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Modelling and Analysis of Fir-Tree Joint in Turbine Disc with Solid and Hollow Blade

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ABSTRACT

The fir-tree joint used to hold a blade in place in a turbine structure is usually identified as a critical component which is subject to high mechanical loads. It is generally assumed that the main loading which act on the blade, the radial centrifugal tensile load results from the rotation of the Disc. Aim of project is to carry out three-dimensional finite element analysis of fir tree root of turbine rotor blade for two different design criteria (solid and hollow fir tree root) with different operational loads & different coefficient of friction, and hence to obtain the stress distribution and displacement value at different critical regions. Modal analysis is to be carried out to determine the vibration characteristics (natural frequencies and mode shapes) of turbine blade. The stress and vibration analysis are carried out using finite element method, Since hollow blade has less mass compared to solid blade, there is no much significant variation in the stress level and both the stresses lie within the limiting stress level as it is evident from the result, so as the mass is reduced the efficiency is increased in the turbine. The selection of any of above Turbine rotor blades has no major effect due to vibration and it is stable during operating.

Keywords— **Finite element analysis Fir tree, Modal analysis, Vibration characteristics**

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I. INTRODUCTION

Gas turbine engine design is most critical design. A good design provides all the strength and rigidity to fulfil design requirements. The various elements of the gas turbine engine are compressor, combustion chamber, convergent-divergent nozzle ,turbine and exhaust system . The sectional view of the gas turbine engine as shown in Figure 1.

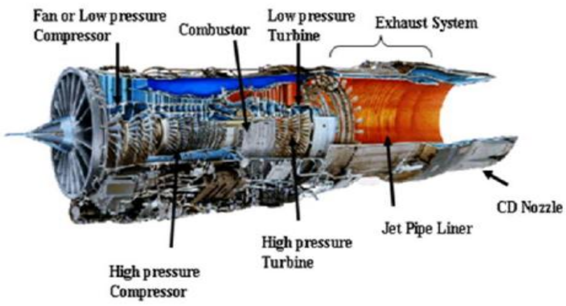


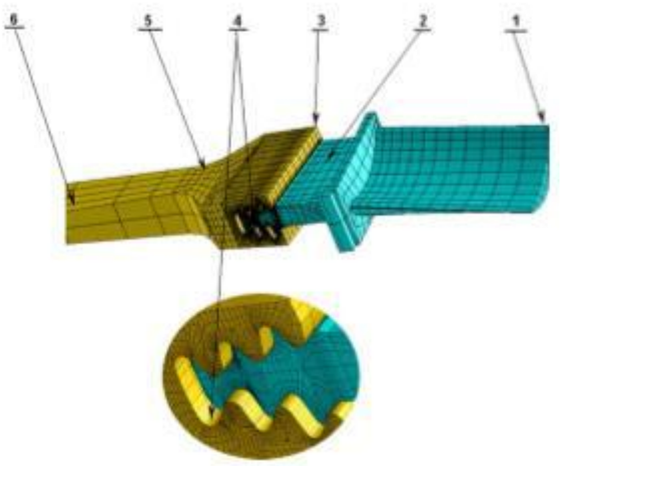
Fig.1: Sectional view of the gas turbine engine

The thermodynamic process requires a supply of air under pressure. The purpose of the compressor is to increase the pressure of the air. A compressor includes a rotor which consists of rotating blades imparts motion to a mass of air and a stator which consists of stationary blades transforms the velocity into pressure. In the moving blades the velocity of the flow increases because of the motion imparted to the air and the pressure increases because of the configuration of the blades (divergence).The transfer of velocity into pressure in fixed blade is because of the divergent nozzle. The air received by compressor is sent to the combustion chamber, that air is mixed with mixes fuel and sprayed through nozzles in the front chamber. The mixture is

II. RELATED WORK

A fir-tree joint may be used in turbine structures to attach a blade to the rotating Disc. Mechanical loads are transferred through the joint from the blade to the turbine disc. The ultimate aim of the fir-tree joint is optimization of program to make it enable the designer to explore different candidate characteristics at the primary stage, varying from relatively simple designs to complex ones, at a reduced cost compared to using previous manual methods (such costs have often prevented the exploration of more complex profiles and different size and shape of the teeth). These process involves the advantage of feature- based parametric construction tools such as CATIA and large-scale structural finite analysis packages, along with an optimization program implementing various search strategies. Although this problem is basically a structural analysis problem, the methodology employed here is quite

III. JOINT ANALYSIS



(1) Top part of the blade;
(2) Bottom part of the blade (connection between fir-tree slots and blade);
(3) Outside corner of the disc;
(4) Corner of 3rd lower slot of the dovetail-rim region of disc;
(5) Central part of disc;
(6) Bottom part of disc.

burned at high temperatures to generate the heat energy. The combustion process is initiated by injector and it is isolated after start-up, and remains working continuously until the fuel supply is shut off. In a gas turbine engine, the output of the turbine is used to turn the compressor (which may also have an associated fan). The hot air at the exit of the turbine is then transferred into the atmosphere by a exhaust nozzle which provide thrust or propulsion power. The exhaust gas of system passes through the turbine to atmosphere at a velocity in desired direction and provides the resultant thrust [1-2].

different. The use of the CATIA system and finite element analysis software together gives it the capability to model the variations parametrically both for dimensions and in the concept of topology is used, and to analyse the effect of dimensional features on the stress distribution based on the finite element analysis results. Further- more, the above process may be incorporated into a search loop to automatically find the best solution against predefined constraints. The CATIA based design optimization is illustrated in Fig. 2. In this structure, CATIA is used to generate the model definition based on rules which may be stored in a knowledge database and related information is used for further simulation. The geometry is then transferred to the analysis code along with any geometry dependent properties to evaluate the design performance. The optimization givesmore accurate solution for a particular group of design parameters.

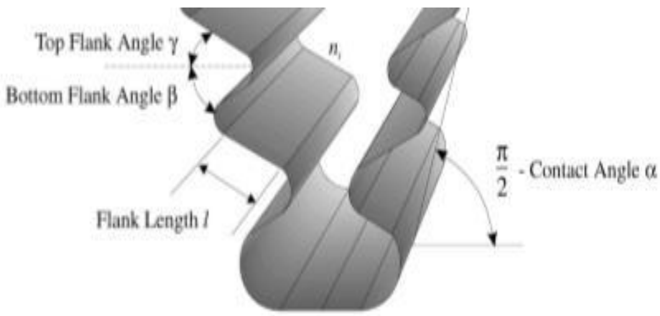


Fig.2: Structural view of turbine disc.

The work carried out in this paper is to development of geometric model of Disc and Blade of turbine. Geometric modelling has to be carried out by using Catia software. Then the Geometric model will be converted into Finite element model using commercially available software such as Ansys workbench. The above figure shows structural view of turbine disc. The major function of the turbine is to extract energy from the hot gas flow to drive the compressor and the accessory gearbox. Gas turbine disc works mostly at high temperature gradients and are subjected to high rotational speed. This high speed causes a large centrifugal forces in discs and simultaneous high temperature reduces disc material strength. The joint between the turbine blade andthe disc usually represents the most critical area from the point of view of the static and fatigue approaches. The forces corresponding to these regions are mainly the centrifugal forces and temperature stresses. Generally the turbine disc have three critical regions for which lifetime certification is necessary: the fir-tree root region, the assembly holes, welded areas and finally the hub region. Fig. 2 shows these areas along with their associated loads.

A. Design with Uncertainties

A part is designed for therequired structural performance and its expected service life, existence of uncertainties in different parameters can affect its service life. From a design point of view, uncertainties may arise due to variations in loading, boundary conditions,environmental conditions and geometric parameters and fluctuation in material properties such as the yield strength, Ultimate strength and Poisson’s ratio, etc. Uncertainties can also result from assumptions made while modelling a real engineering problem. Variations due to manufacturing may result in a final part which has deviations with respect to the nominal geometry. The fluctuation in the dimensional parameters may result in a scatter in the overall efficiency, life and performance objectives of the model. It has become necessary to learn and verify the effects of uncertainties on the efficiency of the part, at the time of designing it, with a goal of optimization. For this reason the two most commonly used approaches used by researchers are robust design and reliability-based design.

1. Reliability Based Design Optimization (RBDO)

To prevent catastrophic failure while designing a critical component in a structural sys- tem, reliability-based design optimization can be adopted. The constraint conditions of the optimization problem are characterized by the probability of its structural failure. Reliability-based design optimization can be considered as the process of minimizing the cost function under the observance of probabilistic constraints instead of the conventional deterministic constraints. The occurrence of probability of failure in the reliability analysis may be achieved using various different methods. The simplest and most direct method to gather such information is to perform Monte Carlo simulation on a large amount of sampled data which can be a computationally expensive workout. The first and second order reliability type requires an additional nonlinear con- strained optimization procedure for locating the most probable point of failure making the RBDO a two-level optimization process. A calculated regression based response surface methods have been used for structural reliability analysis to overcome some of these computational burdens. However, the approximation methods used for the constraint functions can suffer in accuracy when the constraint functions are highly nonlinear.

2. Robust Design Optimization

Engineering components can be designed by optimizing the parameter values with respect to a single or multiple objective functions. These parameter values are then delivered to the manufacturing unit in the form of engineering drawings with tolerances on the geometric entities. At the time of manufacturingcomponents they are subject to variations in the stresses due to the processes used for manufacturing. Variations in designed parameters canalso occur during at the time of operation. Robust design is the field of research that aims to tackle suchproblems by minimizing the effect, of variations in the design parameters, on the performance of the component. The optimum design is sought with- out eliminating the source of uncertainty or variation. The robust designs may have slight worse nominal performance as compared to an optimized nominal performance. Some designs can show improvements in both nominal performance as well as the extent of variation in performance; however these are not properly optimized.A survey have given a more comprehensive list of different approaches to perform compact design optimization. Taguchi’s work on developing a design methodology that accounts for the uncertainties in the framework of quality engineering has been regarded as one of the earliest works on robust design.

B. Different Methods Adopted In Fastening Blades to Discs

Fig 3. shows the various methods adopted in fastening blades to discs. These are: pin joint, dovetail joint and fir-tree joint. Dove-tail joints are commonly used for the disc blade attachments in compressors whereas fir trees are used for the turbine disc blade attachments. . Fir-tree fasteners are commonly used in turbines because they provide adequate multiple areas of contact over which large centrifugal stresses can be accommodated.

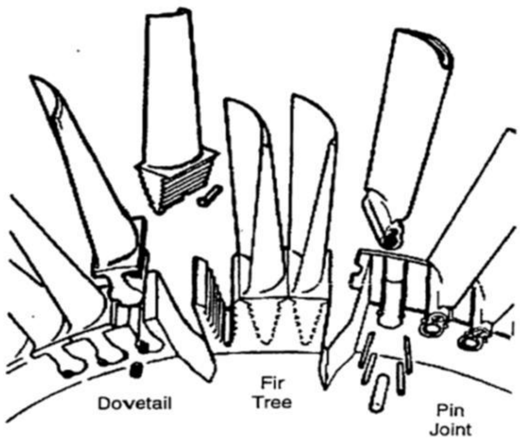


Fig.3: Different blade fastening arrangements

IV. CONCLUSION

The Natural frequency of vibration is found to be similar by Analytical method and FEM Method.

V. FUTURE WORK

1. Determination of Radial and Circumferential Stresses for Circular disc with hole by Analytical and FEM Method.
2. Determination of Radial and Circumferential Stresses for Solid Circular disc by Analytical and FEM Method.
3. Validation of Stresses

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