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PARTICLE SIZING USING BACKSCATTERED LIGHT

The paper presents the theoretical and experimental study of backscattered light generated by a transparent particle moving through the probe volume of a Phase Doppler system. The aim is to determine particle size and refractive index. For the signal simulation Fourier Lorenz-Mie theory as well as geometrical optics are used. The results and conclusions are verified experimentally.

LDA, PHASE DOPPLER SYSTEM, PARTICLE SIZING AND THEORY OF SCATTERING

1. INTRODUCTION Although the Phase Doppler (PD) technique has become a standard instrument for the diagnosis of two-phase and multiphase flows in many industrial applications, there exist numerous cases in which the system cannot be used because of the limitations on the optical access to the flow. It is well known that to achieve a linear phase-diameter relationship, the receiving angles for the detectors should be carefully chosen. The optimisation is based on the condition that the detectors collect the light scattered from only one scattering order. Typically, reflection or first order refraction is used. Thus, most instruments are configured for side-scatter detection. This leads to difficulties of probe volume alignment for the transmitting and receiving modules, complicates the traversing system design and, particularly in many industrial applications, precludes application completely. Therefore, particle characterisation with backscattered light, if possible, would be very attractive, allowing integration of the transmitting and receiving parts into a single module and requiring only one optical access to the flow.

2. STUDY OF A BACKSCATTERED LIGHT Light scattered by the particle ín backscatter contains many scattering orders, including primarily reflected light (first order) and second-order refraction (third order) contributions. Since the phase-diameter relationship of each scattering order is different, the resulting net phase-diameter curve exhibits very large oscillations and jumps, making particle sizing impossible.

The solution which is considered here is to focus the illuminating beams to extremely small sizes, hence amplifying the Gaussian beam effect [1,2]. Different scattering orders then generate separate signals, shifted in time and not overlapping. Using ray tracing for the spherical particle and a receiver at the scattering angle ϑ_S (Figure 1), it can be seen that the incident rays responsible for the first-order and the third-order rays are spatially separated. These rays intersect the particle surface at unique incident points. If the beam diameter is comparable to the particle diameter, a moving particle produces first-order and third-order signals with a time delay between the maxima of the fractional signals. The time shift depends on the particle size, refractive index, particle velocity and trajectory and the position of the detector. In the present paper, properties of such phase Doppler signals are studied theoretically and experimentally to define the potential and limitations of the particle characterisation with time-shifted signals.

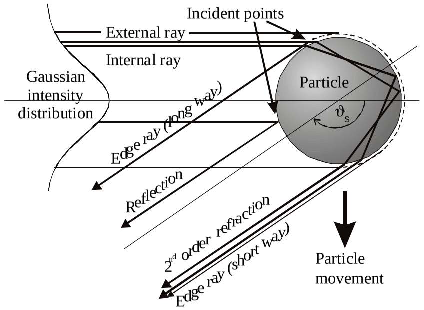

Fig. 1: Ray tracing for the backscatter

Conventional Lorenz-Mie theory cannot be used for the calculation of the signals, since the particle is illuminated with an inhomogeneous wave. Therefore, the Fourier Lorenz-Mie theory (FLMT) [3] is used to simulate the signal. First calculations were performed on the basis of geometrical optics (GO) for a spherical particle [4], which has serious limitations but allows prediction of the general features of the signal. To demonstrate the most important differences, the signals simulated with FLMT and GO are presented in Figure 2.

The simulated signal with GO incorporates reflected and 3rd order components, overlapping in time. The same central burst of FLMT simulated signal can be seen in the lower diagram. However there are two additional bursts before and after the central one. The incident zones for these additional bursts are located on the outer edge of particle, hence the signals are produced by the surface waves, which cannot be described within the GO framework.

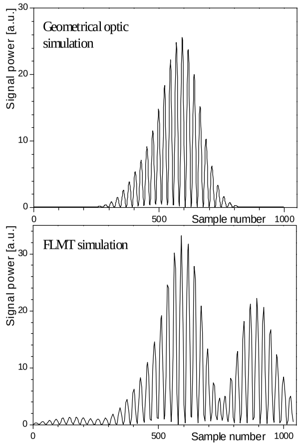

Fig. 2: Signal simulation

The study of scattering modes leads to several important observations:

- All incident points lie on the surface of the particle and in the scattering plane defined by the position of the detector and the beam axis, hence they are located on a single line

- Each beam has a corresponding set of incident points. Therefore minimising the cross-beam angle and enlarging the detector elevation angle results in highly modulated time-shifted signals
- Taking into account additional signals generated by surface waves, two to four fractional signals can contribute to the entire detector output, depending on the detector position.

FLMT-based signal simulation delivers the exact particle sizing factors for different optical configurations and their sensitivity to the refractive index. Signals produced by surface waves have the maximum feasible sizing sensitivity and they are insensitive to the refractive index. These features provide particle sizing for much smaller particles than a reflection-based method, enlarging the sizing range and improving the accuracy.

The study of 3rd order scattering has shown that it contributes with one or several modes. With the refractive index less than 1.4 it could be one or two contributing modes, for a larger refractive index – one to three.

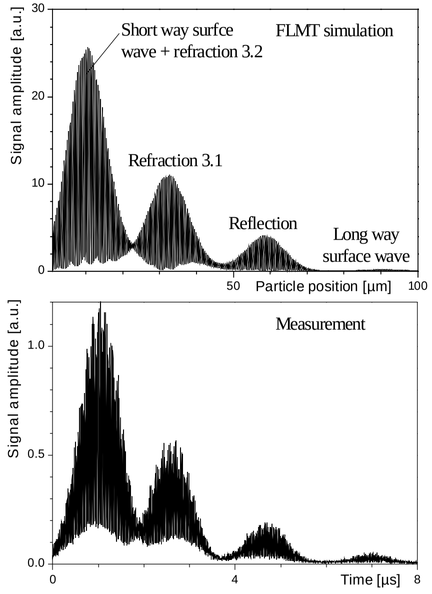

Fig. 3: Simulated and experimental signals

The set-up for the experimental study of the signals incorporated an Argon-Ion air-cooled laser, a standard DANTEC colour separator and a fibre,based, two-velocity component optical head. Adjustable beam separation and beam expansion optics provided a wide range for the probe volume parameters. The beam diameter was focused to 20 µm. A frequency shift of 40 MHz was applied to one of the beams to provide a sufficient number of cycles in the very short signal bursts. For signal registration several arbitrarily positioned photomulitplier units were used. A vibrating-orifice droplet generator, fixed on a mechanical traversing system produced a stream of water droplets. The bursts were stored in a digital oscilloscope and read out to a PC. Processing software separates the bursts and computes the arrival time, amplitude, phase and modulation frequency for each fractional signal [5].

As an example of typical multiburst signals, Figure 3 compares simulated signals (FLMT) and experimental signals for the receiver and particle trajectory in the plane of the beams. The particle generator was adjusted to produce water droplets of nominal diameter 95-102 µm. The bursts are produced by (from left to the right): short way surface wave overlapped by 3.2 mode, 3.1 mode solely, reflection solely, long way surface wave, which is even better seen on the experimental trace. Signal processing for this case yielded a particle velocity of 13.34 m/s. The particle diameter, estimated by the time shift of different fractional signals, was found in the range of 92 – 110µm, with upper values calculated using the 3.1 scattering mode.

3. CONCLUSION Time-shifted and separated signals from different scattering orders can be used for particle sizing. The most sensitive configuration of the system was found for the case when the illuminating beams, detectors and particle trajectory are all in the same plane. In the next steps the influence of particle trajectory and particle shape, together with refractive index determination will be studied more close.

4. REFERENCES

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ИЗМЕРЕНИЕ РАЗМЕРОВ ЧАСТИЦ В ОБРАТНОРАССЕЯННОМ СВЕТЕ

В работе приведены результаты теоретического и экспериментального исследования сигнала в обратном рассеянии, регистрируемого при движении частицы через измерительный объем фазово-доплеровской системы. Целью исследования является получение информации о размерах и показателе преломления частицы. Моделирование сигнала выполнено с помощью теории Фурье Лоренц-Ми и с применением геометрической оптики. Результаты и выводы подтверждены экспериментом.

ЛДА, ФАЗОВО-ДОППЛЕРОВСКАЯ СИСТЕМА, ИЗМЕРЕНИЕ РАЗМЕРОВ ЧАСТИЦ, ТЕОРИЯ РАССЕЯНИЯ