

尾缘吹气式火焰稳定器试验研究

北京航空航天大学 杨茂林** 全中 白兴艳 岳连捷 张频捷

【摘要】 本文提出了一种新型火焰稳定器—尾缘吹气式火焰稳定器,它具有流线形头部,槽宽小,尾缘吹气并供油,不加力时流阻很小,加力时吹气扩大回流区,是一种机械与气动稳定结合的稳定器。对该稳定器进行了试验研究,得到流阻损失、贫熄边界、燃烧效率等性能的初步结果,表明该稳定器具有优越性,并有希望用于加力燃烧室。

主题词: 火焰稳定器 加力燃烧 气动稳定

分类号: V 235. 113

1 引言

高性能推进系统加力燃烧室,要求稳定器流动损失小,燃烧效率高,稳定范围宽。有些要求之间常互有矛盾,一般来说,损失大是换取燃烧性能好的代价。

气动稳定器不加力时不吹气,其流阻特别小。有的在射流中加喷燃油,以扩大贫熄边界。70、80年代美国和印度都进行过研究^[1-3]。气动稳定器曾受到相当重视,但至今未见使用。分析其原因,可能是:(1)用于气动稳定的吹气是一种消耗,引气量大了是不行的;(2)单靠气流稳定不很可靠。本文在已有工作基础上提出一种新的稳焰装置,并进行了初步的可行性研究。

2 新型火焰稳定器方案

尾缘吹气式气动稳定器,见图1和图2。稳定器的前部为U形壳体,后部为大顶角V形

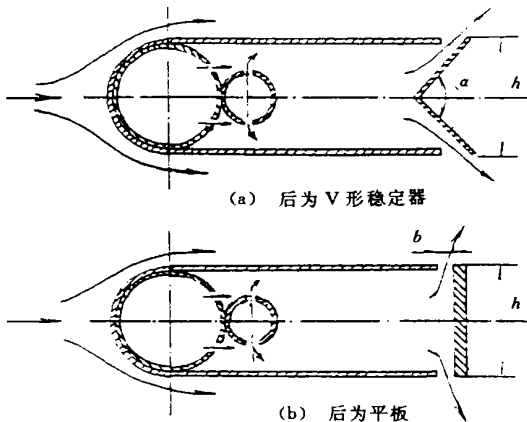


图1 尾缘吹气式气动稳定器方案示意图

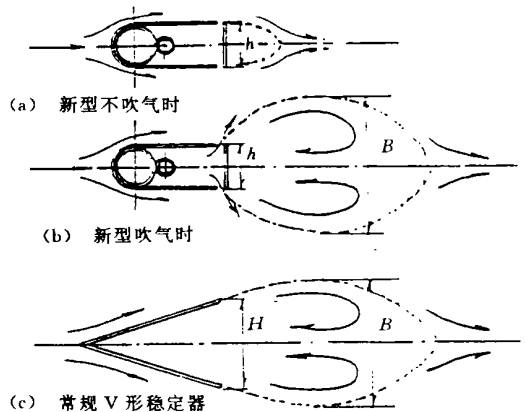


图2 新型稳定器与常规V形稳定器的比较

槽。其尾缘形成吹气窄缝,前后部形成的内腔为混合室,其前端有供气、供油管,其上分别开多个吹气孔和多个喷油孔,组成气动雾化喷油装置,加力时雾化燃油与空气在混合室形成的油气混气由稳定器尾缘窄缝吹出形成气动稳定。前端为半圆形的U形壳体,实际为稳定器的整流罩。文献[4]表明U形稳定器与槽宽相同的各种顶角V形稳定器相比,压力损失很小。且半圆形前端对喷油和来流方向不敏感。这是一种新型气动稳定器或机械式与气动式组合的稳定器。

本实验中二元稳定器长 170 mm,槽宽 36 mm,在通道内堵塞比仅为 12%,稳定器沿流向长 84 mm。吹气缝宽 b 可变,实验中选为 3 mm。后部大顶角V形槽顶角 α 可变,试验中 I 型后部为平板(相当于顶角 $\alpha = 180^\circ$),II 型为 $\alpha = 120^\circ$ V形槽。油气混气由尾缘窄缝与主流成 90° (I 型)或 60° (II 型)吹出。

3 试验设备和测量系统

试验由暂冲气源供气,经稳定箱和整流网格使进口流场均匀。加热器加热来流,自动调节系统保持所需来流参数。试段长 900 mm,截面 $300\text{ mm} \times 170\text{ mm}$ 矩形通道,前后段开有观察窗。稳定器水平安装在试段管道中心,其前缘与来流方向垂直。前方供油杆在稳定器尾缘上游 295 mm 处,水平安装(也可垂直安装)顺喷,喷孔直径 0.5 mm 和 0.7 mm 两种。高能电点火器安装于稳定器尾缘附近 10 mm 侧壁上。

气冷多点总温总压组合探针水平固定在试段出口截面,“扫描”测取出口测量截面上总温和总压分布(一般总温 45 点,总压 54 点)。试段进口参数: $T_1 = \text{室温} \sim 600^\circ\text{C}$, 压力 $p_1 = \text{常压}$, 来流速度 $v_1 = 10 \sim 100\text{ m/s}$ (加热器不工作), $v_1 = 30 \sim 200\text{ m/s}$ (加热器工作时); 稳定器内供气压力: $p_{as} = 0 \sim 0.6\text{ MPa}$ (表压); 加力供油压力: $p_f = 0 \sim 2\text{ MPa}$ (表压)。

4 试验结果分析

4.1 燃烧状况

(1) 稳定器尾缘吹气对燃烧的影响。由照片(a)可见,火焰在稳定器尾缘缝隙后侧开始,在射流核心与回流区之间的剪切层中发展。火焰扩张角 β 在根部较大,向下游发展逐渐减小,随着吹气压力 p_{as} 的增加, β 明显增加(比较照片(a)与(b)),回流区明显加大,这是由于吹气射流动量增加,使回流区扩大,有利燃烧。但 p_{as} 过高,将造成熄火,这主要是由于射流速度过大,回流区边缘速度过大,不利于火焰稳定。另外,尾缘油气比过贫也是重要原因。

(2) 来流速度 v_1 对燃烧的影响,由照片(c)和照片(d)可见,随 v_1 增加 β 减小。

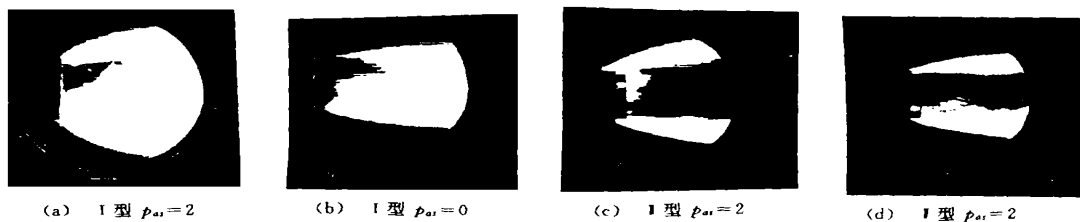


图3 尾缘吹气对燃烧的影响((a)~(c) $v_1 = 50\text{ m/s}$, $T^* = 597\text{ K}$, (d) $v_1 = 90\text{ m/s}$)

(3) 不同类型稳定器火焰扩张角 β 不同,在相同来流和吹气供油条件下, I 型的 β 较 II 型的为大。I 型的吹气射流速度 v_j 在纵向的分量大,所造成的回流区也大。 β 也就更大。但 II 型

的火焰由于底部 V 形槽的存在而更加靠近尾缘。两种稳定器在吹气时 β 均较槽宽相同的常规 V 形稳定器的大, 回流区宽度增加, 焰面覆盖宽, 表明新型火焰稳定器燃烧状况改善。

4.2 流阻损失

分别用总压恢复系数 σ^* 和压力损失系数 Ψ 来表示流阻损失。 $\sigma^* = p_1^*/p_2^*$, $\Psi = (p_1^* - p_2^*)/(\rho_1 v_1^2/2)$, 其中 p_1^* 和 p_2^* 为进出口气体平均总压, $\rho_1 v_1^2/2$ 为进口平均动压头。

由图 4~图 7 可以看出: (1) 不加力时, 新型稳定器流阻损失比相同槽宽的 V 形稳定器的还略小, 按照文献[4], 将比 B_g 为 30% 的 30 °V 形稳定器流阻损失小至少 50%。(2) 加力时, 新型稳定器流阻损失随吹气量增加而增加, 相当于一个槽宽更大的 V 形稳定器, 以流阻损失增加为代价, 换得回流区加大, 燃烧性能改善。(3) 新型稳定

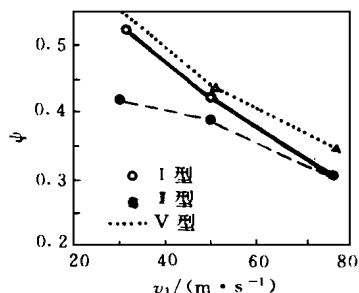


图 4 Ψ 随 v_1 的变化

($p_{as} = 0$, $T_i^* = 298$ K)

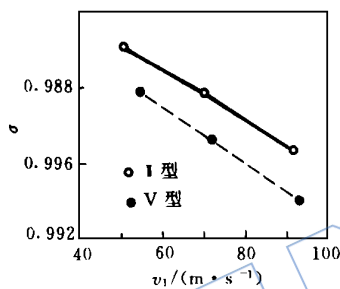


图 5 σ 随 v_1 的变化

($p_{as} = 0$, $T_i^* = 597$ K)

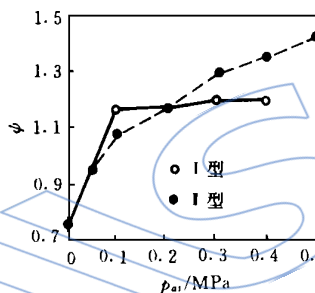


图 6 Ψ 随 p_{as} 的变化

($v_1 = 50$ m/s, $T_i^* = 597$ K)

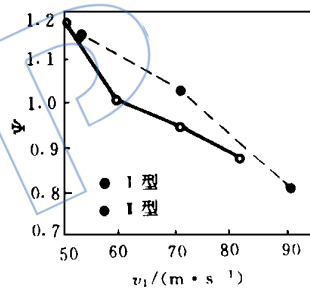


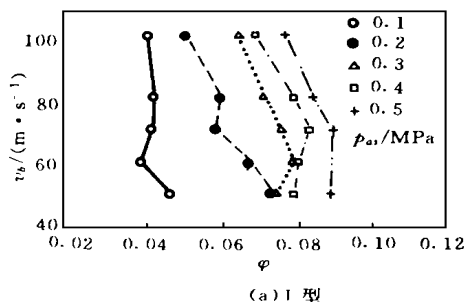
图 7 Ψ 随 v_1 的变化

($p_{as} = 2$ MPa, $T_i^* = 597$ K)

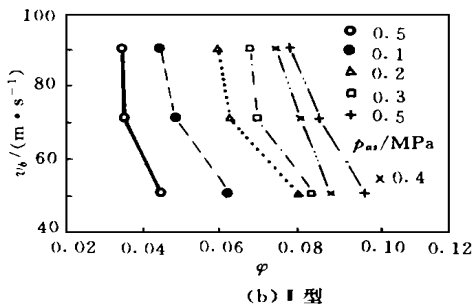
器是一个可变堵塞比的可调稳定器。(4) II型较 I 型流阻损失略小, 但所产生的回流区也略小。

4.3 贫熄边界

用总当量比 $\Phi = L_0(m_f + m_{fs})/(m_{al} + m_{as})$ 来表示油气比, 其中 m_{fs} 与 m_{as} 分别为稳定器中油、气流量, m_f 与 m_{al} 分别为稳定器前油、气流量。



(a) I 型



(b) II 型

图 8 贫熄边界 ($T_i^* = 597$ K)

由图 8 可以看出: (1) 吹气式新型稳定器的贫熄边界与槽宽大一倍的 V 形稳定器的大体相当 ($H = 74$ mm, V 形稳定器贫熄油气比为 0.02 左右^[5])。比均匀混气情况下的贫熄范围宽

10 倍^[5]。(2)吹气过大,不利于贫熄。(3)随着速度增加,新型稳定器的贫熄范围变宽。

4.4 燃烧效率

图 9 和图 10 可以看出: (1)新型稳定器的燃烧效率较槽宽相同的 V 形稳定器显著提高,吹气压力为 0.2 MPa, $v_1 = 50$

m/s 时 I 型稳定器燃烧效率较槽宽相同的 V 形高 15%。(2)新型稳定器的燃烧效率随吹气压力增加和来流速度增加而增加,这对组织燃烧有利。随着 v_1 提高,燃烧室出口温度 T_2^* 增加。这是由于供氧充分,湍流强度增加,燃烧强化。同时作用于油气射流的气动力增大,使燃油雾化、蒸发混合改善,有利燃烧。随 v_1 增大,回流量增加,卷吸到回流区中的燃油量也增加。这些因素均使火焰变得更旺。但 v_1 过高,则稳定器边缘速度过大,加之油气比过贫,则火焰将被吹灭。

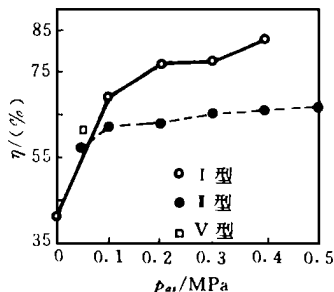


图 9 η 随 p_{as} 的变化
($v_1 = 50$ m/s, $T_1^* = 597$ K)

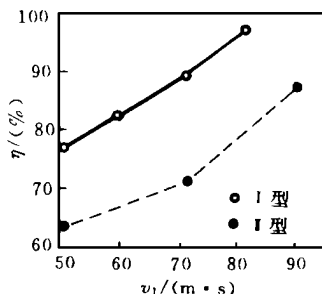


图 10 η 随 v_1 的变化
($p_{as} = 0.2$ MPa, $T_1^* = 597$ K)

5 结 论

(1)新型气动稳定器是一个可变流阻损失系数的火焰稳定器。不加力时流阻损失很小。(2)新型稳定器的贫熄边界与堵塞比大一倍的 V 形稳定器的贫熄边界相当。随来流速度增加,新稳定器的贫熄范围变宽。(3)新型稳定器由于稳定器中供油显著改善点火性能。(4)新型稳定器回流量大,尾缘浓度合适,尾缘附近火焰扩张角大,既有利于火焰稳定,也有利于提高燃烧效率。与一个相同几何堵塞比的 V 形稳定器相比,新型稳定器的燃烧效率高 15%~30%。(5)新型稳定器由于内部通气而得到冷却,将适合在更高进气温度下工作。(6)新型稳定器尾缘吹气量较少。控制用气量 1%~2%,以减小对主机性能的影响。(7)新 I 型与新 II 型相比,α 大则吹气对燃烧性能改进更显著,但流阻损失要大些。设计时需求得折中。

初步试验表明,新稳定器具有新的特点和优点,是有希望的,应进一步进行研究。

参 考 文 献

- 1 Peck R E, Samuelsen G S. Generalized Stability Criteria for an Opposed- Jet Flameholder. AIAA 82- 4229
- 2 Sridhara K, Chidananda M S, Paranjpe P A. Jet Curtain Flameholder for Aircraft Afterburners. 78- GT- 95
- 3 Sridhara K, Chidananda M S. Fresh Mixture Entertainment in a Jet Curtain Flameholder. Fifth International Symposium on Airbreathing Engines, February 1981
- 4 Edwards J L, Meacham I. Reheat for Gas Turbines. Journal of the Royal Aeronautical Society, 1955, 59: 127
- 5 杨茂林等. 燃油分布对 V 形稳定器后燃烧的影响. 航空动力学报, 1996, 11(1): 48- 52

(责任编辑 杨再荣)

by the former researcher on rubbing of rotor and stator. The vibration characteristics for some types of rubbing for the dual- shaft engine are analyzed and discussed. The theoretical results are consistent with data measured on a dual- shaft aircraft engine.

Key Words Double spool jet engines Collisions Vibration analysis

STRESS ANALYSIS OF TRAPEZOID TOOTH BELT WITH FEM

Wu Cong, Wang Yong, Ding Weiping, Wang Buyang

(Dept. of Mechanical Engineering, Northwestern Polytechnical University, Xi'an 710072)

ABSTRACT The geometric nonlinearity of synchronous trapezoid tooth belt is taken as the point of departure. A nonlinearity finite element solution of the synchronous belt is provided on the basis of elastic linear finite element method to solve two- dimensional stress distribution problem. The level stress distribution for a tooth of the synchronous belt is researched with help of this method. Finally, for an example, a maximum stress point and stress distributions of a synchronous belt tooth have been found out and compared with its elastic linear solution.

Key Words Gears stress Distribution Nonlinearity Finite element analysis

NUMERICAL PREDICTION OF COLD FLOW FIELD BEHIND EBM C FLAMEHOLDER

Yue Lianjie, Yang Maolin, Huang Yong, Xu Hang

(4th Dept. Beijing University of Aeronautics and Astronautics, Beijing 100083)

ABSTRACT A numerical prediction of the cold flow field behind a novel flameholder- Edge Blowing Mixture Curtain (EBM C) in two- Dimension duct was completed by using a modified k- ϵ model and S M P L E R method. The influence of the airflow parameters and the flameholder geometrical parameters on the recirculation zone was also studied. The prediction provides basis for designing the novel flameholder and studying its combustion performance.

Key Words Aerodynamic stabilization Flame holder Flow field Prediction

EXPERIMENTAL INVESTIGATION ON EBM C FLAMEHOLDER

Yang Maolin, Quan Zhong, Bai Xingyan, Zhang Pinjie

(4th Dept. Beijing University of Aeronautics and Astronautics, Beijing 100083)

ABSTRACT A novel flameholder is presented, as named Edge Blowing Mixture Curtain (EBM C) flameholder. It has a streamline form head, small base width, with air and fuel mixture flowing from the slots at its edges into the main flow. It has small cold pressure loss without reheat and variable blowing on reheat so as to enlarge recirculation zone and improve combustion performance. An experimental investigation of this flameholder was carried

out, and its pressure loss, lean flame blowoff range and combustion efficiency were researched. It seems that the EBM C flameholder is superior to the conventional V - type one.

Key Words Flameholders Afterburning Aerodynamic Stabilization

NUMERICAL MODELING OF TURBULENT FLOW AND HEAT TRANSFER IN A PIN- FINNED CONVERGENT PASSAGE OF GAS TURBINE GUIDING VANE

L iu Dong, Gu Weizao, L iu Wenyan

(Institute of Engineering Thermophysics Academia Sinica, Beijing 100080)

Deng Huayu (Gas Turbine Establishment)

ABSTRACT A numerical model of cooling air flow and heat transfer in a pin-finned convergent passage of gas turbine guiding vane was set up, which employed a turbulent k- ϵ model, a 3D Body Fitted Coordinates (BFC), the SIMPLEST Algorithm and the whole field solving method of convection- conduction conjugate heat transfer problem, taking the interlinks among the flow field, pressure field, the temperature field, the property variation and the effects of compressibility and 3D heat conduction inside a guiding vane shell into consideration. The computation results are in a good agreement with experimental data.

Key Words Blades Cooling Heat transfer Numerical simulation

RESEARCH ON EFFECT OF CHEMICAL - EQUILIBRIUM ON THERMODYNAMIC CYCLE PERFORMANCE OF GAS TURBINE ENGINES

Tu Qiye, Wang Zhanxue, Wang Shu, Tang Diyi

(7th Dept Northwestern Polytechnical University, Xi'an 710072)

ABSTRACT A quickly convergent algorithm to solve the chemical equilibrium equations is adopted and new subroutines are developed to serve as interfaces between the high temperature components routines and the chemical equilibrium routines. The effect of chemical equilibrium on each individual component is also given quantitatively and the mechanism is analyzed. Finally, an engine performance with considering the chemical equilibrium is compared with one without considering the chemical equilibrium.

Key Words Chemical equilibrium Gasturbine engines Performance