DESIGN ANALYSIS AND LIFE ESTIMATION OF A FIRST STAGE ROTOR BLADE USING NICKEL BASED SUPER ALLOY (CMSX4)

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ABSTRACT

In a combined cycle gas turbine (CCGT) plant, electricity is the output, which is obtained from a high temperature heat input which is generally obtained by burning of fuel. When the turbine blades are in continuous usage, they are vulnerable to high cycle fatigue failures. The major reason for these failures is the resonance which occurs at blade critical speed dry startup and shut down condition and in certain cases due to excursion of machine near an operating speed which is close to one of resonances. From the above criteria the failure of a First Stage rotor blade leads to callastropic effect. The material of the blade is considered as CMSX4 which is Nickel based super Alloy (Al₂O₃, TiN and AlN). Mathematical calculations using inlet and outlet triangles and S.N diagram approach are carried out. From the paper, it can be concluded that due to the continuous operation of a CMSX4 rotor blade, power capacity of plant increases.

Keywords: CCGT, CMSX4

1. INTRODUCTION

High pressure steam produced in the thermal power plant with water as working medium requires components which are bulky and should possess great strength. When high temperatures are generated, expensive alloys made of nickel or cobalt must be used in the place of inexpensive steel. The lower temperature of a steam plant is fixed by the boiling point of water while the alloy limits the practical steam temperature to 655°C. Due to constraining of these limits, the steam plant has a fixed upper efficiency of 35 to 42%.
The main components of an open circuit gas turbine cycle are a compressor, a turbine and a combustor. Lower quantities of expensive materials can be used in gas turbines because the amount of metal that must tolerate the high temperatures and pressures is relatively smaller. The input temperature (900 to 1,400 °C) to the turbine and the output temperature (450 to 650 °C) of the flue gas are relatively higher in such cycles. This is therefore high enough to provide heat for a second cycle which uses steam as the working fluid; (a Rankine cycle). Steam is generated in a combined cycle power plant by using the heat of the gas turbine's exhaust and passing it through a heat recovery steam generator (hrsg) with a live steam temperature maintained between 420 and 580 °C. Cooling of the condenser of the Rankine cycle is usually done by water from seas, lakes, rivers or cooling towers. The temperature obtained so can be as less as 15 °C.

In an automotive power plant, an Otto, Diesel, Atkinson or similar engine would provide one part of the cycle and the waste heat would power a Rankine cycle steam or Stirling engine, which could either power ancillaries (such as the alternator) or be connected to the crankshaft by a turbo compounding system.

Fig1: Operation of a Combine Cycle Plant

Blade fatigue is recognized to be a major cause of downtime in turbo machines. The impact of blade failure can be very costly in terms of cost production and part replacements.
2. LITERATURE REVIEW

A Survey by 'Dewey and Rieger(2000) reveals that high cycle fatigue is alone is responsible for at least 40% failures in high pressure stage of steam turbines. Blade failures due to fatigue are predominantly vibration related and suppression of blade vibration becomes a priority item for reducing the number of industrial blading failures. 'Stuart Moffatt(2003) describes paper on blade forced response prediction for industrial gas turbines.'Mikio Oi (1999) suggested structural analysis and shape optimization in turbocharger development.

3. PROBLEM DEFINITION

The present study attempts to understand and analyze the turbine blade through Finite Element Modeling with a view to determine stresses and estimate the blade fatigue life.

4. METHODOLOGY

The gas turbine rotor blade is analyzed using ANSYS 9.0 for the mechanical stresses. By constructing velocity triangles at inlet and exit of the rotor blade the tangential and axial gas forces are determined. Moving blades in the turbine are meant for conservation of the kinetic energy of the flowing steam or gas into the mechanical work on the turbine shell the work done by working fluid is transmitted to the shaft through the disc on which the blades are mounted.

The attachments of the blade are drum or disc of turbine short blades having small centrifugal forces are generally made with T-shaped tangs and are attached to the discs. If the blade and the tangs are of same width spacers are used to get the proper blade passage.

The equations of motion for SDOF using Newton’s Laws of motion

\[ Mx + cx + kx = F(t) \] \hspace{1cm} (1)

\[ X = A \sin (\omega t + \phi) \] \hspace{1cm} (2)

Simple Displacement functions for the element can be written as

\[ U = w_1 + \frac{1}{l} (w_2 - w_1) \xi \] \hspace{1cm} (3)

Life Assessment from Soderbergs equations

\[ \log S = -A \log N + B \] \hspace{1cm} (4)

\[ S = S_e \]

\[ A = \frac{1}{3} \log (0.9s_u/s_e) \]

\[ B = \log \left( (0.9s_n)^2 / s_e \right) \]

5. RESULTS AND DISCUSSIONS

Typical stress field on the blade at resonance frequency is 1773HZ is given. It can be seen that maximum stresses 70.549 kpa is developed at trailing edge of the root of the blade.
Table 1: STRESSES DEVELOPED AT ROOT OF THE UNIFORM BLADE

<table>
<thead>
<tr>
<th>Turbine Speed</th>
<th>Frequency</th>
<th>Stresses developed at root of the blade</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>300.0</td>
<td>5.98</td>
</tr>
<tr>
<td>666</td>
<td>400.00</td>
<td>22.48</td>
</tr>
<tr>
<td>876</td>
<td>525.8</td>
<td>883.34</td>
</tr>
<tr>
<td>943</td>
<td>566.1</td>
<td>96.02</td>
</tr>
<tr>
<td>1012</td>
<td>607.3</td>
<td>31.62</td>
</tr>
<tr>
<td>1595</td>
<td>955.0</td>
<td>1.26</td>
</tr>
<tr>
<td>1950</td>
<td>1170.0</td>
<td>4.00</td>
</tr>
<tr>
<td>2000</td>
<td>1200.0</td>
<td>0.77</td>
</tr>
<tr>
<td>2953</td>
<td>1773.0</td>
<td>70.55</td>
</tr>
<tr>
<td>4080</td>
<td>2400.0</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Fig 2: Vonmises stresses induced in the Blade  
Fig 3: Modal Analysis of turbine blade
6. CONCLUSIONS

The structural, life estimation and modal analysis are carried out. From the Worth Maximum stress induced is within safe limit. Maximum stresses and strains are observed at the root of the turbine blade and upper surface along the blade roots. So it can be suggested that Design, Analysis and Life Estimation of Blade is Safe.

7. REFERENCES