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Review on Stress analysis and efficient modelling of a Fir Tree joint in an aero engine

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***Abstract*—one of the major sources of the stress arising in the turbo-machinery blades are the centrifugal and thermal loads acting at any section of the airfoil. Fretting is a phenomenon occurring between two surfaces having relative oscillatory motion of small amplitude fretting damages occurs on the surfaces of contacting components . Accounting for these phenomena stress evaluation of the blade attachment region in the disc has to be performed in order to avoid blade failure. This paper presents a work on geometric models in order to achieve minimum fretting action and stress distribution based on the response surface method and Using design of experiments, central composite design and anova method are opted to obtain optimum geometric parameters these geometric parameters are validated to get the expected results.**

***Index Terms*—Fretting action, response surface method, Design of Experiments, Optimization.**

I. Introduction

The Gas turbine engine design is the most highly advanced design. A good design is one which provides all the strengthand rigidity to meet all its design requirements. The structural components of the gas turbine engine consist of compressor, combustor, turbine, exhaust system and a convergent divergent nozzle. The sectional view of the gas turbine engine as shown in Figure 1.

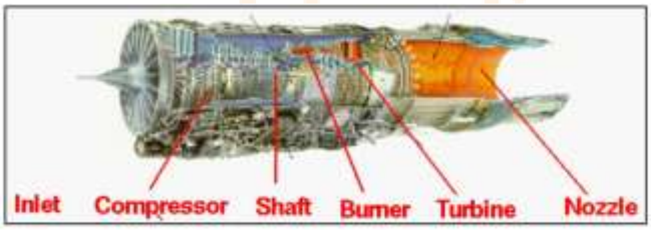

Figure 1. Sectional view of gas turbine engine

The thermodynamic process requires a supply of air under pressure. The purpose of the compressor is to raise the pressure of the air besides a small rise after air intake. A compressor includes a rotor (mobile blades) which imparts motion to a mass of air and a stator (stationary vanes) which transforms the velocity into pressure. In the mobile 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). In the stationary vanes the velocity is transformed into pressure because of the divergent air path, and the flow is straightened. The combustion chamber receives air from the compressor and it mixes with fuel sprayed from nozzles in the front of the chamber. The mixture is burned at high temperatures to generate the maximum possible heat energy. The process of burning is initiated by igniter plugs, it is isolated after startup, and continues 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 propeller or a fan). The hot air flow leaving the turbine is then accelerated into the atmosphere through an exhaust nozzle to provide thrust or propulsion power. The exhaust system passes the turbine discharge gases at some velocity to atmosphere, and in the required direction, to provide the resultant thrust.

II. Literature survey

The literature review was carried out to understand the background of this project work.

Review on turbine and compressor blade

Jianfu Hou et al. [6] investigated the gas turbine blade for mechanical loads and fatigue loads. To evaluate the steady state stresses and dynamic stresses a non-linear finite element analysis was performed. From the analysis, the peak stress were found at the top of fir-tree trailing corner.

Mirzaei et al. [7] conducted three dimensional stress analysis and fatigue life analysis of gas turbine first stage blade. Form the analysis it was observed that, for the mechanical loads maximum tensile stress was found at suction side of the blade. This high stress is shifted towards the corner of the rib when the mechanical and thermal loads are applied together. The hottest region if found to be at leading edge of the blade.

Bok-Won Lee et al. [9] investigated fretting fatigue of compressor blade in an aircraft engine. The author focused on the root cause for the failure of compressor blade made out of Titanium alloy Ti–6Al–4V. In the investigation a retaining pin was considered at the interface as a locking mechanism for the blade. The findings from the investigation proved that the stress concentration at the retaining pin under fretting condition leads to crack initiation at the contact region.

Morishita et al. [11] investigated the multi fatigue property for Ti-6Al-4V. The author concluded that the multi axial fatigue life depends on the multi axial stress and reduces with increase in the stress value Kermanpur et al. [12] investigated the failure of jet engine blade made of Ti-6Al-4V. The author concluded that the failure of blade occurred as a result of the fretting fatigue phenomenon.

Review on turbine disk of an aero engine

M. L. Xie et al. [13] investigated 2^{nd} stage turbine disc at fir-tree region for the fracture failure. The fracture analysis were done for fracture failures due to design failure, due to the first order bending frequency of turbine blade, due to low fatigue resistances of material GH2036 and due to corrosion factors. The fatigue failure were observed for the material GH2036 and improvement of fatigue life achieved using the material GH2132 alloy.

Lucjan Witek et al. [15] performed finite element analysis of fir-tree root for three tooth configuration at different rotational speed. From the analysis it was found that high stress were located at the 3^{rd} lower slot corner of fir-tree root. It also observed that, increase of plastic strain at constant rate from 16000 rpm till 20000 rpm.

Amr Elhefny et al. [16] analyzed turbine disc to evaluate the stresses and deformations using finite element analysis. Based on the FE results, the turbine disc model has been optimized by performing following analysis, considering disc with uniform thickness, with 2 thickness, considering hub with 2 thickness, disc with additional mass from the analysis, the weight reduction is achieved with 25% increase of stress.

Shlyannikov et al. [17] the steam turbine disc having crack due to damage accumulated during service is analyzed for the structural integrity for the load conditions of startup & shut down operating cycles by performing fracture analysis. The elastic – plastic and elastic analysis results of crack growth rate and residual stress were compared.

Review on blade disk interface of an aero engine

B Kenny et al. [18] at turbine disc and blade joint region the stress distribution were evaluated using the technique called two dimensional photo-elastic frozen for axially loaded assembly. From the study it was observed that steep gradients of principle stress were at fillet radius region of fir-tree joint.

Aditya S. Deshpande et al. [19] studied critical geometrical parameters of turbine and compressor blade attachment regions due to manufacturing and handling processes and using co-ordinate measuring machine these dimensions were measured. It was observed that, the working stresses were found to be the main influence by small changes in these critical dimensions, the better control on these dimensions can be taken by including the manufacturing limitations by making parametric geometry.

S.A. Meguid et al. [21] investigated a turbine disc fir tree region for the finite element analysis. The study revealed that the maximum stress occurred at the bottom of the tooth i.e. below the contact pair, and magnitude of the induced stress depends on the factors like number of teeth, contact angle and flank length

M. Ciavarella et al. [22] derived new consequences for the fretting fatigue damage using analytical approach. Flat surfaces with fillet corners of dovetail joint was chosen for the study at tangential and normal load condition for stress evaluation. From the study it was clear that the tensile stress concentration increases and surface damage parameters decreases for the almost flat surfaces.

Singh et al. [23] analyzed the fir-tree region of a turbine disc and attached blade by treating the total fir-tree region as an assembly of many steps. Using a generalized root step, the analysis was conducted to obtain its stiffness and deflection using the FE method. It was observed that all the deflections depend on the geometrical parameters of fir-tree region and the variation has been found to be nearly linear.

Praveen Silori et al. [25] conducted three dimensional finite element analysis on fir-tree region of turbine at different skew angles such as 30^0, 35^0, 40^0, 45^0 and 50^0 and different temperatures such as 1000 and 2000 degree Celsius. From these analysis it was observed that the effect of skew angle on the assembly were significant.

Shivani Pande et al. [26] investigated blade and disc region of first stage turbine using 3D finite element analysis. For analysis following parameters were considered, Number of teeth n = 3, Contact angle $\alpha = 20°$, Bottom Flank angle $\beta = 40°$, Top flank angle $\gamma = 40°$ Flank length l = 2.5 mm from this study, it was observed that the maximum stress concentration occurs at just below the lower contact point between the blade and the disc.

From the review of literature [1-26] the authors have reported experimental and numerical analysis of fir-tree region at aero-engine turbine blade disc interface. The authors have considered the various parameters such as, speed, flank length, contact angle and co-efficient of friction (COF) to analyze fretting fatigue characteristics. But research work focusing on analyzing the effect of aero-engine blade/disc parameters on responses such as von-mises stress, maximum and minimum principle stress, maximum shear stress and contact pressure by adopting central composite design (CCD) approach is scarcely reported. Hence the present project focuses on achieving optimal blade parametric combination in order to minimize the effect of fretting fatigue.

III. Related Work

- Initially simulation runs were carried out by considering the fretting parameters to identify most influencing parameters and their levels for the analysis using ANSYS
- In order to minimize the analysis runs, Central composite design was adopted
- Based on CCD design matrix was developed and standard geometrical models for fir-tree region of aero-engine turbine disc and attached blade were designed in UNIGRAPHICS with appropriate dimensions. The dimensions for the model were taken from Meguid et al. [21] and Tiago et al. [43]. Parasolid file of the model was then imported into FE analysis package ANSYS 17.0. `
- 3-D nonlinear structural analysis was carried out using appropriate boundary conditions to measure the responses Such as von-mises stress, maximum principle stress, minimum principle stress, maximum shear stress and contact pressure which were responsible for fretting phenomenon
- Analysis of variance was performed to identify the significant factors for each response. Regression models were prepared for each of the response using
- MINITAB
- Grey Relational Analysis (GRA) was used to achieve the parametric conditions that correspond to the minimal response values
- Multi objective optimization was carried out using response optimizer of RSM in MINITAB 17.0 and a confirmation test was done in ANSYS 17.0 to check the desirability of the solution obtained from the response optimizer Figure 3.1 shows the methodology adopted for the present project work.

IV. Conclusion

The following conclusions can be drawn from the results obtained.

- The maximum stress occurs at the fillet location on the blade due to more load is accumulated at the location.
- From the analysis of variance methodology von-Mises stress, maximum principle stress, minimum principle stress, maximum shear stress and contact pressure are influenced by bottom flank angle, contact angle, skew angle and number of teeth.
- From 3D surface plots it has been observed that as bottom flank angle increases and skew angle decreases, all response values decreases gradually, and observed that all response value is minimum when skew angle is 0^0.
- This study shows the importance of calculating the clearance between the teeth of the blade and disc, for the calculation of thermal expansion of the bodies indicates the smallest possible value of clearance, thus obtaining the lower stress for the geometry to be developed. However this factor was not evaluated in this study.

V. Future Work

As turbine blade flank length & depth is very imported dimension in the turbine rotor. The optimized dimension should be made to have minimum stress & displacement at the root of the blade & disc. As turbine blade require cooling to reduce the thermal stresses, the size of the cooling passage is very important. The optimized size should be made to have maximum cooling of the blades but there should not be over cooling as it affects the thermal efficiency.

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