FINITE ELEMENT ANALYSIS OFAXIAL FLOW TURBINE

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Abstract: **In the field of competition, all companies should supply their goods and services with high quality, in shortest period with lower prices than its competitors in order to keep their capacity and power to compete. The Axial Flow Turbine wheel is the most efficient types of water turbines.For the industrial application of turbines, it must be ensured that the turbine wheels could be used safety under the fatigue life and the deformations produced by the pressure of the fluid. In conventional runner the jet of water is directly strike to splitter of the rotor rotor geometry and transfers the force to it than rotor rotor geometry convert it into momentum by which the shaft is rotate and giving us power Rotor geometry dimensions maintained should be an optimized one; else it will lead to cost implication/will lead to failure of the turbine. This project set out to verify finite element analysis, or FEA, when applied to Axial Flow Turbine. In this study, we carried out the structural/thermal and modal analysis of the Rotor geometry in the Axial Flow Turbine using ANSYS Workbench 17.0. The main objective is to find out the Displacement, Equivalent and Fatigue stresses in the rotors when subjected to structural and thermal Loads.Validation of the FEA results is supported by stress analysis using classical theory of mechanics. Numerically calculated stresses are compared with the an extremely powerful tool when employed correctly.**

I.INTRODUCTION

In the history of energy conversion, however, the gas turbine is relatively new. The first practical gas turbine used to generate electricity ran at Neuchatel, Switzerland in 1939, and was developed by the Brown Boveri Company. The first gas turbine powered airplane flight also took place in 1939 in Germany, using the gas turbine developed by Hans P. von Ohain. In England, the 1930s' invention and development of the aircraft gas turbine by Frank Whittle resulted in a similar British flight in 1941.

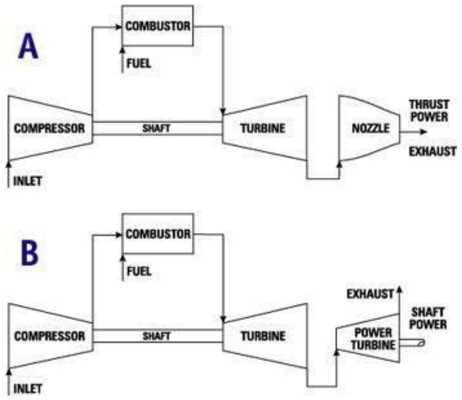

Fig. 1 Schematic for a) an aircraft jet engine; and b) a land-based gas turbine

The name "gas turbine" is somewhat misleading, because many it implies a turbine engine that uses gas as its fuel. Actually a gas turbine (as shown schematically in Fig. 1) has a compressor to draw in and compress gas (most usually air); a combustor (or burner) to add fuel to heat the compressed air; and a turbine to extract power from the hot air flow. The gas turbine is an internal combustion (IC) engine employing a continuous combustion process. This differs from the intermittent combustion occurring in Diesel and automotive IC engines.

A.AXIAL FLOW TURBINES

The axial flow turbine consists of one or more stages located immediately to the rear of the engine combustion chamber. The turbine extracts kinetic energy from the expanding gases as the gases come from the burner, converting this kinetic energy into shaft power to drive the compressor and the engine accessories. A working liquid contains P.E. (pressure head) and K.E. (velocity head). The liquid may be compressible or incompressible. A few physical standards are utilized by turbines to gather this energy: The turbines can be classified as (1) impulse and (2) reaction. In the impulse turbine, the gases will be expanded in the nozzle and passed over to the moving rotors. The moving rotors convert this kinetic energy into mechanical energy and also direct the gas flow to the next stage (multi-stage turbine) or to exit (single-stage turbine). Impulse turbines alter the direction of stream of a high speed liquid or gas jet. The subsequent impulse turns the turbine and leaves the liquid stream with to the blading on the rotor. the efficiency of a compressor, and the design process is often much simpler. is much more difficult to arrange for an efficient deceleration of flow than it is to obtain an efficient acceleration.

II. PROBLEM DEFINITION

The stress analysis of almost every part of a gas turbine is of major concern to the designer. The rotor disc, which transmits torque from the rotors to the shaft of the engine, constitutes an important part of the turbine. The problem of optimizing the disc configuration becomes more significant with the ever increasing demand for higher power and lighter weight of the gas turbine. The continuing emphasis on longer life together with reliable and safe operation in severe environments requires greater accuracy and speed in the mechanical analysis of the various parts of the turbine, especially the rotor disc.

Fig. 2 Rotor Assembly of Axial Flow Turbine

The objective of present day structural design is to arrive at the most efficient structure, subjected to certain constraint conditions, for the specified load and temperature environment. In the design of the rotor disc certain geometrical restrictions may be imposed on the profile of the disc by its functional aspects as well as the geometry of other parts of the turbine. In a turbine disc, in addition to the stresses resulting of the system makes it impossible to consider the entire system with all its generalities, for the analysis. In general the component parts of the rotor are analysed separately, and evenso making several simplifying assumptions to facilitate the analysis. Invariably both the disc and the loading are considered to be axisymmetric while analysing the stresses.The stress analysis of typical rotating rotor for axial flow rotors is quite well understood, and reliable methods for calculation of steady stresses from rotation and thermal loading are available.

III.DESIGN OF AXIAL FLOW TURBINE ROTOR

By using standard assumptions, theoretical calculations are made to obtain the dimensions of the rotor geometry. Also some of the dimensions are taken from the literature survey.

A.DESIGN PARAMETERS

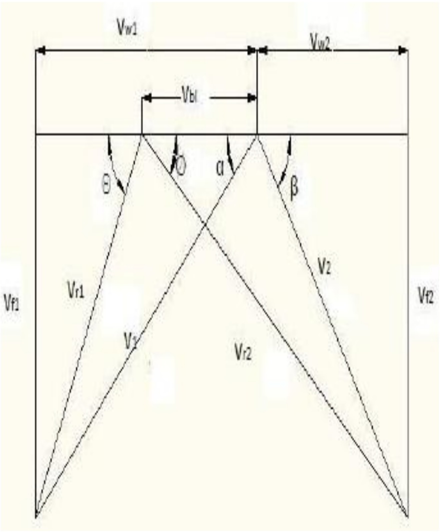

Fig. 3 Velocity Triangle

Inlet flow angle α = 18

Inlet rotor angle Θ = 45

Outlet flow angle β = 36.75

Outlet rotor angle = 13

Diameter of rotor mid span = .15+.60 = .75

Design speed of turbine = 4500 rpm

Rotor velocity Vbl = (π*d*n)/60 = 176.714 m/s

Inlet flow velocity V1 = 360 m/s

Inlet relative velocity Vr1 = 234.28 m/s

Inlet whirl velocity Vw1 = 342.380 m/s

Inlet flow velocity Vf1 = 111.246 m/s

Outlet relative velocity Vr2= 234.28 m/s

Outlet whirl velocity Vw2 = 51.561 m/s

Outlet flow velocity Vf2 = 52.701 m/s

Finding tangential Force (Fr) and Axial force (Fa) on each rotor

Tangential force in Newton's Ft = M (Vw2 – (-Vw3)]

Axial Force in Newton's FA = M (Vf2 – (-Vf3)]

Where m represents mass flow rate of gases through the turbine in kgs / sec.

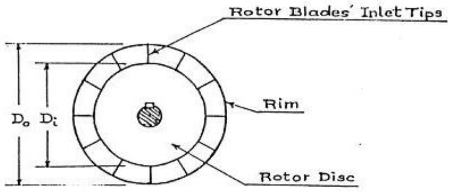

Fig. 4 Rotor Assmbly Configuration

Outer Dia of the Rotor (with rotor height) Do = 900 mm

Inner Dia of the Rotor (root of the rotor) Di = 600 mm

M = p2 x π (D0-Di)/4 x V f2

= 0.524*π*(0.9-0.6) *52.701/4

= 6.506 kg/m^3

Ft = 6.506*(342.380-(-51.561))

= 2563 N

Fa = 6.506*(111.246+52.701)

= 1067 N

No of rotor passes = 60

For single rotor

Ft = 2563/60

= 43 N

$Fa = 1067/60$

$= 18 N$

B.POWER GENERATION:

$P = m \{Vw1\, U – (-Vw2\, U)\}$

$= 6.506*\{342.380+51.561\}*176.714$

$= 456.914\ KW$

C.CENTRIFUGAL FORCE

$R1 = 300\ mm = 0.3\ m$

$R2 = 450\ mm = 0.45\ m$

Angular velocity $w = \pi*d*n/60$

Speed $n = 4500\ rpm$

We know that $F = mr\omega 2$

Consider a small segment of mass *m*δ, of length having width δr at a distance *r* from the centre.

Then the equation for the centripetal force δF on this small segment is given by:

$\delta F = \delta m w2r$

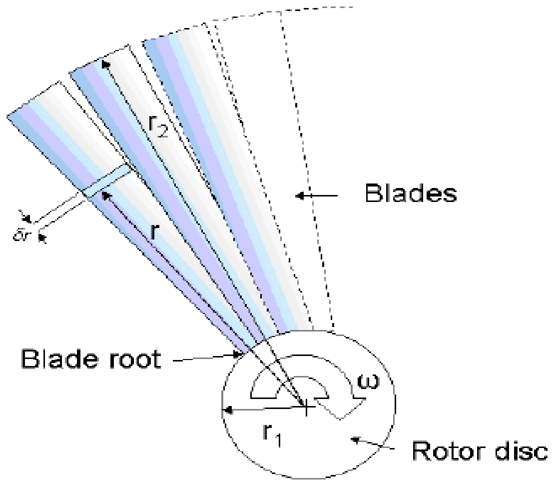

Fig. 5 Rotor Assembly Configuration

In practice, a rotor tapers in thickness towards its tip; but, for simplicity, assuming the rotor to have a constant cross sectional area A(m2) and material density ϱ (kg/m3), we can write:

$\Delta m = \varrho A \delta r$

$\delta F = \varrho * A * \delta r * w2 * r$

$dF = \varrho * A * w2 * r * dr$ on integrating

$F = \varrho A W^2((R2)^2-(R1)^2)/2$

IV.INTRODUCTION TO FINITE ELEMENT ANALYSIS

The finite element method (FEM) (its practical application often known as finite element analysis (FEA)) is a numerical technique for finding approximate solutions of partial differential equations (PDE) [17] as well as of integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge-Kutta, etc. Finite Element Modeling is one of the most robust and widely used phenomenon to virtually Investigating the faults occurring in real time problems which are in general difficult to witness. a region by dividing it into small plugrete elements composed of interconnecting nodes. Finite element analysis obtains the solution to the model by determining the behavior of each element separately, then combining the individual effects to predict the behavior of the entire model. The interconnecting nodes of the elements make the solution of one element dependent on another, meaning that to reach an accurate solution, FEA must solve each element several times, possibly thousands of times, to reach a solution. The accuracy is also dependent upon the number of elements. More elements will increase the model’s solution accuracy, but as the number of elements increase, the solution time increases as well. Finite element analysis can be used with either 2-D or 3-D models. 3-Dmodels generally offer a more accurate analysis as they include all three planes of the physical world. A 3-D model is also composed of a great deal more nodes and elements as well, drastically increasing solution time. For this r, and θ, where θ is taken as 360°. Planar geometry generates a model using Cartesian components x, y, and z, where z is specified as some constant value for the entire model. The iterative nature of FEA makes the analysis of models impractical by hand but perfect for computers. Several electromagnetic FEA packages exist, ranging from fully three dimensional packages such as ANSYS and Maxwell 3D, to simpler 2-Dpackages like Maxwell 2D, Quickfield, and FEMM. All FEA computer simulations consist of three parts; the preprocessor, analysis, and postprocessor. The preprocessing consists of constructing the model from nodes, curves, and surfaces, models, this often involves a flux density plot, and the determination of circuit characteristics such as voltage drop, resistance, reactance, and inductance. These 3 steps are done in ANSYS 17.0 [20] tool.

A. MODEL GEOMETRY

In evaluating the geometry, there are several prime considerations. In addition to the necessity to accurately represent the actual geometry of the vessel or component of the vessel, one must consider the loading and support (boundary) conditions and the mesh to be employed. The extent of the rotor modelled is also of prime concern when the decision is made to model only part of an overall system. Rotor is modelled using the 3D Package Software CATIAV5.

B.MATERIAL PROPERTIES

The physical properties of the material such as elastic modulus, Poisson's ratio, coefficient of thermalexpansion etc. vary with the temperature. As the disk is subjected to severe thermal gradients, the, the density of the material is constant throughout the diskeven under a wide range of temperatures.The Material INCONEL 718 Material is used.This alloy is made of Niobium, Chromium & Nickel.

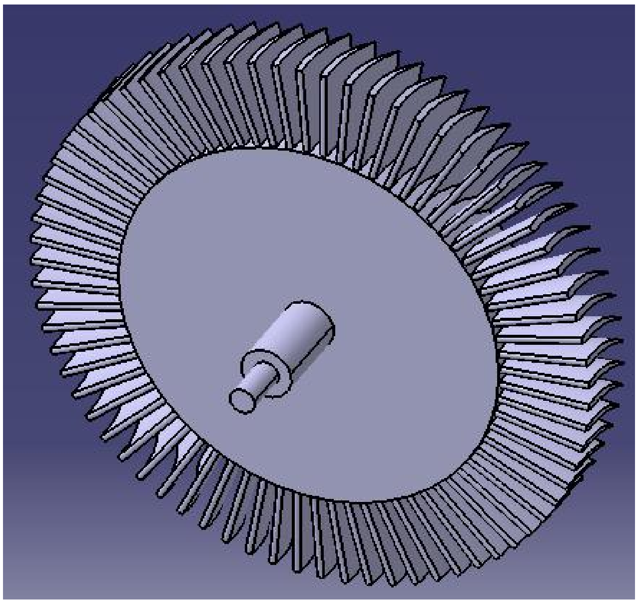

Fig. 6 Rotor Assembly Model

C.PREPROCESSING

The accuracy of the FE model is highly dependent on the mesh employed, especially if higher order (cubic, quadratic etc.) elements are not used. In general, a finer mesh will produce more accurate results than a coarser mesh. At some point, one reaches a point of diminishing returns, where the increased mesh density fails to produce a significant change in the results. At this point the mesh is said to be "converged." This process of refining the mesh and evaluating the results is normally referred to as a "mesh convergence" study or analysis. Although many FE codes contain "error estimates" of one sort or another, mesh convergence remains the most reliable means of judging model accuracy. Coarse meshes almost always under-report the stresses in a model. It is not uncommon to have maximum ence, gross errors in stress estimates are quite possible.Meshing has been done by using the method of fine elements of Tetrahedron. In Tetrahedron method the component is been divided into small triangle on its surface which gives number of nodes and elements of that component (Figure 7.2).

D.BOUNDARY CONDITIONS FOR STATIC STRUCTUAL ANALYSIS

- The Rotational velocity is applied to all bodies is 15000 RPM.
- Fixing condition is applied as Remote displacement that is Rotation in Z direction is free and other Degree of freedom is fixed.
- This remote displacement support is applied both ends of the shaft.
- Pressure load is applied on the faces of all the bodies' i.e. 0.9 bar.

E.BOUNDARY CONDITIONS FOR THERMAL ANALYSIS

- The temperature is applied in the shaft and bottom of the rim as 30^{o}C. Temperature is applied in outer rim and all rotors as 300^{o}C.

F.BOUNDARY CONDITIONS FOR MODAL ANALYSIS

A modal analysis determines the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamicanalysis, a harmonic analysis, of a structure for dynamic loading conditions. To include the pre-stress effects, we are considering here the **Static Structural** analysis in the **Initial Condition** environment field.

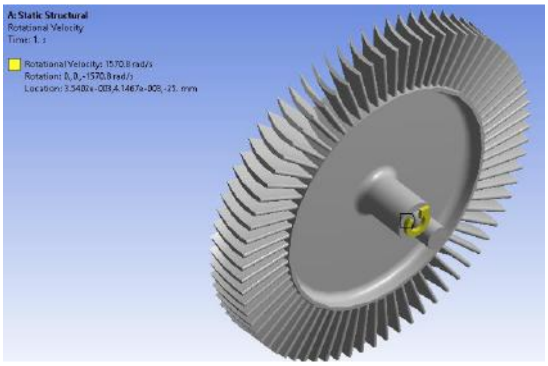

Fig. 8Static Structural Analysis –

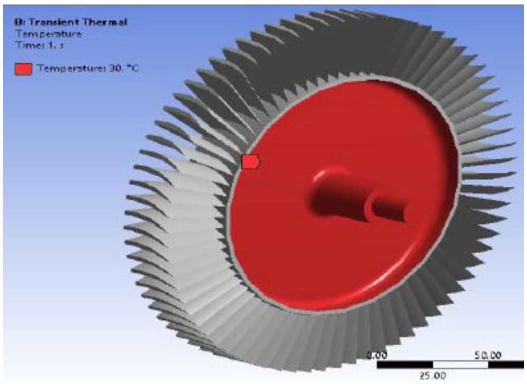

Fig. 9 Transient Thermal Analysis – Boundary Condition

G. POST PROCESSING

After applying the load and constraints, the turbine rotor is analysed for its structural strength, thermal considerations and modal analysis for its natural frequencies. Maximum stresses are observed at the trailing edge of blade near to the root. And the results are presented in the figure 6.10 to 6.13 as shown below.

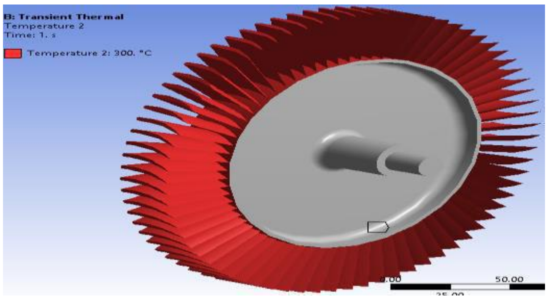

Fig. 10 Transient Thermal Analysis – Boundary Condition

From the below result, it is clear that the equivalent tri-axial stresses [10] are equally distributed along rotor geometry& they are highly concentrated on the root of the rotor blades and also at the most stress concentration area ie. The shaft's connecting radius to the rotor. Also it is evident that the total deformation is distributed in andescending manner from the top of the rotor blade to the shaft area.

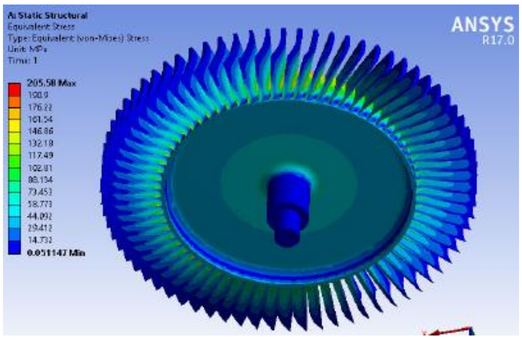

Fig. 11Equivalent Stress Plot of Rotor Assembly

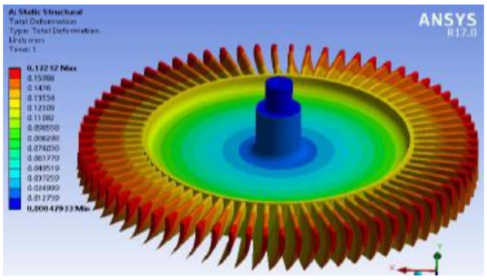

Fig. 12Total Deformation Plot of Rotor Assembly

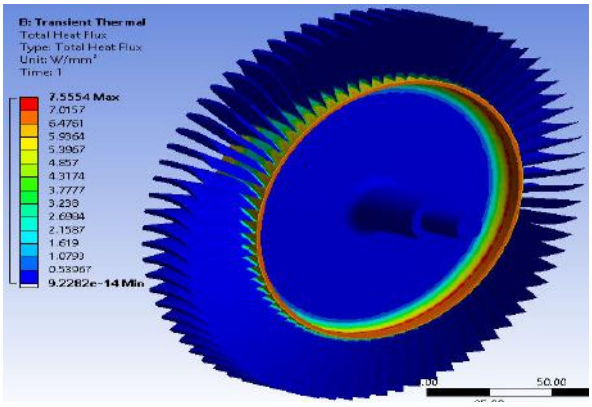

Fig. 13Total Heat Flux Plot of Rotor Assembly

V.RESULTS

This paper presents an efficient design process for gas turbine rotor housing.Boththe analysed stress values ie. Equivalent Stress and Maximum Principal Stress values are very less when compared to the Allowable Stress Values & Yield Strength Values as shown earlier in the Table of Material Properties.

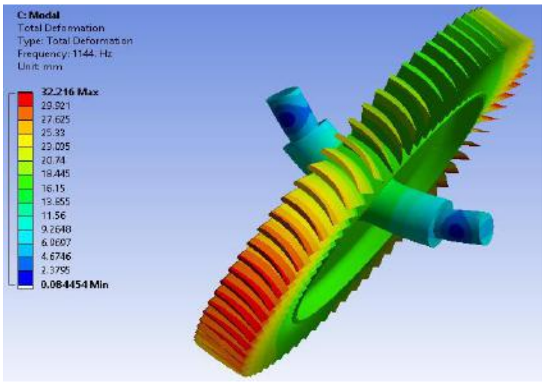

Fig14.Total Deformation Plot of Rotor Assembly

Maximum Equivalent Stress Value from the result = 206 MPa

But the Tensile Yield Strength of the Material Inconel 718 = 1069 MPa

Factor of Safety (FOS) for Equivalent Stress = 1069/ 692

Therefore FOS = 5018 for Equivalent StressHere the FOS is more than 1.5 which is extremely important in aero space applications.

Also the total deformations with respect to x, y & z axes are 0.17 mm which is very less which is less than 1 mm. Also the total heat flux of 7.5 W/mm^2 is concentrated only on the corner of the rim area which is very less..The results were compared with the experimental results in the literature and they were in good agreement.These show that the design of the axial flow turbine rotor is extremely safe during element engineering simulation of various stress and deformation tests at high pressure.

VI.CONCLUSION

Rotors are the most important parts of any Axial Flow Turbine in the Aviation Industry. And the design should satisfy the criteria's given in the international code, ASME Section VIII Division 1. They have to be designed carefully to cope with operating temperature and pressure. The research work deals with the modeling and analysis of turbine rotor. The structural finite element analysis was performed for the turbine rotor using ANSYS Workbench 17.0 software. The turbine rotors are subjected to high mechanical stresses and are operated in aggressive environments. The turbine rotors are made of exotic materials to survive in this environment. Material Inconel 718, which is used in the manufacturing of aero turbine rotor have been considered for the analysis under same operating conditions and the results are tabulated. FEA is a powerful tool in analyzing the various structures and the results provided by ANSYS Workbench 17.0 proved once again its reliability. The current capabilities of FE software on desktop computers provide the aero design engineers with the ability to employ FE analysis on a nearly routine basis. Aero design engineers must have a reasonable understanding of FE fundamentals to adequately use this design tool. The guidelines presented are intended as a starting point for the engineer tasked with conducting an FE analysis of a gas turbine rotor component. It is hoped that they will prove helpful. In the end, however, no set protocol of canned, "we solve everything automatically" can guarantee an accurate analysis for every project.

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