Time-shift technique for characterization of transparent particles in sprays

W. Schäfer¹*, C. Tropea¹,²

¹: Institute of Fluid Mechanics and Aerodynamics, Technische Universität Darmstadt, Germany
²: Center of Smart Interface, Technische Universität Darmstadt, Germany

* Correspondent author: w.schaefer@sla.tu-darmstadt.de

Keywords: optical particle characterization, time-shift technique

The measurement technique presented in this study is based on the time-shift technique first introduced by Semidetnov (1985)[1] and further developed in Damaschke et al. (2002)[2] and Albrecht et al. (2003)[3]. The time-shift technique has also been called the pulse displacement technique and several variations have been discussed by Hess and Wood (1993)[4] and Lin et al. (2000)[5].

The measurement principle illustrated in Fig. 1 is based on the light scattering from a shaped light beam whose size is smaller than the size of the particle. Depending on the scattering angle \( \theta_s \) and the relative refractive index \( m \) different scattering orders are detected, with their incident points \( \theta_i^{(p=0)} \) and glare points, whose position can be calculated by ray tracing methods. When a particle with velocity \( v \) and size \( d \) passes through a shaped beam, typically Gaussian in intensity, it transforms the intensity of light beam in space \( I(z) \) into a time signal \( S(t) \), being the sum of all scattering orders (reflection (p=0) and second-order refraction (p=2) for backscatter) and their respective modes \( (p=1, p=2) \) for backscatter) and their respective modes \( (p=1, p=2, p=2.1) \). The time dependent signal can then be expressed by the transformation

\[
I(z) = I_0 \exp \left\{ \frac{z^2}{b_z^2} \right\} \quad \text{and} \quad S(t) = \sum_{p=0, p=1, \ldots} A_p \exp \left\{ -\frac{(v(z - g_p(m, \theta_s)))^2}{b_v^2} \right\}
\]

\[
= \sum_{p=0, p=2, p=2.1} A_p \exp \left\{ -\frac{(t - t_p)^2}{\sigma^2} \right\}
\]

This signal contains information about the particle size and velocity for a given scattering angle, relative refractive index and the beam size \( b_z \), where \( t_p \) indicates the time position of the peaks, \( A_p \) their amplitudes and \( \sigma \) the width of individual peaks. Because the beam size is smaller than the particle size, the scattering orders are detected without coherent overlapping. Consequently, the time between peaks can be expressed as

\[
\Delta t = \frac{(d/2)f(m, \theta_s)}{v}
\]

where \( f(m, \theta_s) \) is the relative position of the incident points. However, in order to determine the particle size through measurement of the time between signal peaks (scattering orders) the velocity must be known.

The shape of each individual peak (reflection and second-order refraction) takes the shape (and width) of the light beam intensity profile and depends only on the velocity of the particles. Therefore the width of the signal peak in time is directly related to the width of the light beam in space through the velocity, and this offers a method to determine velocity without knowing the particle size.

To ensure that each signal peak is clearly distinguishable for the velocity measurement the light beam width should be about four times smaller than the particle size. Although the time-shift technique is a known measurement method, until now it has not been applied to spray characterization because of several secondary problems. These problems will be outlined in the full article and several enhancements will be introduced making the technique much more attractive and reliable for spray characterization. In particular a validation criterion has been found which greatly improves the reliability of individual drop measurements. Furthermore, different configurations have been developed allowing measurement of not only transparent but also non-transparent (metal, ink) particles as well as particles of suspensions (milk, coffee) and crystals (ice, sugar, salt).

References