Particle Dynamics Analysis

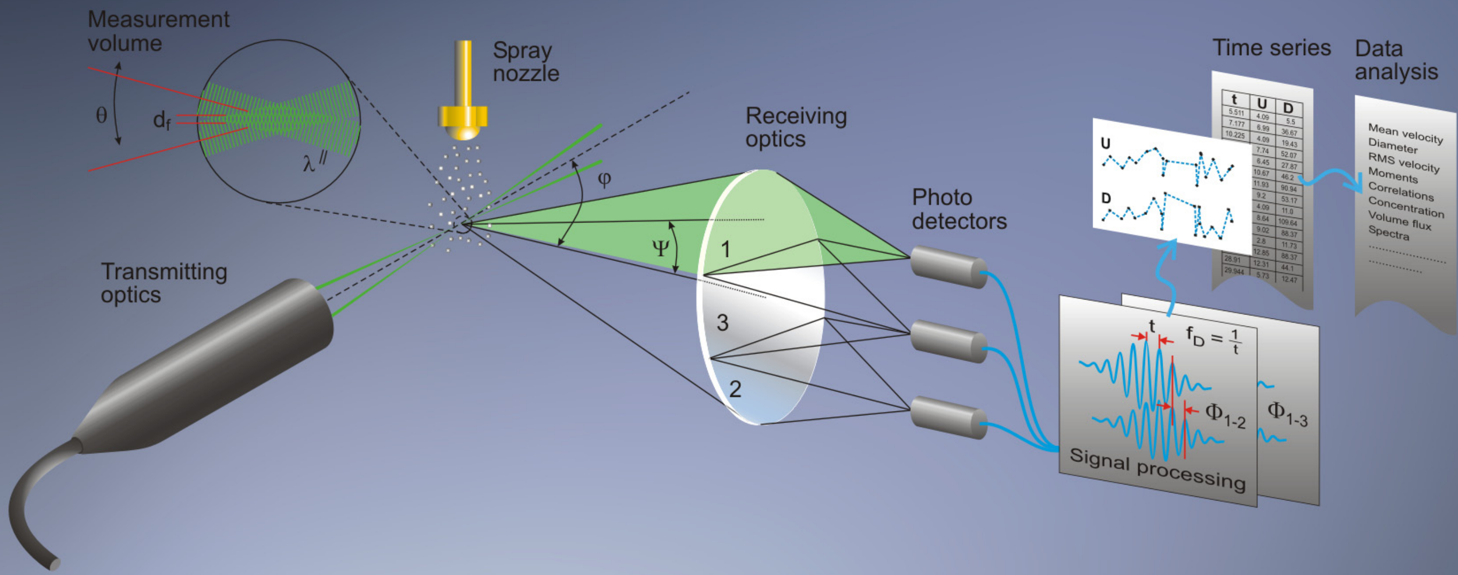
Introduction

Particle Dynamics Analysis (PDA) is an optical technique to measure the size and velocity of spherical particles simultaneously. These particles can be droplets, bubbles or solid particles, as typically occur in sprays, liquid atomisation, bubbly two-phase flows and multiphase flows with, for example, glass beads.

The measurements are performed on single particles, thus allowing detailed analysis of particulate flows. The distribution of statistical size and velocity moments in a flow field can be measured, as well as particle concentration and local size-velocity correlation. Movement of the measurement point in the flow allows mapping of entire flow fields.

Features

- Size range from sub-micron up to several millimetres
- Velocity range from zero to supersonic
- One, two or three velocity components simultaneously
- No calibration required
- Instantaneous and time-averaged information
- High spatial and temporal resolution
- Non-intrusive



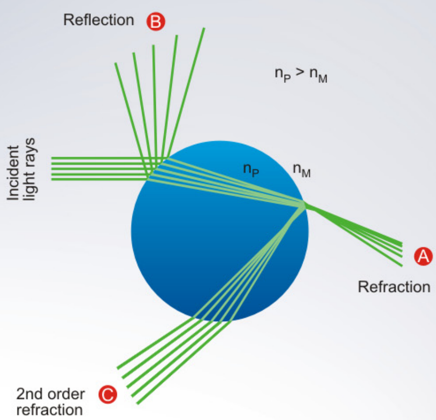
Principles

The PDA technique is an extension of laser Doppler anemometry and is based upon phase Doppler principles.
Two or more detectors collect the light scattered by single particles passing through the measurement volume.

Light scattering

The phenomena of light scattering can be visualised by ray tracing. The light which is incident on e.g. a water droplet is partially reflected from the surface and partially transmitted and refracted in both forward and backward directions after one internal reflection. The scattered light intensity is not uniform in all directions and also depends on the relative refractive index:

$$n_{rel} = \frac{n_{Particle}}{n_{Medium}}$$



Scattering angle

The position of the receiver (scattering angle φ) must therefore be carefully selected to ensure that one light scattering mode is dominant.

Commonly used scattering angle ranges are:

- A 30° - 70° for refraction
- B 80° - 110° for reflection
- C 135° - 150° for 2nd order refraction

Particle velocity

The particle velocity U is calculated from the Doppler frequency f_D of the signal from any one of the detectors:

$$U = \frac{\lambda}{2\sin(\theta/2)} f_D$$

Particle size

The particle size D is derived from the phase difference Φ between the signals from two detectors.

If light scattering is dominated by reflection:

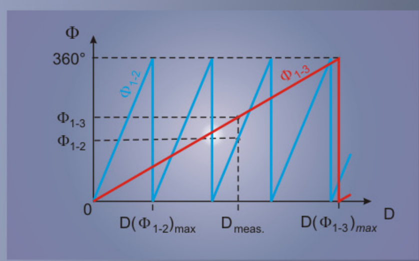
$$\Phi = \frac{2\pi D}{\lambda} \frac{\sin\theta/2 \ \sin\psi}{\sqrt{2(1-\cos\theta/2\cos\Psi\cos\varphi)}}$$

If light scattering is dominated by refraction:

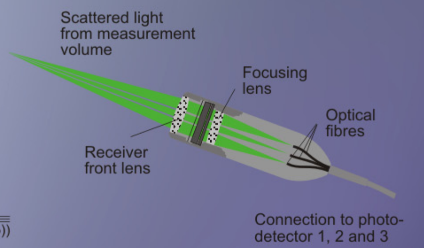
$$\Phi = \frac{-2\pi D}{\lambda} \frac{n_{rel} \sin\theta/2 \ \sin\psi}{\sqrt{2(1+\cos\theta/2\cos\Psi\cos\varphi)(1+n_{rel}^2 - n_{rel}\sqrt{2(1+\cos\theta/2\cos\Psi\cos\varphi)})}}$$

Three detectors

The maximum particle size that can be unambiguously measured with two detectors corresponds to a phase shift of $\Phi_{1-2} = 360°$. Reducing the distance between the detectors can extend the particle size range. This however, will also reduce the measurement resolution. Using three detectors provides both a large measurable size range (Φ_{1-3}) and a high measurement resolution (Φ_{1-2}).



State-of-the-art PDA receivers have three pre-aligned receiving apertures integrated into one fibre optical probe.



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