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旋流加力室火焰前锋的计算

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一、基 本 方 程

1. **微分方程** 计算旋流加力室火焰前锋的位置，基于气泡理论[1]。由于旋转力场，冷气流离心向外运动，迫使径向点燃的火焰微团向心运动。火焰微团的位置由轴向和径向速度来确定。假设这两个运动是独立的。轴向运动由冷的未燃气体算出，因压力损失，速度随管长增加；火焰微团的径向运动可由下列方程描述：

$$\frac{d^2R}{dt^2} = -\left(\frac{R\omega^2}{\rho_B/\rho_a}\right)\left(1-\frac{\rho_B}{\rho_a}\right)+\left(\frac{A_B C_D}{2V_B}\right)\frac{\rho_a}{\rho_B}\left(\frac{dR}{dt}\right)^2 \tag{1}$$

式中：ρ_B、V_B、A_B分别表示火焰气泡的密度、容积和投影面积。C_D是基于气泡投影面积的阻力系数。ρ_a为未燃气体的密度。ω系旋转角速度。R是离旋转中心的距离。

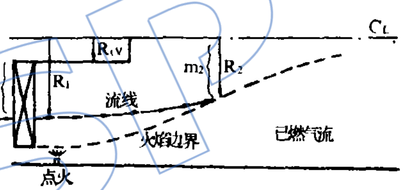

图1 旋流加力室示意图

2. **旋转角速度ω** 对小叶片角(≤35°)，叶片出口处，可近似认为轴向速度和切向速度沿半径为常量。叶片出口处旋转角速度为

$$\omega = V_u/r = V_x\tan\alpha/r \tag{2}$$

在叶片的下游，由于燃气的膨胀，冷的未燃混气被迫移向中心。角动量沿流线守恒，所以沿流线 $V_u r$ = 常数。叶片下游的角速度可用方程(3)来计算。加力室示意图见图1。

设R_1与R_2处冷气流静温相等，$T_1 = T_2$，静压为P_1和P_2，马赫数为Ma_1，和Ma_2，V_{u1}和V_{u2}为切向速度，已知$A_1 = \pi R_1^2 - \pi R_{iv}^2$和$A_2 = \pi R_2^2 - \pi R_{iv}^2$，从连续方程及角动守恒原理已得

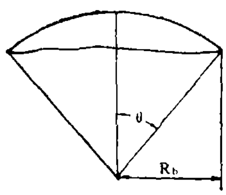

图2 火焰气泡形状

$$\omega_2 = \frac{V_{u1}}{R_2}\sqrt{\frac{(A_2P_2Ma_2)/(P_1Ma_1)+\pi R_{iv}}{A_2+\pi R_{iv}^2}} \tag{3}$$

3. **密度比** 假设整个燃烧过程中密度比ρ_B/ρ_a恒定，和混气在化学恰当比下完全燃烧，则$\rho_B/\rho_a = T_a/T_B$。若进口温度T_a是913K，燃烧后绝热温度T_B是2323K，则ρ_B/ρ_a为0.393。

4. **$(2V_B)/(A_BC_D)$ 项** 这是气泡半径的函数。应用气泡理论模型及其几何形状假设，可得气泡体积V_B(见图2)。

$$V_B = \pi R_b^3[\cos^3\theta/3 - \cos\theta + 2/3]/\sin^2\theta$$

当$\theta = 46°$，$C_D = 0.728$[2]，则

$$(2V_B)/(A_BC_D) = R_b/1.618 \tag{4}$$

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对管内流动，并假定气泡直径与先锋点火夹层的尺寸相同。当点火夹层尺寸为2.82cm时($R_b = 1.41$cm)，($C_D/2l$)在计算程序中取114.8〔1/m〕。

5. **静压**　在R_1处的出口截面上，一旦ω、ρ_B/ρ_a和($2V_B/A_BC_D$)算出，径向火焰速度可用下述方式逐步计算。每个小的时间增量(5×10^{-5}s)可计算出烧掉的混气数量，冷、热气流的重量流量W_c和W_h就要相应调整。同时允许热气流膨胀到冷气流中去。A_c和A_h是冷、热气流占有的流通面积，则总流通面积$A_t = A_c + A_h$。静压可由下式算出：(P_c^* 和P_h^* 为冷、热气流的总压)

$$A_c = W_c\sqrt{T_c^*}/P_c\sqrt{[2g\gamma/(\gamma-1)\tilde{R}][(P/P_c^*)^{\frac{2}{\gamma}}-(P/P_c^*)^{\frac{\gamma+1}{\gamma}}]} \tag{5}$$

$$A_h = W_h\sqrt{T_h^*}/P_h\sqrt{[2g\gamma/(\gamma-1)\tilde{R}][(P/P_h^*)^{\frac{2}{\gamma}}-(P/P_c^*)^{\frac{\gamma+1}{\gamma}}]} \tag{6}$$

设压P_c^*是不变的，而P_h^*按烧去的混气数量沿轴向减少。轴向速度可由静压计算出来。这样，燃烧膨胀过程的第一步完成了。以后各步重复进行直到全部混气烧完。

6. **流阻系数Ψ_α**　旋流加力室的流阻主要与旋流角α有关，α增大则损失增加[3]。

$$\varphi_\alpha = \sec^2\alpha - 1 \tag{7}$$

二、计算结果及讨论

计算程序的简要说明见文献[4]。现将计算结果介绍如下：

1. 随α角增大，L缩短(图3)，L/D下降。因旋流强度增加，离心力增大，火焰传播速度提高。若$\alpha = 45°$，L/D = 1.19，比传统的加力室L/D = 2.5低得多。

2. 当$\alpha > 55°$，φ增加很快(图4)。当$\alpha = 45°\sim55°$，$\varphi_\alpha = 1\sim2.04$。若再考虑其它因素，则数值与传统加力室的流阻相当。如果采用可调叶片，则非加力状态流阻可大为减少。

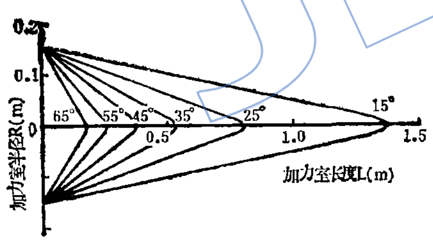

图 3　火焰前锋位置随旋流角的变化

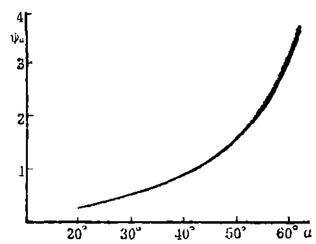

图 4　流阻系数随旋流角变化的曲线

3. 计算结果表明，当$\alpha > 45°$，旋流强度大于3500g，计算进口总压从10KPa至200KPa，火焰前锋位置无明显变化。这与文献[1]的实验结果基本符合。

作者对曾求凡教授的帮助表示感谢。

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A UNITED OPTIMUM METHOD FOR AN AXIAL TURBINE STAGE

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Abstract

A united optimum method for designing an axial turbine stage is provided which combines the blade geometry optimization with the optimization of meridian passage according to the blade twist. The physical models,mathematical expressions and procedures for optimum selection of the blade geometry,meridian passage and its twist are described respectively, and then a united procedure is proposed. A numerical example has been calculated with this procedure. In the result,this method is proven of both theoretical and practical values and may furnish the basis for CAD of a turbine stage.

EFFECT OF BIMODAL AP PARTICLE SIZE DISTRIBUTION ON ALUMINUM COMBUSTION IN PROPELLANTS

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Abstract

A Series of researches on degree of aluminum agglomeration and combustion in propellants have been completed experimentally. The results show that AP particle size distribution is an important factor effective on aluminum combustion in propellants. It is found that the smaller AP particles are, the less the possibility of aluminum agglomeration is. This conclusion supports the "Pocket Model", submitted by N. S. Cohen and is consistent with the results calculated with empirical formulas. The effect of bimodal AP particle size distribution is elaborated in this paper. It is suggested that the most suitable content of fine AP particle in the composition of propellants be about 40%. The result is helpful to the composition design of new propellants.

TECHNICAL NOTES

PREDICTION OF THE FLAME FRONT IN AN AUGMENTOR WITH SWIRLING FLOW

Tan Haoyuan and Guo Ningqun

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Abstract

A computing program has been worked out for prediction of the flame front in a swirl augmentor. The positions of flame front and the coefficients of pressure loss have been calculated for a variety of swirl angles. The results of the analysis indicate that the ratio of

the length of flame front to the diameter of augmentor equals 1.2 ($L/D=1.2$) when the swirl angle of 45° is selected. The coefficient of pressure loss in the swirl augmentor is not larger than that of a conventional afterburner. There is no obvious effect of pressure on the position of flame front.

MEASUREMENT OF RESIDUAL TIME OF GAS IN RECIRCULATION ZONE BEHIND FLAMEHOLDERS

Jiang Leiyong and Zhang Xunan

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Abstract

An instrument has been developed which provides sensitive and reliable measurement of the residual time of gas in the recirculation zone behind flameholders with flame. The experiments with this instrument show that the mean residual time is inversely proportional to the upstream velocity.

FUEL CAPTURE ON THE SURFACE OF V-SHAPED FLAMEHOLDER

Liu Zhigang, Wang Jiahua, Li Gaiqi

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Abstract

A new method for measuring the fuel capture on the surface of flameholder by means of V-shaped capture gutters is proposed. The relationship between fuel capture rate and individual parameters has been analysed. An empirical formula has been established. In the calculation, the concept of considering the edge of fuel droplet groups as reference trajectory has been set up. The fuel capture rate on the surface of V-gutter flameholder has been calculated and the results are in good agreement with the experimental data.

ENHANCEMENT OF HEAT TRANSFER IN TURBINE BLADE COOLING

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Abstract

An experimental study on fully-developed turbulent air flow in rectangular passages with two opposite rib-grooved roughened walls has been performed to determine the effects of the rib-grooved pitch-to-height ratios on friction factor and heat transfer coefficients. A general method for predicting average friction factor and average Stanton number in rectangular ducts with two smooth and two opposite rib-grooved walls is developed. Experimental results show that the performance of the heat transfer in the passages with rib-grooved roughened walls is better than that in the passages with rib roughened walls at the same s/h. This work may be useful to internal cooling design of the gas turbine blade.