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Technical Note

Contact analysis and optimization design of blade and disc assembly based on mesh deformation

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1. Introduction

In all kinds of connection structures, fir-tree form is widely used in the connection of turbine blade and disc of modern aeroengine because of its higher utilization ratio of material, better bearing capacity and smaller circumferential size, etc. However, the contact area of the fir tree structure is very small, which cause serious stress concentration. It is a kind of routine method to reduce contect stress by establishing parameterization model (Song 2002, Hai 2005), and in these methods, finite element stress arialysis is conducted on the mid-section of the disc, which pertains to plane stressconditions. Clearly, the distribution along root centre line does not take into account (Meguid 1996). In fact, it is difficult to analyze the contact stress using general three-dimensional mesh, which lead to the difficulty of parameterization menthod.

In this work, the refine finite element mesh of blade and disc was generated using software of hypemesh. Accurate analysis of aeroengine turbine blade and disc joining structure was carried out by software of MSC.Marc. Furthermore, the optimization of contact stress was implemented by adjusting fit clearance of mortise and tenon. Then the more reasonable joining structure was obtained.

2. Contact analyses

The geometry model of turbine blade and disc was built using CAD software of UG. There are 41 mortises uniformly distributing along circumference in the turbine disc. In order to simplify calculation, only 1/41 of disc was employed. Finite element mesh (FEM) is made by software Hypermesh (Fig. 1). In FEM model, there are 32854 nodes and 26242 elements. The number of contact elements is 7485.

The blade and disc is under centrigugal loading with a rotation of 27000 r/min, thermal loading. The temperature of blade and disc is obtained from fluid analysis of CFD software Fluent, as shown

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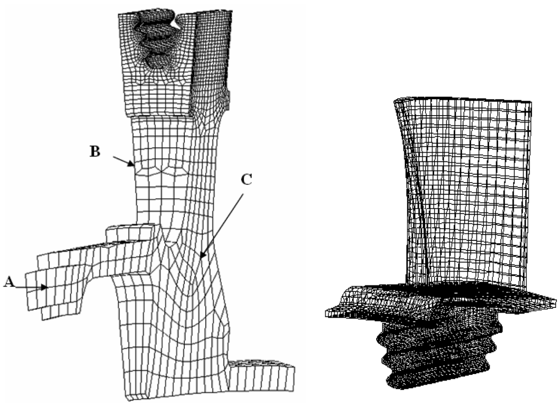

Fig. 1 Finite element mesh of disc and blade

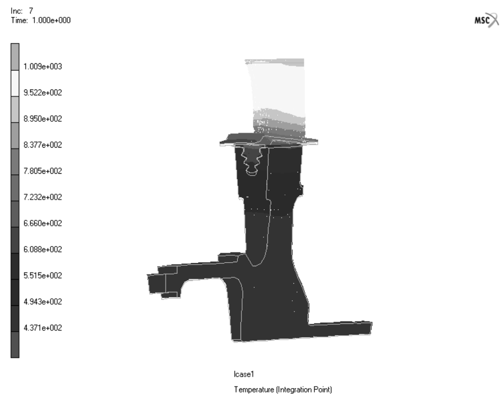

Fig. 2 Distribution of the temperature

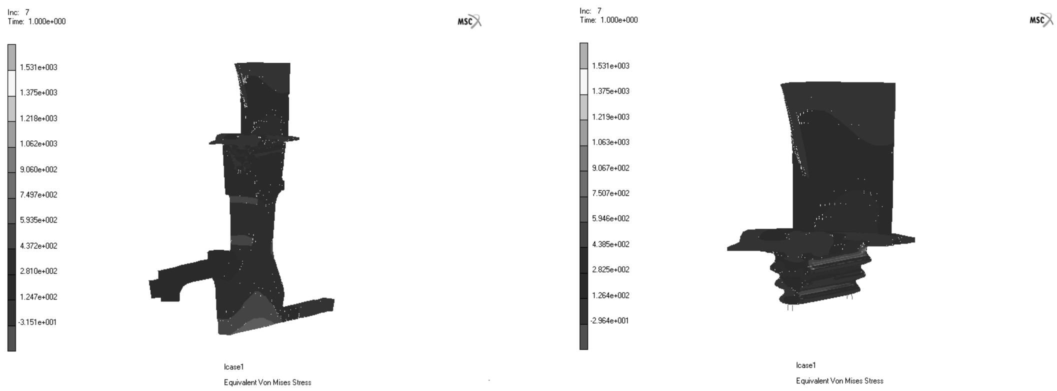

Fig. 3 Distribution of Mises stress

Table 1 The maximal contact stress in each tooth

	Blade concavity	Blade back		Blade concavity	Blade back
Inlet edge of the 1st tooth	1418MPa	1448 MPa	Trailing edge of the 1st tooth	720 MPa	1215 MPa
Inlet edge of the 2nd tooth	678 MPa	390 MPa	Trailing edge of the 2nd tooth	286 MPa	337 MPa
Inlet edge of the 3rd tooth	752 MPa	392 MPa	Trailing edge of the 3rd tooth	798 MPa	502 MPa

in Fig. 2. The displacements of the underside and surface A are restrained. Cyclosymmetric condition is applied to surface B and C. For restraining the rigid displacement of blade, 4 springs which $K = 0.2$ KN/mm are founded between the bottom of mortise and tenon and one node at the bottom of the tenon is tied to a nearby node which located at the bottom of mortise (Ding 2004).

The material of blade is DD3 single crystal and the orientation is [001]. The material of disc is FGH95 powder alloy. FE results are illustrated in Fig. 3. The distribution of contact stress in each tooth is shown in Table 1.

As shown in Table 1, the distribution of contact stress around the teeth is extraordinarily non-uniform. Stress in 1st tooth is much larger than the other two and there is obvious stress concentration. In this case, the biggest Equivalent Von Mises Stress which occurred at the blade back inlet of the first tooth is 1448 MPa. Stress concentration phenomenon is obvious at this point. A large number of experiments have shown that cracks originate at the first tooth. The result agrees with engine running experiment.

3. Optimization analyses

The fit clearance is adjusted by transforming the FE nodes of tenon in contact area alone normal direction to optimize the distribution of stress, as shown in Fig. 4. The method of operation is transforming the nodes along axis *Z*, displacement is *a*. Then along axis *Y*, displacement is *b*. $|a| = |b| = \sqrt{2}d/2$. Based on this method, the software iSIGHT is used as platform to make the optimization process run automatically. The optimization objective is decreasing contact stress in the tenon and optimization algorithm routine is Sequential Quadratic Programming. Optimization procedure of object variable is shown in Fig. 5.

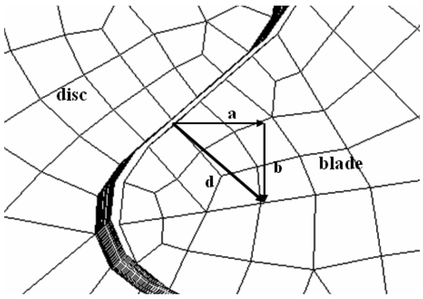

Fig. 4 Transformation method

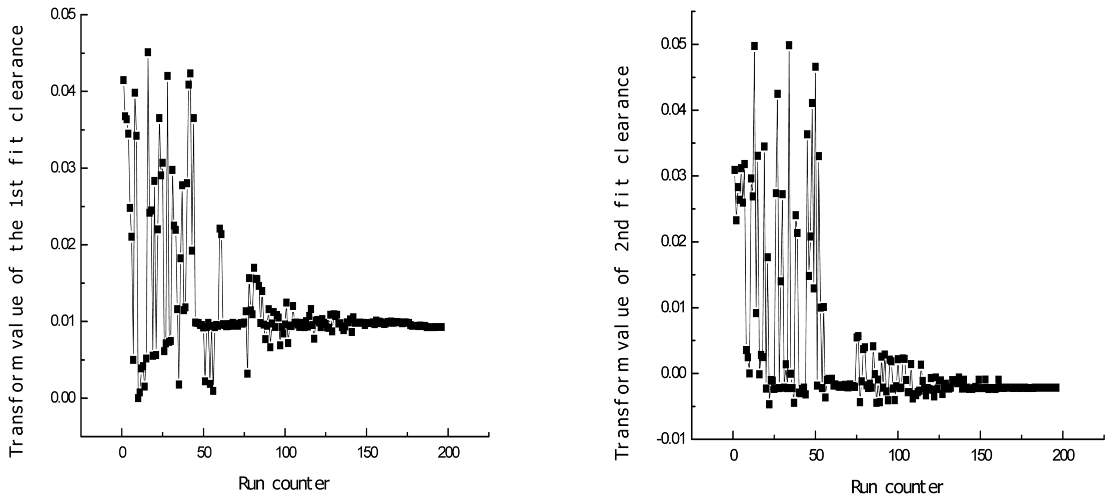

Fig. 5 Optimization procedure of object variable

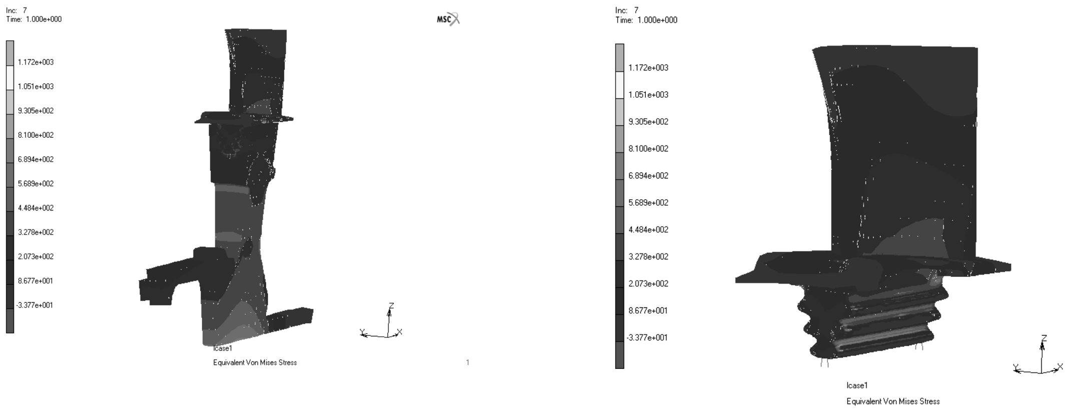

Fig. 6 Distribution of Mises stress after optimization

Table 2 The maximal contact stress of tenon after optimization

	Blade concavity	Blade back		Blade concavity	Blade back
Inlet edge of the 1st tooth	920 MPa	906 MPa	Trailing edge of the 1st tooth	371 MPa	666 MPa
Inlet edge of the 2nd tooth	930 MPa	782 MPa	Trailing edge of the 2nd tooth	702 MPa	566 MPa
Inlet edge of the 3rd tooth	928 MPa	530 MPa	Trailing edge of the 3rd tooth	764 MPa	538 MPa

4. Optimization results

The contact stress has been greatly improved after optimization. Equivalent Von Mises Stress of the best solution is 930 Mpa (Fig. 6) and it descends 38%. The biggest stress is on the second tooth and the obvious stress concentration phenomenon at the blade back inlet of the third tooth has been released. The second and the third tooth bear more contact stress, Table 2. The stress in the first tooth where cracks firstly occurred descends remarkable. And the distribution is more uniform. As shown in Fig. 6, contact status has been greatly improved with this method.

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