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A Raman anemometer for component-selective velocity measurements of particles in a flow

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Abstract An anemometer for the measurement of the velocity of particles of different components in a flow, separate and apart from that of the flow itself, is described. As a component-selective mechanism Raman scattering is used. The velocity is measured by relating the autocorrelated scattering signal to the known laser beam profile.

1 Introduction

Until now it was not possible to measure the velocity of particles of different substances or components moving in one flow at different speeds, separately and apart from the velocity of the flow itself. Raman scattering which results in specific spectra for each specific component, offers the opportunity to distinguish different constituants. Therefore, a Raman anemometer like the one designed and built in our laboratory makes it possible to perform such component-specific velocity measurements.

Possible applications of this Raman Anemometer are:

(i) determination of velocities in flame spectroscopy

(ii) flows of mixtures and/or suspensions, especially in case particle velocities close to the walls are of interest, e.g. in blood flows,

(iii) measurements of specific diffusion coefficients of particles of different components in solution.

2 Description of the Raman anemometer

Usually in anemometry the laser Doppler method is applied (Cummins and Pike 1973, Durrani and Greated 1977, Whitelaw 1976). Unfortunately, for a Raman anemometer this method turns out to be unusable, mainly due to the apparently small amount of Raman scattering as compared with the Mie scattering used in the laser Doppler technique. Secondly, as one of the major parameters determining the scattering intensity turns out to be the dimensions of the laser beam profile at the intersection area (as it is reflected in the fringe pattern), another severe limitation emerges in cases in which the particle dimensions exceed the fringe periodicity.

In order to avoid the problems mentioned above, a Raman Anemometer is designed, based upon using not the fringe pattern of two intersecting beams as is done in laser Doppler anemometry, but the known intensity profile of the single laser beam itself (Florisson 1981). In first approximation this profile may be considered as Gaussian.

In figure 1 the Raman anemometer based upon this method is shown in principle. Scattered light from the particles in the flow is filtered by a monochromator, by which only a selected Raman line is allowed to pass. The effective dimensions of the

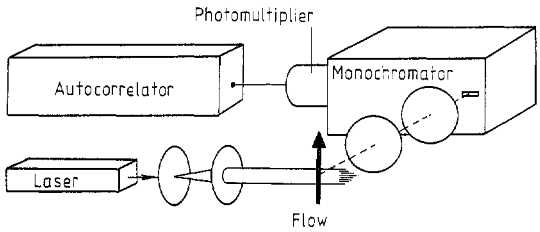

Figure 1 The Raman anemometer.

scattering volume are determined by its imaging upon the entrance slit of the monochromator. This monochromator has to be a double one in order to remove the background scattering due to the Rayleigh and Mie scattering wing.

The measured signal, i.e. detected photons which are Raman scattered from particles passing through the scattering volume, is analysed using a digital double-clipped autocorrelator (Cummins and Pike 1973). From the shape of the resulting autocorrelation function, given for a laminar flow by (Florisson 1981, Florisson and de Mul 1981)

$$A(\tau) \sim \exp(-v^2\tau^2/2\sigma^2),$$

the particle velocity v of the component at the Raman line of which the monochromator is tuned can be directly calculated (2σ is the diameter of the beam cross section, measured between the e^{-1}-intensity points). Factors affecting the shape of the autocorrelation function are: (i) the particle dimensions as compared with the diameter of the laser beam; and (ii) the finite dimensions of the effective scattering volume, caused by its imaging on the monochromator entrance slit.

Fortunately, it turns out that these two influences can be corrected for easily (Florisson 1981, Florisson and de Mul 1981). Furthermore, it can be shown (Florisson 1981, Florrison and de Mul 1981) that with this method, despite the low scattering intensity, no limitations concerning the particle dimensions (at least up to about 1 mm) are present, as is the case in ordinary laser Doppler techniques.

3 Results of tests

The Raman anemometer was tested with a number of samples. Here only the test measurements with crystallites of nitrochlorobenzene in water will be mentioned. This sample was chosen because of its fairly good Raman scattering properties. A laminar flow was simulated using a slowly rotating glass drum, by which the particle velocity was known quite satisfactorily. The concentration was so chosen that only one or a few particles crossed the scattering volume at the same time.

Figure 2 shows typical examples of the autocorrelation functions resulting from this experiment. In the figure the influence of different monochromator slit widths is also

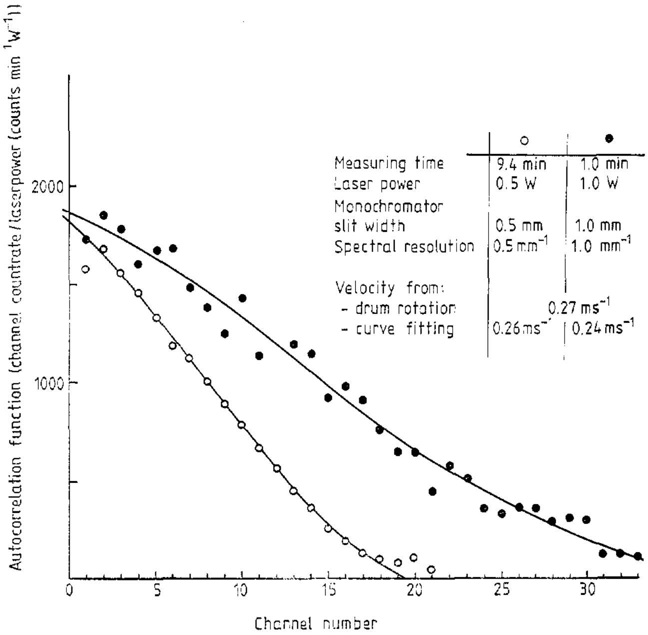

Figure 2 Nitrochlorobenzene/water flow: normalised autocorrelation functions (background subtracted) for two different slit widths, and the same particle velocity. ○, ●, measured; ——, calculated. Particle dimensions: 0.20 ± 0.05 mm; beam dimension: $\sigma = 0.46$ mm; exciting wavelength: 514.5 nm; Raman peak at 134.3 mm^{-1}; one-to-one imaging of scattering volume to monochromator entrance slit, clock frequency: 10 kHz.

shown. The velocity calculated from these functions agrees, within the error limits, with the preset one. In order to test the ability of the apparatus to distinguish between particles of different components, it is sufficient here to investigate whether a velocity measurement can be performed using the background scattering of the particles (thus next to the Raman peak in the spectrum). It turned out that after having measured for 15 minutes (i.e. much longer than the time needed for the Raman experiment) no decaying autocorrelation function had yet resulted.

Further tests and improvements of the method and the apparatus are in progress.

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