successful function, maintaining the best performance, low price, the gas turbine has the smallest power and the shortest start-up time. Gas turbines use high-temperature and high-pressure combustion gas and air sources to generate strength, thereby increasing Range of different circles and rotating blades [7]. Choi and Lee studied the failure of the gas turbine by studying the damaged surface of the blade and the stress analysis of the blade, and perceived the maximum stress Occurs due to the pressure curve formed through operation [8]. Turbine blades IN 738 and U500 already used to set the natural frequency of turbine blade vibrations. The finite element method is used to analyze each influence from engine speed and the natural frequency and vibration of the thermal field blade [9]. In order to know the performance of turbine blades and minimize the chance of fail, the author uses complex materials Replace titanium alloy [10].

The aim of this research is to perform a numerical analysis to find and compare the natural frequencies, stresses, strains, and deformations of two alloys of two different types (GTD-111 and IN-73) used in the manufacturing of gas turbine blades.

2. Materials and Method
Modal Analysis was carried out on GTD-111 and IN738 nickel based alloy which are conventionally used for gas turbine blade applications. The GTD-111 and IN738 material properties are presented in Table 1; [8].

| PROPERTIES                  | ALLOY VALUES |
|-----------------------------|--------------|
|                             | GTD 111      | IN 738       |
| Specific Heat (J/KgK)       | 460          | 510          |
| Young’s Modulus (GPa)       | 130          | 149          |
| Density (kg/m3)             | 8870         | 8550         |
| Poison’s ratio              | 0.33         | 0.30         |
| Thermal conductivity (W/mk) | 16           | 14.3         |
| Thermal expansion (°C)      | 9x10^{-6}    | 12.5X10^{-6}|
| Yield strength (MPa)        | 564.32       | 792          |
| Melting temperature (°C)    | 1699         | 1400         |
| Bulk Modulus (Pa)           | 1.0833x10^{11}| 1.247X10^{10}|
| Shear Modulus (Pa)          | 5x10^{10}    | 5.73X10^{10}|

FEA offers a far additional complete set of results than experimental studies and is commonly quicker and fewer expensive. Finite part modal analysis used during this study depends 122 on the discretization of the pure mathematics to resolve advanced structural equations by effectively subdividing the structure in associate degree assembly of straightforward finite elements. The FEA designed the rotary engine blade style for analysis applying a combined system of points or nodes joined into a grid referred to as mesh.
The nodes were designed at a special density throughout the model. Figure 1 shows the Flow Chart of study Steps by exploitation ANSYS 2019R3. The steps used within the course of the analysis are as follows [9]:

i. Prepare a three dimensional model in SOLIDWORKS 2018.
ii. Import the SOLIDWORKS model in ANSYS 2019 software.
iii. Mesh the ANSYS model.
iv. Apply boundary conditions.
v. Solve the system equations to find out the unknowns.
vi. Validation of solutions obtained with the operating conditions.

![Flow Chart of Design Step by Using ANSYS 2019R3.](image)

**Figure 1.** Flow Chart of Design Step by Using ANSYS 2019R3.
3. Modelling and Analysis of Turbine Blade
The model was obtained from South Baghdad Power Station, located in Baghdad Iraq, Rivers Tigirs. The power plant with a total installed capacity of 130.14MW. The power plant consists of frame 9 Gas turbine, commissioned in 2004. Gas turbine blade geometry with supposed dimensions is shown in ‘Figure 2.a’ the form is generated in SolidWorks 2018 and exported to the software ansys 2019, at first, the turbine blade is discretized by applying tetrahedral elements. The whole number of nodes and elements are 23435 and 13377, sequentially as shown in ‘Figure 2.b’

(a)   (b)

‘Figure 2.a’. Gas Turbine Blade Geometry in SOLIDWORKS,  
(b). Meshed Blade using ANSYS

The geometry of the gas turbine blade is created in SOLIDWORKS and then carried into ANSYS for merge. The aerofoil outline of the rotor blade was made on the XZ level with the leading of key points marked by the coordinates. Then a number of splines were implemented within the key points, creating the 2D aerofoil shape. The geometry of the blade meshed with 8 nodded tetrahedral brick element but the element type used for this objective was Tetrahedron 10. It has 3 degrees of freedom out of the node, that is, translation in X, Y and Z directions were used. The element has elasticity, creep, swelling, stress stiffening, high deviation, and high strain capabilities etc. The blade dimensions are given in Table 2 and ‘Figure 3’ [9];
Table 2. Gas Turbine Blade Dimensions [11]

| PARAMETER                      | VALUES (MM) |
|--------------------------------|-------------|
| BLADE SPAN                     | 285.1       |
| BLADE AXIAL CHORD LENGTH       | 107.93      |
| BLADE ROOT LENGTH              | 123.94      |
| PITCH                          | 49.88°      |

THICKNESS OF THE TOTAL BLADE

| THICKNESS 1                    | 15.78       |
| THICKNESS 2                    | 26.27       |
| THICKNESS 3                    | 31.56       |
| THICKNESS 4                    | 27.92       |
| THICKNESS 5                    | 18.15       |
| THICKNESS 6                    | 10.59       |
| THICKNESS 7                    | 7.5         |

Following parameter has been taken for calculation of forces applying on the blade:
- Height of blade (H) = 285.1 mm
- Diameter of rotor (D) = 0.8056 m
- Average diameter (Dm) = 0.7599 m
- Speed (N) = 3000 rpm (High Rotational Speed)
- Blade’s Number = 92

For max diagram efficiency nozzle angle (α) should be as small as possible. Due to manufacturing constraint it is taken as 13.88°.

Velocity of blade \( V_b \) = \( \frac{\pi D m N}{60} \) = 119.3 m/sec.  \( (1) \)
Since,
\[ V_b = \frac{\cos \alpha}{2} = \text{Absolute velocity}(V_1) = 245.77 \text{ m/sec}. \]  
\[ (2) \]

\( \alpha = \) Inlet blade angle.
\( V_1 = \) Linear of inlet gas velocity m/sec.

### Table 3. Area Data of the Gas Turbine Model (MS9001E) of the (Al-Karat gas Turbine power station) in Karbala, Iraq [10]

| Parameters                                      | Values       |
|------------------------------------------------|--------------|
| (Active Power)                                  | (80 Mw)      |
| (Pressure of intake air)                        | (101.3 kPa)  |
| (Turbine pressure \( P_3 \))                   | (1012.9 kPa) |
| (Turbine temperature \( T_3 \))                | (1025 °C)    |
| (Exit pressure of air from the compressor)      | (1013 kPa)   |
|                                                   | (911.7 kPa)  |

### Table 4. Parameter of Blade for Gas Turbine Model MS9001E
At Generating Max. Power 130.14 MW, [11].

| Parameter                                      | Value         |
|------------------------------------------------|---------------|
| Turbine pressure at 130.14 MW                  | 1647.774 kN/m²|
| Blade area                                     | 0.03 m²       |
| Load on all blades for first disc              | 49432.2 N     |
| Number of blade in first disc                  | 92            |
| Load on one blade                              | 537.3 N       |
| Turbine temperature \( T_3 \)                 | 1025 °C       |
| speed                                          | 3000 rpm      |

### 4. Results and Discussion
This results obtained from ansys 2019. The natural frequency value of blades depends on its geometry, size, elastic properties, quality and boundary conditions. Then design of the blades away from the resonance frequency. This reduces the vibration amplitude and the risk of part breakage. The results obtained from the modal analysis are presented in this section.

4. 2 modal analysis of GTD-111 blade material

‘Figure 4’ shows Deformation (0.00020 m) at frequency (183.86 Hz) 1\(^{\text{st}}\) mode, and ‘figure 5’ Deformation (0.00026 m) at frequency (295.94 Hz). 2nd mode, ‘figure 7’ shows the amplitude change's magnitude with the frequency generated on the blade's front surface. The amplitude will convert at higher values in both frequencies, (183.87 Hz) and (295.9 Hz). The Vibration's amplitude will be reduced to a minimum at about (250 Hz).
Figure 4. Deformation at frequency 183.86 Hz. 1ST mode

Figure 5. Deformation at frequency 295.94 Hz. 2nd mode
4.1 Static analysis of GTD-111 blade material

‘Figure 7’ illustrates the stresses analysis by the Equivalent normal stress method. The maximum value of stress was (51.7 MPa) near the root zone. ‘Figure 8’ shows the amount of max. The normal elastic Strain that will occur due to the external load's influence, which is about (4.027 *10^-6). ‘Figure 9’ shows the Total deformation (5.79 *10^-6 mm) in the gas Turbine Blade.
Figure 8. Equivalent elastic strain

Figure 9. Total deformation
4.2 modal analysis of IN-738 blade material

'Figure 10' shows Deformation (0.0205 m) at frequency (632.78 Hz). 1st mode, and 'figure 11' Deformation (0.026 m) at frequency (1021.4 Hz). 2ND mode, 'figure 12' shows the amplitude change's magnitude with the frequency generated on the blade's front surface. The amplitude will convert at higher values in both frequencies, (635.74 Hz) and (1021 Hz). The Vibration's amplitude will be reduced to a minimum at about (950 Hz).

Figure 10. Deformation at frequency 632.78 Hz. 1st mode

Figure 11. Deformation at frequency 1021.4 Hz. 2ND mode
4.3 Modal analysis

Was carried out on a turbine blade in order to determine the natural frequency and modes shape in every frequency. The natural frequency is the frequency at which an object vibrates when excited by a force. The structure has the least resistance to force, and failure may occur if it is not controlled. The modal shape is the deflection of an object at a given natural frequency. Resonance is the condition of maximum amplitude vibration and minimum resistance to oscillation. In order for the resonance condition to occur, the shape and frequency of the force must correspond to the natural frequency and mode shape of the structure (blade). The boundary conditions of modal analysis are related to those of static structure analysis. Therefore, all stresses and deformations caused by centrifugal force are included in the modal analysis. Rotating turbine blades have greater bending stiffness than stationary blades, because rotation can cause a stiffening effect due to centrifugal force. The strengthening effect also depends on the speed. Therefore, the natural frequency of the gas turbine blades is a function of the turbine speed. The contour of the mode shape is presented in the form of deformation in three orthogonal directions. The color profile indicates the maximum deformation area of each mode, and the corresponding natural frequency of the mode shape. Turbine blades exhibit several modes, which appear at various excitation frequencies, such as the first deflection or first flap (1F) mode (mode 1), the first torsion mode (1T) and mode 2, the second flap Mode 3 (2F) shown in 'figure 4,5' show the results for the primary two modes of free vibration for (GTD-111 alloy) turbine blade. To (GTD-111 alloy) turbine blade, natural frequency of free vibration differs from (183.86 Hz) to (295.94 Hz). Thus, the results for the primary two modes of vibration for NI-738 Alloy turbine blade is shown in ‘figure 12, 13’, respectively. For NI-738 Alloy, natural frequency of vibration differs from (632.78 Hz) to (1021.4 Hz). Natural frequencies for the first two modes of free vibration for GTD-111 alloy and IN-738 alloy turbine blade are detailed in Table (5).

4.4 Static analysis of IN-738 blade material

‘Figure 13’ illustrates the stresses analysis by the Equivalent normal stress method. The maximum value of stress was (1.1616 *10^7 MPa) near the root zone. ‘Figure 14’ shows the amount of max. The normal elastic Strain that will occur due to the external load's influence, which is about (0.086). ‘Figure 15’ shows the Total deformation (2.79 *10^-6 mm) in the gas Turbine Blade.
Figure 13. Equivalent Stresses

Figure 14. Equivalent Elastic Strain
**Figure 15. Total Deformation**

It can be observed that the GTD-111 is the best material alloy for blade of gas turbine as shown in Table (6).

**Table 5. Free Vibration for Varies Turbine Blade Material (Natural Frequencies)**

| Modes | GTD-111 | IN-738 |
|-------|---------|--------|
|       | Frequency (Hz) | Deformation (m) | Frequency (Hz) | Deformation (m) |
| 1     | 183.86 Hz     | 0.00020 | 632.78 Hz     | 0.0205 |
| 2     | 295.94 Hz     | 0.00026 | 1021.4 Hz     | 0.026 |

**Table 6. Statics Analysis Results.**

| Material | Equivalent elastic strain (Max) | Equivalent Stresses (MPa) (Max) | Deformation (mm) (Max) |
|----------|---------------------------------|---------------------------------|------------------------|
| GTD-111  | 4.0277*10^-6                   | 51.718                          | 5.796*10^-6            |
| IN-738   | 0.08616                         | 1.1616*10^6                     | 2.79 *10^-6           |

5. **Conclusions**

From the results of this work the following conclusions can be obtained:

1. Using GTD-111 and IN-738 alloys to conduct extensive numerical research on gas turbine rotor blades.
2. Developed a model to calculate stress and strain, and study the effect of displacement.
3. Numerical analysis results show that, compared with IN-738 material, GTD-111 alloy has smaller displacement, strain and stress distribution.
4. In addition, compared with IN-738, GTD-111 alloy produces less stress, deformation and strain. In modal analysis, the blade deformation of GTD-111 alloy is very low compared with other materials.
5. Therefore, the resonance delay of GTD-111 alloy is mechanically more reliable. Therefore, compared with IN-738 alloy, GTD-111 titanium alloy is the most suitable material for gas turbine blades.

**References**

[1] Gülen S C 2019 Gas turbines for electric power generation. *Cambridge University Press*.

[2] James AW 2014 Structural Alloys for Power Plants Gas turbines: operating conditions .components and material requirements 3 21 Doi10. 1533 /9780857097552.1.3,

[3] Singh H P Rawat A Manral, A R. & Kumar P 2020 Computational analysis of a gas turbine blade with different materials. *Materials Today Proceedings*. 
[4] Al Adawi S K S & Ramesh Kumar G R 2016 Vibration diagnosis approach for industrial gas turbine and failure analysis. *Current Journal of Applied Science and Technology* 1-9.

[5] Barhm M. 2017 Failure analysis of gas turbine blade using finite element analysis. *International Journal of Mechanical Engineering and Technology* 7 (3) 299-305.

[6] Kumagai A & Topping T D 2017 *High cycle fatigue (HCF) testing of steel for Federal Aviation Administration (FAA) part qualification* Master's thesis.

[7] Teja P S Babu P K Rao K K. Babu M M & Sreenivasan M 2020 Numerical analysis of vertical axis gas turbine blade of different materials. *Materials Today Proceedings* 33 1038-1043.

[8] Aniekan Ikpe E A Oghenefejiro Efe-Ononeme E B & Godfrey Ariavie O C 2018 Thermo-Structural Analysis of First Stage Gas Turbine Rotor Blade Materials for Optimum Service Performance. *International Journal of Engineering and Applied Sciences (IJENAS)* 10 Issue2 118-130.

[9] Efe-Ononeme, O E Aniekan, I K P E & Ariavie G O 2018 Modal analysis of conventional gas turbine blade materials (Udimet 500 and IN738) for industrial applications. *Journal of engineering technology and applied sciences* 3(2) 119-133.

[10] Kadhim H J Kadhim, T J & Alhwayzee M H 2020 A Comparative Study of Performance of Al-Khairat Gas Turbine Power Plant for Different Types of Fuel. In *IOP Conference Series: Materials Science and Engineering* Vol 671 No 1 p 012015 IOP Publishing.

[11] Alaa J A Muhammad Z K and A J O Numerical analysis for determination of the vibrations and another parameter of the first stage blade of the gas turbine model (MS9001E). *International conference on electromechanical engineering and its applications ICEMEA*.