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高能激光中的气动光学现象研究

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摘要 主要介绍气动光学(Aero-optics)的研究方法, 研究内容以及强激光在可控气流介质及大气中传输时, 强激光与气体相互作用引起气流折射率、相位畸变、热晕等现象和规律的研究工作。

关键词 气动光学, 强激光, 光束传输

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Aero-optics in High Power Laser

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Abstract When optical beam passes through a turbulent, a medium of varying index of refraction, its optical wavefront emerges aberrated. The interaction of light with the fluid is termed aero-optics. This paper gives a brief reviewing of the aero-optics reach methods and the applications in the high power laser.

Key words aero-optics, high power laser, laser transit

1 引言

当一束光通过密度变化的流体介质时, 由于折射率随介质密度的变化而变化, 使得传播光束的波前产生畸变, 而影响成像质量。光与流体介质的相互作用规律的研究一般可以分为光与液体和光与气体介质的相互作用。光在气体中的传播规律研究可分为大气光学和气动光学。大气光学主要研究光与大气的相互作用、以及光在大气中的传输规律, 通过自适应光学对大气湍流的补偿, 改善光通过大气的成像质量。而在有些气流条件下, 如机载激光、光学寻敌导弹等高速飞行中的成像系统和光束发射系统的窗口的附面层、湍流等产生的波前畸变, 很难通过自适应光学进行补偿。气动光学就是研究光与气流附面层、剪切层、湍流层等气流的相互作用和传播规律^[1], 以及高功率密度的激光在可控气流中或特定管道中的传输的基本现象、基本规律^[2]; 同时利用光束在气流中传播时, 波前变化与气体密度变化之间的规律, 实现对气体流场的非接触测量, 如气流的光学层析法等^[3]。

2 气动光学的研究方法和内容

为了在实验室中能模拟机载激光等系统在高速飞行时表面的附面层、剪切层、湍流层等流动气体的光学特性, 可以通过不同的流体混合或不同温度或不同速度的流体的混合产生剪切层和湍流层^[4,5]。图 1 给出了一种利用不同速度的流体混合过程产生湍流层方法^[5]。在两束不同速度的流体交界面产生湍流层, 如图 2 所示。应用建立在 Hartmann 波前传感器技术基础上的 SABT (small-aperture beam technique) 技术, 可以测量湍流层产生的波前畸变随时间的变化情况, 如图 3 所示。一定的流场对应一

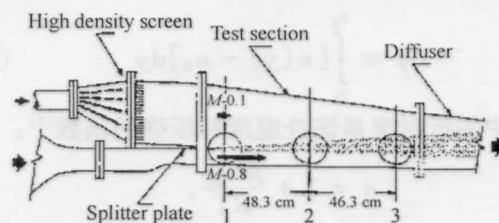


图 1 利用两束不同速度的气流产生湍流层的设备示意图^[5]

Fig. 1 Schematic of ART facility, from Ref. [5]

定的波前畸变,因此可对一定条件下如机载激光系统的波前畸变进行预补偿。

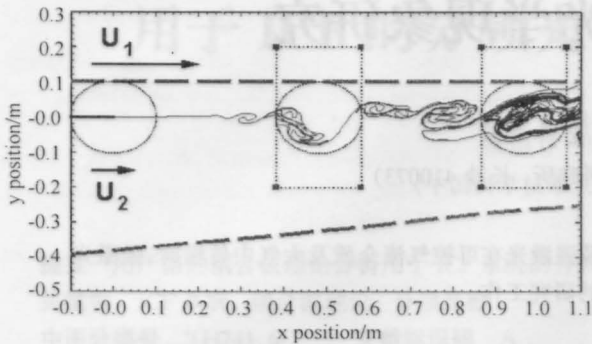


图2 不同流速的气流产生的流场

Fig.2 The turbulence vortices field produced by mixing fluids with difference velocity

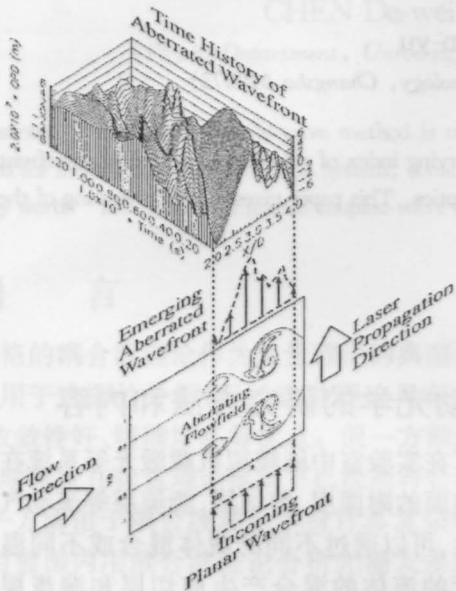


图3 采用SABT方法测得的湍流场中的OPD的时空分布^[6]

Fig.3 Time series of experimentally measured OPD's for proagation through a 2-D heated Jet using SABT; wavefronts oriented in the streamwise (Ref. [6])

如图4所示,波前的变化与折射率 n 的变化为:

$$\Delta\varphi = \int_{x_1}^{x_2} [n(y) - n_0] dy \quad (1)$$

而流场中的折射率是该处温度和压强的函数^[5]:

$$n = 1 + \frac{\rho K_{GD}}{RT},$$

K_{GD} 为 Gladstone-Dale 常数。通过波前重构得到折射率的空间分布,从而获得流场的温度、压强等量的空间分布,实现流场空间成像^[3]。图5显示了采用多路高速光学层析系统^[3]、它由8套 Hartmann 波前

传感器组成,能以 5 kHz 频率测量二维流场,用它显示流场分布情况。图6为不同频率声场作用下圆形热射流内部的特性,并依其相关特性重构测量横断面的温度场,精度可达到 2 mm/0.7 °C。

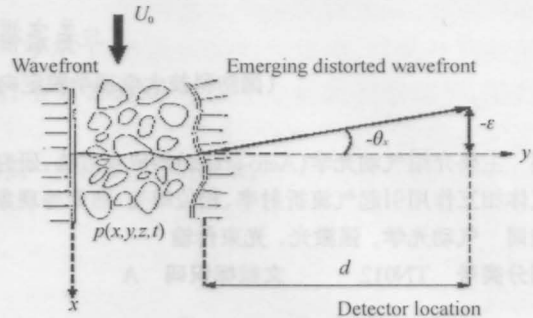


图4 当一束平面波或探测光束通过一折射率变化的流场时光束发生偏转

Fig.4 Planar wavefront and prob beam distorted by variated fluid density field

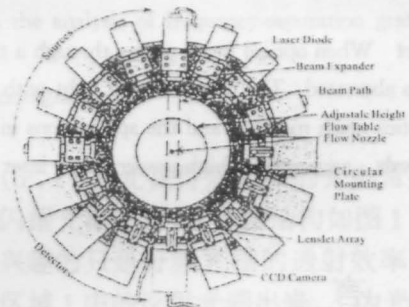


图5 采用8套 Hartmann 波前传感器实现流场的光学层析测量示意图^[3]

Fig.5 Schematic of the optical tomography apparatus made up of 8 diode laser illuminated Hartmann sensors (Ref. [3])

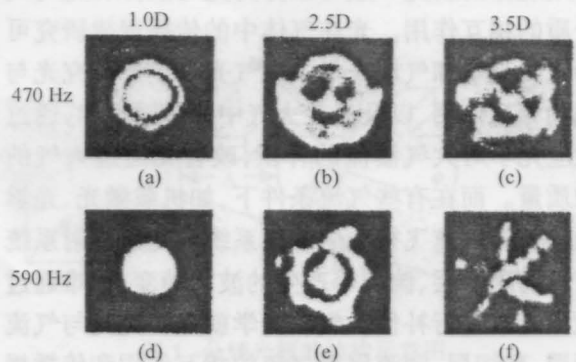


图6 不同横切面的光学层析结果

Fig.6 Tomographic image sequences depicting the evolution of internal phase features of the heated round jet with downstream locations at two different forcing frequencies

在激光武器系统中,强激光束通过中继光路传输到光束定向器。中继光路中激光功率密度相当

高,中继光路中的空气对激光能量的吸收,引起折射率的不均匀分布,产生热晕。中继光路中的光学元件对激光的吸收产生畸变,而影响光束质量。一般在中继光路中采取一定方式的吹风,减少折射率不均匀分布的程度,同时对光路中元器件起到冷却作用。对机载激光武器,中继光路的吹风系统增加了额外的负担,机载激光武器中的中继光路可以采用充有一定气体的管道。气动光学研究吹风方式、吹什么样的气体,降低管道中气流密度不均匀程度,以及在管道中所充气体对激光吸收程度等。在强激光领域,基于 Hartmann 波前传感器的光学层析法对管道流场气动光学特性的这一方法,可研究强激光穿过吹气的传输管道时,气体对激光的吸收会造成气体内部温度分布不均匀,和瞬变的不均匀管道流场。

总之气动光学的研究内容在机载激光系统、强激光等领域研究有重要的应用价值,对发展流场非

接触测量法有重要意义。

参 考 文 献

- 1 K. G. Gilbert, L. J. Otten. *Aero-Optical Phenomena-Progress in Astronautics and Aeronautics*, New York, 1982. 80
- 2 P. I. Shen, M. Anderpont. Thermal blooming of HEL in the non-flowing beam tube with various wall temperature. *Proc. SPIE*, 2000, **4034**:100
- 3 L. McMackin, R. J. Hugo *et. al.*. High speed tomography system for imaging dynamic transparent media. *Opt. Express*, 1997, **1**:302
- 4 S. Doerr, C. J. Wissler *et. al.*. Aero-optics reseach at the Phillips Laboratory. *Proc. SPIE*, 1993, **2005**:129
- 5 R. J. Hugo, E. J. Jumper. Time-resolved wave front measurements through a compressible free shear layer. *AIAA Journal*, 1997, **35**:671
- 6 E. J. Jumper. Recent advances in the measurement and analysis of dynamic aero-optic interaction. AIAA-97-2350

Abstract When laser beam passes through the medium, the refractive index of the medium is not uniform due to the absorption of the laser energy, which causes the thermal blooming. The optical elements in the relay optical path will be distorted by the absorption of the laser energy, which affects the beam quality. In the relay optical path, a certain blowing method is adopted to reduce the degree of the refractive index non-uniform distribution, and at the same time, the optical elements in the path are cooled. For the airborne laser weapon, the blowing system of the relay optical path increases the additional burden. The relay optical path of the airborne laser weapon can adopt a pipe filled with a certain gas. Aerodynamic optical researches the blowing method, the blowing gas, the reduction of the non-uniformity of the gas density in the pipe, and the absorption degree of the laser energy by the gas in the pipe, etc. In the field of high power laser, the optical tomography method based on Hartmann wavefront sensor is used to study the aerodynamic optical characteristics of the pipe flow field when the high power laser beam passes through the blowing transmission pipe. The absorption of the laser energy by the gas will cause the non-uniform temperature distribution inside the gas, and the transient non-uniform pipe flow field.

总之气动光学的研究内容在机载激光系统、强激光等领域研究有重要的应用价值,对发展流场非

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参 考 文 献

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- 2 P. I. Shen, M. Anderpont. Thermal blooming of HEL in the non-flowing beam tube with various wall temperature. *Proc. SPIE*, 2000, **4034**:100
- 3 L. McMackin, R. J. Hugo *et. al.*. High speed tomography system for imaging dynamic transparent media. *Opt. Express*, 1997, **1**:302
- 4 S. Doerr, C. J. Wissler *et. al.*. Aero-optics reseach at the Phillips Laboratory. *Proc. SPIE*, 1993, **2005**:129
- 5 R. J. Hugo, E. J. Jumper. Time-resolved wave front measurements through a compressible free shear layer. *AIAA Journal*, 1997, **35**:671
- 6 E. J. Jumper. Recent advances in the measurement and analysis of dynamic aero-optic interaction. AIAA-97-2350