Issue 1 vol 4 ISSN: 2321-8134

IJFEAT

INTERNATIONAL JOURNAL FOR ENGINEERING APPLICATIONS AND TECHNOLOGY

REVIEW ON THERMAL FAILURE OF AEROGAS TURBINE BLADE

Tanvir Shaikh[1], AnuragBhagat[2], Abhinav Dethe[3], Vaibhav Jaiswal[4]

[1]*Student, Department Of Mechanical Engineering, JDIET,Yavatmal,Maharashtra, India, shaikhtanvirr18@rediffmail.com*
[2]*Student,Department Of Mechanical Engineering, JDIET,Yavatmal,Maharashtra, India,anuragbhagat290@gmail.com*
[3]*Student, Department Of Mechanical Engineering, JDIET,Yavatmal,Maharashtra, India,abhinavdethe14@gmail.com*
[4]*Student, Department Of Mechanical Engineering, JDIET,Yavatmal,Maharashtra, India,balluv@gmail.com*

Abstract

With the excess in demand for power supply and more proficient turbojet engines, gas turbine designing is being pushed to its limits. Turbo machines are becoming larger as compared to the machines of past decades. Because of increase in size, the cause and chances of failure have also increased. Gas turbine blade is the component which is exposed to high operating condition, thus experience different failure modes. Constant mechanical and thermal stresses act on totally different sections of blade. Newer super-alloys with increased metallurgical properties are being developed and tested to counter the stresses performing on the blades. Advance additive producing techniques are used to produce next generation super-alloys. Failures because of mechanical and metallurgical anomalies are indirectly associated with the high operational temperature and may be correct up to anexact limit. Thus thermal protection is required for blades. Advance cooling techniques and coatings are being used for this purpose. Different literatures were combined to compile all the data analysed on blade failure and the preventive techniques being used.

Keywords:*Gas turbine blade, Turbine entry temperature, Thermal failure analysis &Blade cooling.*

***

1. INTRODUCTION

For last many decades the gas turbines are being used to produce either specific thrust power in an aircraft jet engine or shaft power to turn an electric generator. The thermal efficiency and power output of a gas turbine are critically dependent on the gas temperature at the turbine inlet.

The heat transferred to the gas turbine blade will increases as the turbine entry temperature increases. With increasein the turbine entry temperature, thermal efficiency and power output of the gas turbine increases. Butincrease in TET induces thermal stresses in theturbine blade and is limited by the maximumallowable blade temperature. Therefore, there’s arequirement of cooling the blade for safer operation.The blades are cooled with air drained from the compressor of the engine. Since this extraction affects the thermal efficiency and thepower output of the engine, it is important tounderstand and optimize the cooling technology for agiven turbine blade geometry under engineconditions.The first patent for a combustion turbine was filed inEngland and granted to John Barber in 1791. Modernversions of this turbine were patented by Franz Stolzeand Charles Curtis in the late nineteenth century .However, these designs were Not feasible from theperspective that the power required to drive thecompressor was more than the power output gainedfrom the turbine. To overcome this difficulty, the turbine inlet temperature had to be increased, whichwas not feasible at the time due to melting pointlimitations of the blade material. The jet engine racewas later fuelled by World War II with Germany’sJunker and Great Britain’s Rolls-Royce successfullystarting production towards the end of the war.Although most turbine developments thought thefifties and sixties were created in aircraft industry,power generation soon followed suit with GeneralElectric being able to transfer knowledge to thepower generation industry. The 1960s marked aparadigm shift with the introduction of coolingtechnology within turbine blades and vanes.Increasing the blades material properties in turbineengines became just as important as cooling theblades and these two fields became complementary toevery different. During the consequent four decades,advancement in cooling technology saw yieldedturbine inlet temperature increases of up to 500k.

2. CAUSES OF FAILURE OF GAS TURBINE BLADE

Modern gas turbines are very compact and have an extremely high energy conversion rate. Today's gas turbine can reach thermal efficiencies in excess of 40% as result of the increased thermodynamic parameters like pressure ratio and turbine inlet temperature. Both of the parameters have an immediate impact on the thermal load and thus on the cooling system of the combustor hardware. The temperature of gases released by combustion is about 1800 to 2100 deg C which is far too hot for entry to nozzle guide vanes and turbine blades from the material point of view. For the most widely used nickel or cobalt based alloys, the maximum temperature should not exceed 1400 degree C. The mechanical strength of those materials declines speedily at high temperatures.This results in failure of different components of gas turbine such as nozzle guide vanes, turbine blades, turbine rotor, turbine stator, bearing, combustor etc. Therefore thermal analysis of these components is necessary.

3. FACTORS WHICH INFLUENCE THE GAS TURBINE BLADE ARE AS FOLLOWS:

- **Operation environment (high temperature, fuel and air contamination, solid particles, etc.).**
- **High mechanical stresses (due to centrifugal force, vibratory and flexural stresses, etc.).**
- **High thermal stresses (due to thermal gradients).**

The type of damage which occurs in gas turbine blades and nozzles after a service period can be divided into:

- **External and internal surfaces damage (corrosion, oxidation, crack formation, erosion).**
- **Internal damage of microstructure as γ [Ni3(Al,Ti)] phase aging , grain growth, grain boundary creep voiding, carbides precipitation and brittle phases formation.**

Surface damage produces blades/nozzles dimensional changes which result in operational stress increase and turbine efficiency deterioration. In service, blade material deterioration is related to the high gas temperature, high steady state load levels (centrifugal load) and high thermal transient loads. However, the degree of deterioration in individual blades differs due to several factors such as:

- **Total service time and operation history (number of start-ups, shut-downs and trips).**
- **Engine operational conditions (temperature, rotational speed, mode of operation, base load, cyclic duty).**
- **Manufacturing differences (grain size, porosity, alloy composition, heat treatment).**

The micro structural changes due to blade operation at high temperature include irregular growing of γ particles and formation of carbides in grain boundaries and matrix. This leads to alloy creep properties reduction. In order to have an instrument for the deterioration evaluation of gas turbine blade alloy, it is necessary to correlate the influence of service induced micro structural degradation to the change in mechanical properties.

In general, blade failures can be grouped into two categories:

- **Fatigue, including both high and low cycle fatigue and**
- **Creep rupture.**

3.1 Creep Failures

All turbine blades and sometimes the high pressure stages of compressor blades are subject to creep as anatural consequence of operating at high temperatures and stresses, and creep is eventually the life-limiting process for all blades so exposed. In normal service, creep manifests itself as blade ‘‘stretch’’ in which theblade elongatesin service. Repair and quite probably replacement of both blades and shroud. Blade stretch is measured routinely during inspectionsand the length trimmed to restore the correct tip clearance. The blade is discarded when the accumulatedstrain reaches a pre-determined value.

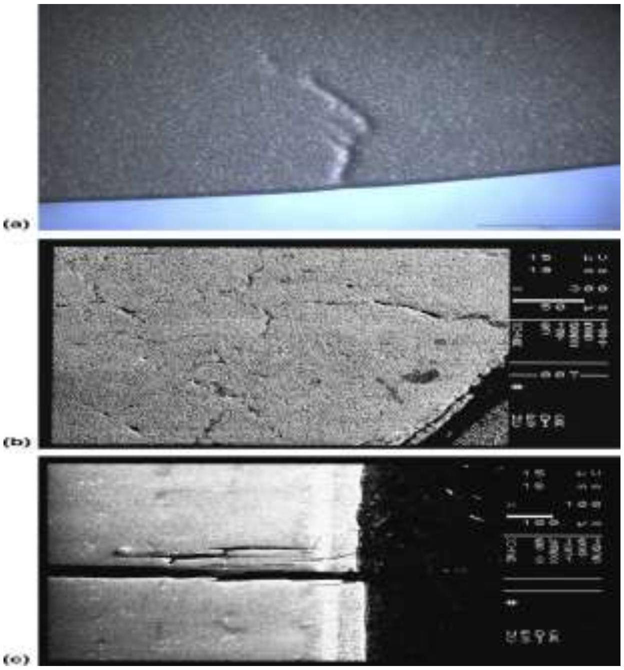

Fig. 3.1. (a) Creep damage observed during routine inspection; (b) grain boundary separation found on metallographic examination ofthe same blade; (c) appearance of creep cracking in a directionally solidified blade material.

3.2 Fatigue Failures

High cycle fatigue (HCF) failures are rare in gas turbine rotating parts, unless some form of initiating damage, such as FOD from ingested debris has been inflicted or where a manufacturing defect is present (Fig.3.2.1). Gas turbine blades are carefully designed to avoid HCF, since they accumulate stress cycles at a prodigious rate.

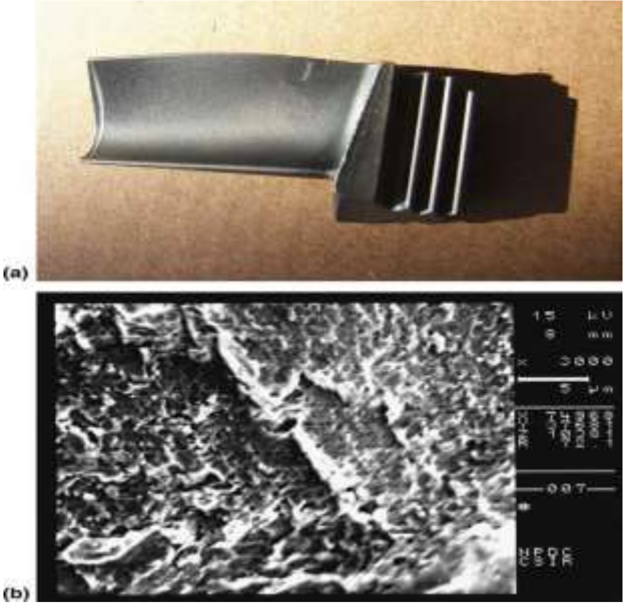

Fig. 3.2 Fatigue cracking, initiating at metallurgical defect, found in trailing edge of blade to the right of the pencil mark, and SEM image of crack surface showing striations, confirming the fatigue mechanism.

3.3 Corrosion Failures

Both compressor and turbine blades are exposed to aggressively corrosive conditions (Fig 3.3). The ingested air may well contain sodium and chlorine, in the form of salt from sea air or from runway de-icing treatments or marine environments. Atmospheric contaminants result from natural sources, such as marine environments or through pollution from industry or forest fires, and usually contain sulphur and sodium as the most active elements. Volcanic activity can generate significant levels of pollutants, particularly sulphur. The turbine blades are exposed to strongly oxidizing conditions and the gaseous combustion products contain elements such as sulphur, vanadium or even lead and bromine from the fuel at very high temperatures.

Fig. 3.3 Sulphidation attack of a turbine blade. Such damage can sometimes be repaired by removing the damaged coating and reapplyinga new coating.

3.4 High Temperature Exposure

The turbine blades operate at elevated temperatures at the very edge of metallurgical alloy development. There probable damage mechanisms affect turbine blades, these being mechanical damage through eithercreep or fatigue and high temperature corrosion. The use of light alloys for the high temperature sections of the engine is not feasible since they cannotgenerally be designed to give acceptable creep properties at the high temperatures needed for efficient turbineoperation. In the case of aluminium alloys, the operating temperature is above the melting point. Forthe most part, nickel base alloys are used and the weight penalty is accepted. The use of hollow blades, sometimes with air ducted through the interior for cooling, reduces blade weight. The most common materialsfor turbine blade manufacture are the nickel-based ‘‘super-alloy’’ materials. Used as both forgings and,more popularly for blades as castings, these alloys are able to withstand the very aggressive environment ofhigh temperature and high stress found within the hot gas path of a turbine engine.

Fig. 3.4Thermal failure of gas turbine blade

3.5 Thermal Stresses

Large amount of thermal stress is experienced by the turbine blades due to direct exposure to high temperature gases. Components of first stage of turbine are exposed to large amount of thermal loads resulting in creep and thermal fatigue. Particularly, the blade tips experience large thermal loads due to leakage of flow through the gap between the shrouded casing and the blade tip, increasing the chances of cracking. Large pressure gradient between the pressure side and suction side of blade results in acceleration of leak flow which leads to thin boundary layer formation and elevated heat transfer rate. This increases the turbine power loss and decreased efficiency. A failure of even single crystal directional solidified alloy is majorly due to cracks caused by thermal fatigue. Alloy Failure depends on the cyclic loading at elevated temperature.

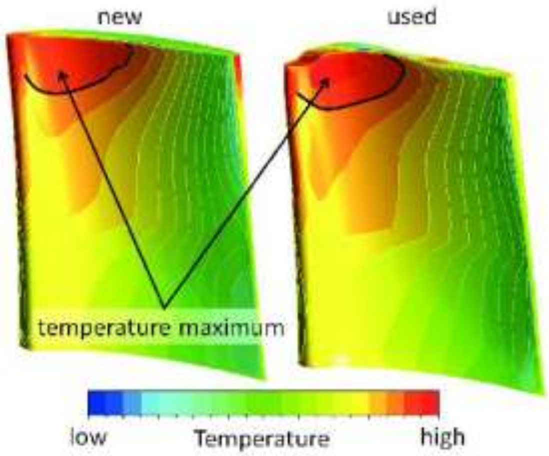

Fig.3.5Temperature variation on different section of gas turbine blade

4. COOLING OF GAS TURBINE BLADE

4.1. Need For Cooling

As the blade material melts at a lower temperature than the operating conditions of the turbine, a cooling method must be incorporated into the blade design to ensure the safe and smooth running of the turbine. It is important, while devising a cooling scheme, to have knowledge about the boundary conditions of the blade during turbine operation, so that more gradients can be avoided. This is because high gradients cause thermal stress cutting the component life short significantly.

4.2. Turbine Cooling Basics

Although cooling is important, it affects the gas turbine operation inadvertently:

1. The cooling air supplied to the blades and vanes is directly bled from the compressor. As a result the mass of air going into the combustor is less.

2. In order to incorporate the various structures like fins, cooling passages etc. the trailing edge thickness of the blades must be increased which adversely affects the aerodynamic performance of the blades

Different parts of the turbine blade are cooled using different techniques. The front part, called the leading edge, is generally cooled by impingement cooling. The middle part is generally cooled by using snake-like passages endowed with ribs along with local film cooling. The back part, called the trailing edge, is generally cooled by impingement and film cooling.

4.3. Principle Of Cooling

As the turbine inlet temperature increases, the heat transferred to the turbine blade also increase. The level and variation in the temperature within the blade material, which cause thermal stresses, must be limited to achieve reasonable durability goals. The operating temperatures are far above the permissible metal temperatures.

Therefore, there is a critical need to cool the blades for safe operation. The blades are cooled with extracted air from the compressor of the engine. As this extraction incurs a penalty on the thermal efficiency and power output of the engine, it is important to understand and optimize the cooling technology for a given turbine blade geometry under engine operating conditions. Gas turbine cooling technology is complex and varies between engine manufacturers. Figure 4.3 shows the common cooling technology with three major internal cooling zones in a turbine blade with strategic film cooling in the leading edge, pressure and suction surfaces, and blade tip region. The leading edge is cooled by jet impingement with film cooling, the middle portion is cooled by serpentine rib-roughened passages with local film cooling, and the trailing edge is cooled by pin fins with trailing edge injection.

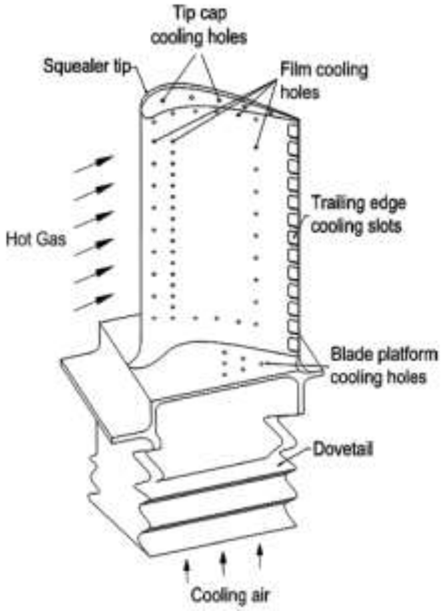

Fig. 4.3 Cooling basics of gas turbine blade

5. CONCLUSION

The thermal analysis is carried out: It is concluded that

- The main cause of failure of gas turbine blade is high working temperature.
- The temperature has a significant effect on the overall stresses in the turbine blade.
- Maximum elongation and temperatures are observed at the blade tip section and minimum elongations and temperature variations at the root of the blade.
- Temperature distribution is almost same at the maximum curvature region along the blade profile.
- Temperature is linearly decreasing from the tip of the base of the blade section.
- More thermal stresses are setup when the temperature difference is maximum from outside to inside.
- Maximum stresses and strain are observed only at blade region in the rotor along the blade length and elongations in Y-direction are gradually varying from the different sections along the rotor axis.

6. REFERENCES

(1) Je-Chin Han, SandipDutta, and SrinathEkkad., "Gas Turbine Heat Transfer and Cooling Technology" Published by Taylor & Francis in 2000

(2)Unger, D., Herzog, H., "Comparative Study on Energy R&D Performance: Gas Turbine Case Study", Massachusetts Institute of Technology, Prepared for Central Research Institute of Electric Power Industry (CRIEPI), August 1998.

(3) Jun Su Park, Dong Hyun Lee, Dong-Ho Rhee, Shin Hyung Kang, HyungHee Cho, "Heat Transfer and Film Cooling Effectiveness On the Squealer Tip of a Turbine Blade," Energy 72, 2014, pp. 331-343.

(4) S. Holdsworth, M. Radosavljevic, P. Grossmann, "Effectiveness Verification of Creep-fatigue Assessment Procedures for Fast Starting Steam Turbines," et al., 2012, ASME Paper GT2012-68223, pp. 367-373.

(5) "Gas Turbines For Autos", May 1946,"Popular Science. Books.google.com.

(6) Polezhaev, J., 1997,"The transpiration cooling for blades of high temperatures gas turbine", Pergamon, Energy Convers. Mgmt., Volume 38, pp. 1123-1133.