

有初始横流的冲击壁面强化的 换热特性实验研究

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【摘要】 对初始横流的冲击壁面强化的换热特性进行了实验研究。实验的参数范围: $Re_j = 5000 \sim 20000$, $Z_n = 1 \sim 3$, $G_i/G_j = 1 \sim 1.3$ 。实验表明: 随着初始横流的增加 (G_i/G_j 的增大), 将改善冲击粗糙肋靶面的换热特性; Z_n 的变化对换热有着明显的影响, 存在一个最佳值; 实验结果还表明冲击孔与粗糙肋相对位置对换热有影响。

主题词: 冲击 换热 冷却 涡轮
分类号: V231.1

1 引 言

由于冲击冷却和粗糙表面强化换热具有换热效率高的特性, 因此吸引了国内外许多学者对此进行研究。但两者的复合冷却即冲击壁面强化复合冷却研究却较少。文献 [1, 2] 曾研究了这一复合冷却技术, 但没有研究初始横流对该复合冷却的影响。本文根据某型航空发动机高温涡轮叶片中弦区的冷却问题, 模拟实验研究了有初始横流的冲击粗糙肋靶面的复合冷却换热特性。研究了初始横流、孔靶间距、对换热特性的影响, 研究中发现冲击孔与粗糙肋相对位置对换热也有影响。

2 实验装置、实验数据及处理方法

实验装置分为两部分: 主流系统和横流系统。空气经过压缩机压缩, 经气水分离器、储气罐后, 分为两路主流和横流。主流流经孔板流量计或转子流量计、扩散段、稳定段, 到实验段, 通过冲击孔形成冲击射流冲击到靶面上。主流流量大时, 用孔板测量, 小流量时用转子流量计测量。横流空气流经横流转子流量计、稳压罐进入横流矩形通道后形成初始横流, 横掠过靶面。

实验段由冲击孔板、横流进口、靶板和加热系统组成(图 1)。靶板由 6 块带有方肋的紫铜块组成, 各铜块之间用石棉垫绝热。靶板的划分是由冲击孔决定的, 冲击孔正对各铜块的几何中线上, 靶板的温度是由 16 对热电偶测得。16 对热电偶分别敷设在 6 块铜块上,

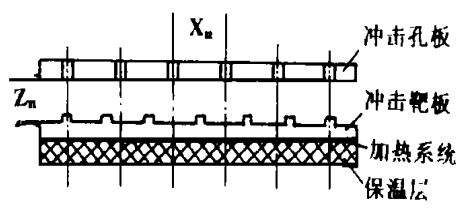


图 1 实验段装置示意图

热电偶在实验前进行了标定。热电偶穿过 0.5 mm 的孔与铜板固定。用康铜膜做成发热元件,其大小一致,分别对 6 块铜块独立加热,由可控硅整流器控制加热量。为了保证冲击孔板与靶板的平行度,靶板和冲击板分别埋在钢板中,两者之间由控制孔靶间距的挡块隔开。

主要参数:冲击雷诺数 $Re_j = 4m / (\pi \mu d_n)$; 每块铜块热流密度 $q_i = (W - W') / (6A_{fi})$, ($i = 1, 2, \dots, 6$); 各铜块的平均努谢尔特数 $Nu_i = (q_i d_n) / [(T_{wi} - T_{aw}) \lambda]$; 整块靶板的平均努谢尔特数 $\overline{Nu} = \sum_{i=1}^6 \frac{Nu_i}{6}$, ($i = 1, 2, \dots, 6$)。式中 W 为整流器输出功率, W' 为系统散失热量, 测量结果表明散热率 $(W - W') / W < 5\%$ 。为验证加热系统的均匀性及测定热电偶测点误差, 在无来流状态下, 对靶板加热, 稳定后测得各铜块上的温度 T_{w1} 为 20.75, T_{w2} 、 T_{w3} 、 T_{w4} 、和 T_{w5} 为 21, T_{w6} 为 20.75。实验中各铜块的热电偶温差小于 1°C , 靶面温度均匀。 T_{aw} 为各个紫铜块的绝热壁温, T_{aw} 是在没有加热下高速射流冲击靶面时测得的靶板温度, 所有热电偶测得温度几乎一致。

3 实验结果讨论

本实验模拟了某型发动机涡轮叶片中弦区复合冷却。几何尺寸无量纲 X 方向冲击孔间距 X_n 为 10, 无量纲 Y 方向冲击孔间距 Y_n 为 10, p/e 为 10, 靶间距 Z_n 为 1~3。实验在不同 Z_n (1~3) 下改变雷诺数 Re_j (5000~20000), 横流密流比 G_c/G_j (0~1.3) 进行了一系列的研究。

图 2 是 $G_c/G_j = 0$ (G_c 横流密度, G_j 为射流密度) 相同雷诺数不同 Z_n 下的 Nu_i 的曲线分布图。由图可见随着无量纲靶间距 Z_n 的变小, 曲线呈上升趋势越来越明显, 和文献[1, 2] 中研究结果相吻合。在 $Z_n = 1$ 和 1.5 时曲线上升趋势明显, 而在 $Z_n = 2.5$ 和 3 时整个曲线相对平缓, 其原因可能是因为前排冲击射流对后排射流形成了横流, 由图 2 知: 一般来讲, 对于粗糙靶板

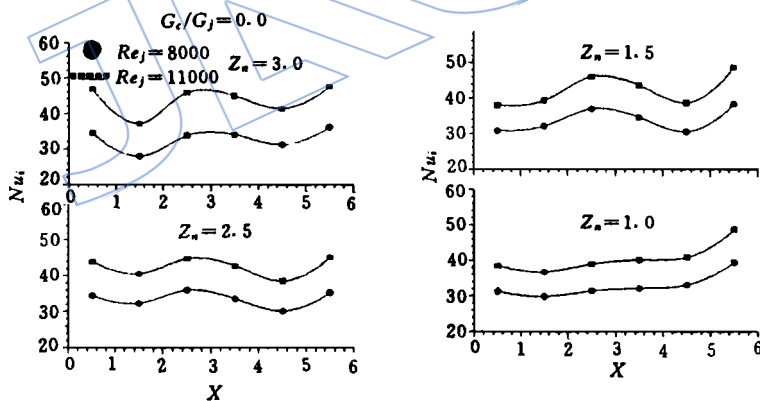


图 2 相同雷诺数不同 Z_n 下 Nu_i 的分布曲线

横流的加入总是使 Nu_i 得到了提高。在相同冲击雷诺数下, $Z_n = 1$ 和 1.5 时由于靶间距小, 横流作用明显, 而 $Z_n = 2.5$ 和 3 时则不太明显。此外, 曲线都波动呈“W”型, 即在 1, 3, 4 和 6 冲击孔处, Nu_i 较高, 而在 2.5 处 Nu_i 较低。这主要是由于冲击孔与粗糙肋的相对位置的影响, 如图 1 所示冲击孔 1 和 6 正对肋, 3 和 4 处于两肋之间, 而 2 和 5 则位于肋边。射流流场分为 3 部分, 即自由射流、驻点流和壁面射流。在 1, 3, 4 和 6 处冲击射流到达靶面后所形成的壁面射流得到了充分的发展。而在位置 2, 5 处, 由于冲击射流与冲击到肋边上几乎一边的壁面射流受到了肋的阻拦后被迫与靶面分离, 导致该处换热效果差。

图 3 是 $Re_j = 5000$, $G_c/G_j \geq 0$ 时, 不同 Z_n 下 Nu_i 的分布曲线。由图可见随着 G_c/G_j 的增加,

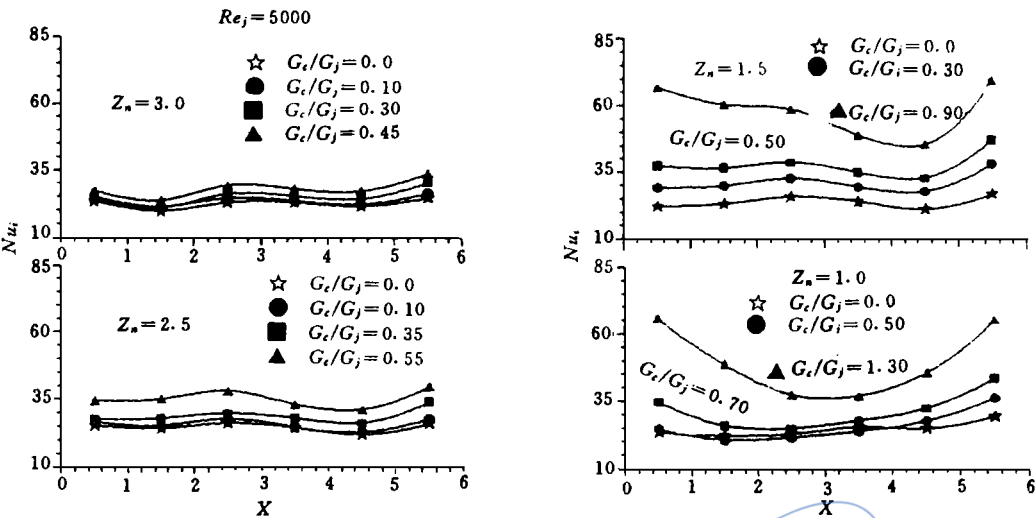


图 3 $G_c/G_j \geq 0$ 不同 Z_n 下 Nu_i 的分布曲线

换热整体得到改善, 其中位于肋边的 2, 5 冲击孔处改善情况有较大差异。位置 2 处换热情况得到改善, 而位置 5 处始终换热差。这是由于位置 2 冲击孔处于肋后, 位置 5 冲击孔处于肋前。而初始横流的加入使冲击射流驻点位置向后发生了偏移, 对位置 2 而言, 驻点后移使贴壁面的壁

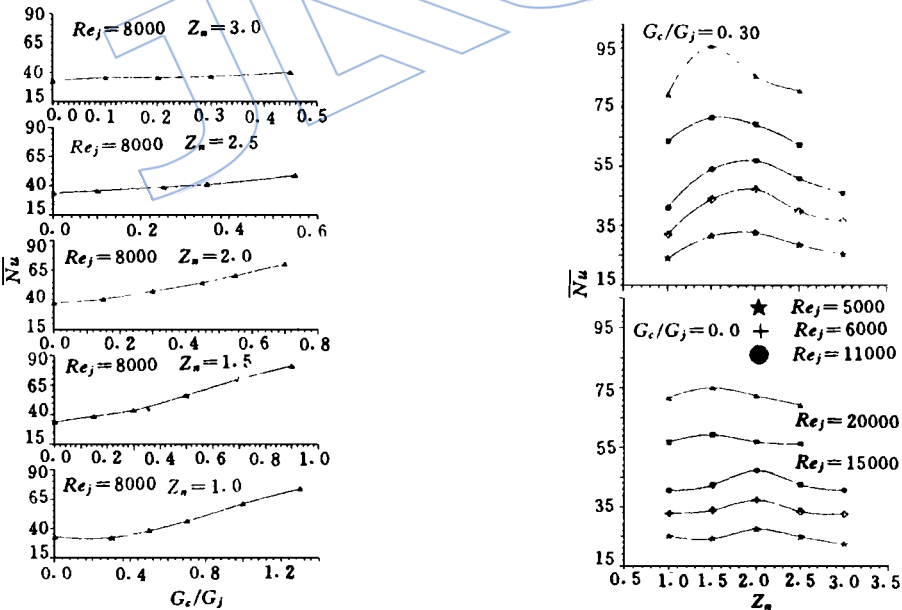


图 4 不同 Z_n 下 G_c/G_j 与 $\overline{Nu_i}$ 的关系曲线

图 5 相同 G_c/G_j 不同雷诺数下 Z_n 与 $\overline{Nu_i}$ 的关系曲线

面射流增多, 换热增强。位置 5 射流冲击到肋根处, 受肋的阻拦使壁面射流的分离量更大, 贴壁

面气流更小,同时横流使与横流流向相反的壁面射流受阻,换热更差。为了讨论靶板的整体换热情况,定义了 $\overline{Nu}$ 。图4是 $Re_j = 8000$, $G_c/G_j \geq 0$ 不同 Z_n 下 $\overline{Nu}$ 的分布曲线。由图可见随着横流的加入, $\overline{Nu}$ 不断升高,相比之下,文献[3]实验得出的冲击光滑靶面 $G_c/G_j > 0$ 时,随着横流的加入,靶板整体换热反而比 $G_c/G_j = 0$ 时 $\overline{Nu}$ 低,但当横流很大以致占主导地位时,换热又变好。这是因为粗糙板使横流在通道内得到了扰动,所以换热效果好。在有初始横流时,冲击粗糙板的换热效果优于冲击光滑板。

图5是相同 G_c/G_j 不同雷诺数下, Z_n 与 $\overline{Nu}$ 的关系曲线。曲线的形状大体呈钟形,即随着 Z_n 的变化, $\overline{Nu}$ 出现了峰值,在所有研究 Z_n 变化的冲击光滑板冷却中文献[1, 2, 4],都指出了 Z_n 具有最佳值。一般认为 $Z_n = 3-4$,且与实验的几何尺寸有关。在本实验条件下,发现冲击粗糙板 Z_n 的最佳值还与射流的雷诺数有关。随着 Re_j 的增大, Z_n 的最佳值变小, $5000 \leq Re_j \leq 11000$ 时, Z_n 的最佳值在2附近,在 $15000 \leq Re_j \leq 20000$ 时,最佳值在1.5附近。图6是 $Re_j = 8000$ 不同 Z_n 下 $\dot{m}_c/\dot{m}_j$ 与 $\overline{Nu}$ 的关系曲线。工程应用中,常在同一冷气量下评价一个冷却方案的好坏。由图5、6知,虽然在 G_c/G_j 相等时, Z_n 的最佳值在2附近,但从所用冷气量这一角度进行比较,发现 Z_n 的最佳值在1.5附近,同时可看出,在小靶间距时,随着 $\dot{m}_c/\dot{m}_j$ 的增加,换热效果越好。这是由于相同 $\dot{m}_c/\dot{m}_j$ 下, Z_n 越小,则 G_c/G_j 越大,即横流速度越大,使横流掠过靶面的速度梯度变大,换热加强。

4 结 论

(1) 在冲击粗糙靶时,由于初始横流的加入,使 $\overline{Nu}$ 得到了提高。(2) 在有初始横流时,由于肋的扰动使粗糙靶换热加强。(3) 随着 Z_n 的变化整个靶板换热情况变化很大,在不同几何尺寸和冲击雷诺数下, Z_n 存在一个最佳值。(4) 冲击孔与粗糙肋的相对位置对换热有影响。

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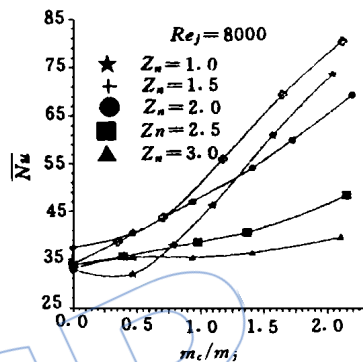


图6 不同 Z_n 下 $\dot{m}_c/\dot{m}_j$ 与 $\overline{Nu}$ 的关系曲线

rotary speeds of the cage and the balls decrease and their skiddings become serious as the thrust goes down, especially to a small value. So the minimum thrust preload for prevention of skidding of the balls on the inner race can be estimated.

Key Words rolling bearings Mechanical drives Kinetic analysis

INTERMITTENT AND CHAOTIC PHENOMENA IN A RUB IMPACT ROTOR SYSTEM

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ABSTRACT Vibration characteristics of a rub impact rotor system supported on oil film bearings were investigated. Elastic impact and the Coulomb type of frictional relationship was assumed. Rotating speed and the system damping were used as control parameters to discover routes to and out of chaos and to study various forms of periodic, quasi-periodic and chaotic vibrations. Very rich types of chaotic vibrations were found for the model discussed. Also the system motion shows two different forms of intermittent phenomena. One is the interchange between periodic and quasi-periodic vibrations. Another is between periodic and chaotic vibrations. Vibration features such as chaotic vibration, intermittent phenomena and broad-band of periodic vibration can be effectively used to diagnose the rub impact fault which often happens in a rotor system.

Key Words Rotors Chaos Vibration Damping

EXPERIMENTAL INVESTIGATION ON ROTOR VIBRATION CONTROL BY ELECTORRHEOLOGICAL DAMPER

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ABSTRACT In this paper the Electrorheological (ER) fluid and its characteristics are introduced briefly and the application of an ER damper in rotor vibration control is studied experimentally. It is found that by increasing the applied electrical field strength, the damping and stiffness of ER damper are increased, the vibration amplitude of the rotor system supported on ER damper is decreased in the sub-critical speed range and at the critical speed, and is increased in the super-critical speed range. The critical speed of the rotor system can be changed by means of the applied electrical field strength. The damping provided by the ER damper has the properties of both the Coulomb damping and the viscous damping. Experimental results show that the ER damper has obvious effect on vibration control, and features instantaneous control, little energy consumption and broad frequency range. Besides, its structure is simple.

Key Words Rotors Electric current Rheostats Vibration Control action

AN EXPERIMENTAL STUDY OF HEAT TRANSFER BY JET IMPINGEMENT ON ROUGHENED SURFACE WITH INITIAL CROSSFLOW

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ABSTRACT Impingement heat transfer from the rib roughened surface with

two-dimensional arrays of circular jet has been investigated in comparison to the jet orifice plate. The study covered jet at $Re_j = 5000-20000$; the initial crossflow rate $G_c/G_j = 0-1.3$; and nondimensional jet-to-surface spacing $Z_n = 1.5, 2, 2.5, 3$. The experimental results show that the impingement heat transfer from the rib roughened surface will be improved by increasing the initial crossflow rate. The heat transfer characteristics are considerably affected by the jet-to-surfaces spacing, and there exists an optimum. The effect of relative position of jet hole to ribs on heat transfer has been observed.

Key Words Shocks Heat transfer Cooling Turbines

EXPERIMENTAL STUDY ON ATOMIZATION CHARACTERISTICS OF PLAIN ORIFICE AT SUBATMOSPHERIC PRESSURE

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ABSTRACT

The atomization characteristics of a plain orifice at subatmospheric pressure were studied by means of pulsed laser holography, and hologram images of cross-spray downstream fuel cloud field were analysed with computer image system. The results obtained show how the mean particle size and particle size space distribution vary with air velocity, ambient pressure and spray fuel pressure. The first, the air velocity is a primary factor that affects the fuel atomization at either normal or subatmospheric pressure, the mean particle sizes monotonically increase as the air velocity decreases. The second, as the air density reduces with descending ambient pressure, aerodynamic force and turbulent fluctuation are reduced which force spray fuel sheet to breakup and drop size to fall to a critical value. As a result, the penetration is augmented, atomization is retarded, and mean drop diameter is increased, as well as fuel density space distribution becomes non-uniform and the quality of atomization obviously deteriorates. Therefore, the ambient pressure is also important to atomization. The last, when the nozzle spray goes across the direction of air, at subatmospheric pressure spray penetration depth rises more rapidly than at atmospheric pressure as the fuel-injection pressure increases.

Key Words Low pressure Plain orifice Nozzles Atomizing Tests

NUMERICAL SIMULATION OF COMBUSTION PROCESS IN LRE TEST COMBUSTION CHAMBER

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ABSTRACT

Two-phase turbulent reacting flow model of the internal operating processes in Liquid Rocket Engine (LRE) is set up in non-orthogonal curvilinear coordinates. By means of this model, numerical simulation of the combustion flow process in LO₂/GH₂ test rocket engine has been accomplished. From the simulation, velocity patterns, contour maps of gas species concentration, temperature, pressure, Mach number, combustion efficiency, and plots of wall temperature and average radiation temperature, and plot of spray vaporization are obtained.

Key Words Liquid propellant rocket engines Combustion processes Numerical simulation