

轴流风扇内部气固两相流动 高速摄影实验研究

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【摘要】 利用高速摄影技术对轴流风扇内部粒子的运动特性进行了测量。实验测量了3个圆周面内跨叶片间粒子的运动规律。所用粒子为1mm直径的泡沫球。对拍摄图像进行处理之后发现:(1)在叶轮通道内压力面一侧粒子浓度比较大,吸力面一侧则比较小,并且在吸力面有无粒子区存在。(2)粒子和压力面发生碰撞和反弹,而不会和吸力面发生碰撞。(3)在压力面一侧粒子的运动速度比较低,而在吸力面一侧粒子的运动速度比较高。

关键词: 轴流风扇 高速摄影 气体—固体流动 实验

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1 实验装置及测试技术

Tabakoff等人的气固两相流的实验主要集中在平面叶栅、管道这些静止通道内部粒子运动特性的研究^[1,2]。对于叶轮机械而言,实验主要集中在粒子对机器整体性能的影响上^[3]。对于叶轮内部粒子运动特性的LDV或高速摄影实验研究,目前还没有这方面的报道。本文安排了一轴流风扇内部气体颗粒两相实验,采用高速摄影和图像处理技术,对粒子在叶道内的位置、运动轨迹、运动速度、粒子浓度的分布以及粒子和叶道壁面的碰撞反弹特性进行了测量。

实验是在轴流风扇实验台上进行的。实验中稳压筒直径为500mm,长度为5m。用于高速摄影的拍摄窗口由透明玻璃密封,面积为60mm×60mm。叶轮外径0.5m,轮毂直径为175mm。叶轮转速为1450r/min。电机功率为750W。所用叶片为单圆弧叶片,圆弧半径 $R=150\text{mm}$,叶片弦长为100mm,叶片安装角 $\beta=37^\circ$ 。实验中所用粒子为1mm直径的泡沫球,密度为 50kg/m^3 。采用日本E-10型旋转棱镜式高速摄影机。在高速摄影实验中,为了获得满意的结果,必须合理地选择摄影参数。首先根据标准粒径范围估计粒子速度的大小,合理地选择镜头和拍摄速度。根据曝光表指示的光强,选择光圈的大小,其中尤其以拍摄速度 R 的选择最为重要。 $R=MV\cos\theta/(Kd')$ 。 R 为拍摄速度,取 4000ft/s ; V 为粒子运动速度(m/s); θ 为粒子运动方向和胶片的夹角, $\theta=0^\circ$; d' 为胶片上画像的模糊量, $d'=0.02\sim0.05\text{mm}$; K 为摄影机快门常数,它和光源的照明度有关,本文取 $K=2.5$; M 为摄影放大倍数, $M=b/B\approx f/s$,其中 b 为胶片画面幅宽(mm), B 为视场宽度(mm), f 镜头焦距(mm), s 为拍摄距离(mm), $M=0.025$ 。

高速摄影结果的处理是在胶片运动分析系统上完成的。定性分析是用高速摄影机摄影后,把胶片放在放映机上,通过延长放映时间可以观察粒子运动的大概情况。本文采用NACDF

- 16C 型放映机。定量分析是通过画像的变位在漫射玻璃上做的投影屏上的图像,用超声波光笔准确确定出粒子的位置,从而可分析出其运动轨迹、运动速度和加速度。胶片运动分析仪型号为 NAC MOVIAS Model 100,其分辨率为 0.1mm。

2 测量结果及分析

实验中稳压筒内气流平均速度 $\bar{c}=11.8\text{m/s}$ 。粒子的质量流量 $\dot{m}_p=8.333\times 10^{-3}\text{kg/s}$ 。颗粒的体积浓度 $\alpha=8.53\times 10^{-5}$ 。用高速摄影进行拍摄时,选用拍摄速度 $R=4000\text{ft/s}$ 。胶片为 $8.1\text{mm}\times 10\text{mm}$ 规格的黑白胶片。每次拍摄需胶片 $30\sim 40\text{m}$ 。共测量了 3 个圆周面,分别在直径为 460mm (叶轮顶部)、 337.5mm (叶轮中部) 和 215mm (叶轮根部) 处。

由于高速摄影机只能拍摄平面内的现象,对于圆周面内粒子运动特性的拍摄,可以通过拍摄大量的平面图像来近似实现。因而是一个圆周面内可以拍摄数十幅像。在拍摄中,摄影机是静止的,而叶轮是旋转的。通过叶片在胶片上的成像可以定出叶片的起始位置,在叶轮转速和拍摄速度一定时,粒子在叶道内的相对位置也就确定下来。

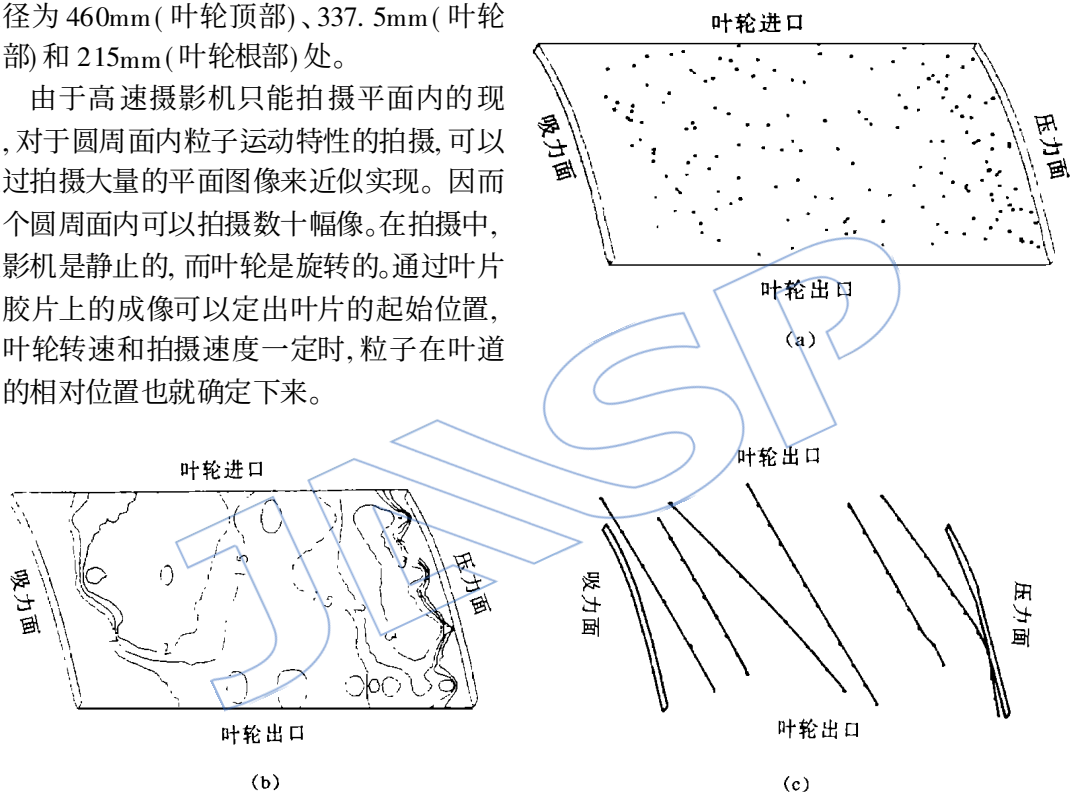


图 1 叶轮中部叶道内粒子(a)位置分布(b)浓度分布(c)运动轨迹

在实验研究中,粒子浓度和速度的测量是极其重要的,但也是比较困难的。首先在胶片运动分析仪上确定高速摄影照片中粒子的位置,然后用人工的方法将叶轮通道分成很多 $10\text{mm}\times 10\text{mm}$ 的正方形网格,再确定每一网格中粒子的数目,从而实现叶道内粒子浓度的定量分析。图 1(a) 为拍摄到的粒子分布。图 1(b) 为粒子浓度分布的定量结果。图中浓度等值线上的数字表示每个网格中粒子数目。由图 1 可以看出,在叶轮中部的跨叶片圆周面内,在压力面一侧粒子的浓度比较高,而在吸力面一侧则比较低。并且在吸力面存在一无粒子区。叶道内粒子浓度呈现这样的趋势可由图 1(c) 说明。由于粒子粒径大而密度小,粒子具有很好的跟随性,由进口至出口粒子呈现由吸力面一侧向压力面一侧运动的趋势。一部分粒子在运动过程中和压力面发生碰撞和反弹,这样在压力面就聚集了较多的粒子,从而导致压力面一侧粒子浓度比较

高。除了叶片头部以外,粒子不可能和吸力面发生碰撞。况且在吸力面附近存在一些区域是粒子永远不能到达的,这就是吸力面上的无粒子区。由图 1(c) 可以看到,粒子和叶片压力面碰撞反弹时,反弹角小于碰撞角。这是由于碰撞是一个不完全弹性碰撞,在叶片法向粒子的动量不守恒,使得粒子法向动量的绝对值减小,也就是粒子反弹后的法向速度小于碰撞前的法向速度。而切向方向粒子的动量损失比较小,从而使得反弹角小于碰撞角。叶轮根部和顶部跨叶片间粒子的浓度分布和运动轨迹也与此相似,不再列出。

由图 2 可以看出在吸力面一边粒子的相对速度偏高,而在压力面一边粒子的相对速度偏低一些,并且在叶轮顶部的相对速度最大,在叶轮根部粒子的相对速度最小。由根部至顶部,随着半径的增加,叶轮的圆周速度 $U = \omega r$ 也随之增大,因而粒子相对速度由根部至顶部愈来愈大也是显然的。对于单相气流场的研究也表明,吸力面一侧气流速度比较高,压力面一侧气流速度比较低。

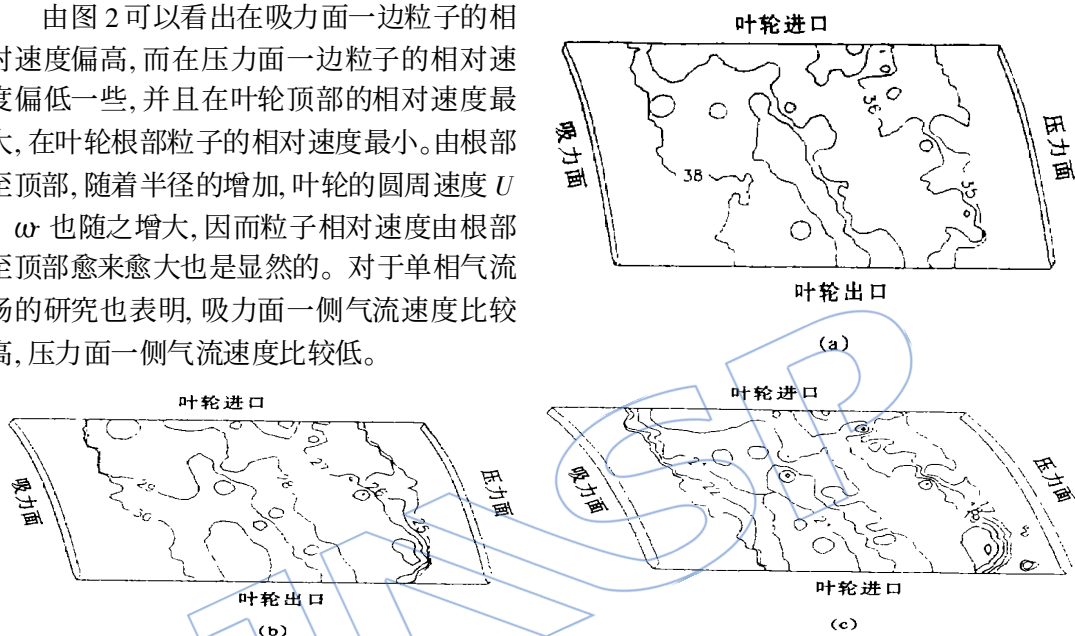


图 2 叶轮内部跨叶片粒子相对速度分布

3 结 论

(1) 在叶轮叶道内部压力面一侧粒子浓度比较高,吸力面一侧粒子浓度比较低。并且在吸力面存在一无粒子区。(2) 粒子在叶道内基本上沿直线运动,并且粒子和压力面发生碰撞和反弹,反弹角小于碰撞角。(3) 吸力面粒子运动速度比较高,压力面则比较低。(4) 利用本文测试结果进行含尘风扇叶片型线的变型设计,提高其抗磨损、抗沉积特性具有重要的指导意义。

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of inner convection within the multihole is the main factor to make the wall temperature being lower.

Key words Combustion Cooling Flame tubes

APPLICATION OF DIACTUATOR DISC THEORY TO AERODYNAMIC COMPUTATION OF AXIAL- FLOW FAN WITH SKEWED- SWEPT ROTOR BLADES

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ABSTRACT

In order to spread the advanced technology of aeropropfan, skewed-swept rotor blades are applied to axial flow fan and compressor. The diactuator disc theory model is adopted to calculate the main flow of the skewed-swept rotor blades in such a manner, as all blades forces affect on the first actuator disc, but the radial forces of blades vanish abruptly on the second actuator disc. Then the radial distribution of the boundary layer thickness (wake thickness) on the outlet surface of the rotor blade is taken as aerodynamic and aeroacoustic characteristic vectors. The effects of the secondary flow, endwall boundary layer, blades rotation and skewed-swept regularity (mainly radial forces of blades) are corrected according to plane cascade testing statistical curves. In addition, the results of four calculations demonstrate the effects of the second actuator disc, radial force and corrected outlet flow angle on magnitudes of the calculation results separately. The aerodynamic and acoustic tests show a good agreement of the calculation results with test data.

Key words Blades Blade forces Aerodynamic computations Diactuator disc theory

PROPELLER PERFORMANCE PREDICTION WITH FREE WAKE ANALYSIS METHOD

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ABSTRACT

The calculations of propeller performance at different advance ratios have been completed with the free wake analysis method. The wake is divided into near and far regions. In the case of heavy load when the advance ratio of propeller is small, the contraction of wake has large effect on the performance of the propeller. The free wake analysis method takes the wake contraction into account. According to lifting lines for the blade loading distribution, propeller performance calculated shows a good agreement with experimental data.

Key words Aircraft propellers Trailing vortex Lift line theory Performance analysis

HIGH- SPEED CAMERA MEASUREMENT OF A GAS- SOLID TWO- PHASE FLOW IN AN AXIAL- FLOW FAN

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ABSTRACT

A high-speed camera is used to measure the motion characteristics of particles in an axial-flow fan. In the experiment the measurements of the motion characteristics of the particles are carried out on three circular surfaces. The employed particles are 1mm diameter foamed plastic spheres. From photo processing some valuable conclusions are drawn as following: (1) In the impeller channel, the concentration of the particles nearby the pressure side is higher, while the suction side is lower. And there is an area where no particle exists. (2) The trajectories of the particles approach to straight lines. Some particles collide with the pressure side and rebound

from it, and the rebound angle is less than the impact angle. (3) The velocities of the particles on the pressure side is lower, while those on the suction side is higher relatively.

Key words Fans High-speed photography Gas-solid flow Experiment

AN EXPERIMENT ON AEROELASTIC STABILITY OF A HINGELESS ROTOR MODEL IN HOVER

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ABSTRACT A 2 m diameter, soft-inplane or stiff-inplane, isolated hingeless rotor model in hover has been tested to investigate its aeroelastic stability. The hingeless rotor blade is constructed with flap-lag-torsion coupling. The investigation aims at effects of structural and dynamic parameters, such as the collective pitch, precone, sweep, blade lag frequency and rotor rotational speed on the aeroelastic stability. A new and simple technique is applied to the tests so that the excitation of cyclic pitch is accomplished at the blade lag regressing frequency in vertical direction. The experiment shows that the aeroelastic stability of the hingeless rotor blade in hover is slightly influenced by the rotor rotational speed and the blade sweep, but strongly influenced by the collective pitch, precone and blade lag frequency.

Key words Hovering Rotor wings Rigid rotors Stability tests Elastic stability

A NEW INDEX FOR EVALUATING EFFECTS OF CIRCUMFERENTIAL GROOVED CASING TREATMENT ON EXTENDING STABILITY

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ABSTRACT Based on the analysis of structural features of the circumferential grooved casing treatment, 3-D incompressible, steady, time-averaged N-S equation, continuity and $k-\epsilon$ two equation turbulence model equations are successfully applied to the flowfield calculation in the cascade with the circumferential grooved casing treatment. The flux of the gas through the treatment groove is proposed as a new index which can quantitatively evaluate the effectiveness and the capability of extending stability by circumferential grooved casing treatment. The effects of structural parameters and treatment positions on the effectiveness of extending stability are analysed and discussed. The conclusions are proved by a great deal of testing results. The method and technique can be applied to analysis and design of the casing treatments in a compressor.

Key words Slots Cases Axial flow compressors Numerical computation