

轴向前倾叶片流场的数值分析

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【摘要】 对一种新式的风机叶片即轴向前倾叶片流场进行数值计算,采用时间推进法计算无粘流场,采用非正交曲线坐标系附面层积分方程求解附面层参数,得到了一些有意义的结果。

主题词: 前倾叶片 附面层 数值分析

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1 前倾叶片无粘流场与附面层参数的求解

将叶片改为沿轴向向前倾斜后,由于部分附面层在未及叶尖区时便被电离叶片,使到达叶尖区的潜移量减少、叶尖的附面层变薄、叶尖区的流动状况得到改善,可明显提高风机性能。这一点已被实践证明^[1]。为了从理论上证明这一结论,本文对前倾叶片的流场和附面层参数进行了详细的计算。

采用时间推进法计算叶片无粘流场的理论,文献[2]已经进行了详细的介绍。为提高其格式精度,按文献[3]的方法进行了修正。其它有关边界条件、初始条件、平滑处理和收敛判据等细节均与文献[4]相同。

本文计算采用 C₄ 叶型,其平均半径处基元级的主要几何参数如表 1 所示。

表 1 叶型几何参数

弦长 (mm)	内径 (mm)	外径 (mm)	最大厚度 (mm)	最大挠度 (mm)	前缘角 (°)	后缘角 (°)	弯角 (°)	安装角 (°)	几何进气角 (°)	几何出气角 (°)
121	228	600	6	4.6	17.5	17.5	34.9	90	72.54	107.5

计算中采用的径向叶片模型由各叶型按叶型中心线与径向线重合而成,前倾叶片模型由径向叶片各基元级叶型沿相应柱面前移不同量而成,使其叶片中心线向来流方向倾斜 31°。计算时前倾叶片和径向叶片具有相同的进出口条件。为了简化计算认为叶尖间隙等于零。

非正交曲线坐标系中使基本矢量 $\bar{e}_1$ 、 $\bar{e}_2$ 和 $\bar{e}_3$ 分别与坐标方向 x_1 、 x_2 和 x_3 同向, $\bar{e}_3$ 垂直于物面, $\bar{e}_1$ 、 $\bar{e}_2$ 在物面上形成非正交网络, $\bar{e}_1$ 、 $\bar{e}_2$ 夹角为 λ_0 。沿 $\bar{e}_1$ 、 $\bar{e}_2$ 、 $\bar{e}_3$ 方向分解叶轮机粘性气体的连续方程和动量方程,引入流动定常及薄剪切层假设后,经推导得到附面层方程:

$$\frac{1}{g_{ii}} \frac{\partial \theta_i}{\partial x_i} + \theta_i \left[\frac{1}{g_{ii} p W^2} \frac{\partial (p W^2)}{\partial x_i} + \frac{1}{q} \frac{\partial}{\partial x_i} \left(\frac{-q}{g_{ii}} \right) - \operatorname{ctg} \lambda k_i \right]$$
$$\frac{1}{g_{22}} \frac{\partial \theta_2}{\partial x_2} + \theta_{i+1} \left[\frac{1}{g_{i+1,j+1} p W^2} \frac{\partial (p W^2)}{\partial x_{i+1}} + \frac{1}{q} \frac{\partial}{\partial x_{i+1}} \left(\frac{-q}{g_{i+1,j+1}} \right) k_{i,j+1} \right]$$

$$\begin{aligned}
& + \delta_1^* \left\{ \frac{1}{g_{ii}} \frac{1}{W} \frac{\partial W_i}{\partial x_i} - \operatorname{ctg} \lambda k_i \frac{W_i}{W} + \frac{E_i}{W} \cos \lambda \right\} \\
& + \delta_{i+1}^* \left\{ \frac{1}{g_{i+1,j+1}} \frac{1}{W} \frac{\partial W_i}{\partial x_{i+1}} + \operatorname{csc} \lambda k_{i+1} \frac{W_{i+1}}{W} + k_{i,j+1} \frac{W_{i+1}}{W} + \frac{E_i}{W} \right\} \\
& + \operatorname{csc} \lambda k_{i+1} \theta_{i+1,j+1} + \frac{D_i}{W^2} \theta_p = \frac{1}{2} C_{ji}
\end{aligned} \quad (1)$$

$$\frac{1}{\rho W q} \left\{ \frac{\partial}{\partial x_1} \left[\frac{p_q}{g_{11}} (W_1 \delta - W \delta_1^*) \right] + \frac{\partial}{\partial x_2} \left[\frac{p_q}{g_{22}} (W_2 \delta - W \delta_2^*) \right] \right\} = F \quad (2)$$

式中: $\theta_1 = \int \frac{\rho W_1}{\rho W^2} (\bar{W}_1 - W_1) dx_3$, $W = \sqrt{(\bar{W}_1^2 + \bar{W}_2^2 + \bar{W}_1 \bar{W}_2 \cos \lambda)}$, $\delta_1^* = \int \frac{1}{\rho W} (\rho \bar{W}_1 - \rho W_1) dx_3$,

$\theta_p = \int \frac{1}{\rho} (\bar{\rho} - \rho) dx_3$, $q = \sqrt{g_{11} g_{22} \sin \lambda}$, $E_1 = \frac{1}{\sin \lambda} [2\alpha(-1)^{-1} \cos(\bar{\omega}, \bar{e}_3)]$, $D_1 = -\frac{\omega_r^2}{\sin^2 \lambda} [\cos(\bar{r},$

$\bar{e}_1) - \cos \lambda \cos(\bar{r}, \bar{e}_{i+1})]$, $k_{-1} = \frac{1}{\sin \lambda} \left[\frac{1}{g_{11} g_{22}} \left(\frac{\partial g}{\partial x_i} - \frac{1}{g_{i+1,j+1} \cos \lambda} \frac{\partial g_{11}}{\partial x_i} \right) - \frac{\partial g_{11}}{\partial x_{i+1}} \right]$,

$k_{i,j+1} = \frac{1}{\sin \lambda} \left[-k_{i-1} - \frac{1}{g_{11}} \frac{\partial \lambda}{\partial x_i} + \cos \lambda \left(k_{i+1} - \frac{1}{g_{i+1,j+1}} \frac{\partial \lambda}{\partial x_{i+1}} \right) \right]$, $g = \frac{1}{g_{11} g_{22} \sin \lambda}$,

g_{11} 为度量系数, δ 为附面层厚度, F 为裹入系数, “ $-$ ” 为表示附面层边缘, W_1, W_2, W_3 为沿 X_1, X_2, X_3 方向的速度分量。非正交曲线坐标系附面层积分方程的求解请参考文献[1]。

2 数值计算结果和分析

叶片前倾对叶片表面附面层增长的影响。图 1 给出了沿叶片展向 3 个不同位置处叶背附面层厚度沿基元级叶型弦向的变化情况。从图中可以看出, 无论是前倾叶片还是径向叶片, 叶背各截面附面层沿弦向和沿径向的变化规律是一致的。但两种情况下, 其相对量大小却明显不同。沿弦向, 叶片前倾后, 只在叶根到叶中区附面层略比径向叶片情况稍厚(或可以认为基本一致)。而在叶中以上和叶尖区域, 叶片前倾后附面层比径向叶片情况薄, 沿径向随半径增加附面层增厚, 叶片前倾后附面层沿径向的增长速度减慢。

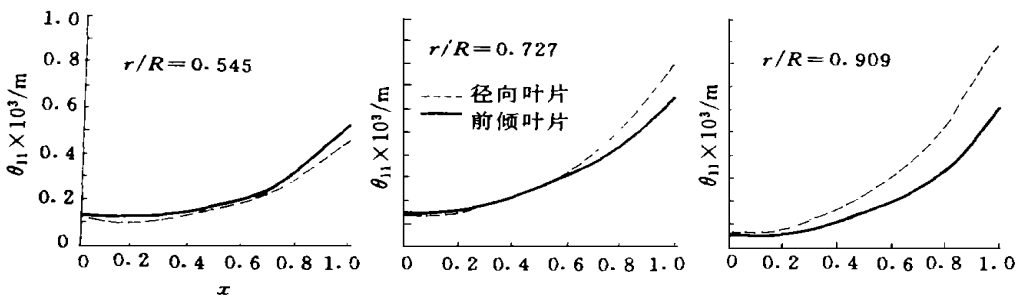


图 1 叶背附面层动量积分厚度分布

叶片前倾对通道涡形成产生的影响。从图 2 中可以看出径向叶片的 1 截面上叶根气流流线产生绕曲, 近叶背区气流产生向上的径向速度, 流道中有欲产生通道涡的迹象。在 2 截面通

count, such as the collective pitch, precone, sweep, and so on. Finally, the aeroelastic stability of Dolphin's Rotor blades is analysed. The experiment shows that the aeroelastic stability of the rotor blade in hover is influenced small by the blade sweep, but strongly by the collective pitch and precone. The experimental results verify the feasibility of the analysis and applicability to rotor design.

Key words Helicopter rotor Hovering Aeroelastic dynamics Stability

A BLADE FLUTTER PREDICTION METHOD INCLUDING SECONDARY FLOW EFFECTS

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ABSTRACT

In order to obtain a better understanding of the secondary flow effects on blade stall flutter, this paper presents an approximate method to analyse the effects of secondary flow on blade aeroelastic stability. The method combines conventional stream-line curvature methods with the secondary flow model to obtain the stationary flow with circumferential nonuniformity, and then incorporates the non-constant phase angle deforming actuator disk method. Several secondary flow effects on aeroelastic stability were analysed respectively. The results show that the effects of the secondary flow on the aeroelastic stability are different. The tip leakage vortex may have greater effect than other vortices, that is consistent with the experimental results.

Key words Secondary flow Blade Aeroelastic Stability Predictions

NUMERICAL ANALYSIS OF FLOW FIELD ABOUT SWEEP-FORWARD BLADES OF COMPRESSORS OR FANS

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ABSTRACT

A numerical analysis of the flow field about sweep-forward blades has been carried out. Time marching method is used to calculate the three-dimensional inviscid flow field. Boundary layer parameters are calculated with integrated boundary layer equations in non-orthogonal axes. The calculated results show that in axial compressors and fans with sweep-forward blades the intensity of passage vortex, secondary flow and tip losses are decreased, the early separation from the blade surface is protected, the flow field in tip area is improved obviously. As a result, the aerodynamic efficiency of axial compressor or ventilator is enhanced.

Key words Sweep-forward blades boundary layer Numerical analysis

HIGH-RESOLUTION IMPLICIT PROCEDURES FOR CASCADE FLOW CALCULATIONS

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ABSTRACT

Based on the high-resolution difference scheme structured from characteristic flux difference splitting, the implicit algorithm of the scheme has been developed. The implicit characteristic boundary procedures consistent with the scheme have been implemented as well. The implicit boundary procedures proposed in this paper eliminate the