

正弯叶片降低叶栅内部损失的数值模拟

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摘要: 计算了直叶片及正弯叶片流场, 计算结果表明叶片正弯曲在流道内, 尤其是吸力面表面建立起“C”型静压分布, 抑制了径向二次流动; 而横向压力梯度的减弱将有利于减少横向流动损失。通过对涡量等值线的分析表明, 正弯叶片栅中的马蹄涡及通道涡的尺度及强度均较直叶片中的小, 而由能量损失系数分布图可知, 采用正弯叶片可以降低叶栅内部流场中的能量损失。

关键词: 正弯叶片; 能量损失; 二次流

中图分类号: O35

文献标识码: A

1 引言

为了提高叶机械的效率, 就应该合理利用和控制其叶栅通道中二次流的产生和发展, 降低叶栅的二次流损失。早在 60 年代起, 各国学者就进行了大量的控制叶栅内气体流动、减少能量损失方法的理论分析与实验研究, 提出了改变通流部分几何尺寸、改善做功量分布和可控涡设计方法等。文献[1]指出, 决定二次流大小的因素主要有两个: 一是壁面粘性效应; 二是壁面压力梯度的大小和方向, 叶栅气动特性好坏取决于壁面静压梯度。如果静压梯度使附面层向一起集聚, 将引起二次流损失急剧增高。如果展向静压分布能消除附面层的集聚, 二次流损失将会大幅度降低, 采用弯曲叶片恰好可以使展向静压沿叶高重新分布。弯曲叶片成型方法^[2]自 60 年代初首次提出以来, 受到世界各国同行专家的关注, 并对其进行了大量的试验研究^[3]和理论探讨。本文计算了某型涡轮第一级静叶在分别采用直叶片和正弯叶片时的内部流场, 计算结果表明采用正弯叶片可以降低叶栅内部流场中的能量损失。

2 计算方法及网格

计算中控制方程采用任意曲线坐标系下的雷诺平均 N.S. 方程, 其形式如下

$$\frac{\partial U}{\partial \xi} + \frac{\partial E}{\partial \xi} + \frac{\partial F}{\partial \eta} + \frac{\partial G}{\partial \xi} = \frac{Jf_1}{r} + \frac{1}{Re} \left(\frac{Jf_2}{r} + \frac{\partial Q}{\partial \xi} + \frac{\partial R}{\partial \eta} + \frac{\partial S}{\partial \xi} \right) \quad (1)$$

式中 E, F, G 为无粘通量, Q, R, S 为粘性通量, f_1, f_2 为源项, 它们的具体形式参见文献[4]。湍

流模型采用 Baldwin-Lomax 代数涡粘模型。对无粘通量采用三阶精度 TVD 格式进行离散, 对粘性通量采用中心差分格式进行离散。

本文对某型涡轮第一级静叶在分别采用直叶片和正弯叶片时的内部流场进行了数值模拟。图 1 和图 2 分别代表本次计算采用的直叶片及正弯叶片形状图。

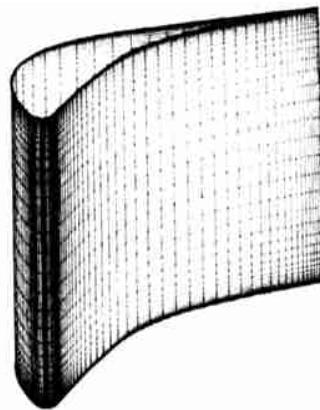


图 1 直叶片形状图

正弯叶片的型线选为根部倾角为 18° 、顶部倾角为 10° 。为了便于对比分析, 两种方案均采用了相同的网格结构, 网格点数取为 $92 \times 41 \times 41$, 其中沿轴向方向进口边界至前缘为 15 站, 叶片流道内部 52 站, 尾缘至出口边界为 25 站。

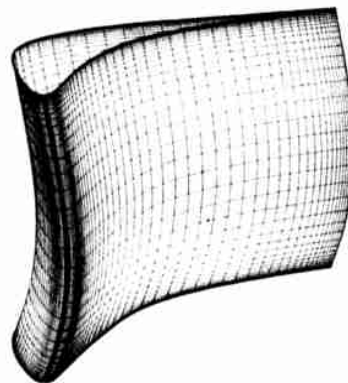


图 2 正弯叶片形状图

3 边界条件

对于三维问题, 利用特征分析可知亚音进口流场的进口边界需给定 4 个物理边界条件。在计算中, 给定进口总压 0.81 MPa , 进口总温 611 K 及进口气流角。由于本次计算为亚音出口, 利用特征分析可知需给定 1 个物理边界条件。在本文计算中, 给定中径处的背压为 0.49 MPa 。求解叶栅流

场时, 还需采用周期性边界条件, 即周期性边界上对应的气动参数相等。此外, 直接在叶片表面、轮毂面、机匣面处施加无滑移条件, 并应用了压力及温度

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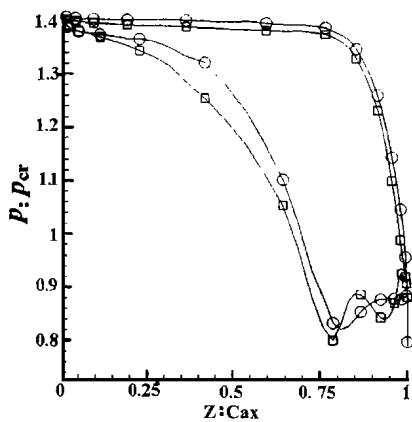


图 3 顶部叶片表面压力分布图

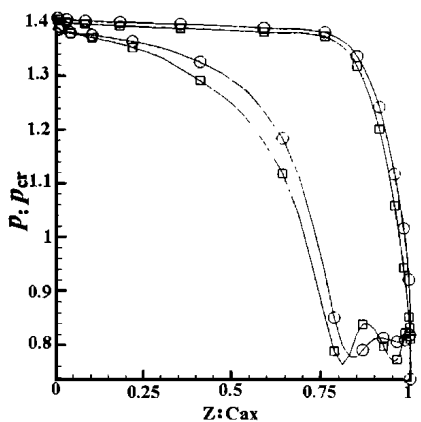


图 4 根部叶片表面压力分布图

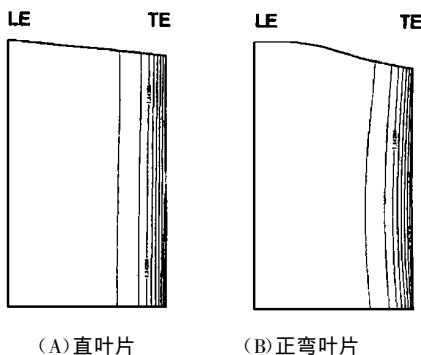


图 5 叶片压力面压力等值线分布图

的法向梯度为零的条件。

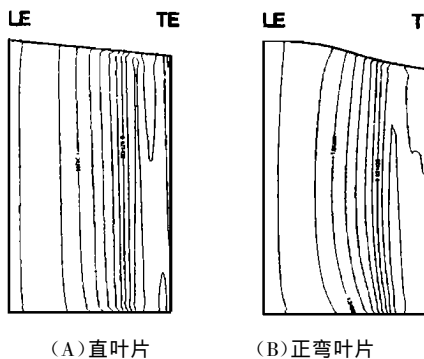
4 计算结果

图 3 及图 4 分别为直叶片及正弯叶片在顶部和根部的叶片表面压力分布曲线(图中 \circ 代表正弯叶片、 \square 代表直叶片)。从图中可以看出,由于正弯叶片的采用导致叶片横向压力梯度的减小,这将减少端壁附近的横向二次流动,从而降低横向二次流损失。

图 5 及图 6 分别是直叶片及正弯叶片在压力面和吸力面上的压力等值线分布图(图中 LE 代表前缘、TE 代表尾缘)。由图可见,采用正弯叶片之后可以在吸力面和压力面上看出明显的根部负径向

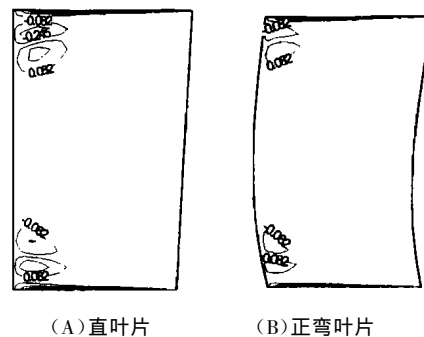
压力梯度,顶部正径向压力梯度压力分布即所谓“C”型压力分布。在该“C”型压力分布的作用下,端壁附近的低能流体将被运输到叶片中部,减弱或抑制了叶栅两端部的低能流体在根部的聚集和分离,从而减少了端部损失。

通过对直叶片及正弯叶片沿主流方向各站上的拟 S_3 截面流向涡量等值线分布图和拟 S_3 截面能量损失系数等值线分布图的详细分析,我们发现在直叶片中马蹄涡及通道涡的尺度均比正弯叶片中的尺度要大,且其强度也比正弯叶片中的强度强,并且采用正弯叶片后在对应两个通道涡所在位置能量损失



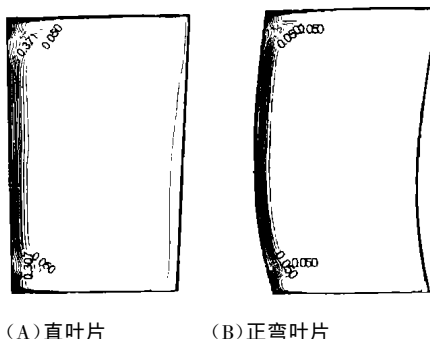
(A)直叶片 (B)正弯叶片

图 6 叶片吸力面压力等值线分布图



(A)直叶片 (B)正弯叶片

图 7 叶片出口流向涡量等值线图



(A)直叶片 (B)正弯叶片

图 8 叶片出口能量损失系数等值线图

道涡的尺度及强度均较直叶片中的小,而由能量损失系数分布图可知采用正弯叶片可以降低叶栅内部流场中的能量损失。

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(何静芳 编辑)

国产引进型 600 MW 锅炉过热器顶棚包墙系统的改进 = **The Improvement of a Boiler Superheater-roof Enclosure-wall System for an Imported Technology-based Domestic-made 600 MW Boiler** [刊, 汉] / Yu Hong, Qu Guobin, Yuan Meiyuan (Harbin Boiler Co. Ltd.) // Journal of Engineering for Thermal Energy & Power. — 2000, 15(2). — 142 ~ 144

A comparison was conducted of several versions of superheater-roof enclosure-wall system for a 600 MW boiler. On this basis proposed are some measures to decrease the steel consumption and flow resistance of the system as well as to ensure its operation reliability. **Key words:** boiler, roof enclosure-wall, superheater, flow resistance, improvement

无电晕式高温高压电除尘器阴极电发射特性试验研究 = **Experimental Study of the Cathode Electron-emission Characteristics of an Electron-emission Type High-temperature and High-pressure Electrical Precipitator** [刊, 汉] / Gu Zhongzhu, Wei Qidong, Yang Yaping, et al (Southeastern University) // Journal of Engineering for Thermal Energy & Power. — 2000, 15(2). — 145 ~ 147

An experimental study was conducted under the condition of different temperatures, pressures and voltages with respect to a cathode material already developed. The results of study show that the temperature, pressure and voltage can exercise an influence on emission current to various degrees. Under a high temperature greater than 800 °C the current density resulting from the thermal emission of the cathode material is at least one order of magnitude higher than that obtained through a corona mode. The emission electrode features a fairly good stability and is fit for long-term use under a high temperature and pressure. The corona-absence type of electrical precipitator boasts a high dust-removal effectiveness under a high-temperature and high-pressure environment. **Key words:** corona, high temperature and high pressure, cathode, electrical precipitator, emission current

石灰石脱硫动力学模型的优选 = **The Optimal Selection of a Limestone Desulfurization Dynamics Model** [刊, 汉] / Zhai Zhonghe, Li Le (Harbin University of Science & Technology), Jin Tielin (Harbin No.703 Research Institute) // Journal of Engineering for Thermal Energy & Power. — 2000, 15(2). — 148 ~ 150

The simulation of a limestone desulfurization system is conducted along with a desulfurization experiment of limestone heat-decomposition products under various operating conditions. As a result, set up and selected is an optimum desulfurization dynamics model. Due to a complicated process of the desulfurization reaction there exist a relatively great variety of such dynamics models which are difficult to be differentiated. In the present paper a sequential-order experimental design method has been introduced to acquire a maximum quantity of experimental information and arrange on this basis the experimental points. By performing a screening-selection according to a standard of maximum posterior probability an optimum dynamics model was acquired. Such a model can provide an important scientific basis for the study of the limestone desulfurization mechanism and the desulfurization techniques based on a calcium-injection in a boiler. **Key words:** limestone desulfurization, sequential-order experimental design, dynamics model, posterior probability

正弯叶片降低叶栅内部损失的数值模拟 = **Numerical Simulation of the Decrease of Internal Losses in a Cascade with Positively-Curved Blades** [刊, 汉] / Wang Songtao, Wang Meng, Feng Guotai, Wang Zhongqi (Harbin Institute of Technology) // Journal of Engineering for Thermal Energy & Power. — 2000, 15(2). — 151— 152

The calculation results of a straight and a positively-curved blade flow field show that the positively-curved blades can create in the flow passage, especially at the suction side surface, a “C” shaped static-pressure distribution. The latter effectively suppresses radial secondary flows. Moreover, the abatement of a transverse pressure gradi-