ANALYSIS OF GAS TURBINE BLADE ASSEMBLY TO EVALUATE THE PERFORMANCE OF VARIOUS NICKEL BASED ALLOYS

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ABSTRACT

The material selection plays a crucial step in the manufacturing and designing of a rotor-turbine blade assembly. This paper summarizes the immense research over three different turbine materials and an analysis is carried out to evaluate over few drawbacks as well as positives of the considered metal alloys. Nickel based super alloys are generally used for the rotor blade manufacturing. Static structural analysis is carried out on the rotor-blade section for a particular working pressure to check the deformation, displacement and Von-mises stresses for Inconel, Ni-Ti and Ni-Cr alloys. The results are compared with each other and the performance characteristics are studied depending upon the material properties. CATIA V5, Analysis and Simulation module is used for performing the present analysis. The current paper emphasizes on the procedures of Analysis and complete comparison of results so as to improve the quality and have a complete clarity about the material impacts over the turbine blade.

Keywords: Turbine Blade, CATIA, Nickel Based Alloys, Analysis.


1. INTRODUCTION

The complete procedures of design of a rotor blade assembly are summarized in the previous work [1]. The extension of the work is proceeded by taking the materials into consideration. These turbine blades are required to withstand large centrifugal forces, elevated temperatures and are operated in aggressive environments. To survive in this difficult environment, turbine blades often made from exotic materials. A key limiting factor in gas turbine engines is the performance of the materials available for the hot section of the engine especially the gas turbine blades[2].When the same is undergone in thermal analysis, as the number of holes is increases, the temperature distribution increases [3]. Analysis is conducted over the turbine
rotor blade unit taking into consideration the tangential inlet of gases over the turbine blade with a pressure of 10 bar for three different materials. One of the research summarizes that the Titanium alloy had the best performance[4]. In other research carried out, it was marked for Inconel 718 as best suitable for high temperature application [5], also based on the plots and results of Inconel 718 was considered as the best material which is economical, as well as it has good material properties at higher temperature as compare to that of Titanium T6 [6]. Al 2024 as well was termed as the best material in another research[7]. A similar work done on Nickel alloys with graphite and coating with cobalt gave good results towards Thermal analysis [8]. Hence a work is carried out on Nickel based alloys to estimate the material performance.

2. METHODOLOGY

Modeling of the turbine blade as well as the rotor were modeled using surface modeling and assembled in CATIA V5 which was elaborately shown in our previous paper [1]. A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed, that is, the loads and the structure's response are assumed to vary slowly with respect to time. A static structural analysis is performed using CATIA V5 software for the present work for which external pressures are applied. The operating life of a turbine largely depends on the mechanical and chemical properties of the materials used for turbine blades. Nickel based super alloys are generally used for the manufacturing of the blades. Static analysis is performed for the performance of the rotor blade assembly using three different alloys are done.

2.1. Static Analysis

Initially a new material as per the requirements is loaded to the material library by feeding the material properties. Loaded material is assigned to the rotor blade assembly and the model is dumped to Analysis and Simulation module. As the rotor is fixed to the shaft, the inner diameter of the rotor is clamped as a fixed constraint, and the tangential pressure flow of 10 Bar is posed on to all the 16 turbine blades as shown in the Fig. 1. The deformations, Von mises stresses and principal stresses are checked for the loading conditions.

2.2. Nickel-Chromium alloy (Inconel)

Analysis is performed on the above turbine blade assembly with the Inconel alloy as a material and the deformation and stresses are as shown:
Figure 2 Von-Mises stresses for Inconel alloy

Figure 3 Translational displacement of Inconel alloy.
2.3. Nickel-Titanium alloy

Analysis is performed on the above turbine blade assembly with the Inconel alloy as a material and the deformation and stresses are as shown:

Figure 4 Principal stresses of Inconel alloy.

Figure 5 Von-Mises stresses for Ni-Ti alloy.
2.4. Nickel-Copper alloy

Analysis is performed on the above turbine blade assembly with the Nickel-Copper alloy as a material and the deformation and stresses are as shown:

Figure 6 Translational displacement of Ni-Ti alloy.

Figure 7 Principal stresses of Ni-Ti alloy.
Analysis of Gas Turbine Blade Assembly to Evaluate the Performance of Various Nickel Based Alloys

Figure 8 Von-Mises stresses for Ni-Cu alloy

Figure 9 Translational displacement of Ni-Cu alloy.

Figure 10 Principal stresses of Ni-Cu alloy.
Table 1 Material Properties of the Nickel based alloys

<table>
<thead>
<tr>
<th>S.No</th>
<th>Material</th>
<th>Ni – Cr</th>
<th>Ni-Ti</th>
<th>Ni- Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Young’s modulus</td>
<td>1.43e+011N_m2</td>
<td>8e+010N_m2</td>
<td>1.56e+011N_m2</td>
</tr>
<tr>
<td>2</td>
<td>Poisson’s ratio</td>
<td>0.344</td>
<td>0.33</td>
<td>0.34</td>
</tr>
<tr>
<td>3</td>
<td>Density</td>
<td>8249kg_m3</td>
<td>6450kg_m3</td>
<td>8860kg_m3</td>
</tr>
<tr>
<td>4</td>
<td>Yield strength</td>
<td>5.5e+008N_m2</td>
<td>6e+008N_m2</td>
<td>1.7e+008N_m2</td>
</tr>
<tr>
<td>5</td>
<td>Coefficient of thermal expansion</td>
<td>1.77e+007_Kdeg</td>
<td>1.1e-005_Kdeg</td>
<td>25_Kdeg</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

Table 2 Results of static analysis conducted for three different alloys

<table>
<thead>
<tr>
<th>S.No</th>
<th>Material</th>
<th>Principal Stresses (N-m^2)</th>
<th>Von Mises Stresses (N-m^2)</th>
<th>Displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>1</td>
<td>Ni – Cr</td>
<td>4.18e+006</td>
<td>-2.35e+006</td>
<td>4.49e+006</td>
</tr>
<tr>
<td>2</td>
<td>Ni-Ti</td>
<td>4.26e+006</td>
<td>-2.34e+006</td>
<td>4.61e+006</td>
</tr>
<tr>
<td>3</td>
<td>Ni- Cu</td>
<td>4.26e+006</td>
<td>-2.35e+006</td>
<td>4.49e+006</td>
</tr>
</tbody>
</table>

The analysis is performed by fixing the clamp or constraint at the mid portion of the turbine as shown in Fig. 1. The basic meshing is taken as linear tetrahedron. The structure computation is calculated with the fine mesh comprising of 25589 nodes and 104622 elements. The deformation of the rotor is negligible as the inner side of the rotor is fixed to the shaft portion. As it is pure structural which depends upon the geometry as well as the clamping, the deformation of the rotor is completely independent of the structure itself whereas the translational displacement slightly depends upon the material used at the tip of the blade exclusively. Hence the deformation of the blade unit as tabulated has the maximum translational displacement value of 0.00756mm for the Ni-Cr alloy, whereas Ni-Cu has the minimum displacement of 0.00385mm comparatively. Going further in the analysis, the pressure of 10 bar is applied on to the 16 blades tangentially. The deformation, principal stresses and Von mises stresses are calculated for the three different materials. The properties of those materials are as tabulated in Table 1. Applied resultant load resultant for Ni-Cr, Ni-Ti and Ni-Cu alloys is as follows:
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Figure 11 Applied load resultant

The results of strain energy for Ni-Cr alloy is noted as 1.38e-003J and that of Ni-Ti and Ni-Cu being 2.53e-003J and 1.279e-003 respectively.

4. CONCLUSION

CATIA V5 which is a complete sophisticated suite, is completely utilized for the present work which gives more efficient results and also saves time. As the rotor-turbine blade is modeled in the CATIA software itself, it does not require any special formatting of the model file instead it is directly used as is. The analysis was successfully carried out for the three different alloys. The maximum principal stresses obtained for Ni-Ti and Ni-Cu alloys are same and this principal stresses of maximum value is occurring at the joining of the blade profile and the rotor, and is still under sustained condition. Maximum and minimum principal stress for Ni-Cr alloy is very close enough to the other two alloys showing almost the same behavioral conditions. Looking at minimum principal stresses and Von mises stresses are least values. Among the three material turbine assemblies, the one with Ni-Cr shows the maximum displacement of 0.00756 and the least displacement being Ni-Cu alloy. Therefore Ni-Cr alloy’s behaves better in terms of principal stresses and Von mises stresses are least comparatively though the translational displacement is more. Ni-Cu alloy also has a fairly good behavior which has a dominant low translational displacement and the Von-mises stresses being the same as that of Ni-Cr.

REFERENCES


