第 6 卷 第 1 期 航空动力学报 Vol. 6 No. 1
1991 年 1 月 Journal of Aerospace Power Jan. 1991

二维任意区域贴体曲线坐标的弧长参数生成法

南京航空学院 石周和 张惠民 王立成

为了求解飞机和发动机这类极其复杂的流场, 首先必须发展一种快速、有效和灵活的贴体曲线坐标生成法。

目前存在着多种贴体曲线坐标的自动生成法, 其中尤以椭圆形偏微分方程生成法应用最广。然而, 对极其复杂的区域, 微分方程生成法呈现了如下缺点, 使其应用受到一定限制。

1. 控制函数 (源项) 很难选择;
2. 分块后很难使网格曲线在拼接处光滑;
3. 对局部加密的网格收敛很慢[1]。

为了克服这些缺点, 人们已想过许多办法, 例如对控制函数进行加权平均或对已生成的网格曲线进行光顺[1,2]。虽然这些方法解决了一些具体矛盾, 但并没有从根本上克服椭圆形微分方程生成法的缺点。为了满足流场计算的需要, 本文发展了一种以网格曲线的弧长作为参数来生成二维任意区域贴体曲线坐标的方法, 避开了偏微分方程生成法中所遇到的问题。

本方法有两个基本特点, 第一是将复杂区域分为若干个曲边四边形的组合, 第二是用弧长作参数来生成各子块的网格曲线。通过分块, 就把任意区域的网格生成工作分成了两个部分, 其一是生成各曲边四边形的边界, 其二是对每个曲边四边形生成适合于流场计算的网格。第一部分工作没有实质上的困难, 本文使用的方法是: 对原有边界, 在必要处对型值点进行插值, 对新增边界, 先用 Hermit 多项式进行曲线拟合, 再对拟合曲线进行插值。为了用一种又快又好的方法对曲边四边形生成所需要的网格, 我们注意到实用网格系统中有一个明显的现象: 网格点之间的坐标增量总是沿其网格线连续地、光滑地从一边变化到另一边的。为了实现这一目标, 本文假定当地坐标增量比沿其弧长线性分布, 即有下述关系存在:

$$CY = \frac{SY_{i,j}}{SY_{i,jmax}} \tag{1}$$

$$CX = \frac{SX_{i,j}}{SX_{imax,j}} \tag{2}$$

$$\Delta X = \left(CY \frac{X_{i,jmax} - X_{i-1,jmax}}{X_{imax,jmax} - X_{1,jmax}} + (1 - CY) \frac{X_{i,1} - X_{i-1,1}}{X_{imax,1} - X_{1,1}} \right) (X_{imax,j} - X_{1,j}) \tag{3}$$

$$\Delta Y = \left(CX \frac{Y_{imax,j} - Y_{imax,j-1}}{Y_{imax,jmax} - Y_{imax,1}} + (1 - CX) \frac{Y_{1,j} - Y_{1,j-1}}{Y_{1,jmax} - Y_{1,1}} \right) (Y_{i,jmax} - Y_{i,1}) \tag{4}$$

$$X_{i,j} = X_{i-1,j} + \Delta X \tag{5}$$

本文于 1989 年 7 月收到。

$$Y_{i,j} = Y_{i,j-1} + \Delta Y \tag{6}$$

$$i = 2, 3, \cdots\cdots, imax - 1 \quad ; \quad j = 2, 3, \cdots\cdots, jmax - 1$$

式中各符号的意义如图 1 所示。

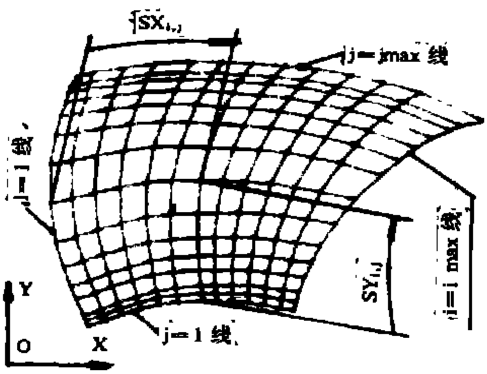

图 1 子块及术语说明

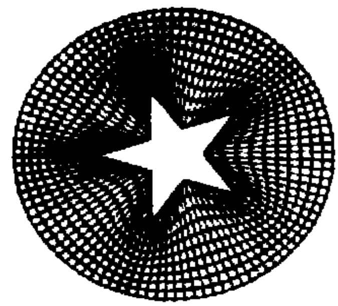

图 2 内边界是五星的光滑网格

初场可由 $CX = (i - 1)/(imax - 1)$、$CY = (j - 1)/(jmax - 1)$ 及 (3) ～ (6) 式得出。由初场可算出网格曲线的弧长，再由 (1) ～ (6) 式又可得出新场。如此循环，一般经 2～4 次迭代即可使新旧场之间的最大坐标改变量小到 10^{-4} 量级，从而得到所需的网格系统。

当原边界某处出现尖点时，本方法可在紧靠该处的区域内部预先拟合一条光滑曲线作为新边界，然后在保留原边界的情况下用新边界产生网格，保证使区域内部的网格线足够光滑。图 2 是应用这一技巧的一个例子。

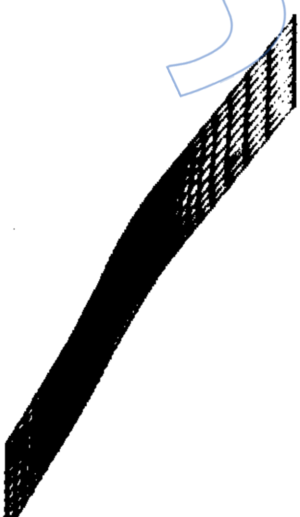

图 3 跨音压气机叶栅的变形“H”网格

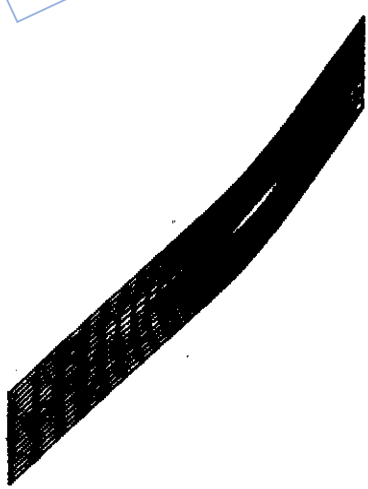

图 4 跨音压气机叶栅的“C”网格

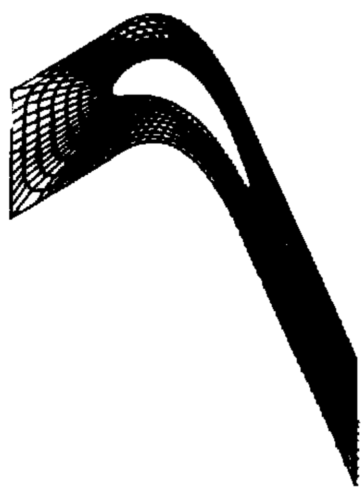

图 5 涡轮叶栅的“C”网格

图 3 至图 5 是用本方法生成的三个叶栅流场计算中实用的网格。图 6 是用图 4 网格计算得

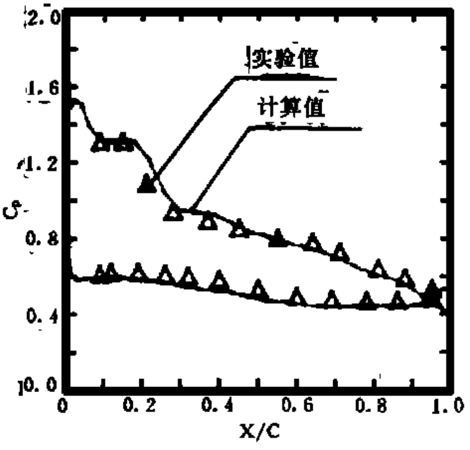

图 6　跨音压气机叶栅 $Ma_1 = 0.92$ 时的 C_p 曲线

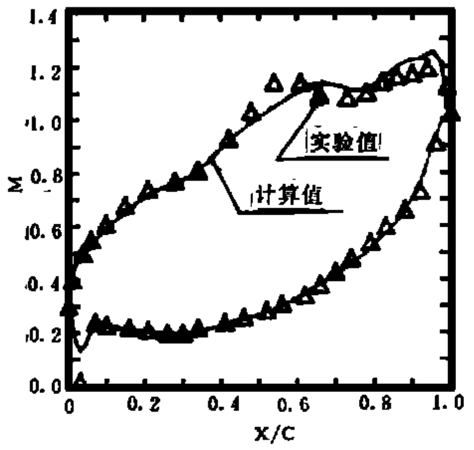

图 7　涡轮叶栅 $Ma_2 = 0.97$ 时的表面马赫数分布

到的叶型表面压力系数分布。图中符号意义、叶栅数据及实验结果见文献 [3]。图 7 是用图 5 网格计算得到的叶型表面马赫数分布，图中符号定义、叶栅数据及实验结果见文献 [4]。流场计算采用有限控制体方法求解 Euler 方程，有关细节将待另文叙述。由图可见，流场计算结果与实验值吻合良好，它们说明了本网格生成法及流场计算方法的有效性。

参 考 文 献

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[3]　Schreiber, H. A., Starken, H., "Experimental Cascade Analysis of a Transonic Compressor Rotor Blade Section", ASME 83-GT-209.

[4]　Kiock, R., et al, "The Transonic Flow Through a Plane Turbine Cascade as Measured in Four European Wind Tunnels", Journal of Engineering for Gas Turbines and Power, Vol. 108, April, 1986.

A RESEARCH ON CRACKED FAILURES OF FIR-TREE SERRATION IN AEROENGINE TURBINE DISC

Yao Huaxing and Yan Shalin

(Shenying Aeroengine Company)

ABSTRACT A lot of cracked failures of fir-tree serration accurred in the second stage turbine disc of a large numbers of certain types aeroengines in service. The characte of these cracks belongs to mechanical fatigue. In order to find out the cause for the cracked failure, the vibrating stresses of the second stage turbine blades on test bench and their vibrating strains in flight tests have been measured in the conditions of high temperature and high rotational speed. The measured data indicate that several resonance zones really exist in the second stage turbine blades of type A and B engines. Some methods for elimination of the cracked failures of fir-tree serration in the turbine disc are provided. According to the experiece in service, a modification of type B engine hase eliminated the cracked failures of fir-tree serration of turbine disc in its service life.

RELIABILITY ANALYSIS OF DIRECTIONAL SOLIDIFICATION BLADE

Lü Wenlin and Duan Zhenlong

(Northwestern Polytechnical University)

ABSTRACT The stochastic Finite Element Method and Hasofer-Lind Method are adopted to analyse the reliablity influence of stochastic pressure field on the directional solidification blade. This method and program are verified by calculation of the Monte-Carlo Method.

AN EFFICIENT 2D-GRID GENERATION APPROACH USING ARC-LENGTH AS A PARAMETER

Shi Zhouhe, Zhang Huimin, Wang Licheng

(Nanjing Aeronautical Institute)

ABSTRACT A fast and efficient grid generation program has been developed for any two-dimensional configurations. In this scheme, the separate grids are generated in each zone with a high speed algorithm which makes the ratio of the coordinate increments satisfy a linear distribution along arc-length of a grid curve, and then they smoothly joined along the common boundaries to establish the grid for the complex configuration. The advantages of the scheme are as follows: First, the mesh lines have continuous slopes from one zone to another; Second, the degree of the mesh lines clustering can be well controlled by the distribution of the boundary points; And the third, the computational speed is ten and even several hundred times faster than the elliptic grid generation scheme which has been widely used nowadays.