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Laser Velocimeter with Transverse and On-Axis Sensitivity

Laser Doppler velocimeters (LDV) are used for the measurement of localized fluid velocities without perturbation of the flow field. The basic principle of operation is that coherent light is scattered and shifted in frequency by particulate matter carried along in a moving field. Modern laser velocity instruments employ a crossed-beam, dual-scatter system in which parallel incident beams are focused in the flowing stream through the same lens; light collected from the intersection volume at any angle contains a Doppler frequency resulting from the heterodyning of the scattered light from the two incident beams. Velocimeters of this type are only sensitive to the component of velocity perpendicular to the bisector of the angle between the two beams and in a plane defined by the two beams; the velocity component is obtained from measurement of the beam intersection angle and the heterodyne signal. In early instruments, called local oscillator velocimeters, the incident and scattered light were recombined at the photocathode of a photomultiplier tube to produce a beat signal linearly related to the average velocity of the fluid within a small scattering volume.

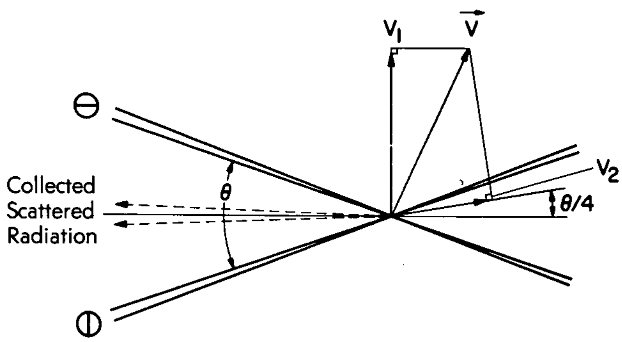
A dual-scatter system in the forward scatter, off-axis configuration appears attractive from the viewpoint of signal-to-noise and spatial resolution, but it is more convenient to use a confocal backscatter on-axis velocimeter which utilizes a common lens for both the transmission of the outgoing beams and the collection of scattered light; moreover, with this configuration, any velocity component in a plane normal to the transmitting axis can be measured. Unfortunately, the "on-axis" component is difficult to obtain from a confocal backscatter system, but a technique which utilizes only two outgoing beams polarized normally to one another can be processed in such a manner that a local oscillator signal is obtained (corresponding to the nearly on-axis velocity component), and the usual dual-scatter (transverse) velocity is also retrieved.

When the two outgoing beams are polarized normally to each other, the usual dual-scatter fringes are not seen in the intersection region for observations made parallel to either of the incident polarizations. However, fringes of maximum contrast are observed at either $+45°$ or $-45°$ with respect to either of the incident-beam polarization directions; additionally, the fringes observed at these angles are displaced from each other by exactly one half of the fringe spacing, implying that Doppler signals generated by each of these sets of fringes differ in phase by π. This property has been independently applied in differencing techniques to enhance the Doppler signal and subtract unwanted signals common to both detectors, such as the dc pedestal in a single-particle laser Doppler velocity (LDV) system and the amplitude fluctuations in a multiple-particle LDV arrangement.

Although signal enhancement is potentially useful for LDV work, the primary utilization of the normal polarization technique described here is that the two outgoing beams are effectively distinguishable from each other, and observation of the scattered radiation at a polarization of either 0° or 90° will only allow light scattered from one beam or the other to be seen (since linear polarization is preserved in the backscatter geometry). Utilizing these two facts, an optical system was designed which can simultaneously detect two independent velocity components, one

(continued overleaf)

very nearly along the LDV axis and the other transverse to the axis. The dual-scatter signal can be retrieved by observing at either +45° or —45°, conveniently obtained through use of a Wollastrom prism. (The differencing technique is optional, and may or may not be used as desired.)



A local oscillator arrangement sensitive to the on-axis velocity component and utilizing only one of the outgoing beams is quite easily incorporated. A reference beam is obtained as a spurious reflection from the splitter cube and aligned with the returning scattered radiation. Only scattered light from the vertically polarized outgoing beam heterodynes with the (vertically polarized) local oscillator beam. A small fraction of the collected backscattered light (0.20 cm^2 out of 25 cm^2 on the receiving lens) is all that is needed to obtain a very strong local oscillator Doppler signal. Utilization of such a small fraction of the scattered light for the on-axis component has the advantages that most of the scattered radiation still contributes to the dual-scatter signal, and the aperture broadening of the local oscillator system is minimal. In particular, it is only that portion of scattered radiation which passes through the transparent glass slide and is parallel with the local oscillator beam at the focus of the collecting lens which gives rise to a heterodyne signal.

The two measured velocity components are shown in the diagram. They are not exactly orthogonal, but are separated by $(\pi/2 + \Theta/4)$. Since Θ is typically quite small, usually a few degrees, $\Theta/4$ is much smaller than $\pi/2$ and the two components are orthogonal for all practical purposes. However, the measurement directions are well defined, and for two-dimensional flow, the exactly on-axis component can be computed from

$$v_{axial} = v_2 \sec \Theta/2 + v_1 \tan \Theta/4$$

where the independent velocity components v_1 and v_2 and computed from the measured Doppler frequencies:

$$\upsilon_1 = (2nv_1/\lambda_0) \sin \Theta/2$$
$$\upsilon_2 = (2nv_2/\lambda_0) \cos \Theta/4.$$

Frequency shifting the vertically polarized beam with a single Bragg cell will give both components directional sensitivity, a vital feature if the velocity vector direction is not known beforehand. Frequency shifting one of the laser beams (by amount υ_m) in either a dual-scatter or a reference (or local oscillator) system will bias the Doppler signal, υ_D, so that it is added to, or subtracted from υ_m, depending upon flow direction. Thus, with one Bragg cell in the system ($\upsilon_m = 37.20$ MHz), the spectrum analyzer will display $\upsilon_m \pm \upsilon_1$ and $\upsilon_m \pm \upsilon_2$ from the two tubes, respectively, depending on the absolute directions of the velocity components v_1 and v_2.

Note:

Requests for further information may be directed to:

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Patent status:

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