

Review of Process and Material used for Design of Gas Turbine Blades

Jaishri patel¹, Jaishri dubey² Rajni Dewangan³ Prakash kumar sen⁴ Shailendra kumar bohidar⁵

^{1,2,3}Student, Bachelor of Engg. (Mechanical Engg.),

Kirodimal Institute of Technology, Raigarh, Chhattisgarh, India

^{4,5}Faculty, Department of Mechanical Engg,

Kirodimal Institute of Technology, Raigarh, Chhattisgarh, India

ABSTRACT

Gas turbine blades have numerous applications in the aerospace industry. This paper is focused on different design blades of gas turbine. The gas turbine obtains its power by utilizing the energy of burnt gases and the air which is at high temperature and pressure by expanding through the several rings of fixed and moving blades. The first centrifugal stress act on the blade due to high angular speeds and second is thermal stress that arises due to temperature gradient within the blade material.

Keyword: - Aluminum and steel alloye, Airfoil, gas turbine blade.

I. INTRODUCTION

The turbine is a rotary mechanical device that extracts energy from a fluid flow and converts into useful work and purpose of turbine technology are to extract the maximum quantity of energy from the working fluid to convert it into useful work with maximum reliability, minimum cost, minimum supervision and minimum starting time.

Gas turbine are used extensively for aircraft propulsion, land based power generation and industrial application. Thermal efficiency and power output of gas turbine increases with increasing turbine rotor inlet temperature. The current rotor inlet temperature level in advanced gas turbine is far above the melting point of the blade material. Therefore, along with high temperature development, sophisticated cooling scheme must be developed for continuous safe operation of gas turbine with high performance. [1]

The number of turbine stages varies in different types of engines, with high bypass ratio engines tending to have the most turbine stages.

The number of turbine stages can have a great effect on how the turbine blades are designed for each stage. Many gas turbine engines are twin spool designs, meaning that there is a high pressure spool and a low pressure spool. Other gas turbines used three spools, adding an intermediate pressure spool between the high and low pressure spool. The high pressure turbine is exposed to the hottest, highest pressure, air, and the low pressure turbine is subjected to cooler, lower pressure air. That difference in conditions leads the design of high pressure and low pressure turbine blades to be significantly different in material and cooling choices even though the aerodynamic and thermodynamic principles are the same. The length of a blade depends on the style (impulse or reaction), the overall size of the turbine, whether it is an axial flow or radial flow turbine, and where the vibration environment. All three of these factors can lead to blade failures, which can destroy the engine, and turbine blades are carefully designed to resist those conditions. [2]

II. GAS TURBINE AND TURBINE BLADE

An internal combustion engine in which expanding gases from the combustion chamber drive the blade of a Turbine is known as Gas Turbine.



Fig 1. Gas Turbine Simple Open Cycle

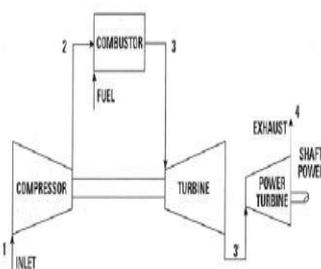


Fig 2. Turbine blade

Any of a number of blades like vanes assembled around the periphery of a turbine rotor to guide the steam or gas flow is known as Turbine blade. [3]

III. PRODUCTION OF BLADES

Blades may be considered to be the heart of turbine and all other member exist for the sake of the blades. Without blade there would be no power and the slightest fault in blade would mean a reduction in efficiency and costly repairs. The following are some of the methods adopted for production of blades:

- □Rolling: Sections are rolled to the finished size and used in conjunction with packing pieces. Blades manufactured by this method do not fail under combined bending and centrifugal force.
- □Machining: Blades are also machined from rectangular bars. This method has more or less has the same advantage as that of first. Impulse blade is manufactured by this technique.
- □Forging: Blade and vane sections having airfoil sections are manufactured by specialist techniques.
- □Extrusion: Blades are sometimes extruded and the roots are left on the subsequent machining. This method is not reliable as rolled sections, because of narrow limits imposed on the composition of blade material [4].

IV. TUBINE BLADE MATERIAL

Advancements made in the field of materials have contributed in a major way in building gas turbine engines with higher power ratings and efficiency levels. Improvements in design of the gas turbine engines over the years have importantly been due to development of materials with enhanced performance levels. Gas turbines have been widely utilized in aircraft engines as well as for land based applications importantly for power generation. 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 [4].

The material available limits the turbine entry temperature (TET) the properties required are as follows (a) tensile strength (b) resistance to high frequency vibration fatigue stresses(c) low frequency thermal fatigue stresses (d) resistance to erosion and corrosion [5].

1. Stainless Steel Alloy

In spite of this there is a group of iron-base alloys, the iron-chromium-nickel alloys known as stainless steels, which do not rust in sea water, are resistant to concentrated acids and which do not scale at temperatures up to 1100°C. It is this largely unique universal usefulness, in combination with good mechanical properties and manufacturing characteristics, which gives the stainless steels their *raison d'être* and makes them an indispensable tool for the designer.

The usage of stainless steel is small compared with that of carbon steels but exhibits a steady growth, in contrast to the constructional steels. Stainless steels as a group is perhaps more heterogeneous than the constructional steels, and their properties are in many cases relatively unfamiliar to the designer. In some ways stainless steels are an unexplored world but to take advantage of these materials will require an increased understanding of their basic properties [6].

2. Titanium Alloy

These titanium alloys are mainly used for substituting materials for hard tissues. Fracture of the alloys is, therefore, one of the big problems for their reliable use in the body. The fracture characteristics of the alloys are affected by changes in microstructure. Therefore, their fracture characteristics, including tensile and fatigue characteristics should be clearly understood with respect to microstructures. The fracture characteristics in the simulated body environment also are identified because the alloys are used as biomedical materials. The effect of living body environment on the mechanical properties is also very important to understand.

3. Alpha Structure (α Alloy)

With alpha stabilizer elements present, these alloys possess excellent creep resistance. They are also used largely in cryogenic applications.

4. Alpha Beta Structure (α - β Alloy)

This group contains both alpha and beta stabilizer elements. This is the largest group in the aerospace industry.

5. Beta Structure (β Alloy)

With beta stabilizers this group has high harden ability and high strength, but also a higher density. Titanium alloys use in aero engines, Automotive, Airframes and road transport, Dental alloys, geothermal plant, Marine and Military hardware [7].

6. Aluminium Alloy

The production of primary aluminium is a young industry - just over 100 years old. But it has developed to the point where scores of companies in some 35 countries are smelting aluminium and thousands more are manufacturing the many end products to which aluminium is so well suited. Alloy A380 (ANSI/AA A380.0) is by far the most widely cast of the aluminium die-casting alloys, offering the best combination of material properties and ease of production. It may be specified for most product applications. Aluminium Alloys use in Electrical Conductors, Transport, Packaging, and High pressure Gas Cylinders [4].

V. THE DESIGN PROCESS

The design process of a gas turbine is an iterative process between different phases of complexity where the result from one phase is the input to the following. The design method and work procedure described in this chapter is mainly based on the methodology presented by Moustaphaetal. [8].

But is also well represented by the actual procedure used in the industry. Since the task of this thesis was to achieve a scaled design of an existing rotor blade, the design process explained here has not been strictly followed but modified to fit the purpose. Still, the main ideas and goals of each design step are valid and acts as good guidelines of what parameters to modify at each step. In general some basic conditions are initially known, or at least are said to be known, in form of specifications.

These conditions naturally depend on the application of the turbine. Different applications require certain specifications that have to be fulfilled. Required output for power generation or thrust propulsion for aeronautic use combined with requirements on machine weight, shaft rotational speed and inlet conditions generally forms the initial starting point for the design.

Figure 3 shows the basic design process from an aerodynamic design perspective. The different steps will be discussed in the same order as in the work process in the diagram.

1. 1D Mean line design

It is customary to start the design with a mean line 1D design of the turbine. As a one dimensional analysis, no variation in the radial or the tangential direction will be captured and the flow will only be calculated along a streamline at, or close to, the mean radius. However far from representative of the real flow it is sufficient enough as a first approximation. In this phase of the design many of the parameter come to play as

preliminary guidelines and every manufacturer has its own restrictions regarding the acceptable range of every parameter. For an example, the choice of stage reaction decides the velocity triangles at the leading and trailing edges and is therefore one of the more crucial parameters to decide initially. Again there are many philosophies regarding the choice of optimal stage reaction and no explicit answer exists. The overall purpose of the mean line design is to determine the basic parameters of the turbine at mid radius. Together with empirical or semi empirical loss models a first estimation of the performance of the turbine stage can be made already at this early stage.

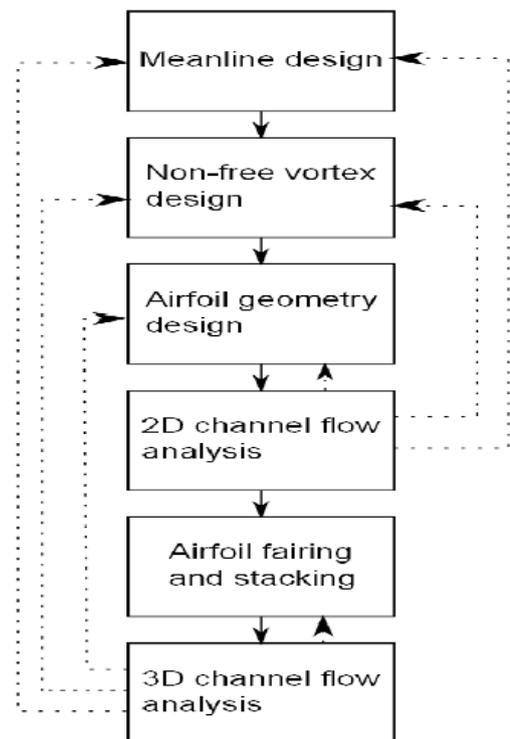


Fig 3. The aerodynamic design process.

2. 2D Through flow design

The next step is to consider the radial variations together with the axial variations. This is done in a two dimensional through flow design. Even though no three-dimensional effects can be captured, the main flow behaviour is provided. The goal in the through flow design is to estimate, and optimize, the radial distribution of work in the turbine. This is done by calculating the flow along a number of streamlines at different radii, see Figure 4 The radial distribution of the flow is governed by the radial equilibrium equation. One of the earliest design philosophies in turbo machinery was to design with constant specific work across the span. If also the loss and axial velocity distribution is constant over the span the free vortex equation can be derived, which for a long time was the praxis of turbine design. The drawback

of this method is that the variation of the blade inlet angle may differ greatly from hub to tip which will expose the blade to high mechanical stresses, and nowadays it is more common to apply a non-free vortex design (non constant work distribution across the span).

Either way the radial equilibrium must still be fulfilled. Since many of the design parameters are still not decided assumptions have to be made about the flow blockage due to the blades themselves. Further simplifications and assumptions are introduced with respect to boundary layer thickness and losses before the radial equilibrium equation can be solved. The effects of viscosity may be neglected or included in the calculations. A viscous solver, as the name implies, takes viscous effects into account and will give a more physical result at the expense of being more time consuming and the accuracy of the result will still be a coarse approximation of the real flow. An inviscid solver is more dependent correlations of assumptions and but with well calibrated loss models and reasonable assumptions a good result could still be provided. The first result from the through flow calculation has to be validated and most certainly remade later in the design process when further and more accurate information is known from three dimensional flow analysis

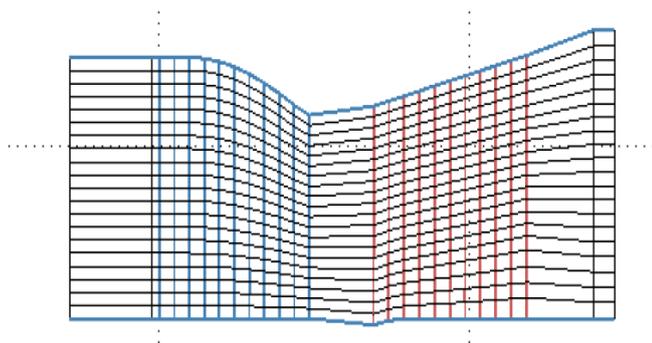


Fig 4. Through flow computational domain of the test turbine build

3. 2D Airfoil design

With the flow conditions given at a number of sections by the through flow design the airfoils for each section can be designed. The number of required sections will depend on the complexity of the blade, where simple blade geometries require fewer sections. At this step the metal angles of the blades will be decided with regard to incidence for the inlet angle and deviation for the outlet angle. The goal with the aerodynamic design of the airfoils is to minimize the aerodynamic related losses but still fulfil structural and manufacturing limitations and, if necessary, requirements regarding internal cooling flows. Nowadays the actual geometry of the airfoil surface is commonly created by computer programs where the curvature is described by a number of Bezier

polynomials. The curvature is defined as a function of the first and second derivate of the coordinates and must be designed without any discontinuities. During the design, the Mach number distribution along the airfoil surface is calculated and the geometry should be optimized to give the desired distribution. Governing parameters could be absolute values, e.g. subsonic Mach numbers, or other parameters as the diffusion coefficient. Many airfoil design programs also have functions for loss correlations implemented which directly give the designer further hints about the performance of the airfoil.

When the airfoils at every section have been determined they are stacked and the full three dimensional geometry of the blade is created. There are many ways to stack the sections depending on the design philosophy. To ensure that the centrifugal force on a rotating blade does not introduce any bending moments it is desirable to stack the sections with their centre of mass along a radial line. However, from an aerodynamic point of view it is often desirable to lean or bow the blade to minimize the effects of secondary flow losses and tip leakage. Hence the final design is a compromise between performance and structural limitations.

4. 3D Flow analysis – CFD

The final design or control step is a fully three dimensional flow analysis of the proposed design. This is done by CFD (computational fluid dynamics) where the complete Navier Stokes equations are solved to some extent depending on the method. A full 3D simulation of a turbine stage can take from a couple of hours up to weeks or even months to solve depending on the method and the requirements of accuracy of the solution. The purpose of the CFD analysis is to validate the performance prediction from the through flow analysis or to enlighten unknown flow behaviour that has not been accounted for. Based on the CFD result the blade design may have to be reconsidered, in which case the designer has to change the airfoil design or even revisit the through flow or mean line design. It is clear that a good initial design saves a lot of time and the more work and thought spent at the earlier steps, the more likely it is that the designer does not have to redo the whole procedure. Finally it should be said that the results from a CFD calculation are not more accurate than the boundary conditions, which in many cases are not fully known. Even apart from this there are bound to be approximations, both in the model of the blade geometry and in the CFD code with regard to turbulence modelling, numerical discretization etc. and the actual performance of the blade will differ from the calculated result. [9]

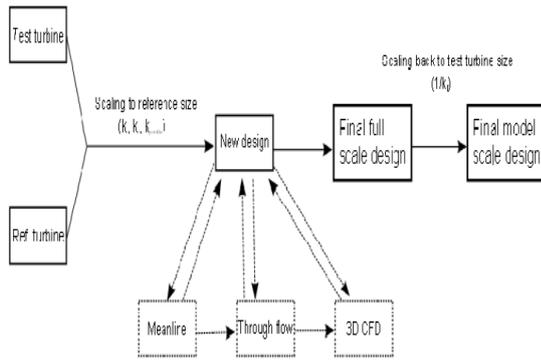


Fig 5. Design process

	leading edge geometry (circle, ellipse, spline) blade angles	radial smoothing of the blade
	inlet metal angle, exit metal angle	high aspect ratio of surface mesh
	inlet & exit wedge angle	

VII. CONCLUSION

The design of the blade is based on an industrial gas turbine, which acted as a reference. The design was performed at the reference scale and with similar gas conditions. The improvements in net specific work and efficiency due to each modification are assessed and the selection of optimum design point is discussed. Future trends will very likely show a systematic commercialization of the standard techniques. Their application is mandatory to maintain design process efficiency and keep leading in the cost-; time and innovation competition world-wide. 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 objectives of the present work.

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VI. CONSTRAINT IN DESIGN OF TURBINE BLADE

The design of a turbo machinery blade is an iterative process, where a number of (sometimes competing) targets have to be met.

The following is a list of the major design constraints and variables which are checked during the design phase:

Table 1 Constraints
Mechanical Thermodynamic constraints [10]

Constraints		
Mechanical	Thermodynamic constraints	
aerodynamic block axial positioning of the blade	2-D, quasi 3-D	3-D
annulus definition, curved blade edges axial position	Through flow values	stack (positioning of blade sections along in the radial direction)
torsion and bending modes of the blade	air inlet & exit angles, mach numbers, pressures, temperatures	end bends
life (for turbine blades)	turbulence ratios	
FOD (foreign object damage)	Passage area, throat area	end wall treatment
	Stagger	3-D blading
	Camber	tip leakage flow
	position of maximum thickness	casing & hub treatment
	curvature distribution on suction and pressure side	non-axisymmetric end-walls