

轮盘槽底低周疲劳寿命预测

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航空构件要求重量轻, 多半采用弹塑性设计, 应力集中区域的材料通常是应变循环而不是应力循环, 所以局部应变法已成为比较流行的一种寿命预测方法。本文采用了这种方法。

鉴于试验更能真实地反映疲劳累积损伤的过程, 所以本文除了用局部应变理论估算寿命之外, 还利用光滑试样的疲劳试验预测了轮盘槽底的裂纹起始寿命。实践证明这种寿命预测方法比仅用计算公式估算寿命效果要好。对于中值寿命, 轮盘和光滑试样的寿命之比仅为 1.2 倍。

轮盘的材料是 30CrMnSiA。疲劳试验是在空一所的 HPS- 80 多路径向加载疲劳试验台上进行的。光滑试样的非对称应变循环试验在本所红山疲劳试验机上完成。应力分析和寿命估算用的材料性能数据是委托北京航空材料研究所做出的。

1. 轮盘试件的主要几何参数 整个轮盘试件的最大外径为 490mm, 外缘有 36 个径向槽沿圆周均匀分布, 槽底孔径 5mm, 该处盘厚 14mm, 36 个加载点处的螺栓孔孔径 16mm, 辐板部分的厚度为 3.5mm, 见图 1。

2. 轮盘疲劳试验载荷和槽底应变状态

试验过程中由 36 个作动筒同步协调, 对盘施加径向拉力, 模拟叶片作用在盘上的离心力。单个作动筒的疲劳载荷和轮盘槽底应变状态如图 2 和图 3 所示。图中 P 表示单个作动筒载荷, σ 和 ϵ 分别表示轮盘槽底应力、应变。 $P_{max}=79830\text{N}$, $P_{min}=9800\text{N}$, $\epsilon_{max}=1.0860\%$, $\epsilon_{min}=0.3722\%$, $\Delta\epsilon=0.7138\%$ 。

3. 轮盘疲劳试验结果 由于利用飞利轮这种型式的试验器本身带来的优点——可以随时观测试件考核部位的裂纹, 所以该项试验获得了大量的裂纹起始和扩展数据。除了一、二个槽孔之外, 绝大部分都已出现疲劳裂纹。轮盘主断口疲劳裂纹前缘线呈弓形, 中截面处裂纹深度较大, 4.1mm。两侧较短一些。由扫描电镜得到的微观断口形貌也已证实轮盘槽底出现的裂纹确为疲劳裂纹。

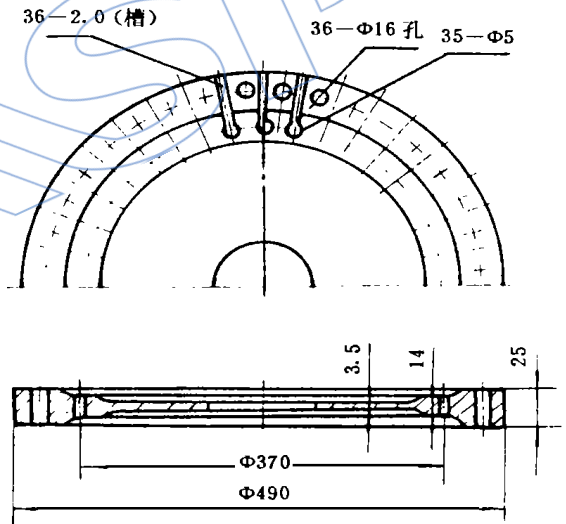


图 1 轮盘试件

轮盘槽底典型的裂纹扩展曲线如图 4 所示。由非线性拟合得到的裂纹长度和循环次数的关系式 ($a = KN^b$) 推算出裂纹长度 a 等于 0.794mm 时每个槽底的裂纹起始寿命 N_0 。最后由统计分析得出盘的中值寿命 $N_{50} = 8462$ (循环次数)。

4. 预估寿命与实际寿命的比较 寿命估算时用了全应变—寿命公式, 并且考虑了平均应力的影响, 即

$$\epsilon_a = \{(\sigma_f' - \sigma_m) / E\} (2N_f)^b + \epsilon_f' (2N_f)^c$$

式中, ϵ_a 为总应变幅, σ_m 为平均应力, σ_f' 、 b 分别为疲劳强度系数和疲劳强度指数, ϵ_f' 、 c 分别为疲劳延性系数和疲劳延性指数, E 为弹性模量, N_f 为循环寿命。

表 1 预估与实际寿命比较

$N_{\text{预}}$	$N_{\text{盘}}$	$N_{\text{盘}} / N_{\text{预}}$
4847	8642	1.8
6949	8642	1.2

就中值寿命而言, 预估寿命 $N_{\text{预}}$ 与实际寿命 $N_{\text{盘}}$ 的比较见表 1。表中最后一行是光滑圆棒试验结果, 其上一行数值是理论计算结果。

5. 结论 我们得出的 30CrMnSiA 轮盘槽底的预估寿命接近于它的实际寿命, 二者之比在 2 倍以内。并且用光滑试样的疲劳试验来预测轮盘槽底的低循环裂纹起始寿命, 效果尤为理想。实际寿命与预测寿命之比仅为 1.22 倍, 得到了既安全精度又高的预测寿命, 这说明实验更能真实地反映疲劳累积损伤过程。

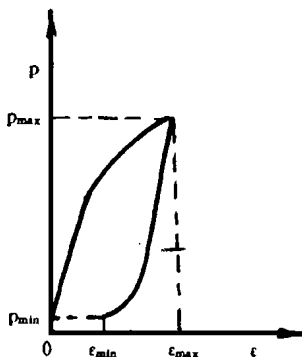


图 2 疲劳载荷—槽底应变关系

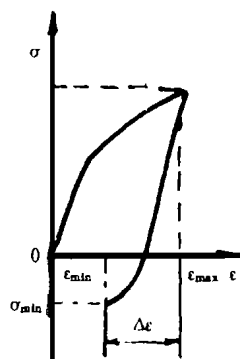


图 3 槽底应变状态示意图

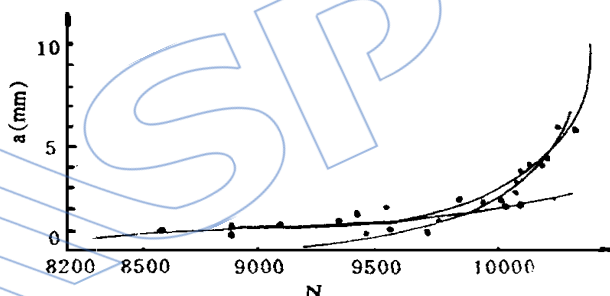


图 4 裂纹扩展曲线

NATURAL VIBRATION ANALYSIS OF TURBOMACHINERY DISK WITH SMALL MISTUNED BLADES

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ABSTRACT

A numerical approach is developed for natural vibration analysis of turbomachinery disk with small mistuning blades by using modal synthesis technique. Due to lack of rotational periodicity, the group theory method for the tuned bladed-disk assemblies is not applicable to the mistuned ones. According to the matrix perturbation theory, the modes used for synthesis in this paper are taken from a tuned bladed-disk corresponding to the small mistuning one. This new technique keeps the advantages of the group theory method and makes the final eigenvalue problem of small size. A computer program has been written to analyse the natural vibration characteristics of turbomachinery disk with small mistuning blades. The computational results prove that the method is very efficient.

TECHNICAL NOTES

VERTICAL ROTATING TESTER WITH VARIABLE-AMPLITUDE CYCLE FOR GAS TURBINE DISKS

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ABSTRACT

A microcomputer-controlled high-speed high-temperature rotating tester with variable-amplitude cycle has been constructed and operated to estimate the LCF life of gas-turbine disk. So far the tester has worked about 2500 hours (total cycle index is about 50000), without essential troubles. The data of the variable-amplitude LCF life for several disks have been obtained. These data are of high quality. It is testified that the test equipment is sufficient for performance research of rotating disks with diameter up to 1m and weight up to 300kg. The disk is mounted vertically on flexible shaft; an D. C. motor (125kw) drives the disk up to 25000rpm. The heater can raise the temperature of the disk up to 800 ± 5 . The average speed error for a run is less than 0.1%; the maximum instantaneous error is about 0.5%. A vacuum pump is used to sustain about 400 to 667Pa in the chamber of the tester.

A LOW CYCLE FATIGUE LIFE PREDICTION FOR DISK GROOVE BOTTOMS

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ABSTRACT

According to the theory of local strain fatigue, the fatigue experiments for the 30CrMnSiA disk have been completed on a multichannel radial loading fatigue rig ("Ferris" wheel). A good number of the crack propagation curves of the groove bottoms in the disk have been obtained. The calculations show that the median LCF life to

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 predicted 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 describes 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 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