AIJREAS VOLUME 5, ISSUE 3 (2020, MAR) (ISSN-2455-6300)ONLINE
Anveshana's International Journal of Research in Engineering and Applied Sciences

PERFORMANCE STUDY ON AXIAL FLOW GAS TURBINE AT HIGHER TEMPERATURES

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Abstract:

A parametric study is carried out for aerodynamic performance of turbines including geometrical requirements, thermal requirements, mechanical integrity and manufacturing requirements. Life cycle costs, product cycle time and weight are additional, possible criteria during the parametric study. Preliminary design plays an important role in reaching the final design of the turbine This research work thoroughly focuses on how the blade configuration are designed to achieve the desired output. Development of the axial flow gas turbine was hindered by the need to obtain both a high-enough flow rate and compression ratio from a compressor to maintain the air requirement for the combustion process and subsequent expansion of the exhaust gases. the profile generation, in addition to aerodynamic performance, additional constraints for castability, structural requirements and thermal requirements need to be considered. Thus profile generation is a trade-off between contradicting requirements of aerodynamic performance, structural and thermal performance.

Key Words: *Axial, Blade, Combustor, Efficiency and Reaction Turbine.*

1.0 INTRODUCTION

The main components of a micro gas turbine engine are a centrifugal or mixed flow compressor, a combustion chamber and a single stage axial-flow or radial flow turbine. The goal of this thesis is to formulate a design methodology for small axial-flow turbines. This goal is pursued by developing five design-related capabilities and applying them to develop a turbine for an existing micro gas turbine engine. Firstly, a reverse engineering procedure for producing digital three-dimensional models of existing turbines is developed. Secondly, a procedure for generating candidate turbine designs from performance requirement information is presented. The third capability is to use independent analysis procedures to analyse the performance of a turbine design.

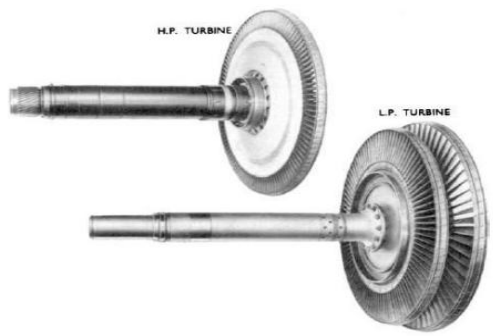

Figure 1: Axial flow Turbine Rotor

The fourth capability is to perform structural analysis to investigate the behavior of a turbine design under static and dynamic loading. Lastly, a manufacturing process for prototypes of a feasible turbine design is developed. The reverse engineering procedure employs point cloud data from a coordinate measuring machine and a CT-scanner to generate a three-dimensional model of the turbine in an existing micro gas turbine engine. The design generation capability is used to design three new turbines to match the performance of the turbine in the existing micro gas turbine engine. Independent empirical and numerical turbine performance analysis procedures are developed. They are applied to the four turbine designs and, for the new turbine designs, the predicted efficiency values differ by less than 5% between the two procedures. A finite element analysis is used to show that the stresses in the roots of the turbine rotor blades are sufficiently low and that the dominant excitation frequencies do not approach any of the blade natural frequencies.

2.0 LITERATURE REVIEW

In general, military aero gas turbine engine high pressure and low-pressure turbines are of single stage configuration with a view of light weight, low initial and maintenance cost due to reduction in number of components and expensive air-cooled aerofoils [1]. Though single stage offers compactness and simplicity, it results in high turbine stage work loading and expansion ratios. This leads to reduction in the turbine efficiency which in-turn results in higher Specific Fuel Consumption (SFC) of the engine. Lower SFC can be achieved by higher overall engine pressure ratio, Turbine Entry Temperatures (TET) and higher component efficiencies. Higher TET's leads to higher specific thrust but reduces turbine component's life. Hence design of single stage high energy efficient turbine with required life is a challenging job. Hence, a lot of research work is going to improve the turbine efficiency in this regard [2, 3, 4 and 5]. In the mean line design, the meridional flow path, mean velocity triangles, number of vanes and blades are obtained. Therefore, parametric study of the mean line design satisfying the conflicting requirements of aerodynamic performance and thermal, structural and casting requirements plays an important role in reaching the final design of the turbine [6]. The parametric study presented in the paper is a generalized design procedure which can be used for the stator and rotor blades of both high pressure and low-pressure turbines.

3.0 RESEARCH METHODOLOGY

A computer code is developed for the mean line design of an axial flow turbine to achieve high turbine efficiency by considering aerofoil cooling, castablity, structural aspects and weight. The inputs for the design code are turbine inlet mass flow (m), inlet total pressure (P0), Turbine Entry Temperature (TET), power to be produced, turbine spool speed (rpm), stage loading (ψ) / mean radius (Rm), flow coefficient (φ), exit swirl angle (α3), and total to total isentropic efficiency (η). In the code, the mean radius is calculated from the stage loading or vice-versa. Using the input parameters, the meridional flow path, mean velocity triangles, stress function and reaction are calculated. The losses are estimated using the empirical correlations given in the references Incidence losses are estimated using the correlations given in the reference The optimum space-chord ratio and hence the number of blades are estimated using the correlation as explained in The corresponding aerofoil geometric characteristics are obtained based on the method explained in reference The code is updated with the in-house database and design experience. The code also can estimate the creep life using the Larson-Miller Parameter for the selected materials. A first estimate of the weight of the module is calculated in the code using the empirical method outlined in the reference Castablity requirements in terms of the trailing edge radius and minimum wall thickness are taken into consideration. The design code takes into consideration the structural requirements in terms of area taper ratio, Stress function and AN2 (annulus area * rpm2) value. The code takes into account the cooling requirements in terms of blade maximum thickness to chord ratio (Tmax/c) value.

Parametric study of the mean line design of a turbine

A parametric study of the mean line design of an axial flow turbine is carried out to understand the effect of various parameters. The code is modified to evaluate the effect of the input parameters (a) stage loading (b) flow coefficient (c) exit swirl angle. One of the parameters is held constant and then other two parameters are varied. The code provides a quick and vast database of the variations of the output parameters with respect to the parametric study variables.

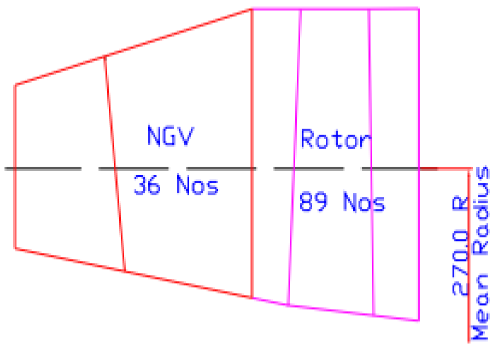

Figure 3.1 Meridional Flow path

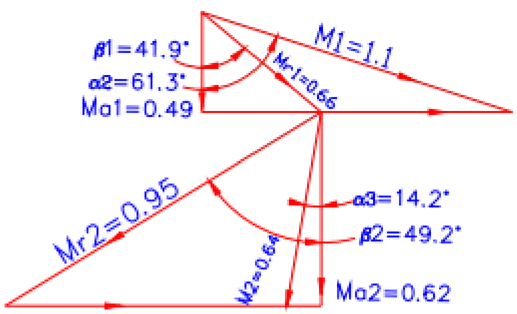

Figure 3.2 Mean Velocity Triangle

AEROFOIL PROFILE GENERATION BY BEZIER CURVE METHOD

Bezier curves are basically smooth curves which are drawn between two points using two or more control points which guide the path of the curve. The slope of the curve at the end points is defined by the control points. Since the control points are independent of one another, the relative position of these control points with respect to the end points only determines the shape of the curve. Therefore, any number of curves can be fitted between the endpoints by changing the relative position of the control points the method of aerofoil profile generation using Bezier curves modifies the way of defining the curves connecting the five points and defines the profiles at different radii like the 11-parameter method. Thus, the advantages of the 11-parameter method are retained. In both the 11-parameter method and the modified method, the profiles are generated from scratch based on the flow conditions at different radii obtained from a hub to tip analysis code developed using the Stream Line Curvature (SLC) method.

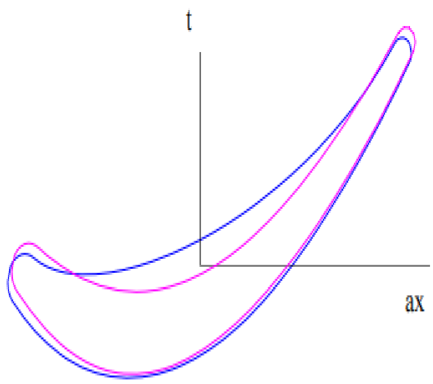

Figure: Profiles generated using the 11-parameter method (Magenta) and Bezier curves (Blue) profile

4.0 RESULTS AND DISCUSSIONS

A parametric study of the mean line design of an axial flow turbine is carried out to understand the effect of various parameters. The code is modified to evaluate the effect of the input parameters (a) stage loading (b) flow coefficient (c) exit swirl angle. One of the parameters is held constant and then other two parameters are varied. The code provides a quick and vast database of the variations of the output parameters with respect to the parametric study variables. Variations of turbine efficiency, stress function (AN2 value) and weight with respect to stage loading and flow coefficient is obtained. Figure shows the variation of the turbine efficiency with stage loading for different flow coefficients in the range of 0.95 – 1.04 at a constant exit swirl angle at the turbine stage exit.

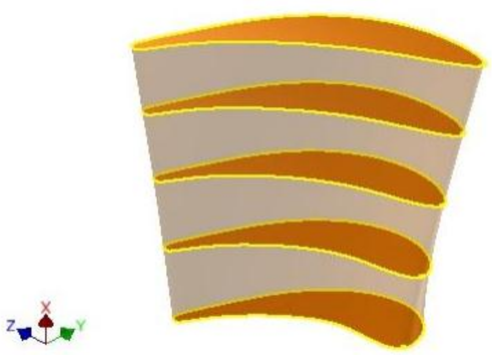

Figure 4.1 : Rotor blade profile stacking

Table:4.1 The input condition of the Low Pressure

S.No	Parameter	Value
1	Inlet Total Temperature (T0in)	1385 K
2	Inlet Total Pressure (P0in)	802 kPa
3	Inlet Mass flow	52.7 kg/s
4	Rotational Speed	13040 rpm

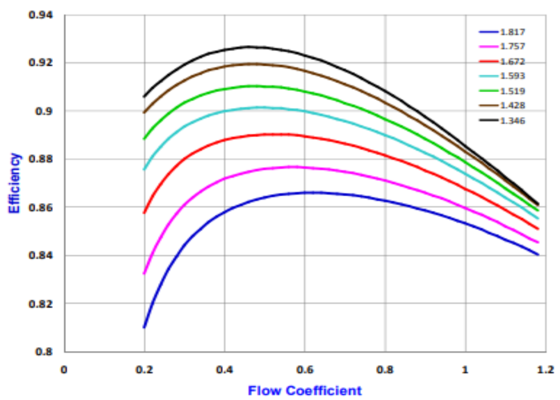

Figure 4.1 Turbine Efficiency Vs Flow Coefficient for different stage loadings at constant swirl angle

It is seen that for each stage loading, there is an optimum flow coefficient at which the turbine efficiency is maximum. This is because when the flow coefficient increases the exit Mach number increases and the exit angle of the flow decreases, which have opposite influence on the losses.

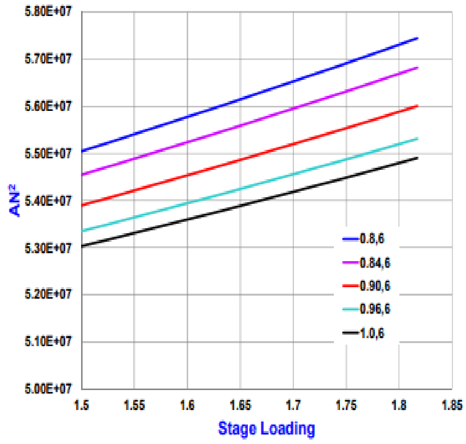

Figure: AN2 Vs Stage Loading for different flow coefficients at constant swirl angle

the variation of the AN2 value with flow coefficient for different stage loadings at a constant swirl angle. It is seen that as the flow coefficient increases, the AN2 value decreases because lower area is required to pass the same mass flow.

Conclusion:

A multi-disciplinary approach has been attempted for the preliminary design of a turbine stage. Preliminary design plays an important role in reaching the actual design of the turbine. Hence it is important that all the key parameters are finalized in preliminary design and fine-tuned to achieve the required performance in the final design. Hence a parametric study is a pre-requisite to any optimization method. This parametric study helps in reducing the number of design iterations by aiding in the proper determination of the key parameters in the preliminary design stage. The utilization of Bezier curves gives better flexibility in meeting the structural, thermal and manufacturing requirements of the turbine vane and blade.

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