

弯扭联合成型叶片控制二次流

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国内外许多学者在设法控制二次流,减小二次流损失这一研究领域进行了卓有成效的工作,其中采用收敛型通道抑制二次流和采用可控涡设计减小二次流损失的技术措施在生产型发动机上均得到了成功的应用。60年代初,苏联的杰依奇教授和本文作者王仲奇教授,为了改善端壁附面层状况和改变沿叶片表面径向压力梯度,以便抑制流体的传输作用,研究了倾斜叶片并提出了弯扭联合成型叶片的设想。目前,它已在许多先进的航空发动机上得到了成功的应用。本文扼要地分析了这种叶片控制二次流的机理,并介绍了它的环形叶栅的实验结果。通过对一小型涡喷发动机涡轮导向器三元气动改型设计的算例分析,说明应用弯扭联合成型叶片是提高发动机性能的一个有效手段。

一、控制二次流的机理

作者在文献[1]中,从叶片表面附面层内、外流体微团受力分析出发,得出了叶片根部产生逆压梯度必须具备两个条件。一是气流折转产生的离心力,二是叶片正倾。在此逆压梯度作用下,沿叶片表面附面层内的低能流体被输运到中径附近,有可能消除在叶片根部吸力面出口区域产生的附面层堆积,从而降低了二次流损失。近一步分析表明,由于弯扭联合成型叶片根部和顶部压力增加,气流速度减小,进而离心力减小,端部的横向压力梯度亦将减小,从而可以减弱通道涡。与此同时,由于吸力面上气流速度和折转角大于压力面上相应值,具有较大的气流离心力。因而当叶片正倾或弯曲时,吸力面上在根部的压力提高比压力面的大,这将进一步减小通道内端部的横向压力梯度和通道涡的强度,导致二次流损失大幅度地降低。

国内外许多有关弯扭联合成型叶片的环形叶栅的实验结果都证实了采用这种新型叶片将比常规叶片带来很大效益。实验结果表明:随气流马赫数 Ma 增加,二次流损失越小,从而证实了气流速度越高,所产生的逆压梯度越大,控制二次流越有效。实验结果也说明,采用弯扭联合成型叶片可使平均能

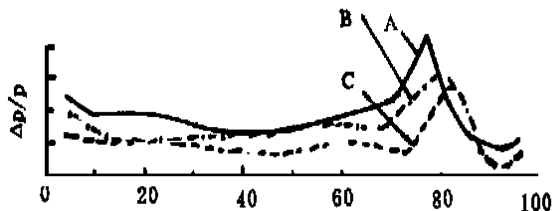


图1 弯与不弯叶片的环形叶栅实验研究

量损失系数下降27.7%。还可看出,沿叶高方向的几乎整个区域内,弯扭联合成型叶片的损失值均比常规径向叶片小。图1中A代表常规径向叶片,B为弯扭联合成型叶片但叶型与A相同,C为叶型经改进后的弯扭联合成型叶片。在设计马赫数 Ma 下,C的全压损失比A下降了50%;B只体现弯曲的影响,它比A的全压损失减小30%。

二、应用算例分析

对一小型涡喷发动机的涡轮导向器进行了改型设计。为了保证原型机中压气机出口流动状态,采用弯扭联合成型叶片替代常规涡轮导向器叶片时应满足下列要求:

- 1 改型前、后由涡轮导向器总压恢复系数、出口截面积和气动函数构成的组合参数 $\sigma_{ca} F_{ca} \cdot q(\lambda_{ca})$ 应保持不变。同原常规导向器相比,新型叶片可以显著地提高 σ_{ca} 以及在亚临界工作状态下使 $q(\lambda_{ca})$ 增加。因此,改型设计中必须相应减小 F_{ca} , 以补偿 σ_{ca} 的增加量。
- 2 保证改型后发动机在设计状态下涡轮和压气机的功率平衡条件。如果涡轮功率设计过大,则 T_3^*/T_1^* 低于设计值时,发动机的转速相似参数已经达到了设计值,发动机性能将达不到改型后的设计要求。反之,如果涡轮的功率设计过小,仍然无法满足性能要求。
- 3 保证原型发动机工作叶片进口流动条件。否则的话,因改用弯扭联合成型叶片所得到的增益,有可能在工作叶片失掉。

改型设计是利用 S_2 流面正问题跨音速程序,在子午面上建立半正交曲线坐标系 (x^1, x^2) , 其中 x^1 取拟流线方向, x^2 取拟径向方向。 S_2 流面上无量纲化的径向运动方程的流函数形式:

$$A_1 \partial^2 \Psi / \partial (x^2)^2 + A_2 \partial^2 \Psi / \partial x^1 \partial x^2 + A_3 \partial^2 \Psi / \partial (x^1)^2 + A_4 \partial \Psi / \partial x^2 + A_5 \partial \Psi / \partial x^1 = A_6 + F_r$$

其中系数 $A \sim A_5$ 见文献 [2], 而 A_6 和 F_r 则分别为

$$A_6 = \sqrt{g_{11}} / W^1 (-W_\Phi / r \cdot \partial(V_{ur}) / \partial x^2 + \partial / \partial x^2 - T \partial / \partial x^2)$$

$$F_r = \partial(V_{ur}) / \partial x^1 + \sqrt{g_{11}} / \sqrt{g_{22}} \cdot W^2 / W^1 \cdot \partial(V_{ur}) / \partial x^2 \partial \Psi / \partial x^2$$

由于是正问题计算,环量 V_{ur} 需在迭代中根据流面形状进行修正计算。图 2 是导向器改型前后反力度沿叶高变化的计算结果,图 3 是两种导向器内第 4 站和出口静压沿叶高的变化。由图

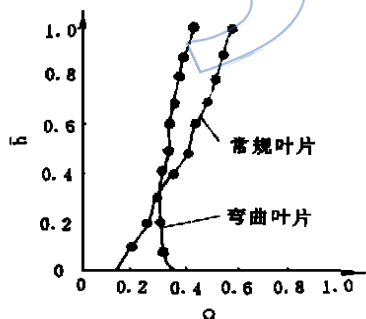


图 2 反力度沿叶高变化的比较

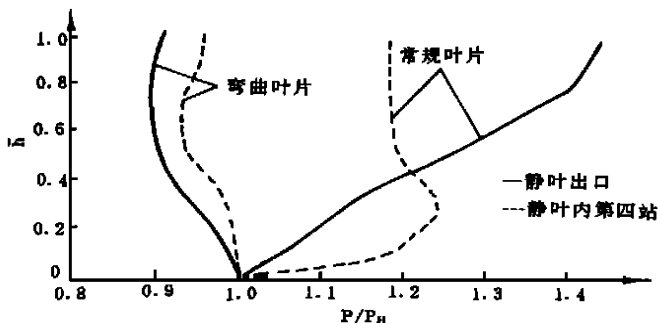


图 3 导向器内和出口静压分布

2 可见,采用以弯曲叶片为主体的综合流型设计涡轮导向器可以改善叶根部流动条件,减小顶部漏气损失。图 3 的计算结果表明,无论是导向器内部还其出口,弯扭联合成型叶片的根部都保持比较高的静压且产生逆压梯度,可以有效地将根部附面层内的低能流体输送到中径附近,使端部附面层减薄,削弱通道涡强度,降低二次流损失。

参 考 文 献

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TECHNICAL NOTES

MIXTURE RATIO FAILURE DETECTION FOR LIQUID PROPELLANT ROCKET ENGINE

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ABSTRACT

The mixture ratio failure detection for liquid propellant rocket engine has been studied by means of Kalman filtering and statistical hypotheses testing. A computer simulation of a variable thrust rocket engine demonstrates that the algorithm developed by authors can effectively detect mixture ratio deviation. The simulation also gives some significant results useful for the practical application and the further research of the algorithm.

APPLICATION OF COMPOUND LEANED BLADES TO CONTROLLING SECONDARY FLOW

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ABSTRACT

Mechanism of controlling secondary flow by using positive leaned blades or compound leaned blades is considered in this paper. The conclusion is that the positive leaned blades produce a converse radial pressure gradient at the hub. Under its action the low-energy fluid in the blade surface boundary layer is migrated from hub to midspan, the blade-to-blade transverse pressure gradient is reduced, passage vortices is weakened and hence the secondary flow losses are decreased. A computation of the compound leaned blades applied to guide vanes in a small engine has been performed as an example. Its results show that by comparison with conventional blades, the degree of reaction and static pressure at the hub of the compound leaned blades are increased, the flow behavior near the hub of working blades is improved; the degree of reaction at the tip is reduced and therefore the leakage losses are cut down too. It is proved that the positive leaned or the compound leaned blades are applicable to controlling the spanwise pressure gradient, the stage reaction and the downstream effect of the secondary flow.

A SMALL FIVE-HOLE SPHERICAL PRESSURE PROBE FOR COMPRESSOR EXPERIMENTS

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ABSTRACT

A small five-hole spherical pressure probe instrumentation system is developed and applied to compressor interstage parameter measurement. This instrumentation system has two features: One is smallness of flow disturbance due to small dimensions of the probe head, the other is an advanced data processing method of this system which comprises perfect probe calibration and data processing procedure. The analysis of the test results demonstrates that its performance is stable, its accuracy and data repeatability of its measurements are quite well. This instrumentation system can be applied to verification of the design parameters.