

涡轮盘榫槽高温复合疲劳试验方案研究

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【摘要】 针对某型航空发动机二级涡轮盘榫齿高温复合疲劳裂纹故障, 采用全尺寸真实涡轮盘作为试验件, 设计了一套新型试验方案, 着重解决了高低周疲劳载荷的加载并互不干扰、高频感应局部加温(550℃恒温)、高周振动振幅控制以及裂纹检测等几大关键技术, 载荷谱与加温均模拟外场真实情况。试验完全实现了故障再现, 这说明: 该试验方案设计合理, 易于推广到其它多种构件的复合疲劳试验, 在工程应用研究中具有重要意义。

主题词: 涡轮 盘 疲劳裂纹
分类号: O346.2

1 试验的新型加载方案

本试验能否再现故障的最为关键的技术是加载方案。加载示意图如图 1 所示。其中 P 模拟低周载荷(主要为叶片离心力), M 模拟叶片振动弯矩。问题的核心在于低高周载荷(P 与 M) 如何互不干扰、合理施加。传统的方案存在严重缺陷: 首先, 低周大载荷直接加在假叶片叶根处的两个承力圆柱上, 当加上高周振动载荷时, 由于叶根部的承力圆柱与低周拉力板圆孔间存在很大摩擦力, 所以高周载荷无法传到榫齿上, 高周振动没有发生作用; 其次, 高低周载荷传到榫齿上的应力分布与实际不符。通过在榫齿上贴应变片测量, 结果也证实了这一点: 当低周载荷在 4 吨以上时, 高周载荷就完全传不到榫齿上了; 同时, 第一齿上的应力小, 第五齿的应力最大, 而实际情况是第一对齿的应力大, 第五对齿小, 这样才导致了疲劳裂纹总是首先出现在第一齿这一故障模式。

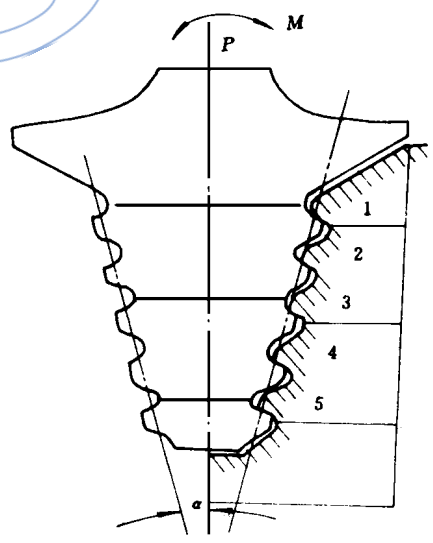


图 1 加载示意图

要实现高周振动载荷很好传递、应力分布合理, 最好的办法是低周载荷由叶片的后方推加到叶根上, 同时使高周振动的支点、亦即低周载荷的施力点后移至榫槽后方, 并在该支点上加轴承, 以减少传振摩擦, 但菲利轮作动筒只能加拉力, 不能直接作到这一点, 又提出了新的加载方案, 如图 2 所示。该加载方案解决了高低周载荷的相互干扰问题, 并使榫齿上应力分布合理。将低周载荷施力点通过一传力圆棒后移至榫槽后方, 用一传力支板

从后方推至叶根的承力圆柱上。在保证低周载荷很好传递使载荷沿榫齿分布合理的同时,加长了高周振动的力臂,而且通过振动支点的后移,在叶片绕该支点振动时,振动力可先到达榫槽再到支点,高周振动力就会不受损失地传到榫齿上。试验结果也证实了这一点。

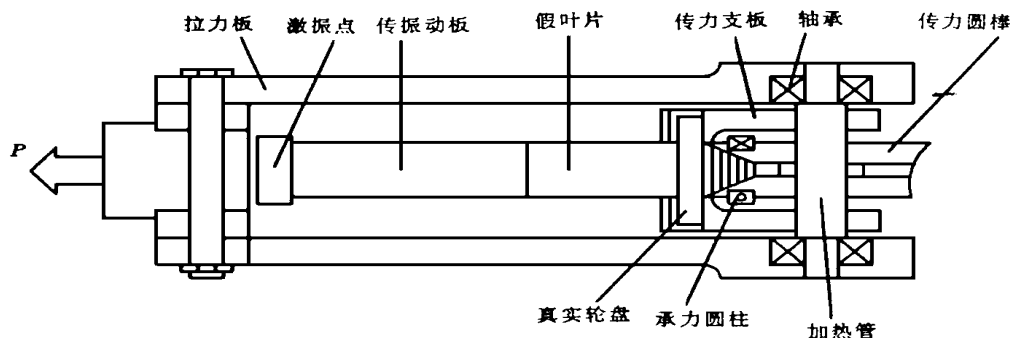


图2 新的加载方案简图

另外,为了防止轮盘转动影响榫齿对高周振动的吸收,在轮盘加载线的垂线方向用假叶片对称加固持拉杆,这同时起到了托起轮盘和定心的作用。同时,在试验榫槽的左右两个榫槽用真实叶片榫头加堵,以更好地模拟轮盘的真实工作状态。适应本试验的需要,对原有的菲利轮液压低周疲劳试验器进行了大规模改造,建立了高温复合疲劳试验系统。该系统采用高频感应加热器,在轮盘试验榫槽周围局部加热,热电偶测温。经过反复探索,找到一种方便有效的加温方法(见图3)。使用该方法,在工作电压电流不大的情况下,十分钟内即可加至 $550 \pm 5^\circ\text{C}$, 保持恒温,并且沿榫槽厚度方向无温度梯度。在试验中榫槽处于高温条件,周

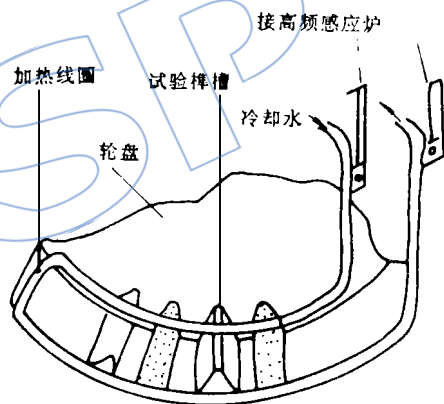


图3 加温简图

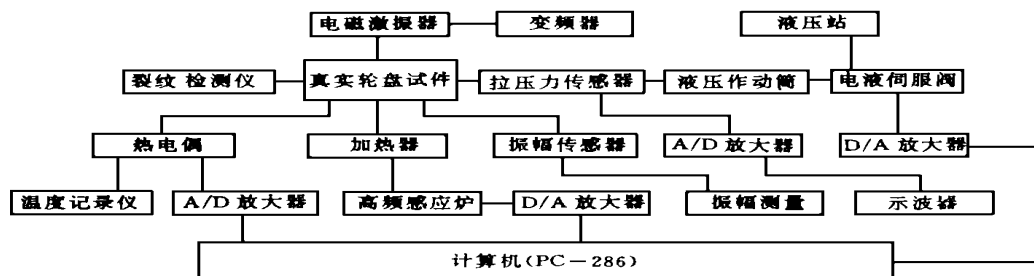


图4 高温复合疲劳试验系统简图

围空间封闭,通常方法不易实现裂纹实时监测。试验采用最新研制的 MDF-1 型裂纹检测仪

进行裂纹检测。该检测仪利用电位法原理, 采用恒流源, 可保证较高的检测精度, 很好地实现了裂纹的实时跟踪^[1]。改造后的试验系统如图 4 所示。

2 试验载荷谱、试验结果及结论

根据某型发动机二级涡轮盘榫齿断口属复合疲劳断裂及叶片在某工作转速下存在共振的空测结论, 选取恒温 550℃ 下低周载荷基础上叠加高周振动载荷的试验载荷谱, 如图 5 所示。低周载荷主要模拟叶片的离心力, 经计算, 叶片的离心力在 6.5 吨左右, 该载荷由微机控制, 通过菲利轮上的液压作动筒施加, 每个载荷块的时间为 20 秒。在整个低周载荷加载过程中叠加高周振动载荷, 考虑到本试验需要较高振动频率且要作两个振动频率的对比, 故选用电磁激励器作为振动源, 振动载荷施加在假叶片的加长部分上, 加力点距叶根约

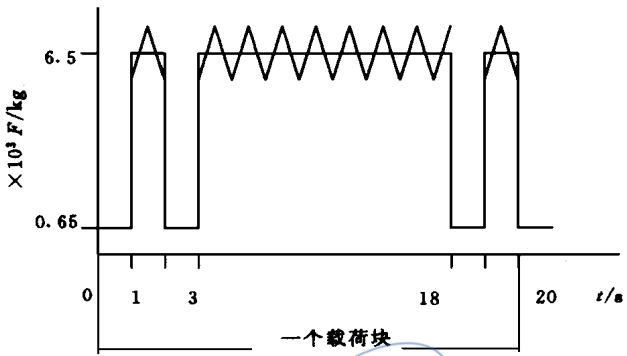


图 5 试验载荷谱(一个加载循环)

280 mm, 激振频率先用 50 Hz。试验过程中使用 ZZF6-1 型电涡流式位移振幅测量仪测定振动振幅, 通过控制振幅使榫齿上的振动应力保持在低周离心应力 0% - 30% 之间可调。

试验盘为已使用 23 小时的无腐蚀涡轮盘, 试验榫槽在装机前用电位探伤仪监测未发现裂纹。整个试验共进行了 7 个小时, 试验榫槽恒温 550℃, 试验载荷谱如图 5 所示, 共加低周载荷块 1260 块, 高周 1.26 × 10⁶ 循环。裂纹检测结果(左边榫槽) 如表 1。

表 1 高温复合疲劳第一榫齿裂纹检测结果

时间(h)	0 : 00	1 : 30	4 : 30	5 : 30	6 : 00	6 : 10	6 : 30	6 : 40	6 : 45	6 : 50	7 : 00
低周载荷块	0	270	810	990	1080	1110	1170	1200	1215	1230	1260
高周循环(× 10 ⁶)	0.0	0.27	0.81	0.99	1.08	1.11	1.17	1.2	1.215	1.23	1.26
检测数值	410	415	423	418	412	415	485	525	706	850	1000
裂纹长(mm)	—	—	—	—	—	—	1.8	2.82	7.46	11.15	15

从表 1 可见, 在试验进行到 6 小时 30 分时开始出现明显裂纹, 从此裂纹迅速扩展, 直至第 7 小时试验结束时扩至 15 mm。而其他各对榫齿经卸盘后检测未发现裂纹。第一榫齿裂纹方位及走向与外场裂纹故障完全一致。这说明: 该新型试验方案很好地模拟了实际使用中造成轮盘第一对榫齿裂纹的主要因素, 加载加温合理, 完全再现了故障。该试验方案设计合理, 易于推广到其它多种构件的复合疲劳试验。可以继续进行大规模的试验, 探求榫齿裂纹腐蚀判废标准。

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tolerant design are combined and a structure life evaluation model is developed. The formulas to determine the service life and the inspection periods of a structure with the high reliability are presented. Then the model is applied to evaluating the inspection periods for aircraft powerplant dynamic components, and an example is given.

Key Words Fatigue Fracture Lifetimes Model

DETERMINATION OF AXIAL PRELOADS OF ROTORS WITH CURVIC COUPLINGS

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ABSTRACT

Rotors with curvic couplings, which are separately prestressed from the front part and the rear part, are often applied to modern turboprop and turboshaft engines. It is very important but difficult to determine the values of preloads for a rotor. The prerequisite of the axial relaxed/pressed forces caused by variety of rotor loads in operation is available, the criteria to determine the axial preloads of rotors are proposed in this paper, which takes into account synthetically the factors, such as tightness margin, strength margin, assembling relationship and etc. Hence the optimization model of the axial preloads is established, and the corresponding solution is presented. The computer program is developed according to the presented criteria and method. Finally, an example is given.

Key Words Rotors Axial preloads Optimization

AN OPTIMUM METHOD OF JOURNAL BEARING STABILITY

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ABSTRACT

The expression of journal instantaneous whirl energy is formulated, based on solution for shaft center whirl orbit of a short bearing under the nonlinear oil film force. An optimization model of journal bearing parameters with optimum stability is established with the aim of minimizing time integration of whirl energy. The model has been solved with the optimal control method. In the last, a numerical example illustrates the determination of the optimal parameters of a given bearing.

Key Words Plain bearings Stability Optimal control

A NEW APPROACH TO COMBINED FATIGUE EXPERIMENT OF TURBINE DISK MORTISES AT ELEVATED TEMPERATURE

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ABSTRACT

Crack and fracture fault emerged in the mortises of a given aero-engine second-stage turbine disk for a long time and seriously endangered the aircraft's regular flight. The fractography analysis indicated that the faults were caused by combined fatigue at elevated temperature. So we were engaged in this experiment to study and research

a new failure criterion of the disk. A real disk was used as experimental component, we worked out a new failure experimental approach, including key technique to ensure the noninterference between the low cycle loading and high cycle loading, the high frequency induction local heating (550°C constant temperature), the control of high cycle vibration frequency and amplitude, and crack real-time detection. Experimental load spectrum and temperature field emulated the reality, and the experiment completely reproduced the practical flight fault. The present experimental approach can be applied to the combined fatigue analysis of any components.

Key Words Turbines Disc Fatigue crack

A STUDY OF A DUAL- PULSE MOTOR TECHNIQUE

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ABSTRACT

A new type of dual-pulse solid rocket motor concept with an intermediate nozzle is presented and a test motor with changeable structural parameters was designed. Several firings of the motor with changing the structural parameters were conducted and the corresponding experimental data were obtained. A two-dimensional unsteady mathematical model was constructed for analyzing the multithroat flowfields, and numerical calculation with this model was completed. The results were compared with the test data.

Key Words Solid propellant rocket engines Flow fields Numerical computation

NUMERICAL SIMULATION OF 3- D FLOW IN A TRANSONIC COMPRESSOR STAGE

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ABSTRACT

An implicit Navier-Stokes solver is presented for numerical simulation of three-dimensional steady compressible turbulent flow in a transonic compressor stage. The LU-SGS (Low-Upper Symmetric-Gauss-Seidel) implicit time-marching scheme developed by Jameson and Yoon is used to improve the computational efficiency. In order to obtain distinct shock system and valid boundary layer characteristics, one kind of high resolution schemes, the third order accurate NND (Non-oscillatory, Non-free-parameter, Dissipative) scheme is incorporated in this solver. The governing equations, the numerical scheme, the grid system and the boundary treatment method are considered in this paper. The Baldwin-Lomax Algebra model is utilized to compute the turbulent viscosity. The viscous flow in a single stage transonic compressor is calculated by this solver. The calculation was performed by coupling the rotor and stator flow fields at each time step through an overlapped grid. The computed results were compared with experiment data.

Key Words Three-dimensional flows Turbulent flow High resolution
Numerical analysis Transonic compressors