

流体动力激励法控制射流结构的初步研究*

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【摘要】 在射流马赫数分别为 0.206、0.361 及 0.831 三种工况下,用环形卡门涡街激励射流。对 3 种不同几何参数的环形卡门涡街发生器,利用总压探针分别测定了激励前后射流速度的轴向分布和径向分布,得到了射流气动参数和涡街发生器几何参数对射流激励效果的影响。还利用单丝热线分别测定了激励前后射流边界层的紊流参数,结果表明,激励之后射流边界层的紊流脉动能量显著增加,这是射流激励后吸卷能力提高的内在动力。

主题词: 激励 射流 边界层 卡门涡 控制
分类号: V211 O35

Brown 等人^[1]尝试用流体动力法激励射流,即将卡门涡街引入射流边界层,结果表明在涡街脱落频率的周期扰动下,可使初始马赫数为 0.58 的常温射流的混合过程明显加快。本文进一步研究了涡街发生器几何参数(尺寸和形状)和射流初速对激励效果的影响,并用单丝热线探测了激励前后射流边界层中紊流能量的变化,所得结果对深入研究这类激励方法有重要参考价值。

1 试验装置和方法

如图 1 所示,主喷口直径 $d_j = 40\text{ mm}$,喷流为常温,其马赫数 Ma_{j0} 可单独调节。副喷口直径 $d_s = 62\text{ mm}$,其马赫数 Ma_{s0} 也可单独调节。试验中采用了 3 种涡街发生器,其中 2 个为圆截面,直径 d_v 分别为 4 mm 和 6 mm,另一个为 V 形钝体,其截面如图 2 所示。

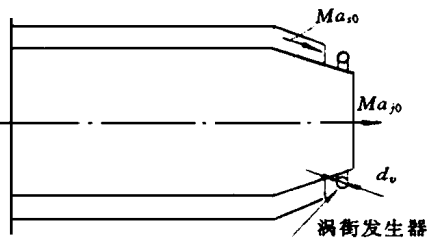


图 1 试验装置简图

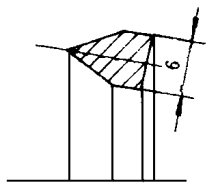


图 2 钝体型涡街发生器

试验时,首先将主、副喷管分别调节到所需状态,然后用总压探针分别测量射流轴线上的速度分布和给定截面上射流速度的径向分布。对比加装涡街发生器前后的速度分布可判定卡门涡街的激励效果。

此外,用单丝热线探测了若干位置上的紊流参数,根据频谱分析仪给出的功率谱,对比加装涡街发生器前后的紊流脉动能量。

2 试验结果与分析

图 3 给出了 3 种不同 Ma_{j0} 及 Ma_{s0} 条件下射流轴心线上的速度分布, 横坐标为无因次距离

(X 原点在主喷口截面中心)。其中“N_o Ring”表示无涡街发生器。可见, 加装 3 种涡街发生器后, 射流轴心线上的速度都有程度不同的降低, 表明射流的吸卷能力加强, 或混合过程加快了。射流的激励效果随着涡街发生器横截面直径的增大而增强。对于低速射流 ($Ma_{j0} = 0.206$ 及 0.361), 圆形截面的激励效果优于相同堵塞面积的 V 形钝体的激励效果。但对于高速射流 ($Ma_{j0} = 0.831$), 却

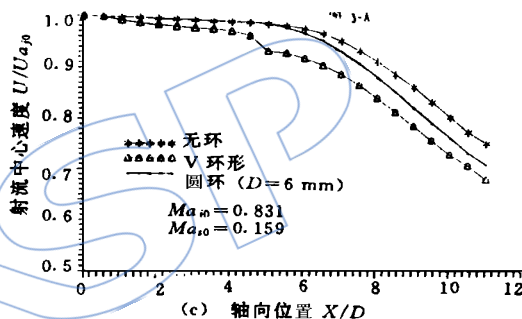
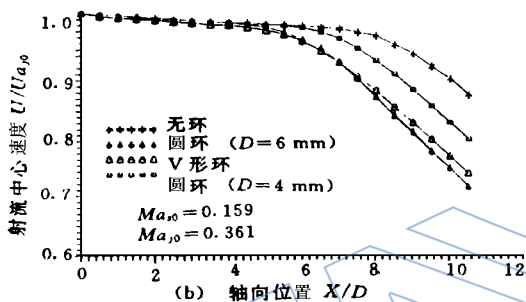
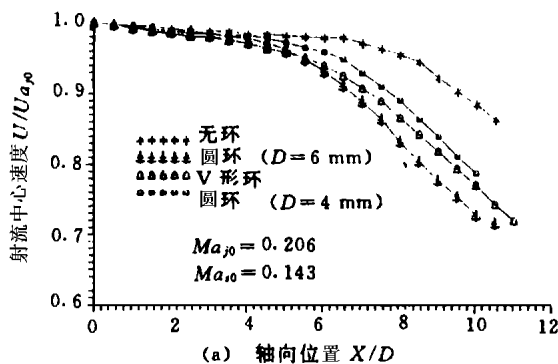


图 3 射流无因次速度在轴向上的分布

变得相反, 即 V 形钝体的激励效果优于相同堵塞面积的圆形截面的激励效果, 这种结果可能与不同条件下形成的涡街特性有关。此外, 相同条件下, 低速射流的激励效果优于高速射流的激励效果。因此对于高速射流应当采用横截面较大的涡街发生器才能获得预期的激励效果。

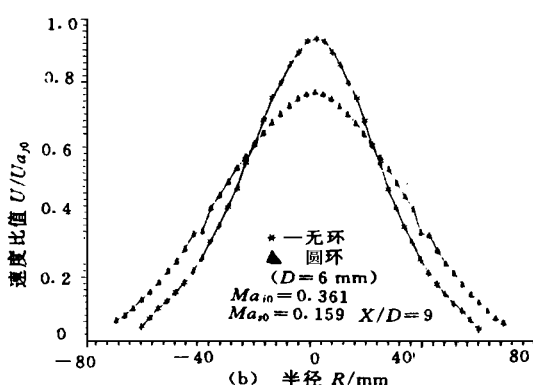
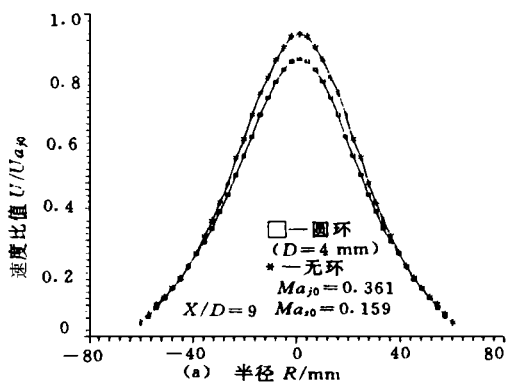


图 4 射流无因式速度在径向的分布

图 4 给出了相同工况下, 2 种涡街发生器在 $X/D = 9$ 截面的速度分布。由此也可明显看出, 射流的激励效果随着涡街发生器横截面尺寸的加大而变得更加明显, 在轴心线上速度加速

衰减的同时,射流变宽,质量流量加大,表明射流的吸卷能力已得到加强。

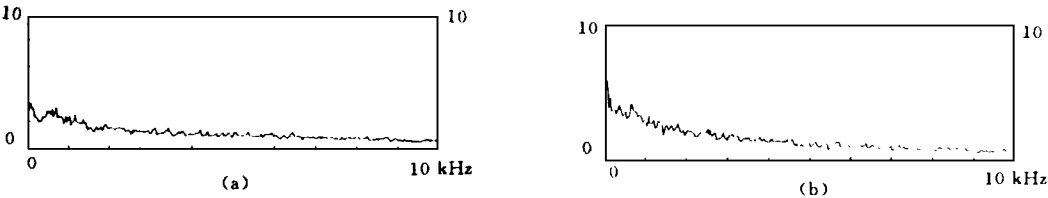


图 5 卡门涡街激励前的功率谱

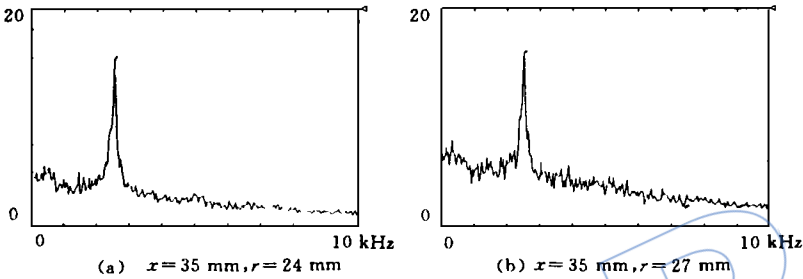


图 6 卡门涡街激励后的功率谱

图 5 和图 6 分别表示加装圆形($d=4$)涡街发生器前后单丝热线信号的功率谱,试验工况为 $Ma_0=0.361$, $Ma_{s0}=0.159$ 。图 6 中的 2 个尖峰对应的频率为卡门涡街的脱落频率,其值分别为 2575 和 2550 Hz。可见,在相同的几何位置,受卡门涡街激励后,紊流脉动能量明显提高,这是引起射流吸卷能力增强的内在动力。利用热线信号得到的涡街脱落频率,可用下式计算圆环涡街的斯特罗赫数 S_t ,即 $S_t=f d/U_s$ 。

表 1 计算值

U_s (m/s)	Re	f (1/s)	S_t
63.04	16810	2750	0.174
56.58	15086	2550	0.181
50.13	13368	2250	0.180

圆环和圆柱的斯特罗赫数是有区别的。

结论 (1) 卡门涡街对射流有明显的激励效果,为达到相同的激励效果,对于高速射流应当采用截面尺寸较大的涡街发生器。(2) 可用单丝热线测定涡街的脱落频率,环形涡街的斯特罗赫数不同于柱状涡街,在本文的参数范围内,环形涡街的斯特罗赫数为 0.174–0.180。(3) 热线信号的频谱分析表明,加装涡街发生器后,射流边界层的紊流脉动能量明显增加,这是引起射流吸卷能力增强的内在动力。

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2 Anatol Toshko, On the Development of Turbulent Wakes from Vortex Streets. NACA TN 2913

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quations are applied to prediction. The experimental and predicted data of the outlet angle due to the secondary flow are presented for three cascades with end – bend blades and one with the corresponding unbended blades. The investigation shows that the change in outlet angle can be accurately predicted by the presented method. Reducing curvature of the blade rear part makes the averaged intensity of the streamline component of the outlet secondary vorticity decrease, but does not change the distance from the center of the vorticity to the end wall.

Key Words Blades Secondary flow Flow fields

*) A MODEL TO CORRELATE FLOW SEPARATION WITH FLOW LOSS IN A TRANSONIC ROTOR

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ABSTRACT

A model correlating flow separation with flow loss is proposed for predicting the incipient location and size of the flow separation in a transonic rotor. The flow fields of several rotors have been investigated with the model. The results show that the flow separation mainly occurs in the tip area owing to strong shock boundary interaction, and the incipient separation point is behind the shock location. The tip leakage flow vortex has a strong effect on the interaction between shock wave and boundary layer.

Key Words Flow separation Losses Rotors

A PRELIMINARY INVESTIGATION ON CONTROLLING JET STRUCTURE BY HYDRODYNAMIC EXCITATION

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ABSTRACT

Jets were excited by Karman Vortex Streets under three conditions of Jet Mach Number 0.206, 0.361 and 0.831. Three vortex generators with different geometries were tested. Jet Velocity distributions with and without excitation were measured by stagnation pressure probe. The turbulent characteristics in the jet boundary layer were detected by a single hot wire probe. It is shown that excited jet velocity decay faster than that of unexcited jet, and turbulent energy in jet boundary layer is significantly increased by vortex excitation. Therefore, jet structure can be effectively controlled by hydrodynamic excitations.

Key Words Excitation Jets Boundary layer Karman vortex Control

A STUDY ON SUPERSONIC 6- NOZZLE EJECTOR PERFORMANCE

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ABSTRACT

The supersonic 6- nozzle ejector performance has been investigated experimentally for the given geometric dimensions. The experiment ranges over $1.98 \leq P_p^* / P_s^* \leq 7.46$, $0.971 \leq T_p^* \leq T_s^* \leq 1.02$ and $L_m / D_m = 0.80$. The entrainment ratio α varies from 6.96 to 11.66 for the ejector with a diffuser, and its corrected value $\alpha^* = T_s^* / T_p^*$ varies from 6.88 to 11.62; on the other hand, the entrainment ratio varies from 2.82 to 6.28 for the ejector without the diffuser, and its corrected value varies from 2.78 to 6.24. The experimental results show that the entrainment ratio and its corrected value decrease with the increase