DESIGNING OF AN AEROFOIL BLADES WITH 2-D GEOMETRY

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Abstract: The overall operating cost of the modern aerofoil blade is greatly influenced by the durability of hot section components operating at high temperatures. In turbine operating conditions, some defects may occur which can decrease hot section life. The purpose of this paper is to illustrate the complete design of an aerofoil blade, along with a model of an improved Blade capable of resting FOD. All the calculation covered in the present paper is based on some predetermined standard requirement, which may be an ideal case. Actually, aerofoil is generally preferred in high power to weight ratio requiring fields so that correct design of the blades is crucial to make the turbine work. Therefore an attempt has been taken to show the basic design, forces action on the blades, material selection for the blade, corrosion, and other damages to the blade, their prevention and other attributes key in blade design.

Index Terms- Aerofoil, Blade, Design, Airflow, Aerodynamics, Gas Turbine Compressor Blade, Optimization

I. INTRODUCTION

A gas turbine, also called a combustion turbine, is a rotary engine that extracts energy from a flow of combustion gas. It has an upstream compressor coupled to a downstream turbine, and a combustion chamber in-between. Energy is added to the gas stream in the combustor, where fuel is mixed with air and ignited. In the high pressure environment of the combustor, combustion of the fuel increases the temperature. The products of the combustion are forced into the turbine section. There, the high velocity and volume of the gas flow is directed through a nozzle over the turbine's blade, spinning the turbine which powers the compressor and, for some turbines, drives their mechanical output. The energy given up to the turbine comes from the reduction in the temperature of the exhaust gas.

Thus moderate analysis of gas turbine blades exposes facts of different engineering concerns. Proper selection of design parameters is real derivatives of huge extrapolation of the topic. Aerofoil profile and cooling effects are the most basics to be taken care off while optimizing blade profile design for maximum efficiency. To find the proper correlation between the designs parameters are the basic objective of the present work. Gas Turbine is basically an aerofoil, or an aerofoil is the shape of a wing or blade (of a Propeller, rotor or turbine).

An airfoil-shaped body moved through a fluid produces a force perpendicular to the motion called lift. Airfoil work on the basis of Bernoulli's principle starting that high speed flow is associated with low pressure and low speed flow with high pressure.

Airfoils are designed to increase the speed of the airflow above the surface of a wing, causing a decrease in air pressure. Simultaneously, the slower moving air below the surface of the airflow increases the air pressure. The combination of the increase of the air pressure below the airflow and the decrease of air pressure above it creates lift. Turbine blades are one of the most important components in a gas turbine power plant. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor. The blade is subjected to differential thermal stresses, erosion- corrosion and a host of other hostile parameters hampering its smooth functioning.

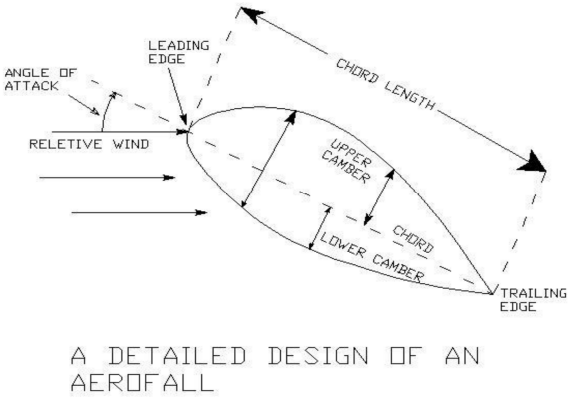


Fig: 1.1. A Detailed Design of an Aerofoil

II. BLADE MATERIALS

Different alloy composition have been developed which have a good stability to withstand the thermal

stresses. These alloys have been modified to give good erosion-corrosion characteristics to the blades. The method of manufacture of the blades plays an important role in determining the strength, uniformity if micro-structure and properties of the blades.

Among the material that has been found to be suitable for use in blades are steels, titanium alloys and nickel base alloys. All the three types of alloys which are mainly used, have varying proportions of chromium and aluminium to improve the strength and corrosion at high temperatures (Titanium alloys are preferred to steel because of its lower density nearly 50%). Titanium has superior oxidation resistance and like other materials it also has a decreasing strength with temperature. However, by alloying with other elements its strength can be stabilized. Latest types of titanium alloys have good properties upto about 550° C (IMI 829).

The mentioned alloy IMI 829 has composition Ti-5.5, Al-3.5, Sn-3, Zr-1, Nb-0.3 and Mo-0.3. Nickel alloys have also been developed extensively and are currently being used for turbines.

These alloys have superior strength and oxidation resistance even though nickel by itself has poor oxidation resistance. This weakness is overcome by alloying with chromium.

Materials working under high stress and high temperature have a particular rate of creep. It means elongation under stress is not a fixed quantity as it is in case of normal temperature. Elongation continues to increase with time and blades gradually reduce the original gap provided at their tips. Therefore, contacts with casing results in failure. The repeated heating and cooling of the material affect the physical properties of the materials.

The four various techniques of manufacturing blades are:
(i) Forging
(ii) Casting
(iii) Fabrication and
(iv) Powder Metallurgy.

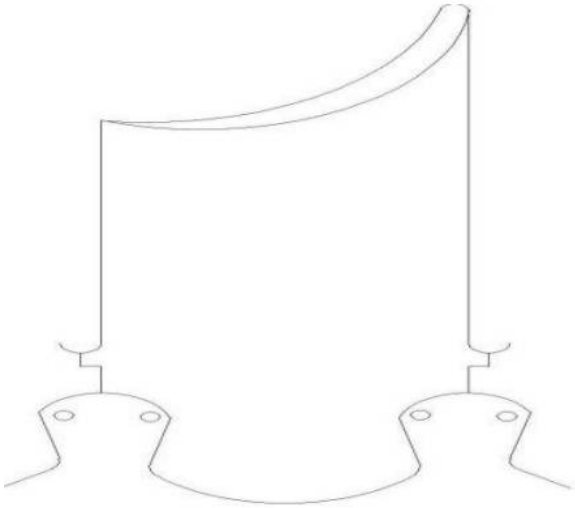
III. BLADE ASSEMBLE TECHNIQUES

The blades of a gas turbine are to be fitted carefully to the discs. This is served by the blade root which is either welded or fixed to the disc circumference. While considering the root the following aspects are to be kept in mind.

(i) The root should be able to transmit the centrifugal force and vibrations to the turbine disc.
(ii) It should be easy to mount the blades on the turbine disc.
(iii) The manufacturing process should be affordable.
(iv) The temperature effects on the blade and the disc should not cause expansion due to high temperature and should not lead to any looseness or deformation of the attachment. Consideration should also be given to the need for cooling the blade. Some degree of freedom is usually given to the blades to counteract vibration.

For turbines the configuration of the blade root disc assembly plays an important role in fixing. Early turbine blades were fitted to the disc by the Delaval root fixing which was later supersede by the fir tree fixing which are used in majority of the gas turbines now-a-days.

The following are some methods for fixing blade to the wheel:
(i) Bulb Root Method
(ii) Tee and Double Tee
(iii) Anchor Pin
(iv) Fir Tree Method
(v) Grub Screw Method
(vi) Welding



3.1. Bulb Root Method

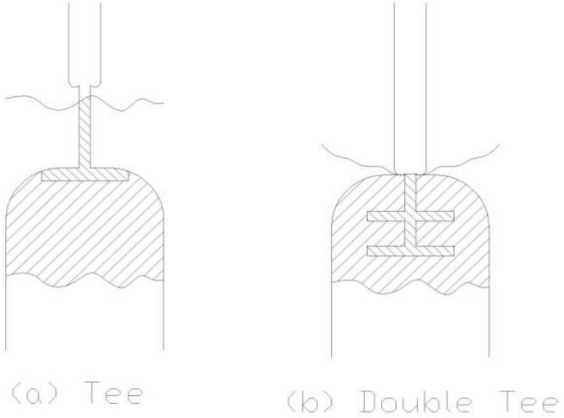


Fig: 3.2. Blade Assembly by 'T' Method

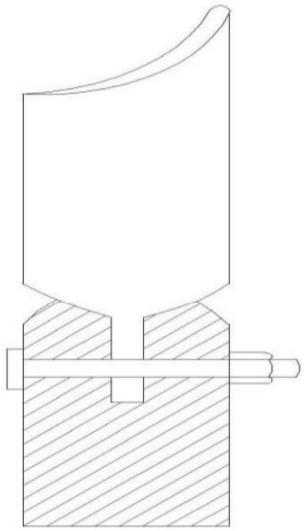


Fig: 3.3. Anchor Pin Method

IV. OPTIMIZATION PROBLEM FORMULATION

For the mathematical formulation Wolfgang Egartner [1] is states that the working range optimization problem, all variables of the forward problem, most of which are state variables and grid node positions (the node positions are variables as MISES is based on streamline curvature discretization), are summarized as

X= X1,…..XN, Xi ϵ Rmc , N – Number of operating points;

The blade profile B-Spline parameter vector is denoted P = (P1 ….. Pmp) and the operating points (like inlet Mach numbers or flow angles), are represented by

q = q1… qN, N – Number of operating points.

The mathematical formulation of the approach includes three steps: using B-spline to represent the turbine blade, using diffusion equation to generate material composition variation, using finite element method to solve the constrained diffusion equation. The implementation and examples are presented to validate the effectiveness of this approach for heterogeneous turbine blade design.

V. BLADE COOLING

Blade cooling is most effective way of maintaining high operating temperatures making use of the available material. Blade cooling may be classified based on the cooling site as external cooling and internal cooling. Another, classification based on the cooling medium is liquid cooling and air cooling.

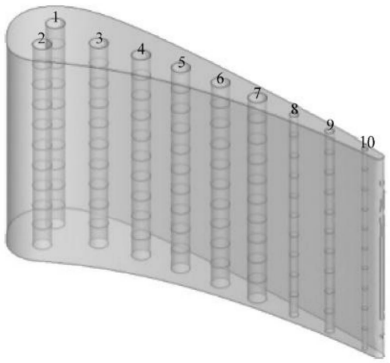


Fig: 5.1. 3-D geometry and the 1-D elements of ten coolant channels.

A. External Cooling and Internal Cooling:

The methods of external cooling are film cooling and transpiration or effusion cooling. Film cooling (fig. 5.2) to local areas can be applied by drilling holes on precision cast blades by the process of electrical discharge machining, EDM, which removes material by the multiple spark discharge action at the end of a special electrode. Besides cooling the blade surface it decreases the heat transfer from the hot gases to the blade metal. Transpiration cooling the air is allowed to effuse or sweat from the pores of the porous blade metal. This provides a blanket of cool air, insulating the metal of the turbine blade from the hot gas. Internal cooling of blades is achieved by passing air or liquid through internal cooling passages from hub towards the blade tip. The internal passages may be circular or elliptical as shown in (fig 5.3) and are distributed over the entire surface of the blade. The cooling of the blades is achieved by conduction and convection. Hollow blades can also be manufactured with a core and internal cooling passage as in (fig. 5.3). The cooling air is first admitted into the inner shell (1) from which it comes out through narrow and long slots (2) and (3) and impinges the inner surface of the leading and trailing edges respectively. The air form (2) after impinging, flows over the inner shell and comes out by the holes (5) in the concave surface near the trailing edge. This type of cooling is called impingement cooling. Based on the cooling medium employed, blade cooling may be classified into liquid cooling and air cooling.

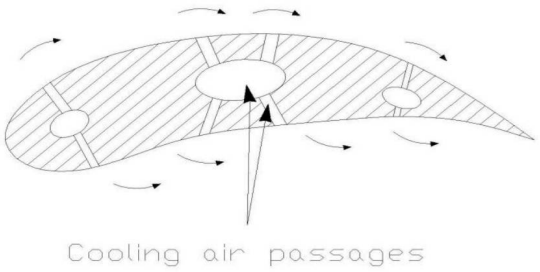


Fig: 5.2. Film Cooling.

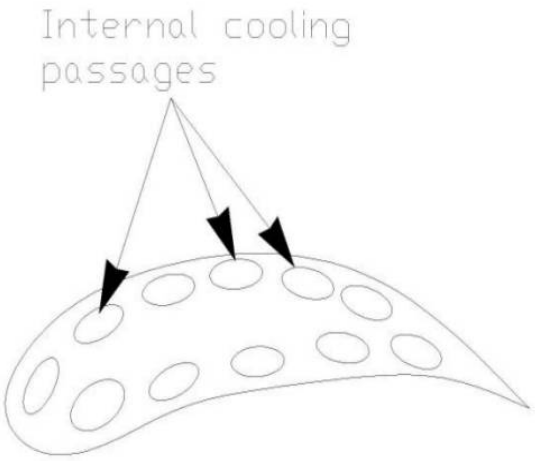


Fig: 5.3. Convection Cooling.

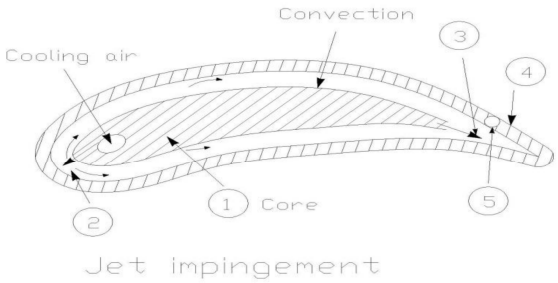


Fig: 5.4. Impingement Cooling

VI. DESIGN OF BLADE FOR PROTECTION AGAINST FOD

Foreign object damage is damage caused by foreign object debris, i.e. a substance, debris or article alien to a vehicle or system that has potential to cause damage. Foreign object damage is any damage attributed to a foreign object that can be expressed in physical or economic terms and may or may not degrade the product's required safety or performance characteristics. FOD is an abbreviation often used in aviation to describe both the damage done to aircraft by foreign objects and the foreign objects themselves. On aircraft carriers, as well as military and some civilian airfields, FOD walkdowns are conducted before flight operations begin. A line of crewmen walk shoulder to shoulder along the flight operations surface, searching for and removing any foreign objects. The objects removed are often also referred to as "FOD" although they haven't caused any damage. In this context a more appropriate translation of the acronym would be "foreign object and debris".

VII. EFFECT OF AIR COOLING ON ENGINE PERFORMANCE

In an engine where air is used for cooling the turbine blades, in effect bypasses part of the turbine and so does less useful work. Thus the engine will run at a higher entry temperature for a given thrust than an uncooled engine. This point is reflected in graph which shows the lesser thrust to temperature curve with air cooling. It also shows that despite this adverse effect the net gain in thrust due to air cooling is 18 percent. Of course, if more air is used for cooling, or more turbine stages require cooling, the trade off is less advantageous.

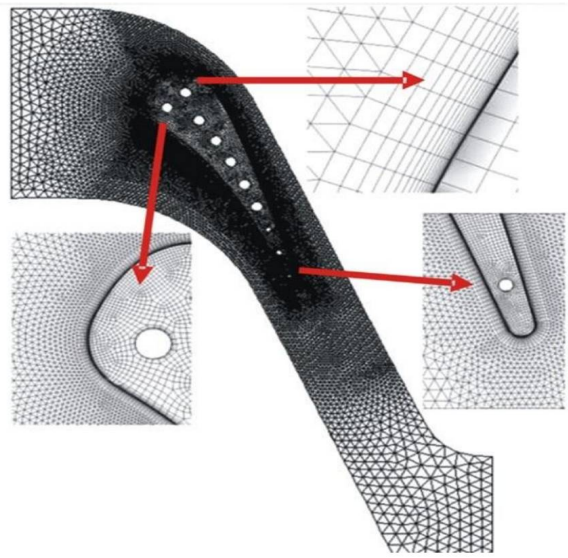


Fig: 7.1. View of numerical mesh on plane of constant span-wise coordinates.

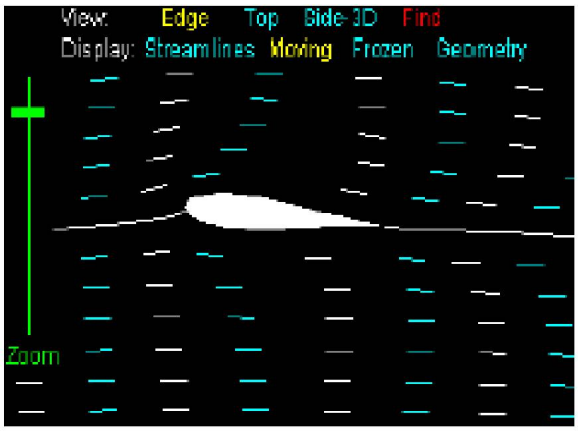


Fig: 7.2. Aerofoil Analysis

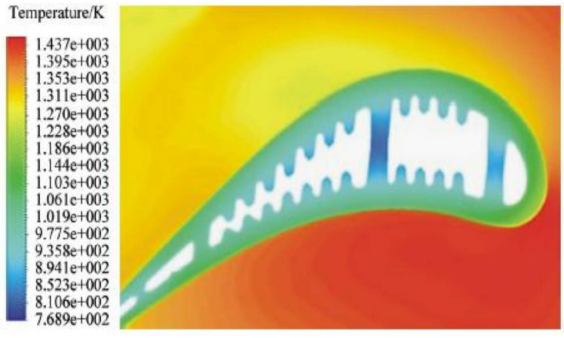


Fig: 7.3. Temperature distribution and flow field

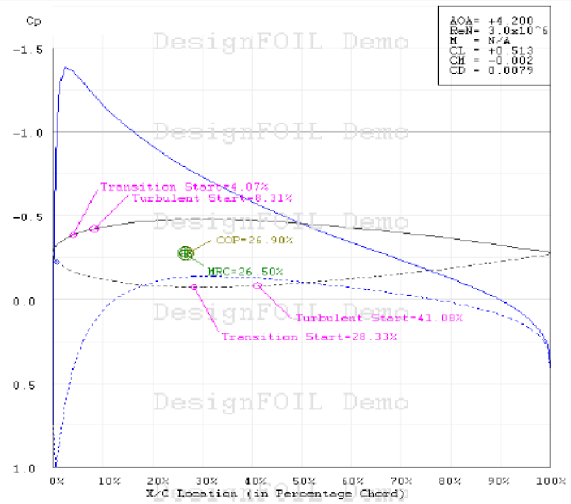


Fig: 7.4. Pressure Coefficient

CONCLUSION

The attempt has been taken to show the basic design, forces action on the blades, material selection for the blade, corrosion, and other damages to the blade, their prevention and other attributes key in blade design. Thus moderate analysis of gas turbine exposes facts of different engineering concerns. Proper selections of design parameters are real derivatives of huge extrapolation of the topic. Aerofoil profile and cooling effects are the most basics to be taken care off while optimizing blade profile design for maximum efficiency. To find the proper correlation between the design parameters are the basic objectives of the present work.

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