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Investigation and efficient modeling of an Dovetail Attachment in Aero-Engine

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Abstract

Fretting is a phenomenon occurring between two surfaces having relative oscillatory motion of small amplitude. Fretting damage occurs on the surfaces of contacting components. An accurate assessment of critical fretting variables such as contact traction, contact condition (stick & slip) and contact stresses over the blade-disc attachment is essential to characterize the fretting performance and to assess the reliability of rotor. Such an understanding helps in the design of lighter engines, with better performance and improved safety. Rotor consists of a number of contact pairs of disc and blade, it would be complex to study all the interfaces together. Hence a simplified approach of studying a single lobe of a dovetail interface for a sector is considered to understand the fretting behavior of fan and compressor blade-disc interface. This paper examines to investigate the acute variations in stress along the Flank length, thickness, for varying friction and rotational speed of the disc/blade interface.

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Keywords: Dovetail, Flank Length, Flank thickness, Rotational Speed.

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1. Introduction

One of the main factors concerning mechanical intergrity of aeroengine turbines is the interface region between the blade and the rotor disc.Stresses generated in this region are mainly produced by the centrifugal force resulting from the rotational speed of rotor mass of the blade, thermal stress, and bending loads and torsion due to the gas pressure. According to Meguid et al, (2000), the joint between a turbine blade and the disc represents the most critical load path within this assembly, and it is crucial to the operational safety and service life of gas turbine engine. In order to accommodate safe stresses values in this contact region, Hyde et al, (1988) studied the contact interfaces for design optimization of casing flanges. Blade disc interface experiences a combination of low cycle fatigue due to major loading events and high cycle fatigue due to minor loading events, during an operation cycle. The interface is subjected high level of contact loadings and cyclic bulk stresses due to centrifugal loads, added to this, vibratory loads act at the interface with oscillatory motion during the engine operation. Thus fretting fatigue plays a key role at the dovetail interface.

Fatigue is an important consideration in the design of rotating components. An early contribution of papanikos et al, (1994) says about his analysis underestimates the Max. Equivalent stress along the interface by as much as 40% this could have serious implications concerning the safety margins of the disc assembly. Beard, (1982) Suggested that more than fifty variables play a role in fretting damages. Amongst them, Contact tractions, slip amplitude and friction coefficient are generally considered to be the primary fretting variables, which play a critical role in the process of fretting fatigue crack initiation and fretting wear.

Waterhouse, (1973) focuses on identifying the driving factors for fretting damage on blade-disk attachment under real engine conditions. Fretting damage occurs on the surfaces of contacting components that are clamped together and are subjected to vibration or change in contact conditions due to the nature of loading, although the clamped bodies are nominally at rest relative to each other. Fretting fatigue, Fretting wear and Fretting corrosion are the major forms of fretting damage and are considered as important modes in the design of engineering components.

Hernan V. Arrieta1 et al., focuses on identifying the driving factors for fretting damage on blade-disk attachment under real engine conditions. Two-dimensional finite element contact calculations were carried out to quantify the influence of the key factors on mechanical quantities (stress and strain). Special attention was paid to material models and surface interaction (friction coefficient and contact conditions) in order to balance computational effort with result's accuracy.

From the literature it is evident that fretting fatigue and fretting wear are considered as critical failure modes of blade disc interface. The current work focuses on studying the state of stress at the contact interface of dovetail blade-disc attachment for varying co-efficient of friction 0.1 to 0.3 at an incremental value of 0.05 and for varying rotational speed from 1000 to 10000 rpm at an incremental steps of 1000 rpm , through 3D analysis, using contact elements at the interfaces. Commercially available FE code ANSYS workbench 14.5 is utilized for the above study. Fig-1 shows 3D geometric model

2. Geometric Configuration

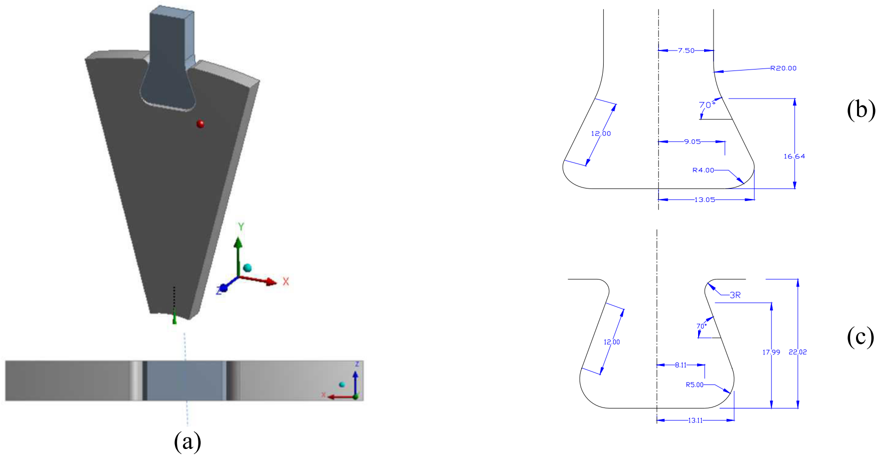
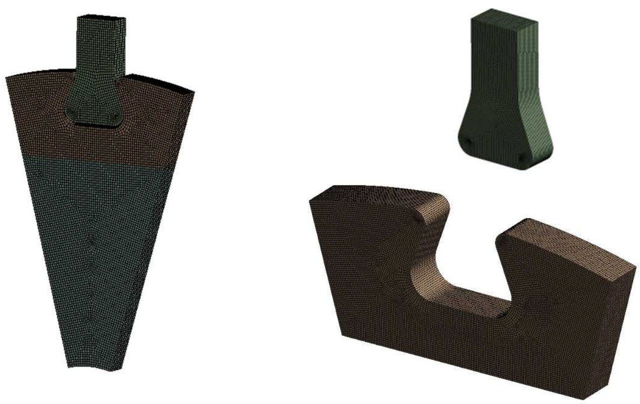


Fig.1: Dovetail Geometry Examined (a) Sector of Dovetail (b) Blade (C) Disc

3. Finite element modeling

The three dimensional analysis will be carried out for the midsection of the disc, thus pertaining to plane stress conditions. There are several methods for discretization available for the generation of finite element meshes in non-linear contact analysis .A free meshing routine was used due to the necessity to model a complex geometry as shown in Fig.1. to cater for large transitions in the stress field. Typical 3D meshes is shown in Fig.2, with Hexamulti element size to 1mm contain hexahedron solid element 187 with 20 nods per element. The second case ,which was further refined to Hexamulti element size to 0.5 mm (Sub model).Both the accuracy pertaining towards solution and computing time were taken into consideration.



(a)Full-Model: Nodes:199759
Elements:80683

(b) Sub-Model: Nodes: 1115928
Elements:276794

Fig.2: Finite Element model of Dovetail Assembly (a) Full Model (b) Sub Modeling

4. Boundary condition / Material Properties:

For the present study, the material used is same as employed by papanikos et al.[2]. The material used for the modeling of the blade/Disc were that of titanium alloy Ti-6 Al-4V and its mechanical properties are young's modulus E=114Gpa, Poisson's ratio √= 0.33 and density ρ = 4429 kg/m3 .All examined models were subjected to centrifugal loading with specific angular velocity, were ω was selected to be 10,000 rpm. In view of symmetry of geometry and loading, only one sector of the disc supporting 12 blades was modeled as shown in Fig-3 .This model was imported to ANSYS and the cyclic symmetry tool was effectively used, greatly reducing computational time, compared to a full disc/blades model that would require a much higher computational effort

4.1 Contact elements:

The surface-to-surface contact is defined between the blade and disc. The outer surface of blades is (along flank length) considered as the contact surface element and the inner surface of disc sector (along flank length) are considered as target surface element. the contact region between the blade and the disc is recognized automatically when geometry is transferred from design modeler to simulation as bonded contact, Further it is changed to frictional conditions between the blade & disc interface as Co-efficient of friction varying from 0.1 to 0.3 in steps of 0.05 (μ= 0.3) for different interface conditions, contact formulation to Augmented Lagrange multiplier method was used to obtain solutions for normal and friction contacts. The dovetail interface was defined as the stiffness matrices of each element are updated at each iteration. Given these definitions, the contact region is considered as a nonlinear contact conditions. The contact elements used are CONTA174 & TARGE170.

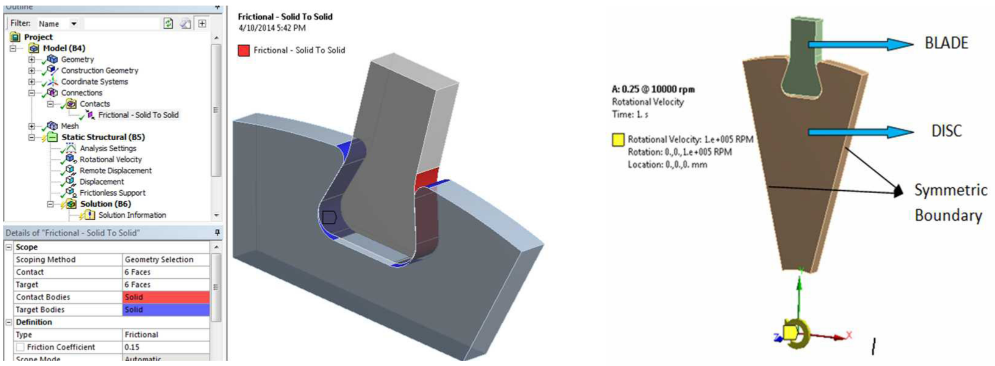


Fig.3:Boundary conditions of dovetail Assembly

5. Result & discussion

3D stress analysis of a typical dovetail assembly of a gas turbine compressor subjected predominantly to centrifugal forces has been carried out to examine the influence of rotational speed and co-efficient of friction between blade and disc

In the current investigation the effects of co-efficient of friction and Angular speed on the physical characteristics upon the tri-axial state of stress present in the disc are studied. The stress characteristics presented in the current investigation are von-Mises along Flank Length, von-Mises along thickness, contact pressure between blade & Disc, von-Mises stress, Maximum principal stress and Displacement in the dovetail assembly.

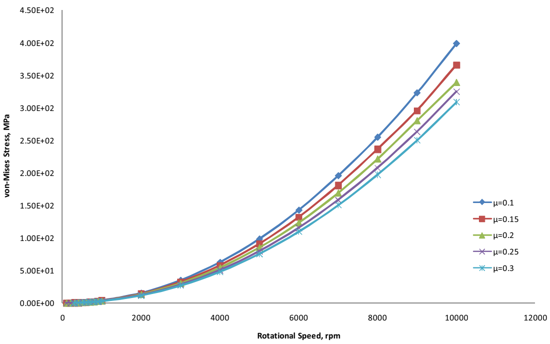


Fig-4: Effect of von Mises Stress for varying speed

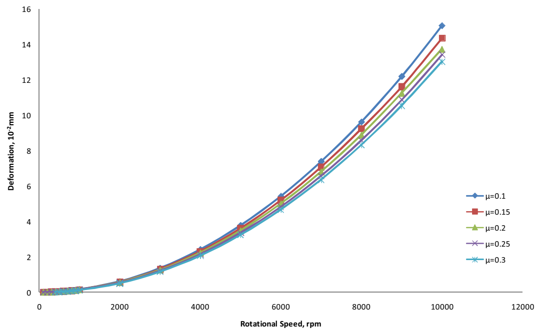


Fig-5: Effect of Displacement for varying speed

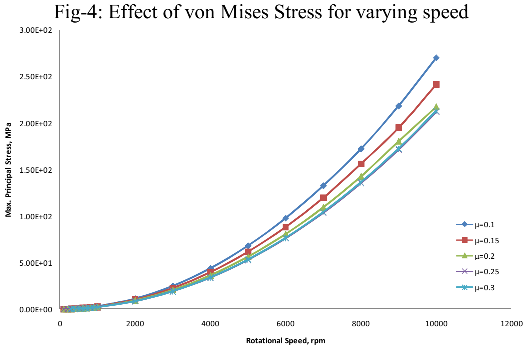


Fig-6: Effect of Maximum principal Stress for varying speed

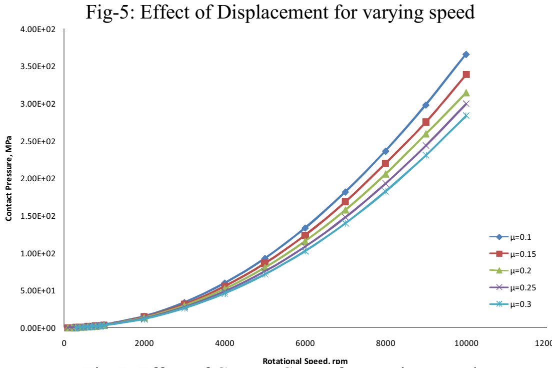


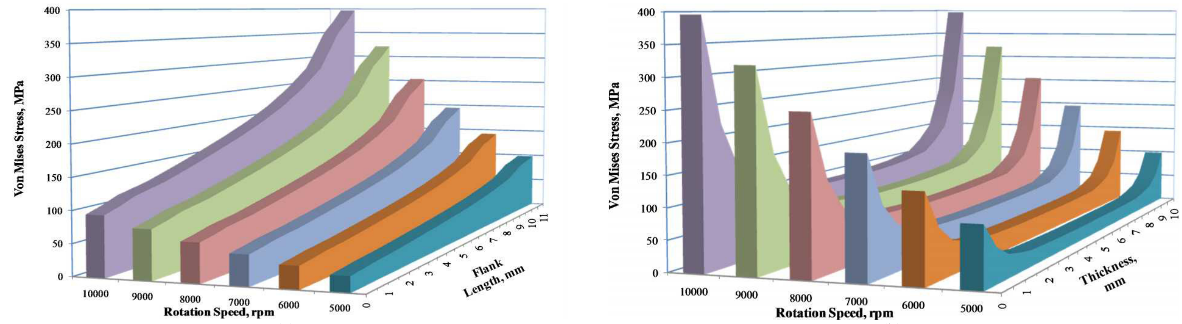
Fig-7: Effect of Contact Stress for varying speed

The independent parameters influencing the stresses encountered in a dove tail assembly such as rotational speed and co-efficient of friction have been varied from 1000 to 10000 rpm and 0.1 to 0.3 respectively. The stress analysis was carried out either by keeping rotational speed or co-efficient of friction as constant and varying the other as mentioned above.

It is evident that for a given rotational speed von-Mises stress decreases with increase in co-efficient of friction though it is marginal. This trend happens to be the same when co-efficient of friction was varied from 0.1 to 0.3 in steps of 0.05 keeping the rotational speed constant at 1000 rpm. however when the rotational speed was increased to 2000 rpm and from there to 10000 rpm in steps of 1000rpm, there has been a steep increasing in von-Mises stress, though showing a decreasing trend with the increase in co-efficient of friction.

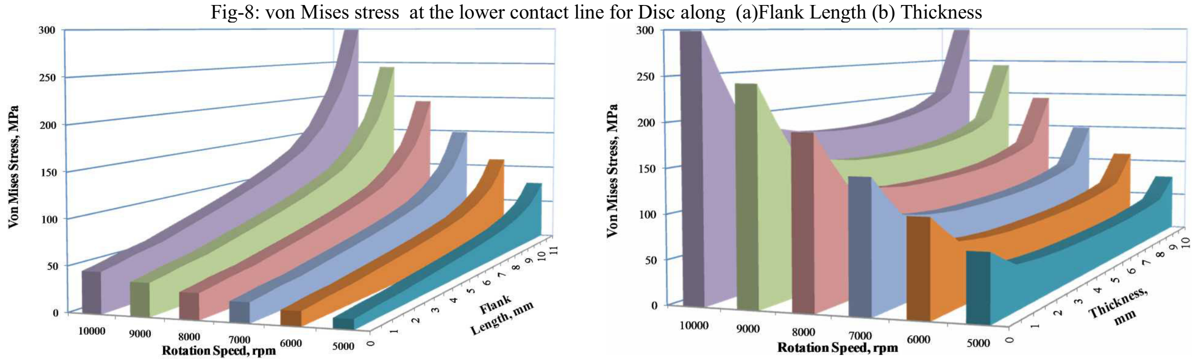
The displacement of the blade root in the dovetail assembly has also been obtained as a function of rotational speed and co-efficient of friction. For a rotational speed, the displacement decrease with the increase in co-efficient of friction which again increase with the increase in rotational speed in the same manner. The relationship between rotational speed and von-Mises as a function of co-efficient of friction is shown in Fig.4 , the relation between displacement and rotational speed for varying co-efficient of friction is shown in fig 5 ,Similar trend has been observed with Maximum stress and contact stress for the relationship between rotational speed and as a function of co-efficient of friction is shown in Fig.6 and fig 7 respectively.

From the Fig 8(a) & 9(a) it evident that the Acute stress gradient is observed at the lower contact point edges of interface region along the flank length of dovetail assembly for all the varying rotational speed along the flank length.



(a) (b)

Fig-8: von Mises stress at the lower contact line for Disc along (a)Flank Length (b) Thickness



(a) (b)

Fig-9: von Mises stress at the lower contact line for Blade along (a)Flank Length (b) Thickness

From the Fig 8(b) & 9(b) it was observed that the stress pattern of blade and disc is symmetric on both sides of contact surfaces, however a peak stress is observed at the outer surfaces or corner contact point edges of interface region along the thickness of dovetail assembly for all the varying rotational speed along the thickness.

6. Conclusion

- The present study concludes that the peak stress at the interface regions of the blade-disc attachment decreases with increase in co-efficient of friction.
- Acute stress gradient is observed at the lower contact point edges of interface region along the flank length of dovetail assembly.
- It was also observed that the peak stress is observed at the outer surfaces or corner contact point edges of interface region along the thickness.

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