Multiaxial Crack Growth Prediction

B. Sheen[1a]

[1]Department of Mechanical Engineering, Imperial College London, London, United Kingdom

[a]bemin.sheen16@imperial.ac.uk

Abstract. Loading conditions in a blisk present a variety of challenges to predicting the trajectory of crack growth. Bladed disks are subjected to foreign object damage which can result in crack initiation near the base of the blade. The resulting crack may propagate through the blade, or more undesirably grow towards the bore of the disk as a result of hoop stress. This aim of this project is to create a validated criterion to predict the direction of crack growth in a Ti-6Al-4V blisk. To aid in developing an improved crack trajectory criterion, a series of fatigue tests will be completed. The specimen for these tests will be designed to replicate the key features of non-proportional crack propagation in a bladed disk.

Introduction

There have been a number of issues in aero-engine bladed disks where cracks have grown in a multiaxial stress field. Multiaxial and non-proportional loading of the crack results in crack growth which does not adhere to classical techniques of predicting crack trajectory which are often based upon the strain energy density or maximum principal stress during a cycle. Additionally, a combination of inter-related factors including mode-mixity, cyclic plasticity, and crack closure are also influential on non-proportional crack growth [1]. Therefore, an improved crack trajectory criterion is needed. Early crack growth models originating from Griffith [2] and later developed by Irwin [3], have proven sufficient for modelling the growth of mode-I cracks under proportional loading cycles. Cracks in real structures are subjected to a mixture of mode-I, II and III loads. Loading is considered to be proportional if the mode-mixity, expressed remains constant during a cycle. Existing crack growth criteria such as the maximum tensile stress criterion (MTS), strain energy density criterion (SED), and maximum shear stress criterion (MSS) are able to provide accurate predictions proportionally loaded for 2D cracks in certain materials. However, these criteria are invalid for non-proportionally loaded cracks.

Several attempts have been made at modelling crack growth in compressor blades. The work of Mangardich et al [4] compared simulated cracks with fractured compressor aerofoils. The aerofoils, made from Ti-6Al-4V were subjected to LCF loads from rotation and heat, and HCF loads from bending. The authors concluded from fractographic analysis of aerofoil fracture surfaces that HCF was predominantly responsible for crack growth. The HCF crack growth was accelerated by the LCF load since it imposed a positive mean stress on the dynamic bending load, however the LCF cycles themselves did not make a significant contribution. The authors found that LEFM and the MTS criterion predicted the crack direction accurately which is in agreement with previous studies on crack growth in Ti-6Al-4V blades [5]. However, Mangardich noted that in many previous studies conducted on blades with dovetail attachments, damping reduced the effect of the vibratory stresses. Byrne et al [6] identified that in Ti-6Al-4V specimens, a crack would initially propagate in LCF until the HCF threshold was reached.

Methods

Crack modelling. Stresses on a rotating blisk have been calculated using FEA on a model of a blisk section. Rotational loading grows the crack in LCF and stresses are found to be concentrated above the base of the blade at the leading edge. Vibratory stresses on the blade promote HCF growth in the crack and result in the non-proportional loading. The size of a flaw created by foreign object damage is assumed to be 0.125 mm and cracks have been modelled in the long crack regime. After completing FEA on an uncracked model, analysis of crack growth is completed in the Fracture Analysis Code 3D (FRANC3D). FRANC3D is a program which is capable of simulating crack growth in 3D models.

Testing. Fulfilling the objectives of this project will require a database of experimental results to produce a crack growth prediction model. Since it is not feasible to conduct a series of tests on whole blisk geometries, testing is being carried out on representative test samples. The experimental results will be compared with the predicted crack trajectories in the test specimen to validate the crack growth model. A cruciform-shaped test specimen with a starter crack machined at an internal filleted corner has been designed to replicate the region around the base of a blade in a blisk. The specimen is loaded in three directions using a biaxial machine and hydraulic fixture. The HCF load provided by blade vibration is emulated in the specimen by loading it in 4-point bending with a set of rollers as shown in Fig. 1.

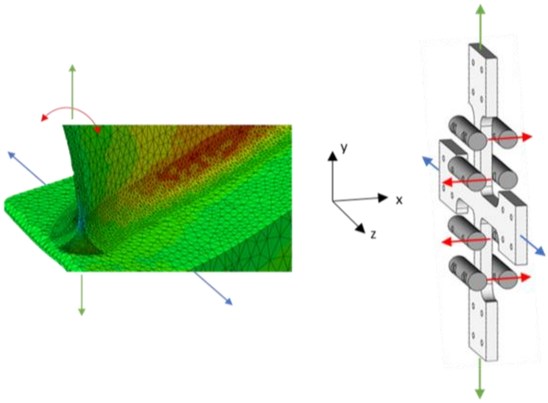

Fig. 1: (a) fillet region at the base of a blade, (b) loaded test specimen

Simulation results

Correlating the simulated crack growth in the sample and blisk geometry is an ongoing process. Fig. 2 displays the stress intensity factors (SIF) along a crack front in a blisk where the blade is in the "first flap" bending mode. A comparable set of stress intensity factors are observed in Fig. 3 from the loading the test sample in 4-point bending.

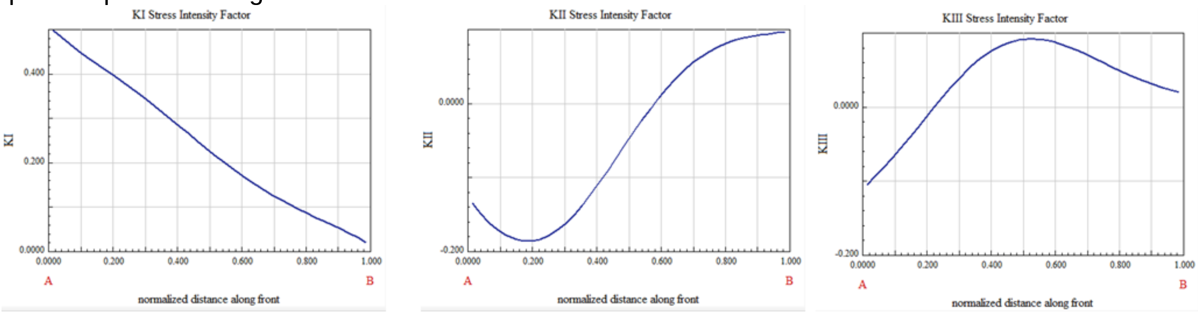

Fig. 2: SIFs of a crack in a blisk under first flap

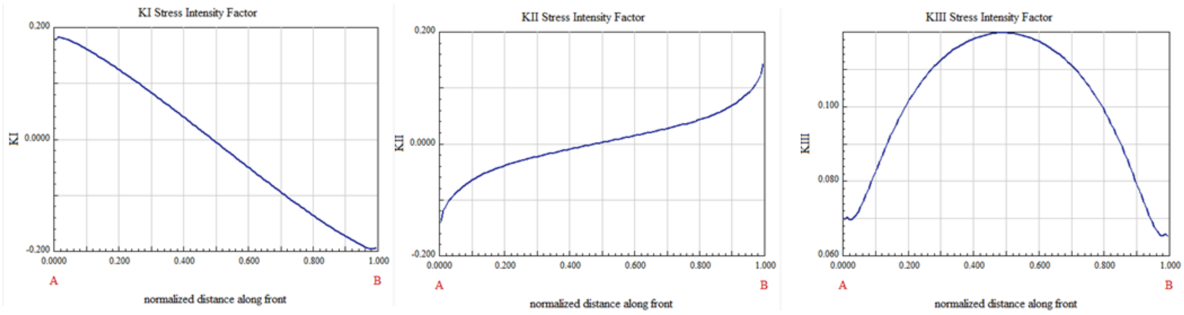

Fig. 3: SIFs of a crack in a cruciform specimen loaded in four-point bending

Conclusion

Results obtained from the completed fatigue tests have shown a good correlation to the simulation results and are being used to update the crack growth model. Applying the growth model to simulations on the blisk geometry has yielded results which show a good agreement with existing data.

References

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