

高压下液体射流破碎雾化特性实验研究*

南京理工大学 张玉荣** 金志明 余永刚

【摘要】 为深入了解高压环境中液体射流破碎雾化过程, 相对准确描述射流形态, 进行了一些实验研究。利用一种高速液体喷射装置, 采用脉冲 X 射线成像技术, 研究了多种喷嘴在不同环境反压中所形成液体射流的扩展结构。虽然 X 光成像方法很难对雾化液滴进行分析, 但它可以显示射流内部结构、分析未破碎部分的形态。实验表明, 随着环境反压的升高, 圆柱形射流的破碎点向喷口移动; 环形射流离开喷口后发生聚合, 聚合点随反压升高而前移。

主题词: 液体射流 破碎 实验 雾化 X 射线
分类号: O358

1 引言

随着科技的发展, 射流在工程技术中得到了广泛的应用, 如喷气发动机、液体火箭发动机、内燃机、射流切割以及空调技术等。目前, 对于高速射流初始阶段破碎雾化过程仍没有一个可靠的理论模型。对于射流研究也大多针对不同工程应用背景, 提出各种方法进行实验研究。由于液体射流雾化过程影响到射流结构、形成液滴的尺寸和速度的分布等, 在建造合理的发动机结构过程中, 发动机燃油雾化的设计和计算是很重要的一步, 所以研究在喷口附近液体射流的破碎雾化机理有很重要的意义。目前对喷射过程实验研究技术主要是高速摄影和闪光成像, 得出许多有价值的结果^[1,2]。但是射流核心一般隐藏在密集的喷雾液滴里面, 由于射流雾化后的遮挡作用, 阴影照像对射流内部结构和射流核的存在分析非常困难。本文应用 X 射线对液体喷射过程进行高速成像, 处理后可得到关于射流内部结构、雾化机理和其密度断面的透视照片, 这样有助于对射流雾化过程进行定量研究, 进而得到相对准确的喷射雾化模型。

2 实验方法

2.1 测试系统

液体喷射雾化实验装置和测试系统如图 1 所示。文献[2]用光学阴影成像方法对射流进行了研究, 为了便于

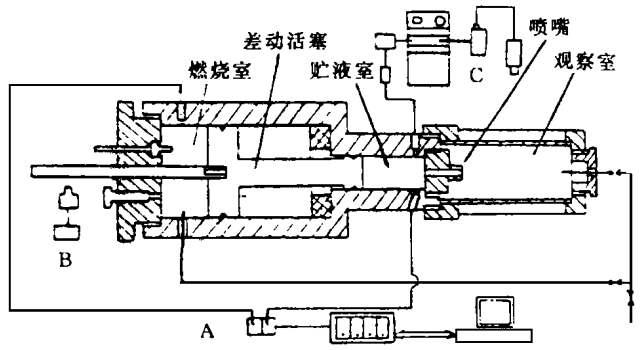


图1 测试系统

(A. 压力测试系统; B. 活塞运动测试系统; C. X 光成像系统)

对比本文所用喷射装置工作过程基本相同。贮液室中液体在活塞推动下经喷嘴形成高速射流, 喷入充满一定预压气体的观察室中。观察室直径 60 mm, 观察窗口长 120 mm, 宽 30 mm。本实验中, 喷嘴主要有圆柱形和环形两种形式。压力测试系统采用频响较高的压电压力传感器, 静态标定系统误差 $< 0.5\%$ 。X 光成像系统如图 2 所示, 采用 Hewlett - Packard 公司生产的 43733A 型闪光 X 射线系统。其曝光时间脉宽为 $30 \times 10^{-9} \text{ s}$ 。

2.2 测试技术

X 光成像是通过 X 射线透射物体后能量衰减而使软片感光成像, 存在提高 X 射线照片的对比度以及高压下 X 射线透射窗口的强度、密封问题。此外高压射流喷射速度很高, 存在 X 射线成像控制问题等等。这些问题都是本实验成败的关键。

为测定射流核头部贯穿速度, 需要获得同一喷射过程的多幅连续照片, 而每个 X 射线管只能得到一幅 X 光照片。本文采用在观察室上开两对相互垂直的窗口的方法, 分别用两个 X 射线管成像, 可以获得射流连续照片, 还能分析射流的立体结构。采用高压自紧方式较好解决了密封问题, 观察室预压可达 10 MPa。选择合适的窗几何参数, 采用有合适的透射率和机械强度的窗口材料减少以对 X 射线的吸收。综合考虑窗口材料的 X 射线透视性能、机械强度、加工性能以及经济性后, 选取铝合金作为窗口材料。

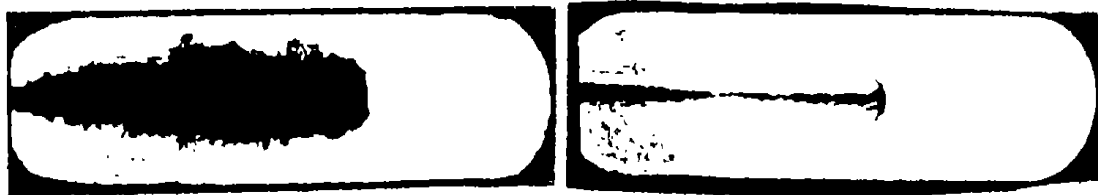
光学成像方法中所用液体工质主要有: 酒精、汽油、煤油、甲醇、硝基甲烷等。对于 X 光成像来说, 以上液体透射率较高。为提高 X 射线照片的对比度, 获得较清晰的射流照片, 采用向酒精中混加 7% 的高原子数元素的方法^[3]。混合后, 酒精的密度和粘性略有变化。

由于高压射流喷射速度很高(可达 200 m/s 以上), 射流在观察室窗口的充满时间很短(约 1 ms 以内), 所以实验中需要准确的 X 光成像触发和控制。用贮液室液体压力触发 X 光同步延时控制电路。时间控制电路直接应用 43733A X 射线系统提供的电路, 时间误差 $< 1.0 \mu\text{s}$ 。

3 实验结果与分析

3.1 圆柱形射流

利用以上实验系统, 本文研究了喷射压力 p_R , 观察室压力 p_C 和喷嘴结构对射流的影响。



(a) 阴影成像

(b) X 光成像

图 3 圆柱形射流成像

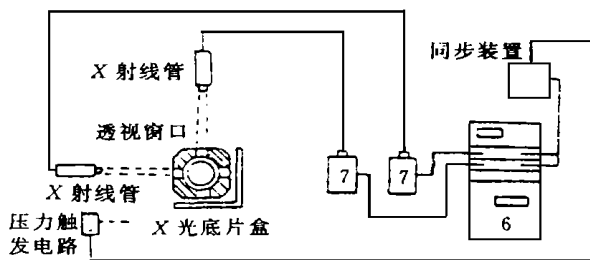


图 2 连续脉冲 X 光成像系统(6. 控制柜 7. 脉冲高压发生器)

图 3 给出了直径 2.5 mm 的喷嘴在同一条件下的光学阴影照片和 X 射线透视照片。可见, 在高压环境中, 射流雾化后的液滴细小浓密, 由于其遮挡作用, 光学阴影成像显示出了射流的外轮廓; 而射流不同部分对 X 射线的吸收强弱不同, 其透视照片揭示出了射流的内部结构。

图 4 是圆柱形直喷孔射流形成和生长瞬态过程的一组照片。在实验中, $p_R = 30 \text{ MPa}$, $p_C = 0.4 \text{ MPa}$, 喷嘴直径 4 mm。由图 4 可见, 在射流初始段, 射流中心保持连续完整, 存在未破碎的射流核, 这与阴影照片中的射流未扩张段相对映。此条件下射流核头部贯穿速度为 142 m/s 。



图 4 射流瞬态发展过程



图 5 反压 p_C 对圆柱形射流核形态的影响

观察室压力 p_C 对射流核形态的影响很大。如图 5 所示, 反压越高, 射流破碎雾化程度越高, 完整射流核长度越短。这和文献[2]的结果相一致。这里, 射流破碎雾化的主要原因是气液间复杂的气动力作用, 破碎的模式是多维的。

3.2 环形射流

在轮廓更为复杂的喷嘴, 如环形喷嘴的情况下, 图 6 证明了高速 X 射线透视照像的优越性。对于射流破碎雾化机理, 用这种方法可以更加合理地得以展示。

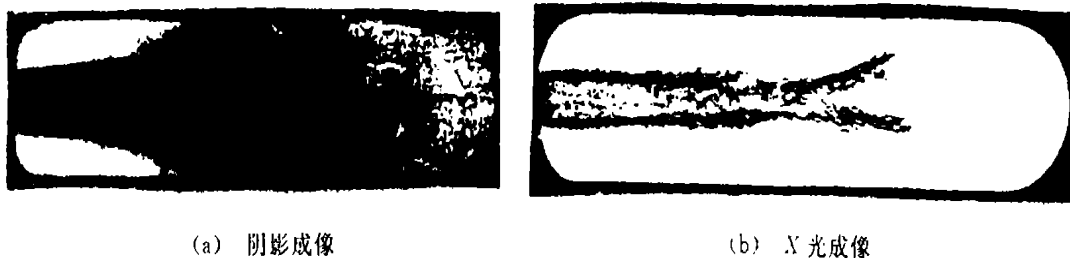


图 6 环形射流成像

图 7 是环形喷口射流形成和生长瞬态过程的一组照片。在实验中, $p_R = 30 \text{ MPa}$, $p_c = 1.0 \text{ MPa}$, 喷口内径 8 mm 。由图 7 可见, 环形射流头部在运动过程中, 由于反压的作用失去对称性, 发生破裂并雾化扩散。整个环形射流核仍保持了对称性, 并从射流出口处开始收缩, 聚合成圆柱形射流向前喷射, 这种现象是阴影成像很难分析的。

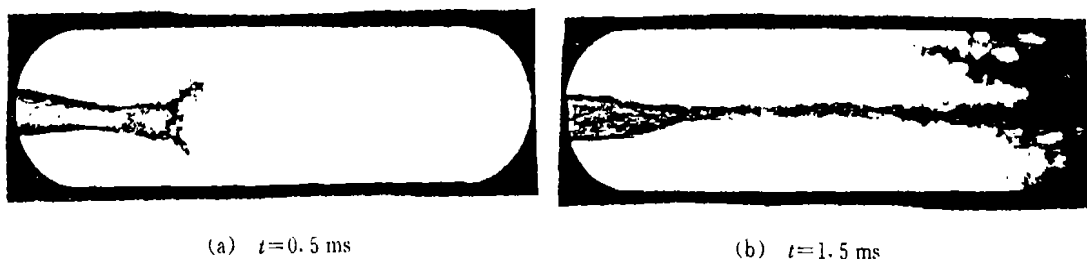


图 7 射流瞬态发展过程

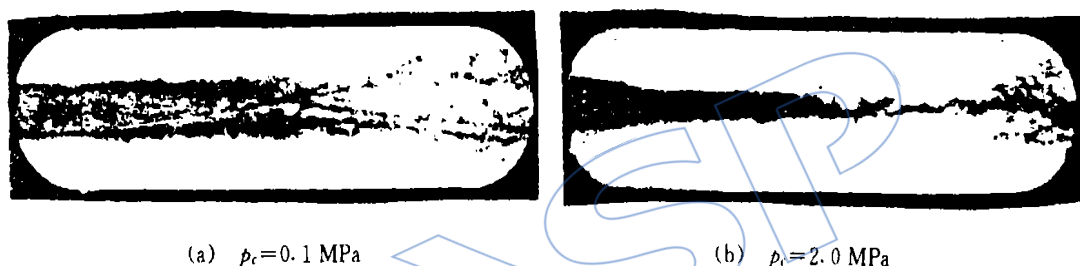


图 8 反压对环形射流核形态的影响

图 8 是观察室环境反压 p_c 对射流喷射过程中射流核形态的影响。常压下, 环形射流在距喷口 65 mm 处聚合成柱形射流, 但射流核内部有气穴存在。加反压后, 射流在距喷口 17 mm 处聚合。可见, 在此条件下, 反压增强了环形射流的稳定性, 反压越高, 射流聚合越早, 不利于射流的破碎雾化。在高压下需改变环形喷嘴和观察室的结构, 以改善环形射流的雾化性能。

4 小 结

已有的液体燃料喷射雾化模型, 多数假设射流瞬时全部雾化, 基本回避了射流雾化的复杂过程。本文研究说明, 在射流初始段存在未破碎雾化部分。在同一条件下, 环境反压越高, 圆柱形射流湍流破碎加剧, 环形射流收缩越快, 环境结构对射流形态影响较大。出于安全考虑, 本文实验中射流雾化后未点燃; 为了模拟高压环境, 受实验装置结构尺寸的限制, 本文没能对持续定常射流进行研究, 以上工作有待进一步完成。

参 考 文 献

- 1 史绍熙, 郝大光, 刘宁等. 高速液体射流初始段的破碎. 内燃机学报, 1996, 14(4): 139
- 2 金志明, 栗保明, 余永刚. 高速液体受限射流扩展形态研究. 爆炸与冲击, 1998, 18(3): 193
- 3 Krehl P, Warken D. Flash Soft Radiography- Its Adaption to the Study of Breakup Mechanisms of Liquid Jets into a High-Density Gas. SPIE Vol1358, 19th International Congress on High-Speed Photography and Photonics, Cambridge, UK, 1990: 162

(责任编辑 杨再荣)

AN EXPERIMENTAL INVESTIGATION OF PIT- ARRAY- PLATE COMPRESSOR CASCADE

Zhang Shunong, Yan Ming, Ren LiYun, Peng Zeyan

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

ABSTRACT

An experimental investigation of end wall flow control for pit- array cascade plate in a compressor cascade wind tunnel has been completed. The experimental comparison of pit- array- plate with original cascade plate shows that: (1) The movement of flow along pitchwise could be obstructed. It delays the formulation or reduces the intensity of passage- vortex; (2) The flow mixing around the end wall region of the cascade could be moderately increased. The accumulation of lower- level- energy air in the corner may be reduced. (3) The flux across cascade increases obviously at a higher incidence. It is beneficial to improve compressor characteristic map and engine performance.

Key Words Compressors Cascades Experiments

2- D MODEL FOR INFLUENCE OF TRAILING EDGE EJECTION ON AERODYNAMIC PERFORMANCE OF A TURBINE CASCADE

Gao Limin and Wang Shangjin

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

Liu Bo

(Xi'an Jiaotong University, Xi'an 710049)

ABSTRACT

In accordance to analysis of interaction mechanism between the ejection and the main flow, a 2- D compressible model of the turbine blade trailing edge ejection has been improved, which uses energy loss coefficient for representing the effect of the ejection on the aerodynamics of the main flow. The aerodynamical loss after the ejection has been analyzed through correlation of the model with the numerical calculation of the cascade main flow field and boundary layer parameters. The comparison between calculation results and experimental data shows that the improved model can exactly describe the mixing process between the main flow and the ejection, and predict the energy loss coefficient for the ejection on the pressure side near the trailing edge and through the trailing edge holes.

Key Words Cascades wakes Aerodynamic characteristics Energy loss

A STUDY ON BREAKUP AND ATOMIZATION OF HIGH PRESSURE LIQUID JETS

Zhang Yurong, Jin Zhiming, Yu Yonggang

(8th Dept. Nanjing University of Science & Technology, Nanjing 210094)

ABSTRACT

In order to find an exact description of jet formation process for the high pressure liquid injection, it is difficult to photograph the mechanism of the liquid jet breakup in the vicinity of the nozzle, because the jet core is hidden behind a curtain of spray cloud. The system built by authors uses flash X- rays to study the liquid jet breakup pro-

cesses. Radiography can hardly resolve the spray cloud, but it is capable of recording the full jet structure and allows to determine the intact core. As examples some liquid jet radiographs have been taken at different fluid pressures and nozzles. The point of cylindrical jet disintegration and the point of annular jet coalescence shift to the nozzle orifice with increasing pressure.

Key Words liquid jet Breaking Atomization X-ray Experiments

A METHOD FOR CONSTRUCTING TWO- DIMENSIONAL DELAUNAY TRIANGULATION OF COMBUSTOR FLUID

Yin He, Chang Lina, Yan Chuanjun

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

ABSTRACT A method is presented here for constructing two- dimensional De-launay triangulation with a new automatic point creation technique. This technique is based on the idea of advancing- front method to achieve good geometry flexibility. The main steps are as follows: The initial triangulation is generated first, according to the given border set. In the initial triangulation usually there are lots of triangles with very small minimum angles which will seriously decrease computational accuracy. The new nodes are introduced with advancing- front method, and added into the existing mesh according to Bowyer- Watson algorithm simultaneously. The procedure is repeated until no more improvement of the grid can be achieved by inserting the new nodes. Its application to triangulating combustor fluid shows that the resulted grids have great regularity and boundary quality.

Key Words Combustion chambers Flow fields Calculations Grids

A STUDY OF COMPUTER AIDED TESTING TECHNIQUE FOR AEROENGINE

Chen Guiying, Li Bin, Lei Yong, Wu Zhizhen

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

ABSTRACT A system engineering method for development of the Computer Aided Testing (CAT) technique was discussed in the light of a comprehensive review of CAT technique, and investigation of CAT Systems. The application of digital filtering to the Aeroengine Test was also introduced. The focus was put on the achievements of multi- signal acquisition, processing and displaying according to Virtual Instrument conception. The necessity and trend of a man- machine harmonious information environment development with supporting of database system in the aeroengine Test field were considered.

Key Words Computer aided experiment Aeroengine Digital filtering methods

A STUDY OF OBJECT- ORIENTED APPROACH FOR AEROENGINE PERFORMANCE SIMULATION

Tang Hailong and Zhang Jin

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

ABSTRACT This paper discusses how to create an extensible, flexible, reliable