Characterization of the Atmospheric Refractive Index

by Thin Laser Beam Wandering

A. Consortini*, C. Innocenti**, S. Ceccarelli*

**Dipartimento di Fisica, Università degli Studi di Firenze;*
***Dipartimento di Chimica, Università degli Studi di Firenze*

mail: *anna.consortini@unifi.it*

Wandering of thin laser beams is a useful tool for investigating atmospheric turbulence and refractive index gradient. It can be used, not only in homogeneous and stationary conditions, as shown in previous years, but also in transient conditions and anisotropy. Experimental results are presented in these two last cases.

1 Introduction

Wandering of thin beams is a sensitive tool for investigating the atmospheric turbulence and its parameters, locally, because the wandering variance increases as the third power of the beam path.

By thin beam we mean a beam whose lateral dimension is not larger than the smallest dimension, the inner scale, of the atmospheric inhomogeneities. Locally means short distances in the atmosphere: in practical situations, in summer over horizontal paths, few meters up to some ten or so meters.

In the past, we applied thin beam wandering to test the propagation theory in stationary conditions, to obtain information on the turbulence strength and to measure its parameters, inner scale and outer scale. See e.g. Ref 1-8 and 10, 11.

Subsequently, we developed a method to measure the gradient of the refractive index, transverse to the beam and averaged over the path, which also allows one to measure the evolution and anisotropy of the gradient. Ref 9, 12 and 13.

Here, after a short description of the phenomenon, some examples of experimental results are presented. First, results obtained in our laboratory under sudden transient conditions are shown. Then results of horizontal propagation in the open air, showing anisotropy are presented.

2 Wandering

When a thin beam impinges on a screen, after a short path in the atmosphere, it produces a small spot, whose position randomly and rapidly fluctuates around a mean position. On its turn the average position can slowly vary in time. The variance of the position fluctuations, evaluated over a given time, is a measure of the turbulence intensity during that time. The variation of the average position is related to the gradient of the refractive index along the path. Very often both are present.

For a beam propagating in the atmosphere, it is useful to consider the two components y and z of the fluctuations in the horizontal and vertical plane, respectively.

3 Laboratory experiments and outside measurements of wandering variances

As an example Fig 1 shows the onset of turbulence. Horizontal and vertical fluctuation variances are reported versus time for a 300 s measurement. Here each point is obtained by averaging the data taken in 10 s, at a rate of 300 data/s and the error bars are evaluated by dividing each interval of 10 s in 10 sub-intervals of 1 s each. They clearly show the time transition from no-turbulence to turbulence regime, when the heater system producing turbulence is turned on after the first 90 s of measurements with the heaters off.

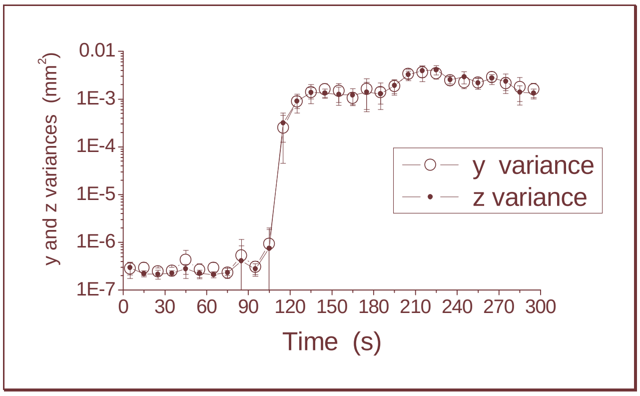

Fig. 1 *Onset of turbulence in the laboratory.*

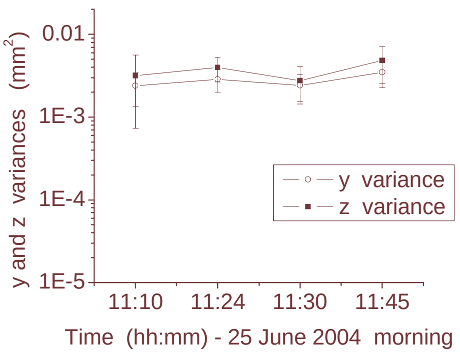

Fig. 2 *Example of anisotropy in the open air*

Figure 2 represents an example of anisotropy measured on a summer day after 5 m horizontal path in the open air over a paved ground. The horizontal axis denotes the measurement time, not a linear time scale.

4 Evolution of the refractive index gradient in the open air

In Fig3 an example is reported of the time evolution of the vertical components of refractive index gradients, average over the path, of two parallel beams, spaced by 11.5 cm, in the open air at a height of about 1.5m over grass, in a summer day.

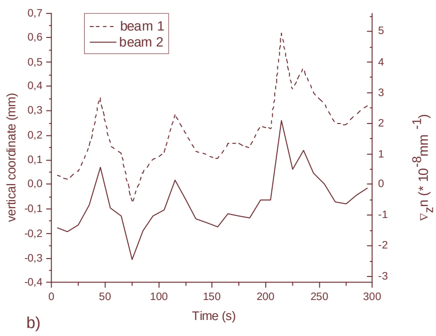

Fig. 3 *Example of time evolution of the vertical components of refractive index gradient. Gradient scale on the right*

5 Conclusions

We have shown some examples of measurements of thin beam wandering. From beam wandering measurements and by using suitable theoretical models one can also obtain information on the atmosphere. For instance from the data of Fig2 and by using a simple model of turbulence anisotropy it is possible to shown that the horizontal component of the turbulent inhomogeneities is larger than the vertical one, which indicates that the turbulence is horizontaly stratified.

6 References of papers on thin beams

[1] Anna Consortini. and Kevin A. O'Donnell, "Beam wandering of thin parallel beams through atmospheric turbulence". *Waves in Random Media* **3**, S11-S28 (1991).

[2] A. Consortini, G. Fusco, F. Rigal, A. Agabi and Y.Y. Sun, "Experimental verification of thin-beam wandering dependence on distance in strong indoor turbulence", *Waves in Random Media* **7**, 521-529 (1997).

[3] A. Consortini, C. Innocenti, G. Fusco and Y.Y. Sun, "Double Passage Enhancement of Thin Beam Wandering Through Atmospheric Turbulence", *J. of Modern Optics* **48**, 1569-1581 (2001).

[4] Anna Consortini, Sun Yi Yi, Li Zhi Ping and Giuliano Conforti, "A mixed method for measuring the inner scale of atmospheric turbulence", *J. of Modern Optics,* **37**, n°10, 1555-1560 (1990).

[5] Anna Consortini and Kevin A. O'Donnell, "Measuring the inner scale of atmospheric turbulence by correlation of lateral displacements of thin parallel laser beams" *Waves in Random Media* **3**, n°2, 85-92 (1993).

[6] A. Consortini, C. Innocenti and G. Paoli, "Estimate Method for Outer Scale of Atmospheric Turbulence" *Optics Communications* **214**, 9-14 (2002).

[7] A. Consortini, Y.Y. Sun, C. Innocenti and Z. P. Li, "Measuring inner scale of atmospheric turbulence by angle of arrival and scintillation", *Optics Communications* **216**, 19-23 (2003).

[8] C. Innocenti and A. Consortini, "Estimate of characteristic scales of atmospheric turbulence by thin beams: comparison between the von Karman and Hill-Andrews models", *J. of Modern Optics* **51**, 333-342 (2004).

[9] C. Innocenti and A. Consortini, "Refractive index gradient of the atmosphere at near ground levels" *J. of Modern Optics* **52**, 671-689 (2005).

[10] Y.Y .Sun, A. Consortini and Z.P. Li, "A new method for measuring the outer scale of atmospheric turbulence" *Waves in random and Complex Media* **17**, n.1, 1-8 (2007).

[11] C. Innocenti and A. Consortini, "Estimate of characteristic scales of atmospheric turbulence by thin beams: comparison between the von Karman and Hill-Andrews models", *J. of Modern Optics* **51**, 333-342 (2004).

[12] C. Innocenti and A. Consortini, "Refractive index gradient of the atmosphere at near ground levels", *J. of Modern. Optics* **52**, pp.671-689, 2005.

[13] A. Consortini, C. Innocenti and S. Ceccarelli, "Measuring the refractive index gradient of the atmosphere", in "*Optics in atmospheric Propagation and Adaptive Systems VIII*", K. Stein and A. Kohnle Eds. .SPIE Proceedings vol 5981, 96-104 (2005).