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Failure Analysis of Gas Turbine Blade using Finite Element Analysis

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ABSTRACT

This paper presents the failure analysis of the turbine blade of a gas turbine engine 9E GE type, installed in a certain type of simple systems consisting of the gas turbine driving an electrical power generator.A non-linear finite element method was utilized to determine the stress state of the blade segment under operating conditions.High stress zones were found at the region of the lower fir-tree slot, where the failure occurred.A computation was also performed with excessive rotational speed. Attention of this study is devoted to the mechanisms of damage of the turbine blade and also the critical high stress areas. Attention of this study is devoted to the mechanisms of damage of the turbine blade and also the critical high stress areas.

1. Introduction

The service life of critical gas turbine components is governed by the modes of degradation and failure such as: fatigue, fracture, yielding, creep, corrosion, erosion, wear, etc. Gas turbine discs are usually the most critical engine components, which must endure substantial mechanical and thermal loading. If a problem arises in the turbine section it will significantly affect the whole engine function and, of course, safety of the gas turbine engine. Blade loss can be contained within the engine casing, while the catastrophic failure of a turbine. Gas turbines for power generation we target (heavy frame) 9E-GE type. Industrial gas turbines 9E-GE is designed for stationary applications and has lower pressure ratios – typically up to 16:1.

The temperature at which the turbine operates (firing temperature) also impacts efficiency, with higher temperatures leading to higher efficiency. However, turbine inlet temperature is limited by the thermal conditions that can be tolerated by the turbine blade metal alloy. Gas temperatures at the turbine inlet between 1200ºC to 1600ºC, but some due to un expectable condition and over loading have boosted inlet temperatures as high as 1600ºC and lead the blades /discs to fatigue and blades fracture, to study the nature of components by using the finite element analysis package such as ANSYS and to decrease the stress over the blade, that recommended by engineering blade coatings and cooling systems to protect metallurgical components from thermal damage. Because of the power required to drive the compressor, energy conversion efficiency for a simple cycle gas turbine power plant is typically about 30 per cent, with even the most efficient designs limited to 40 per cent.

2. Gas Turbine Blade Materials

The materials developed at the first instance for gas turbine engine applications had high temperature tensile strength as the prime requirement. This requirement quickly changed as operating temperatures rose. Stress rupture life and then creep properties became important. Advancements in gas turbine materials have always played a prime role – higher the capability of the materials to withstand elevated temperature service, more the engine efficiency; materials with high elevated temperature strength to weight ratio help in weight reduction. A wide spectrum of high performance materials - special steels, titanium alloys and super alloys - is used for construction of gas turbines blades.

Figure 1 (A). Top view of gas turbine blade, (B) Front view of gas turbine blade

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Coating technology has become an integral part of manufacture of gas turbine engine components operating at high temperatures, as this is the only way a combination of high level of mechanical properties and excellent resistance to oxidation / hot corrosion resistance could be achieved.

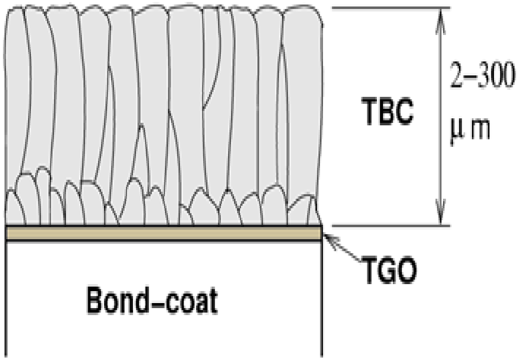

Figure 2. Schematic microstructure of a thermal barrier coating, the columnar microstructure considerably enhances the strain resistance and therefore thermal cycling life.

This situation led to the development of cast nickel-base alloys. Casting compositions can be tailored for good high temperature strength as there was no forge ability requirement. In recent years it has been also used as stage 2 bucket material in some GE engines. The alloy has an outstanding combination of elevated temperature strength and hot corrosion resistance and this makes it attractive for heavy duty gas turbine applications. Developments in processing technology have enabled production of the alloy in large ingot sizes. The alloy is used throughout the heavy duty gas turbine industry. The chemical structure of GTD 111 blade material type:

GTD 111:

Ni14Cr9.5Co3.8W1.5Mo4.9Ti3.0Al0.10C0.01B2.8Ta

3. Finite Element Model Of The Gas Turbine Blade

Parametric geometry models of blade were made, using the FE model of disc presented in Fig. 3. The discretized model of the blade consists of 11,420 nodes, 13,248 elements.

To model the mechanical interface of adjacent surfaces of the blade, the ‘‘master-slave’’ type of contact with friction coefficient of 0.1 was defined.

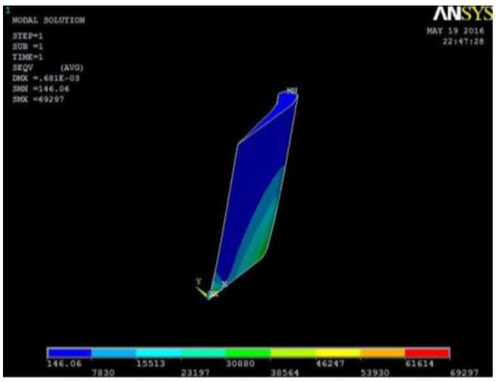

Figure 3. ANSYS model of the thermal induced stress distribution within gas turbine blades

4. Loans, Boundarys Conditions and oats boundarys condions and Material Properties for Femodel

In this section, a study of which variables most effects on the blade life for a typical high pressure, high temperature turbine blade.

A rotating hot section component in a turbine engine is in general subjected to a combination of surface centrifugal loads and thermal loads. The surface loads are associated with aerodynamic forces, resulting mainly from impingement of hot gases on the surfaces of blades. The centrifugal loads arising from the mass of the rotated disc and blades are usually the most critical loads acting on turbine blades. This load was determined through finite element calculation after defining the axis of symmetry, the rotational speed and blade material density. In this analysis, the operational turbine speed of 6000 rpm (rotation per minute) was applied. Computations for the rotational speed range of 0–10000 rpm additionally were performed for analysis of phenomena occurring in the turbine during excessive speed.

The aerodynamic forces were modelled in the simplified procedure as two vectors of 100 N, imposed on the concave surface of blade. The simplified thermal load presented in Fig. 4 was defined.

The turbine blade is manufactured out of GTD 111 material. This alloy is a precipitation-hardened nickel-base super alloy with good strength, ductility, and fracture toughness over a temperature range of 1200 degree centigrade. These properties along with good weld ability and formability account for its wide use in turbine engine applications.

The yield point of GTD 111 alloy is 921MPa, while the UTS (ultimate tensile strength) is 1200 MPa. This GTD 111 material alloy is a precipitation-hardened nickel base alloy, with better creep-resistance for high temperature. The analysis presented in this paper was performed for elastic–plastic blade materials, with isotropic hardening as showing in fig.5

Table1.Stage operating conditions (reference case)

Parameters	Value
Tt,in/K	1484
Pt,in/kPa	1382(13.82bar)
Ps,out/kPa	647(6.47bar)
Pt,in-c/kPa	1420(14.2bar)
Tt,in-c/K	696
peed/rpm	9800

Table 2. Rotor blade metal and coating specifications (reference case)

Parameters	Value
ρme/(kg/m3)	8250
kme/(W/(m ˘ K))	17.7
Cme/(J/(kg ˘ K))	710
ρco/(kg/m3)	6000
kco/(W/(m ˘ K))	2.29
Cco/(J/(kg ˘ K))	470
δco/µm	10

Table 3. Mechanical properties of GTD 111superalloy.

parameter	Value at 1200°C
E/GPa	145
α/K−1	-
υ	0.3

5. Conclusions

In this paper, a three-dimensional finite element model of a gas turbine blade has been established by ANSYS software, and then its thermal fatigue behaviour has been investigated. The following important conclusions have been obtained:

- Due to the non-uniform distribution of displacement, strain and stress in gas turbine blade, the regions located at the top, bottom of suction or pressure sides tend to produce a maximum of displacement, with the occurrence of a bigger strain or stress, where sub-critical cracks preferentially form.
- According to the maximum tensile stress criterion, dangerous regions of a turbine blade with Disc can be predicted. These dangerous regions mainly locate at of the lower fir-tree slot.

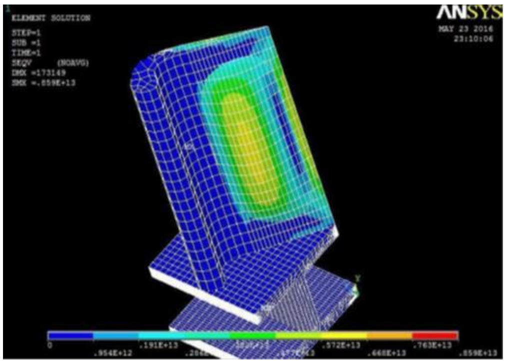

Figure 4. ANSYS model of the stress distribution within gas turbine blade and disc

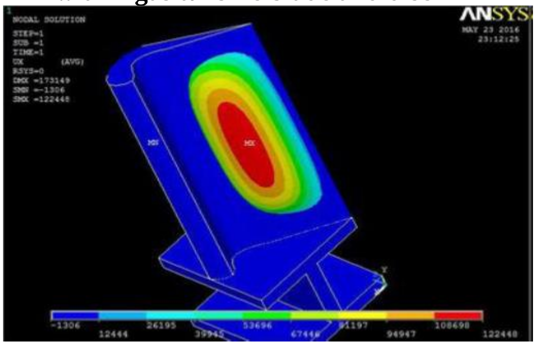

Figure 5. in-plane stresses in top ceramic coat during a whole thermal cycle from both pressure and suction sides of a gas turbine blade

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