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燕尾形榫联接抗微动损伤修形研究

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为了预防和减轻榫联接中微动磨损，提高其抗微动疲劳能力，主要措施有三：第一，在结构设计中，使联接的方式有利于减轻磨损或尽可能地消除接合面；第二，对接触表面作适当的处理，改善表面质量，如表面涂层、离子注入和表面冷加工等；第三，在接触面上加填充物。本文提出用修形方法改变榫联接接合面的形状，改善接触处的有关力学参数，达到减轻联接的微动磨损和提高抗微动疲劳能力的目的。

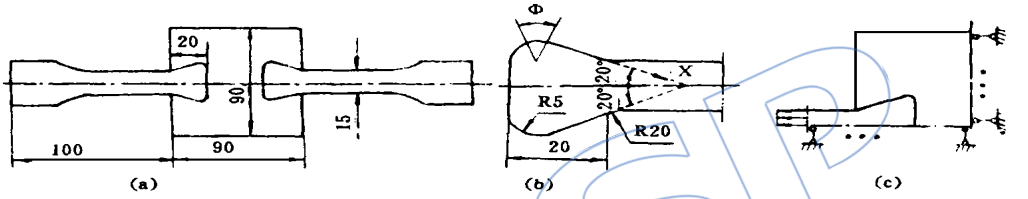

图 1 榫联接的研究模型（a. 榫联接试件；b. 燕尾部分尺寸；c. 计算模型）

1. 榫联接的研究模型 轮盘的榫槽与叶片的榫头联接处的结构和工作状况是相当复杂的。为了便于研究，本文考虑到试验的要求设计了榫联接的板状模型试件，如图 1 (a) 和 (b) 所示。由于模型试件的受力和几何形状具有对称性，因此在用边界元法作数值分析时，采用图 1 (c) 所示的计算模型。

2. 修形方法 榫联接的微动疲劳破坏通常在榫槽接触区的根部。这主要是由于该部分的表面接触压力较大，磨损严重，同时体内边界切向正应力较大。如果对与榫槽的危险根部相接触的榫头根部作出适当的局部修形，可使接触处的力学参数得到合理的改善，避免或减轻根部的微动磨损，提高抗微动疲劳强度。可以有多种方案达到修形目的。考虑到便于加工和研究，本文采用半径较大的圆弧取代榫头根部的部分直线段，如图 2 所示。修形圆弧段的两端应分别与其相连接的直线和圆角相切。修形量完全取决于圆弧半径 R 和修形段的位置参数 L。通过选择适当的参数 R 和 L，可使修形后的接触状态得到改善。

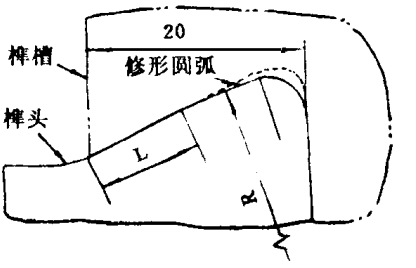

图 2 榫头修形示意图

3. 数值分析 对于不同的修形参数 R 和 L，其修形后的接触区大小及接触处的力学参数（接触压力 σ_N、边界切向正应力 σ_T 和相对滑动幅度）也各不相同。可以把榫头和榫槽的联接看作带摩擦的弹性体接触问题，采用边界元法进行计算，研究不同修形参数情况下，接触状

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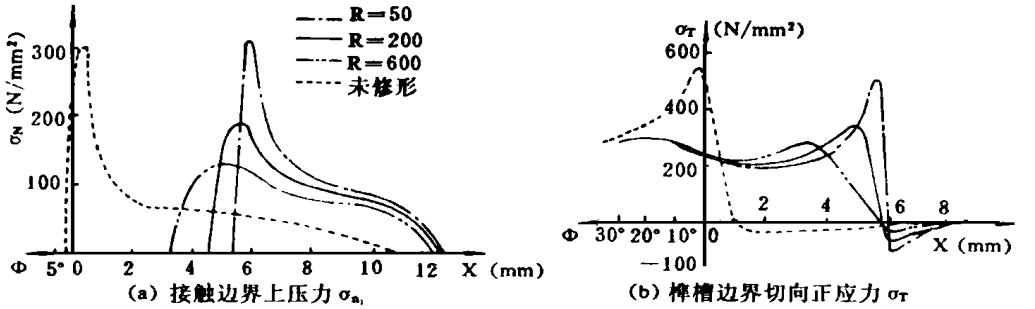

图3 未修形和 $L=8mm$，R 取不同值时有关应力分布（X 和 Φ 的意义见图 1b）

态的变化规律。对未修形榫联接和若干种不同修形参数的修形榫联接进行了数值分析。图 3 给出了未修形和 $L=8$mm、R 取不同值的修形时联接接触处的 σ_N 及 σ_T 的计算结果。在接触界面上，修形榫联接的相对滑动幅度大于未修形的。

4. 从数值计算结果可以得出一些 修形的基本规律 (1) 经过适当修形后的榫联接其接触面上压力的分布变得较平坦，改变了未修形榫头接触压力严重集中于根部的状况。(2) 对于不同的修形位置 (即 L 不同)，其修形圆弧半径 R 太大时，修形量小，修形与未修形的接触状态相近，不能发挥修形的作用；R 太小时，修形量过大，接触处的有关力学参数分布又出现严重集中在局部的状况，失去了修形的意义。因此修形参数必须适当选择。(3) 修形后的榫联接边界切向正应力的最大值有所下降。这是保证修形方法能实施的基础。

5. 对比试验 试件的尺寸见图 1，五组试件是 L (mm) 分别为 8、8、8、9、9；R (mm) 分别为 200、400、100、200、400。试件中榫头的材料是 TC4，榫槽的材料是 GX8。

表 1 试验结果对比

(载荷最小值为 0，未修形端的裂纹位置都在 Ⅰ 处)

试件号	载荷 (kN)	出现裂纹前循环次数		裂纹位置
	最大值	未修形端	修形端	修形端
1	14	469300	614880	Ⅱ
	10	1292900	2966500	Ⅱ
2	12	558000	750600	Ⅱ+Ⅲ
	10	1046570	2106000	Ⅲ
3	12	582120	1006920	Ⅲ
	10	912360	1385400	Ⅲ
4	12	564480	105570	Ⅲ
	10	1057680	1674660	Ⅲ
5	12	696000	1849200	Ⅲ
	10	1116000	2712120	Ⅱ+Ⅲ

全部试件在高频疲劳试验机上进行试验，试验在室温及空气中进行。在试件的两端分别装上未修形的榫头和修形的榫头，保证修形与未修形联接的工作条件相同。当一端出现裂纹长度至 1～2mm 时，取下该端的榫头试件，并将该端装夹在榫槽件上继续对另一端进行试验，当另一端出现裂纹长度为 1～2mm，一次对比试验结束。各试件的对比试验结果见表 1。表中 Ⅰ 和 Ⅱ 分别表示裂纹位置位于 X= 0 和 X= 2～5 附近的榫槽上；Ⅲ表示位于 X= 10～12 附近的榫头上。加载频率：取下未修形端榫头前、后的频率分别为 100Hz、117Hz。

6. 结论 (1) 试验中出现的裂纹均位于接触区内，有磨损痕迹；(2) 修形榫联接比未修形榫联接的微动疲劳寿命高。(3) 修形榫联接的裂纹位置不同于未修形榫联接，这是由于修形的榫联接接触处的力学参数分布有利于提高抗微动疲劳的能力。

crack initiation is 8642 (cycles). In comparison with cyclic rotating tests, the test period on a multi-channel radial loading fatigue test rig can be shortened greatly and the test data can be obtained easily. A smooth round bar specimen experiment method for predicting the LCF life of groove bottom in the disk is provided, which is better than the Morrow method. For the median LCF life, the ratio of the experimental life to the predited life is 1.2.

EXPERIMENTAL ESTIMATION OF LCF LIFE FOR A COMPRESSOR DISK

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ABSTRACT A LCF (Low Cycle Fatigue) test of a single rotor disk of a compressor is presented. The experimental results show that the location and the growth orientation of LCF crack in 9th single rotor disk reproduce those in the global compressor rotor. In addition, the LCF tests of the smooth round bar specimens are accompanied with the LCF tests of a single rotor disk, so as to estimate of the strain history of the eccentric holes in the disk. The statistical data of smooth round bar specimens tested to failure enables to estimate the LCF life to crack initiation for the eccentric holes in the disk of the global compressor rotor.

AN EXPERIMENTAL STUDY ON DISC BURSTING SPEED

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ABSTRACT This paper discribes the experimental work on the research of disc bursting speed. The bursting speed tests for a series of disc models are made successfully. That means: such a difficult experimental technique has been mastered; and the reconstructed horizontal test rig is suitable for the research of disc bursting speed at normal atmospheric temperature and with heating. The results obtained from experiments and calculations are coincident. This work provides the basis for the further research on the bursting speed of aeroengine discs.

MODIFICATION OF SHAPE OF DOVETAIL JOINTS FOR ANTI-FRETTING DAMAGE

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ABSTRACT The fretting damage of the dovetail joints between blades and disks in turbojet engines has significant effect on fatigue life of the joints. In order to improve the resistibility to of dovetail joints fretting damage, an effective method provided, which palliates the fretting wear of the joint. By modifying the shape of the local interface to adjust the distribution of the mechanical parameters. The numerical analysis of the joints with the Boundary Element Method indicates that for the modified joints the peak reaction on the interface drops greatly but the peak stress does not rise at both the contacting and non-contacting interface in elastic bodies. Comparative experiments have been carried out. The

results show that the fretting wear of the modified dovetail joints is palliated, especially at the root of contact surface. The fatigure life of the appropriately modified dovetail joints increases twice.

COMPUTATION FOR CONTACT PROBLEM OF A DISK-BLADE COUPLED COMPONENT

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ABSTRACT Contact stress of a disk-blade coupled component is analyzed by numerical method. The contact problem is reduced to a problem of quadratic programming with linear inequality constraints (LCQP). Objective function of the LCQP is derived from the principle of minimum potential energy of elastic bodies in combination with finite element method. In order to formulate the constrain equations, an imaginary media is introduced between the two contact surfaces. Then the displacement compatibility condition on the contact region can be considered as to make the imaginary media have non-negative volume during deformation. Such geometric condition will be presribed by a set of linear inequalities after discretization. Besides, static condensation technique is also used to reduce the degree of freedoms of the LCQP problem. A practical problem is estimated by our method and SAP5 software. These two results are in good agreement.

INFLUENCE OF SIZE FACTOR ON SCATTER DEGREE OF THE LOW CYCLE FATIGUE LIFE OF A DISK

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ABSTRACT From mathematical statistics of test data has been drawn the following conclusion: the low cycle fatigue life of disks scatters due to their size difference. The cylic stress-strain curve and the strain-life relationship of a materical must consider requirements of the survival probability and believable degree when the low cycle fatigue life of a disk is estimated with the partial stress-strain method. This paper also provides an approximate correction method for the preliminary estimation of the low cycle fatigue life of a disk.