Optics and Lasers in Engineering 55 (2014) 94–98

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

Double-pass propagation of laser pulses reflected by a diffuse whiteboard or a corner-cube retroreflector in turbulent atmosphere

Tao Wang, Wei Wang, Pengfei Du, Dongxian Geng, Gan Gao, Mali Gong*

State Key Laboratory of Tribology, Center for Photonics and Electronics, Department of Precision Instruments, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 22 July 2013
Received in revised form
24 October 2013
Accepted 24 October 2013
Available online 15 November 2013

Keywords:
Atmospheric turbulence
Peak power instability
Laser pulse
Corner-cube retroreflector
Diffuse reflection

ABSTRACT

Atmospheric turbulence affects the transmission of laser pulses through the atmosphere. The effects mean that the peak power of the laser pulses is not stable. For laser pulses reflected by a cooperative target, the peak power instability is greater because of the double-pass propagation of the laser pulses through the same atmosphere. The atmospheric turbulence can be monitored by detecting the peak power instability of echo laser pulses. This paper presents a method for monitoring atmospheric turbulence based on a cooperative target. Comparative experiments are carried out based on using a diffuse whiteboard and a corner-cube retroreflector (CCR) as the cooperative target. The distance between the two terminals of the experimental system is 1550 m. The size of the diffuse whiteboard is $60 \times 60\ \text{cm}^2$. The bottom surface of the CCR is a circle with a diameter of 1 in. and the three mirrors of the CCR are coated with silver. Experiment results show that the peak power instability of echo laser pulses retroreflected by the CCR is 28.3%. This is much larger than that diffuse reflected by the whiteboard (11.2%). This indicates that the method based on the CCR has higher atmospheric sensitivity. In addition, the peak power of the echo laser pulses retroreflected by the CCR is also much larger. Therefore, the system based on the CCR is more suitable for monitoring of atmospheric turbulence.

1. Introduction

Atmospheric turbulence is caused by small temperature variations that manifest themselves as index of refraction fluctuations [1]. When the flow of the atmosphere exceeds a critical Reynolds number, the flow changes from laminar to a more chaotic state called turbulence [2]. Turbulent atmospheric motion represents a set of vortices, or eddies, of various scale sizes, extending from a large size called the outer scale of turbulence, to a small size called the inner scale of turbulence [3]. Atmospheric turbulence affects significantly the transmission of electromagnetic radiation through the atmosphere, particularly laser beams [4]. This deleterious effect has far-reaching consequences on the application of lasers in optical communications, imaging, remote sensing, laser radar, and other applications that require the atmospheric transmission of laser beams [5–7]. Therefore, it is necessary to monitor atmospheric turbulence.

Optical systems, such as a stellar scintillometer and lidar are commonly used in atmospheric turbulence measurement [8]. The stellar scintillometer focuses light from a single star into an instrument package, which is attached to a telescope. The package measure scintillations in the intensity across arriving stellar wave fronts. This measurement is done through a filter at selected spatial wavelengths, and from the resulting scintillation spatial wavelength spectrum, the refractive index structure parameter C_n^2 profile is obtained [9,10]. Recently, based on the Doppler Effect, lidar systems have been used for measuring atmospheric turbulence. The principle of Doppler lidar operation, such as pulsed Doppler lidar, is based on the emission of laser pulses into the atmosphere and the detection of the motions of aerosol density inhomogeneities. C_n^2 values and related parameters can be obtained by lidar [11].

One disadvantage of the stellar scintillometer and many other optical methods is that observations can be made only at night and under clear sky conditions. In addition, the resolution in the final profiles is low. Lidar has the benefits of operating in all weathers, providing long-term continuous data, providing high temporal and spatial resolution measurements, and providing data over altitude ranges of interest [8]. However, most of these systems are bully and complex.

The aim of this paper is simply to realize the function of monitoring atmospheric turbulence other than measuring. Therefore, this paper presents a double-pass system that is smaller and simpler than traditional measurement systems. The research has relevance and offers meaningful value to applications of on-line monitoring and remote sensing for environmental, climate, and agricultural research [12].

Absorption by the atmosphere occurs when a laser photon is absorbed by a gaseous molecule; it is wavelength dependent. Scattering occurs when the laser beam propagates through certain air particles and molecules. As with absorption, scattering is a function of wavelength. There are two principal types of scattering for a

* Corresponding author. Tel.: +86 10 62781515.
E-mail address: gongml@mail.tsinghua.edu.cn (M. Gong).

0143-8166/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.optlaseng.2013.10.022

1.06 μm laser: Rayleigh scattering and Mie scattering. Rayleigh scattering is caused by air molecules and haze, which are small in comparison with the laser wavelength (λ). Rayleigh scattering is also called molecular scattering and the coefficient of scattering is proportional to λ^{-4}. Mie scattering is also called as aerosol scattering. It is caused by particles of comparable size or greater than the laser wavelength. Mie scattering losses decrease rapidly with increasing wavelength and eventually approach the Rayleigh scattering case. Effects of absorption and scattering are fairly well known. They cause a loss of the peak power of the laser pulse transmitted in the atmosphere, rather than peak power instability. Many software packages, such as LOWTRAN, MODTRAN and HITRAN, are used commonly to predict attenuation effects for different wavelengths, based on a variety of conditions, for example, meteorological range, latitude, and altitude [12].

The degree of instability reflects directly the intensity of turbulence [13]. Therefore, atmospheric turbulence monitoring can be realized by detecting the peak power instability of laser pulses propagating through the atmosphere. In this paper, an atmospheric turbulence monitoring system based on a cooperating target is presented. The target is associated with the double-pass propagation of laser pulses through the same atmosphere. In this paper, this system is called the double-pass system for convenience. Compared with the single-pass system, the peak power instability is larger because the atmospheric turbulence affects the laser pulses twice. Therefore, the double-pass system has greater sensitivity.

The double-pass system consists of two dissimilar optical terminals. One is a transceiver and the other is a cooperative target. The transceiver comprises a laser and a receiver. The laser illuminates the cooperator with a detecting laser beam. The receiver detects echo laser pulses reflected by the cooperative terminal, from which the peak power instability is obtained. There are two types of cooperator considered. One is a corner-cube retroreflector (CCR) and the other is a diffuse target. The CCR consists of three planar mirrors placed at an angle of 90° with respect to each other [14,15]. Because CCRs have geometrical optical properties of the beam reflecting upon themselves [16], the monitoring system can be built up as long as the transceiver targets the CCR. The reflection law of the diffuse target meets Lambert's cosine law.

Because laser pulses should pass through the double-pass system twice before they enter into the receiver, the laser is required to transmit a higher powered detecting beam. Therefore, a high peak power pulse laser can be used to generate detecting laser pulses with high peak power; thus, extending the monitoring length of the system [17,18].

The transceiver obtains the peak power instability by processing the received echo laser pulses reflected by the cooperative target. Because the reflection laws of the diffuse target and the CCR are different, the degrees of peak power instabilities caused by atmospheric turbulence are different too. To determine the cooperator with better performance, it is necessary to undertake comparative experiments on the peak power instability of echo laser pulses reflected by the two kinds of cooperative target.

In this paper, the peak power instabilities of laser pulses retroreflected by a CCR and diffuse reflected by a whiteboard across a distance of 1550 m are investigated. The measuring device and method of detecting the peak power instabilities are presented in Section 2. Experimental results are discussed in Section 3, and Section 4 offers the conclusions.

2. Measuring device and method

Schematic diagrams of the experiments are shown in Fig. 1. There are two terminals: one is a transceiver and the other a cooperative target. The distance between the transceiver and the cooperative target is 1550 m. To compare the peak power instability of return laser pulses retroreflected by the CCR and diffuse reflected by the whiteboard, only one of them is used in each measurement. The material of the CCR is BK7 glass. The bottom surface of the CCR is a circle with a diameter of 1 in. The three reflective mirrors of the CCR are coated with silver. The deviation between the return beam and the detection beam caused by the CCR is less than 5 s. The size of the diffuse whiteboard is $60 \times 60\ \text{cm}^2$.

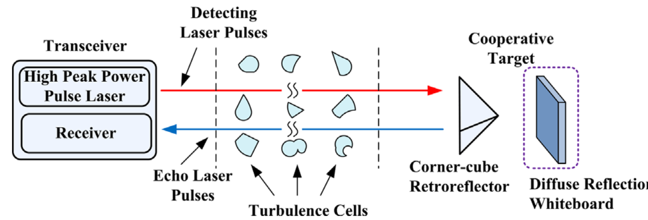

Fig. 1. Schematic diagram of experiments. The transceiver terminal comprises a high peak power pulse laser and a receiver. The cooperator is a CCR or a diffuse reflection whiteboard. The laser in the transceiver terminal transmits laser pulses to the cooperative target. After reflection by the cooperator, the echo laser pulses enter the receiver in the transceiver. The peak power instability is detected by the receiver.

The wavelength of the laser pulses transmitted from the high peak power pulse laser is 1.06 μm. The peak power of laser pulses measured in front of the laser is 5 MW. Safety issues should be considered during the experimentation because of the high peak power laser pulses. It is necessary to ensure that the laser beam is clear of human contact, reflective objects, and other objects that may be irradiated along its path. This is for purposes of safety and integrity of beam propagation. The experiments were carried out in a deserted location in the suburbs of Beijing. The receiver comprises attenuators, a receiving lens, an avalanche photodiode (APD) photodetector, and an amplifier circuit module. Attenuators are designed to prevent the APD photodetector from being saturated and to ensure that both the APD photodetector and the amplifier circuit module work in line during the experiment. During the tests, the attenuation ratio of the attenuator used is 90% for the whiteboard diffuse reflection and for the CCR retroreflection, an attenuator with an attenuation ratio of 99.9% is added. Correspondingly, the transmittance for the whiteboard is 10%, and for the CCR it is 0.1%. Attenuators are placed in front of the receiving lens. Echo laser pulses transmitted through the attenuators are converged into the APD photodetector by the receiving lens. The laser pulses are converted into electrical pulses by the APD photodetector. The amplifier circuit module is applied to amplify these electrical pulses. Then, the amplified electrical pulses are shown and recorded by an oscilloscope. The oscilloscope used in the experiment is a Tektronix MSO 5054.

Shaking of the beam steering may cause instability of the peak power of the laser pulses detected by the receiver, and this effect is considered in the experiment. A platform with the function of precision adjustment and reliable locking is used for laser beam steering. The beam pointing instability of the fixed laser is less than 5% of the beam divergence angle. Considering that the distribution of the beam fits a Gaussian distribution, the relative power variation caused by beam steering is less than $2e-4$. Hence, the effect of beam steering on peak power instability can be neglected.

The telescope aiming system used has a magnification of $10\times$. The optical axes of the telescope, the laser, and the receiver were adjusted along the same direction before experiments. The axes calibration angle error is less than 50 μrad. After adjustment, the telescope, the laser head, and the receiver were all fixed on the platform. The experimental procedure is as follows: First, the cooperation terminal is captured by the telescope. Second, the