

悬臂式挠性薄片气体动压径向轴承 试验研究

中国航空附件研究所 陈元先* 钱传衢

【摘要】 悬臂式挠性薄片气体动压径向轴承的静态加载和运行试验结果分析表明: 悬臂式挠性薄片气体动压径向轴承有较好的弹性; 径向轴承能在较宽的转速范围内稳定运行在, 具有较好的高转速性能, 对工作环境条件不敏感, 并具有良好的动特性。研制的悬臂式气体动压径向轴承满足涡轮冷却器的要求。

主题词: 气体轴承 薄片 试验

分类号: TH133.31

航空涡轮冷却器是一种高速轻载的旋转机械, 其发展对转子支承系统的要求越来越高, 本文为自行研制的航空涡轮冷却器的悬臂式薄片气体动压径向轴承的试验结果分析研究。

1 径向轴承试验件

悬臂式薄片气体动压轴承是由多片相同形状的8片悬臂弹性薄片组成^[1]。悬臂式气体动压径向轴承试验件的几何尺寸为: 轴颈半径 $R = 15\text{ mm}$, 轴承半径 $R_b = 16\text{ mm}$, 轴承长度 $L = 30\text{ mm}$, 轴承薄片数 $N = 8$, 薄片厚度 $t = 0.1\text{ mm}$, 薄片半径 $R_f = 21\text{ mm}$, 薄片重叠角 $\varphi = 47^\circ$ ^[1]。

悬臂式气体动压径向轴承试验件改装作为飞机涡轮冷却器转子的支撑进行试验研究。改装的涡轮冷却器转子一端为涡轮驱动部分, 另一端为负载风扇, 8片气体动压径向轴承薄片周向顺转子旋转方向搭接安装。为避免试验研究中的径向轴承和推力轴承相互影响和不确定性, 采用专门设计的成熟的气体静压推力轴承作轴向辅助支承。

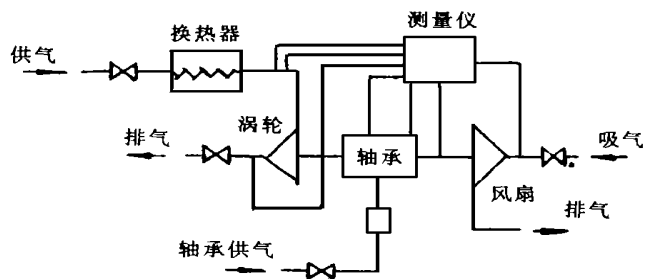


图1 径向轴承试验台示意图

径向轴承试验时测量部分安装有转速、径向位移、摩擦阻力矩和加载力的测量传感器。转速和径向位移用电涡流传感器测量, 摩擦阻力矩的测量用应变仪。试验装置的原理图见图1。

2 试验研究

悬臂式气体动压径向轴承试验研究分为静态特性和运行性能试验研究两部分。

静态加卸载试验是对径向轴承径向加卸载和卸载, 测量和研究径向轴承薄片的弹性变形和摩擦力的情况。图 2 是径向轴承一次加载和卸载循环过程转子轴颈的径向位移试验结果。径向加卸载使轴承薄片承受径向载荷, 产生弹性变形, 薄片弹性变形时产生的变形力, 加上薄片之间的接触摩擦力, 形成合力平衡径向外载荷。从加载变形曲线上可见, 加载载荷在 18 N 之内时, 径向轴承薄片组件的变形量很小, 由于在此阶段外载荷较小, 轴承薄片之间的摩擦力起主导作用, 轴承薄片之间没有产生完全滑动, 径向轴承薄片之间的摩擦力平衡外载荷。当外载荷进一步增大后, 径向轴承薄片组件的变形明显增大, 可以判断轴承薄片之间产生了滑动, 薄片变形产生的弹性变形力和轴承薄片之间的摩擦力的合力来平衡外载荷。这时轴承薄片的弹性变形力是主要的。但是在整个加载变形过程中, 薄片间的摩擦力的影响是明显存在的。

卸载过程中轴承薄片变形恢复有滞后, 卸载时薄片之间的相对滑动摩擦力方向与加载时相反, 同时薄片的变形惯性力的影响也造成薄片复位的滞后。当外载荷完全卸除, 一定时间后薄片可回到原位。证明了轴承薄片的变形在弹性变形的范围内, 薄片弹性特性较好。

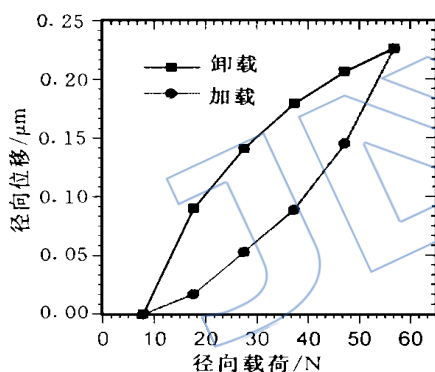


图2 静态加载

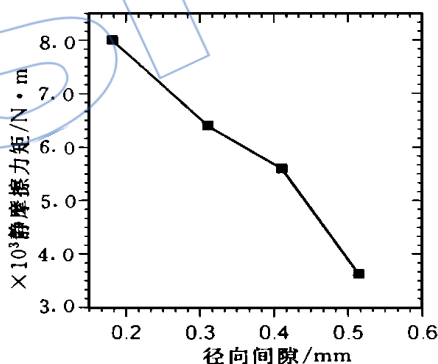


图3 静摩擦力矩

径向轴承的静摩擦力矩试验方法是在转子轴上加一外力臂, 在外力臂处加挂砝码。当加挂砝码增加到使转子开始转动时, 所加砝码重量与力臂的乘积即为径向轴承的静摩擦力矩。图 3 是径向轴承具有不同的轴向间隙时, 转子和径向轴承系统的静摩擦力矩变化关系。当轴承的径向间隙增大时, 摩擦力矩明显降低。由于径向间隙增大时, 轴承薄片对轴颈的摩擦程度降低, 即减小了轴颈与轴承薄片的接触面, 使得摩擦力减小。但径向间隙增大将影响到轴承气膜的稳定性和承载能力, 因此径向轴承的径向间隙不能太大。

将装有悬臂动压径向轴承试验件的涡轮冷却器进行运行试验, 以进行径向轴承的运行试验。运行转速的调节是通过控制涡轮进口工作气体的驱动压力来控制。

图 4 是轴承的间隙为 0.392 mm 和 0.509 mm 时, 涡轮冷却器的起动过程。从变化曲线看, 在起动过程中转子的转动时轴颈和轴承经历了三个阶段:

第一阶段, 转子的驱动力小于轴颈与轴承表面间的摩擦力, 转子已开始有转动, 但基本上仍处于轴颈与轴承薄片的直接干摩擦状态;

第二阶段, 增大转子的驱动力, 转子转动, 但还没有建立起足够的气膜压力浮起转子, 轴颈与轴承薄片时有磨擦和浮起, 转速信号为无规律急剧波动, 是起动阶段的过渡过程;

第三阶段, 驱动力进一步增大, 转子转速升高, 轴颈与轴承表面之间建立起足够的气膜压力形成承载能力, 将转子轴颈浮起在轴承中间, 转速信号急剧升高, 且保持平稳。

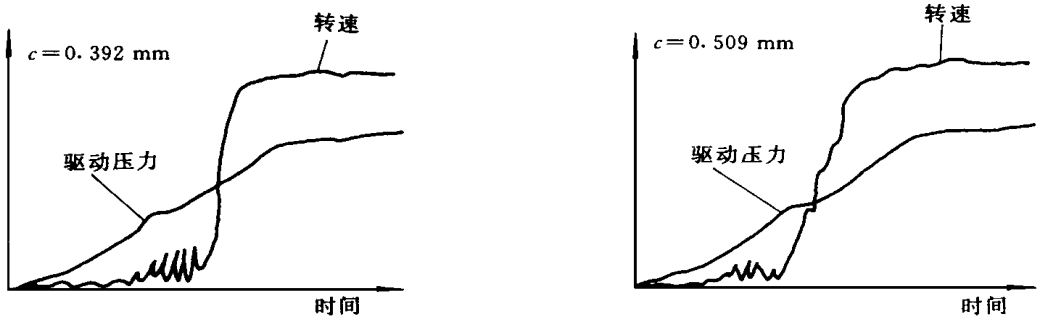


图 4 涡轮冷却器起动过程

由于间隙为 0.509 mm 时转子的静摩擦力矩小于间隙为 0.392 mm 时, 改善了涡轮冷却器的起动性能, 缩短了起动过渡过程。当轴承径向间隙为 $c = 0.188$ mm 时, 当驱动压力为 0.183 MPa 时, 基本没有转速信号, 是处于摩擦状态。到 0.267 MPa 时, 出现转速信号波动, 当驱动压力升高至 0.5 MPa 时, 转速信号仍波动很大, 不能稳定, 表明转子轴颈与轴承之间没有达到完全润滑状态。轴承间隙小时轴承转子系统的摩擦力矩大, 起动困难。

图 5 是不同径向间隙情况下, 出现较明显的第二阶段的驱动压力和转速信号值的对比。三种不同轴承间隙时的涡轮起动特性变化, 完全与不同间隙时摩擦力矩的大小变化规律是一致的。

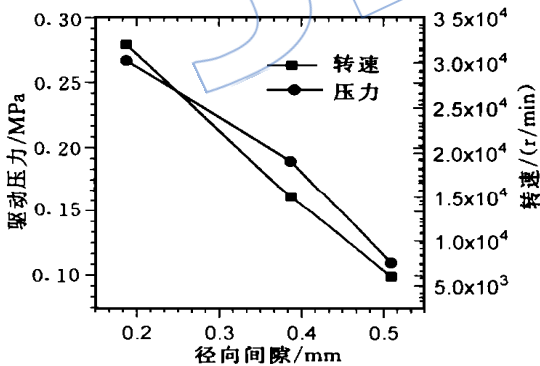


图 5 不同间隙的影响

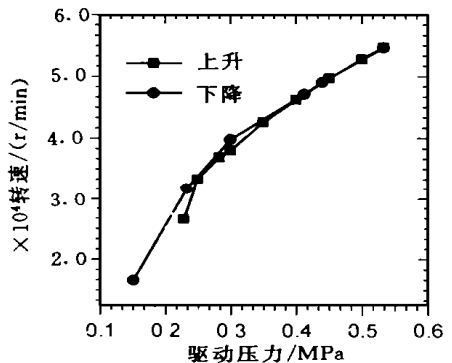


图 6 转速特性

图 6 是试验件涡轮的运行转速特性试验结果。在涡轮的起动过程中, 由于转子轴承系统的摩擦力的影响, 起浮压力为 0.227 MPa, 起浮转速为 26500 r/min。当轴承中形成了完全润滑动压气膜后, 转速随驱动压力变化的运行特性就比较平稳, 这时转子轴承系统的摩擦力矩完全是润滑气膜的摩擦力矩, 比较小。减压停车过程是由高转速下降的减速过程, 在完全气膜动压润滑区时, 转速随驱动压力降低而下降, 变化曲线基本与升速过程的曲线相重合, 在

完全气膜动压润滑区时, 转子轴承系统的动特性是一样的。由于气膜动压效应, 转子减速的完全润滑破坏转速较起动过程的起浮速度低, 减速时的完全润滑破坏最小速度为 17000 r/min , 这时的驱动压力为 0.15 MPa 。这说明只要减小转子与轴承系统的摩擦力, 改善起动摩擦条件, 起动过程的最小起浮速度还是可以降低的。

在试验过程中为进一步提高工作转速, 将试验件风扇的直径变小, 进行高速运行试验, 涡轮的运行工作转速可达 84500 r/min , 涡轮运转十分平稳。

试验件在试验过程多次分解检查轴承薄片和轴颈表面的磨损情况, 分解检查发现轴承薄片的工作表面有摩擦痕迹, 摩擦区主要在薄片尾部区, 在摩擦区域里摩擦痕迹比较均匀, 轴颈的工作表面也有摩擦痕迹。分解检查后又重新装上, 再进行运行试验, 试验件的运行情况和分解检查前的试验情况相同, 重新组装时一般不重新对转子进行动平衡, 重新组装后的良好运行也说明了气体动压薄片轴承对转子动平衡的要求不敏感。证明了悬臂式气体动压径向轴承的动特性好。

3 结 论

本文进行的试验结果分析研究可有以下结论: (1) 径向轴承薄片系有较好的加载和弹性变形等静态特性; (2) 径向轴承的径向间隙对涡轮冷却器的起动过程和静摩擦力矩有重要影响; (3) 在完全润滑时, 悬臂式气体动压径向轴承转速的上升和下降运行特性平稳, 有良好的动力学特性, 径向轴承性能良好; (4) 轴承试验件的多次分解组装后的运行试验证明了研制的悬臂式气体动压径向轴承对环境条件不敏感, 并具有良好的动特性。

参 考 文 献

- 1 陈元先, 杨燕生. 悬臂式挠性薄片气体动压径向轴承分析研究. 航空动力学报, 1999, 14 (2): 183- 186
- 2 钱传衢, 金文荣, 陈兰芳. 悬臂型弹性薄片动压气体轴颈轴承的应用研究. 第四届全国摩擦学学术会议, 1987
- 3 Heuer D F, Collins R A. Dynamic and Environmental Evaluation of Compliant Foil Gas- Lubricated Bearing. AFA PL - TR- 73- 56, 1973
- 4 Emerson T. The Application of Foil Air Bearing Turbomachinery in Aircraft Environmental Control Systems. ASME paper 78- ENAS- 18, April 1978
- 5 Oh K P, Rohde S M. Theoretical and Experimental Load- deflection Studies of a Multileaf Journal Bearing. Top in Film Bearing and Rotor Bearing System Design and Optimization Conference, Chicago, April, 1978
- 6 Heshmat H. Analysis of Compliant Foil Bearings With Spatially Variable Stiffness. AIAA- 91- 2102
- 7 Roger Ku C- P, Heshmat H. Compliant Foil Bearing Structural Stiffness Analysis: Part II—Experimental Investigation. J. of Tribology, July, 1993, 115: 364- 369

(责任编辑 王震华)

FINITE ELEMENT ANALYSIS AND EXPERIMENTAL MEASUREMENT OF STIFFNESS OF HOOP

Y in Zeyong and Chen Yanong

(Zhuzhou Aviation Powerplant Research Institute, Zhuzhou 412002)

ABSTRACT It is important to determine the stiffness coefficients of the hoops precisely for the vibration analysis of a pipeline system. For this purpose the finite element models for calculating the stiffness coefficients of the hoops are established in accordance with the structural features of the various hoops used in aeroengine pipeline systems. The stiffness coefficients of a grounded hoop for single pipe and a hung hoop for double pipes are obtained by the finite element analysis. In addition, the stiffness coefficients of a typical hung hoop for double pipes are measured by using the established experimental method. The comparison between the calculational and experimental results of the hoop shows that the provided method is feasible in the engineering practice of vibration analysis for a pipeline system.

Key Words Hoops stiffness Finite element analysis Measurement

AN ANALYSIS OF A GAS LUBRICATED COMPLIANT MULTILEAF JOURNAL BEARING

Chen Yuanxian and Yang Yansheng

(China Research Institute of Aero- Accessories, Xiangfan 441052)

ABSTRACT A performance analysis model of the gas lubricated compliant multileaf journal bearing of the high-speed rotor for air cycle machine of aircraft environmental control system has been established. In the analysis, the differential method is used to solve the compressible Reynolds equation, which governs the airflow in the journal bearing. The solution is coupled with the load deflection equations of the leaves to obtain such information as minimum film thickness, the stiffness coefficients, and the equivalent damping coefficients. The graphical solutions are provided for a range of relevant geometric and operational parameters. The journal bearing has good stability in all range of eccentricity ratios and all possible operating speeds.

Key Words Gas lubricated bearings Compliant Multileaf Analysis

EXPERIMENTAL STUDY OF A GAS LUBRICATED COMPLIANT MULTILEAF JOURNAL BEARING

Chen Yuanxian and Qian Chuanqu

(China Research Institute of Aero- Accessories, Xiangfan 441052)

ABSTRACT The gas lubricated compliant multileaf journal bearing of the high-speed rotor for air cycle machine of aircraft environmental control system was investigated experimentally. In the earlier work, an analysis model was developed to predict the performance of the air lubricated compliant multileaf journal bearing. In the experiments, the load deflection tests revealed the elastohydrodynamics of the compliant leaves; the starting torque tests found out the frictional influence between leaves and journal; the air cycle machine operational tests demonstrate the dynamic characteristics of the journal bearing. All of the experimental results show that the journal bearing can run steadily in wide operating range, and it

has excellent static and dynamic performance. It is insensitive to environmental conditions.

Key Words Gas lubricated bearing Journal Performance compliant
Multileaf experiments

MULTIVARIABLE CONTROL FOR AEROENGINE WITH 3- LAYER NEURAL NETWORKS

Huang Jinqun, Chai Hongwu, Sun Jianguo

(2nd Dept Nanjing University of Aeronautics and Astronautics, Nanjing 210016)

ABSTRACT A multivariable neural network adaptive control is provided for a turbofan engine. The nonlinear system is compensated dynamically by a 3- layer neural network. An on- line weight- tuning algorithm with simplified Hebbian rule and e- modification is worked out to guarantee tracking performance as well as bounded weights without off- line training. The precise model of the engine is not necessary for design of control system. The multivariable control system has satisfactory performance for the full flight envelope with good adaptation and robustness. Simulation results show satisfactory dynamic and static performance within the whole flight envelope and good effectiveness of reducing interaction in the multivariable system with significant coupling.

Key Words Aeroengine Neural networks Multivariable control

DESIGN OF AEROENGINE LQG/LTR CONTROLLER ACCORDING TO PERFORMANCE TARGET

Tao Tao and Yan Wenbo

(7th Dept Northwestern Polytechnical University, Xi'an 710072)

ABSTRACT When LQG/LTR methodology is applied to control system design, it is not easy to choose proper covariance matrices for Kalman filter design for good dynamic performance and robustness of the control system. The methodology is based on the idea that if the control system is decoupled, the target close loop transfer functions of each channel can be presented according to the demands of dynamic performance. After the recovery procedure is finished, the system performance must approximate the target. With the methodology provided for designing the Kalman filter, the Kalman filter gain matrix can be calculated directly in accordance with the performance targets and state space matrices of the plant so that it is unnecessary to solve the Riccati equation. The simulations show that dynamic performance of the control system designed by using this methodology meets the design target, and its robustness is good.

Key Words Aeroengine Performance Kalman filter Robustness

A NEW VARIABLE STRUCTURE ADAPTIVE CONTROL SCHEME AND ITS APPLICATIONS

Guo Yingqiang, Xu Damin, Fan Siqi

(7th Dept Northwestern Polytechnical University, Xi'an 710072)

ABSTRACT A new variable structure adaptive control scheme is proposed. The