

透平跨音速叶栅的优化设计

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【摘要】 将遗传算法用于透平跨音速叶栅的优化设计, 提出了相应的数学模型和优化方法。优化算例表明, 本文所提出的模型及算法能有效的优化叶型方案, 避免了一般优化算法的局部最优或维数灾难问题, 从而在新的领域内将优化计算在叶轮机械设计中的应用进行了有益的探索。

主题词: 跨音速透平 叶栅 优化设计

分类号: TK14

1 引言

随着计算流体力学和最优化计算方法的迅速发展, 叶栅设计方法已有了很大改进^[1,2]。但是由于跨音速叶栅的内部流场复杂, 影响因素很多, 对其损失机理还有待进一步探索, 难于归纳成常规最优化问题的一般表达式, 因此很难用经典的方法来对跨音速叶栅进行优化设计。近年发展的遗传算法^[3] (GA s) 为跨音速叶栅优化设计提供了可能。GA s 允许所求解的问题是是非线性的和不连续的, 并能从整个可行解空间寻求最优解, 同时由于其搜索最优解的过程是有指导性的, 避免了一般优化算法的维数灾难问题和局部最优问题。GA s 在许多方面发挥了作用^[2,3]。本文将 GA s 用于跨音速叶栅优化设计, 提出了构造染色体及适应函数的模型。文中的算例表明: GA s 不仅能给出优于其它方法的解, 同时还能给出若干个次优解, 为设计人员提供了更多的有价值的参考信息。

2 基于遗传算法的叶栅优化模型

GA s 是借鉴自然界遗传中的自然选择、适者生存的法则, 在计算中也采用了遗传学中的相应名词和方法。在利用 GA s 求解实际问题时, 首先将实际问题的设计变量进行编码, 表示成具有固定结构的符号串, 即染色体。符号串的总位数称为染色体的长度, 每一代所产生的染色体总数称为染色体域。为了计算机实现的方便, 染色体中的符号通常就选为 0 和 1, 由一位或几位符号组成的基本信息单位称为基因。衡量染色体品质的指标是染色体的适应函数, 适应函数是反映实际问题的目标函数。GA s 与传统方法相比, 其主要特点是: GA s 使用参数的编码集而不是参数本身进行工作; GA s 是在点群中而不是在一个单点上寻求优; GA s 仅使用问题本身所具有的目标函数进行工作, 而不需其它任何先决条件或辅助信息; GA s 使用随机转换规则而不是确定性规则来工作。一般的 GA s 包含 3 个基本算子: 繁殖, 交叉, 变异。值得指出的是, GA s 迭代的收敛条件需人为给定, 如设置最大迭代次数判断经过多少次迭代而没有产生更好的解等等。但无论如何, GA s 总能给出一批可能包括最优解的最佳解, 我们可以在这批解基础上得到最优解。

平面跨音速叶栅优化设计模型的建立, 首先要决定染色体的编码及适应函数。

2.1 染色体编码

采用多项式的方法来描述叶栅型线:

$$y = \sum_{i=1}^n a_i x^{i-1} \quad (1)$$

其中 x 表示叶型沿弦线的横坐标, y 表示叶型的纵坐标。对于几何形状不同的型线, 就会有不同的系数 $a_1, a_2, \dots, a_n$ 的数值。因此本文选择为优化设计的设计变量。由于设计变量 $\{a_i\}$ 各个分量对最优解的贡献相当, 结构性强, 因此采用多参数交叉编码^[4]方案。

假设有 n 个参数: $a_i \in [U_{\min}^i, U_{\max}^i]$, ($i = 1, 2, 3, \dots, n$)。采用二进制编码, 先对各参数分别编码, 其中假设各参数的位串长分别为: $L_1, L_2, \dots, L_n$ 位。

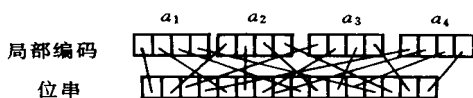


图1 交叉编码方法

$$\begin{aligned} a_i: U_i &\in [0, 2^{L_i}] \\ \delta_i &= (U_{\max}^i - U_{\min}^i) / (2^{L_i} - 1) \\ i &= 1, 2, 3, \dots, n \end{aligned} \quad (2)$$

建立映射: $a_i = U_{\min}^i + U_i \delta_i$, 级联各参数编码成为一个整体。交叉编码的基本做法是将各参数单独编码的最高位安排在位串的 n 个最高位, 各参数的次高位安排在位串的次 n 个位置上, 最后一部分对应了 n 个参数的最低位。如图 1 所示。

2.2 适应函数

GA 的适应函数就是一般优化算法的目标函数, 本文采用平面跨音速叶栅的能量损失系数 ξ_{total} 作为目标函数。为了求取能量损失系数 ξ_{total} 必须先进行叶栅气动正问题的求解。首先采用二维 Euler 方程的时间推进有限体积法对流场进行计算。计算采用 Denton 改进格式, 计算区域、网格划分及边界条件等处理见文献[5]。

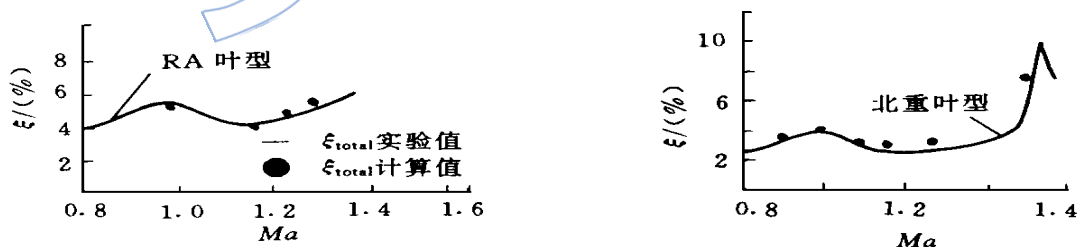


图2 叶型损失计算与实验对照图

在无粘主流场计算的基础上采用积分方法^[6]进行边界层计算, 考虑激波和混合损失, 得:

$$\xi_{\text{total}} = \xi_{\text{bl}} + \xi_{\text{shock}} + \xi_{\text{mix}} \quad (3)$$

对 RA 叶栅与北重叶栅在不同工况下的损失系数 ξ_{total} 进行了核算, 图 2 表示计算值和实验值吻合很好, 可见用能量损失系数作为目标函数进行优化计算是合适的。

本文采用目标函数到适值形式的映射为:

$$f(a_i) = \begin{cases} C_{\max} - \xi_{\text{total}}(a_i) & \xi_{\text{total}}(a_i) < C_{\max} \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

其中 $C_{\max}$ 是一输入参数, 本文算例取值为 1.0。

3 优化算例及分析

对 RA 叶型和北重叶型进行了优化设计。由于对整个叶型难于用统一的多项式拟合, 对影响 RA 叶型和北重叶型效率最大的部分即背弧用最小二乘法的四次多项式来拟合, 优化就是针对该段背弧进行的, 其它部分的优化设计可以此类推。

对于优化过程采用的适应函数, 为了提高优化性能, 对适值进行了有效地调整, 强化各方案之间的竞争性。本文采用线性调整法: $f' = af + b$ 。其中 f 是原适值, f' 是调整后的适值。 $f'_{avg} = f_{avg}$, $f'_{min} = af_{min} + b = 0$ 。其中 f_{avg} 是原适值平均值, f_{min} 是原最小适值。

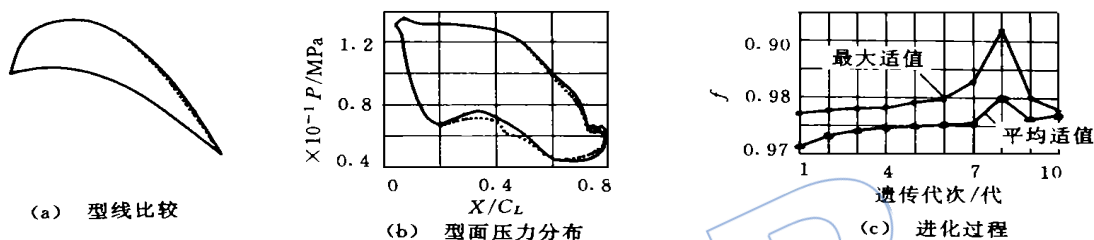


图 3 RA 叶型优化结果

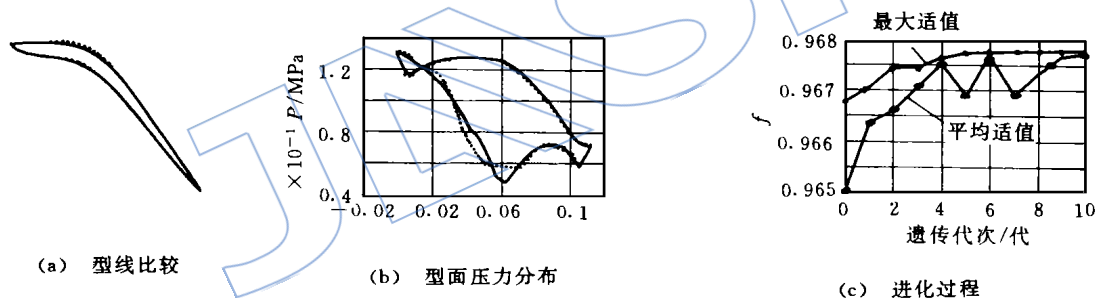


图 4 北重叶型优化结果

整个优化计算是在一定叶栅最大厚度, 安装角, 栅距和弦长下进行的。图 3(a) 是 RA 叶栅的型线变化比较图, 图 3(b) 是 RA 叶栅型面压力分布比较图; 图 3(c) 是 RA 叶栅进化中最大适值与平均适值发展曲线图(图 3 和 4 中, — 初始叶型, - - - 优化叶型), 可以看到优化前后的叶型变化较小, 但吸力面的流场参数变化却较大, 整个流场特性有所改善。图 4(a) 是北重叶栅型线变化比较图, 图 4(b) 是型面压力分布比较图, 图 4(c) 是北重叶栅进化中最大适值与平均适值发展曲线图。北重优化后的叶型型线在头部处有变化而其它部分变化较小, 但北重叶栅优化后叶栅流场的激波强度明显减弱, 气动效率提高。由此可见跨音速叶栅的设计要十分仔细, 叶型的变化对叶栅性能的影响十分敏感的。而本文发展的应用遗传算法进行透平跨音速叶栅的优化设计是能够考虑这些因素的, 其优化结果表明是成功的。

4 结束语

(1) GA_s 是一种行之有效的优化方法, 对于平面跨音速叶栅的优化设计, 只要染色体与适应函数选择得当, 就可以得到最优解。

(2) GA_s 通过发掘和交换历史信息, 采用繁殖、交叉、变异操作, 在遗传过程中既能保留好的方案, 也能在可行解空间有效地产生新方案, 从而避免了一般优化方法的局部最优问题和维数灾难问题。

(3) GA_s 是结构性优化方法, 对于适应函数和约束条件没有严格限制, 求解的问题可以是非线性的和不连续的, 为使用者提供了广泛发挥的余地。应该指出的是, GA_s 作为一种新型的优化方法, 如何更好地使用它还有许多值得研究的问题。对于叶轮机械的优化来说, 如何进行多目标优化还需作出努力。

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can be found out from the program.

Key Words Turbofan engines Mathematical simulation Searching method

NUMERICAL PREDICTION OF TWO- DIMENSIONAL TRANSONIC TURBULENT FLOW IN A DIFFUSER

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ABSTRACT Two- dimensional transonic flow in a diffuser is numerically investigated by solving 2D time- dependent Reynolds- averaged compressible Navier- Stokes equations. The numerical method is based on Van- Leer's flux splitting cell- centered finite volume scheme. Baldwin- Lomax algebraic turbulence model and Johnson- King non- equilibrium turbulence model are tested to simulate largely separated flow. Comparison of the computational results with corresponding experimental data shows that the predicted wall static pressure distributions and shock strength by both two turbulence models agree well with the experimental data, but Johnson- King model does better than Baldwin- Lomax model in the prediction of separation reattachment point.

Key Words Shock wave Turbulence Numerical computation

3D VISCOUS FLOW COMPUTATION WITH ARBITRARY LAGRANGIAN- EULERIAN METHOD

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ABSTRACT Arbitrary Lagrangian- Eulerian schemes are deduced for computation of three dimensional viscous flow in rotating impeller channel. The convection effect is simulated by the pseudo- moving of grids. Viscous sub- cycle time step and Lagrangian sub- cycle time step are adopted to accelerate convergence. The upwind scheme is improved into part- donated scheme to diminish diffusion. Flow rate restriction is used to control dissipative truncation error. A short wave damp is introduced to reduce the computational corrugation. Sub- Grid- Scale (SGS) turbulent model is adopted to simulate turbulent flow. Eckardt's experimental results on centrifugal impeller have verified effectiveness of the method.

Key Words Viscous flow Three dimensional flow Numerical computation

OPTIMIZATIONAL DESIGN FOR TRANSONIC TURBINE CASCADE

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ABSTRACT A design method of aerodynamic optimization is presented for transonic turbine cascades. The method couples Genetic Algorithms (GAs) to a inviscid flow field Euler solver and the boundary layer calculation. The objective function of the transonic turbine cascade is the minimum of loss factor. The multinomial coefficients of blade geometry are taken as design variables. RA cascade and Beizhong cascade have been used as the exam-

ples of optimizational design. It is shown that the aerodynamic performance of the transonic turbine cascades has been improved greatly with little variation of the work and the strength.

Key Words Transonic turbines Cascades Optimization

EXPERIMENTAL INVESTIGATION ON MASS- HEAT TRANSFER OF SHROUDED ROTOR- STATOR SYSTEM

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ABSTRACT According to the theory of analogy between heat transfer and mass transfer, the mass transfer technique is applied to a shrouded rotor- stator system for experimental investigation on its heat transfer. An experimental model is set up: The cooling air is blown axially from the front edge of the stator, and the naphthalene ($C_{10}H_8$) sublimation technique is employed to obtain both local and average mass- transfer coefficients for the rotor surface coated by naphthalene. The heat transfer characteristics of the shrouded rotor- stator system are investigated using the mass transfer analog technique. The emphasis is put on analyzing the effects of the following parameters on the transfer characteristics: The ratio of axial gaps G_s , the ratio of axial clearance G_c , the rotational Reynolds number Re_θ and flow coefficient C_w . Correlations are obtained experimentally, conclusions are drawn for the test conditions as follows: 1. The average mass transfer coefficient increases with increase of the flow coefficient C_w and the rotational Reynolds number Re_θ ; 2. The average mass transfer coefficient decreases with increase of the ratio of axial gap G_s and the ratio of axial clearance G_c ; 3. The peak of local mass transfer coefficient radically moves out with reference to impingement point.

Key Words Rotor Discs Naphthalene Heat transfer

SPRAY CHARACTERISTICS OF A NEW AIR- ASSISTED ATOMIZER

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ABSTRACT The spray characteristics of a new air- assisted atomizer was investigated experimentally. Annular and central swirling air jets smash the fuel jet and make it spray. The radial distributions of the mean and fluctuating velocities of the air flow and drops, the drop size and the concentration were measured at several axial stations with 2D PDA. Two atomizers with different mixing chamber were tested to investigate the effect of the central swirling air jet on the spray structure. The radial distributions of the mean velocity show that a lower axial velocity region and a solid rotation body exist at the center of the spray. The radial profile of drop volume flux peaks drifts off the centerline, indicating a hollow cone spray. The results show that high turbulence occurs at the central region and the region where the central swirling jet intersects the annular jet. The radial position of maximum mean axial velocity moves outwards with increasing strength of swirling. The atomization