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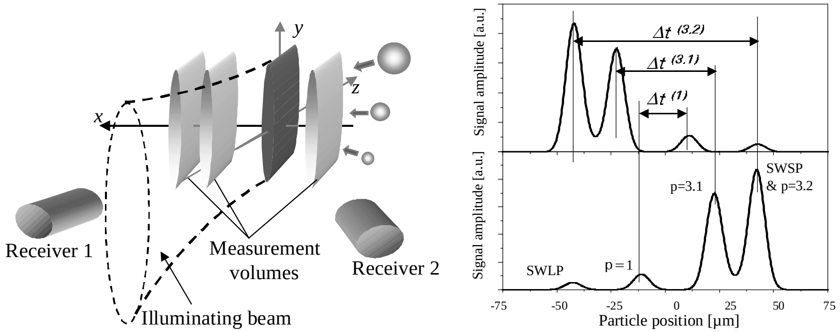
NOVEL TECHNIQUE FOR SINGLE PARTICLE CHARACTERIZATION IN BACKSCATTER

The proposed technique is a combination of the pulse-displacement sizing method and the laser Doppler technique. For the generation of the time-shifted scattering orders a separate single beam/sheet illumination is used. Test measurements have demonstrated that the arrangement using an additional light sheet for the generation of time-shifted scattering orders exhibits several important advantages compared to an optical system based solely on the laser Doppler system.

PARTICLE CHARACTERIZATION, PULSE DISPLACEMENT, LASER DOPPLER

1. INTRODUCTION The conventional phase Doppler technique provides correct particle sizing only when a single scattering mode dominates, e.g. reflection or first-order refraction. In backscatter, the receiver detects the light scattered by several scattering orders, therefore the resulting phase-diameter curve exhibits very large oscillations and jumps, making particle sizing impossible [1].
Retaining a laser Doppler for the velocity measurement, a modified particle sizing approach has been studied in the present work. It is based on the detection of the time-shifted scattering orders, which only occur with shaped beams. This is the so-called pulse displacement technique [2, 3, 4]. With the particle moving through the shaped beam, each scattering order/mode contributes to the signal from its own virtual measurement volume, which is displaced in space. Accordingly, various fractional signals arrive sequentially at the detector. The magnitude of the displacement depends on the scattering order/mode, the receiving location, the relative refractive index and the particle diameter.
Thus, if the different scattering orders/modes are identifiable in the received signal and the particle velocity is known, the diameter can be estimated from the time displacement between fractional signals.

2. FRACTIONAL SIGNALS GENERATION The time-shifted scattering orders can be generated either by the laser Doppler illumination itself or by the separate single beam illumination. The smallest measurable particle size using the time-shift technique is determined by the focused size of the measurement volume [1]. Simulations of this technique using the beams of a laser Doppler system, with the beams focused to 5-10µm, exhibit a systematic increase of error with increasing particle size, caused by the erroneous velocity estimation. The error arises from the non-uniform fringe spacing, which diverges strongly from the center. Therefore the smallest measurable particle size is limited to 20-30µm. The new optical arrangement considered here is a combination of a two-velocity component laser Doppler system (not necessarily highly focused) and a highly focused central light sheet of a different colour, with corresponding separate detectors. For such an arrangement the velocity and time-shift channels are independent, allowing optimization of optics and signal processing for each system separately.



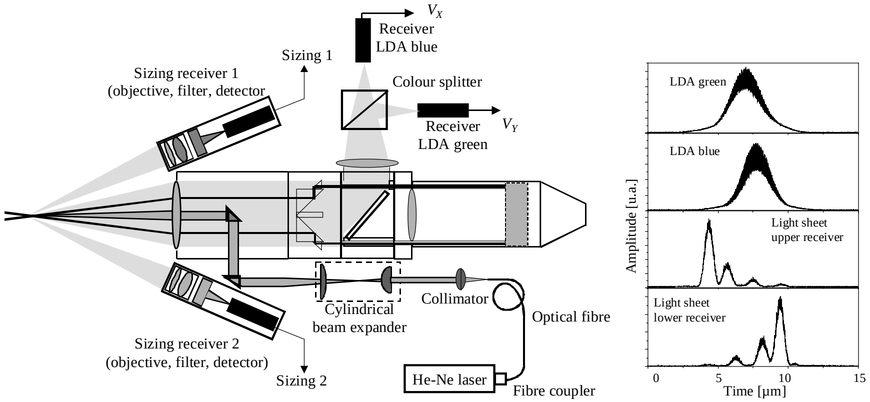
a **b**

Figure 1. Light-sheet illumination. **a** Measurement volumes, **b** Exemplary signals

For the case of a light sheet illumination, virtual light sheets will exist for each scattering order/mode, as shown in Fig. 1a. Typical signals received at two symmetrically positioned detectors are shown in Fig. 1b. A particle moving through the beam results in various fractional signals arriving sequentially at the detector, hence the name pulse-displacement technique. The main components in order of occurrence for a droplet in the air will be: surface wave long path (SWLP), reflection, second-order refraction inner path (p=3.1), second-order refraction outer path (p=3.2), surface wave short path (SWSP). Note that components SWSP and p=3.2 overlap and cannot be separated.
The dependencies of time-shifted signals were studied in [1]. It was shown, that the measurement of the time shift between two fractional signals from the same scattering order obtained on the two receivers, as shown in Fig. 1, is advantageous for the measurement of a small particles. The surface-wave generated signal is the most sensitive to the particle size and least sensitive to other influential parameters. The refractive index influences the position of the p=3.1 fractional signal, which exhibits a monotonic but non-linear increase of time shift. Unfor-

tunately the p=3.1 fraction is also sensitive to the shape of the particle. Therefore either refractive index can be measured or the variations of the particle shape can be discriminated.

3. EXPERIMENTAL SETUP The final optical arrangement for the sizing instrument is shown in Fig.2a.



a **b**

Figure 2. Experimental sizing instrument. **a** Optical arrangement, **b** Signals

As a basis for the setup a standard Ar-Ion based laser Doppler system configured for backscatter operation is used. An additional light sheet is generated using a He-Ne laser, delivered to the probe by an optical fiber, and then focused by a cylindrical beam expander. The light sheet is centered in the laser Doppler measurement volume. Two additional detectors equipped with red filters are mounted symmetrically to the optical axis of the probe. The signals from the four detectors (two velocities, two size) are sampled and stored by a transient recorder and then passed on to a PC for signal processing.

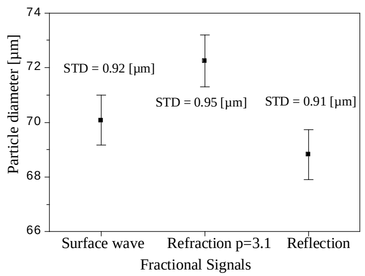


Figure 3. Particle size estimated with different fractional signals

In Fig. 2b the experimental signals produced by a water drop are depicted. The conditions were as follows: laser Doppler wavelengths of 0.514µm and 0.488µm, beam-intersection angle ±5.3°, beam-waist diameter 50 µm; particle sizing channel with 15µm x 150µm light sheet and receiving angles of ±27°.

Water droplets of diameter 70.7µm were generated using a vibrating orifice particle generator. With this particle size all fractional signals are separated and any of them can be used to obtain the particle diameter. This is demonstrated in Fig. 3, in which the sizing results for different scattering orders are shown. For the variance estimate a set of 20 sequential signals has been used. The reproducibility of the measurements was very good, which resulted in very small scatter of the measured size, probably caused by actual diameter variations of the generated particles.

4. CONCLUSION A novel optical arrangement for the combined instrument is introduced, which uses a light sheet for the generation of the time shifted fractional signals. To demonstrate this technique, simulated and experimental signals were obtained and processed. It is found that the newly proposed combined laser Doppler–light sheet method can be efficiently practised for particle characterization in backscatter.

5. ACKNOWLEDGEMENTS This work was supported by “Deutsche Forschungsgemeinschaft” (DFG).

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НОВЫЙ МЕТОД ДИАГНОСТИКИ ЧАСТИЦ В ОБРАТНОМ РАССЕЯНИИ

Предложен метод диагностики частиц основанный на совместном использова-нии способа измерения размеров частицы по задержке импульсов генериро-ванных частицей в различных порядках рассеяния и лазерного допплеровс-кого анемометра. Для генерации порядков рассеяния применен дополнитель-ный пучок излучения в виде лазерного ножа. Лабораторные испытания продемонстрировали сущесвенные преимущества схемы с дополнительным пучком.

ДИАГНОСТИКА ЧАСТИЦ, МЕТОД ЗАДЕРЖКИ СИГНАЛОВ, ЛДА