Velocity Measurement by combining the Doppler Principle with the Schlieren Method

THE object of associating these principles has been to make possible the measurement of the velocity of any phenomenon which will reflect, refract or diffract a laser beam. Our particular interests lie in phase objects relevant to combustion research, such as laminar and turbulent flame fronts, shock and detonation waves and other steep refractive index gradients associated with heat and mass transfer, or pressure changes, but the method is not confined to these.

When the direction of a light beam is deflected through an angle, θ, by encounter with an object moving at velocity, u, at right angles to the incident beam direction, the wavelength is altered due to the Doppler effect so that interference of this beam with an unperturbed one from the same source results in a beat frequency of $(u \sin \theta)/\lambda$, where λ is the wavelength. The use of laser light has some obvious advantages in this context because of its extreme coherency, monochromaticity and brightness.

It has been demonstrated that the change in frequency can be used to measure the velocity of individual particles suspended in a gas[1] or liquid[2], even without a very precise selection of the angle θ. In these attempts, particle scattering was utilized at the focus of a strongly convergent beam. A much wider range of applicability, however, becomes possible when this principle is associated with an optical system which selects rays that have been deflected through particular angles. This can be achieved very simply by using a schlieren system[3-5], provided with a selective aperture[5] instead of the conventional knife edge. Consider, for example, an opaque screen placed a focal length, f, beyond the schlieren lens, which has a small aperture at a distance, d, from the focus of the parallel beam (Fig. 1). Only information of those regions of the test space which deflect light through an angle (d/f) in the particular direction selected by the small hole, P, will pass beyond the screen, where the beam shown can be interfered with a reference beam diverging from a point in the schlieren blind, and the resulting beat frequency monitored by a detector. This reference beam could be obtained from undeflected light passing through an aperture in the schlieren blind, or it could be brought in from outside the test space, independent of the trans-luminating beam. Sometimes it may be more convenient to use, as the second beam, light deflected by the test object in a different direction.

The velocity of phase objects has generally been deduced by measuring the time of traversal of a known distance, using methods such as cine or streak schlieren photography, timing between ionization probes a known distance apart, or repetitive illumination of particles suspended in some associated gas flow. The new method can also be thought of in terms of using interference fringes to mark the object and then recording the fringe separation and the beat frequency as a measure of respective distance and time intervals. In these terms, its merit lies in the non-interfering nature of the well articulated "distance marker" and the use of the beat wave, displayed on an oscilloscope, as a convenient and accurate "clock".

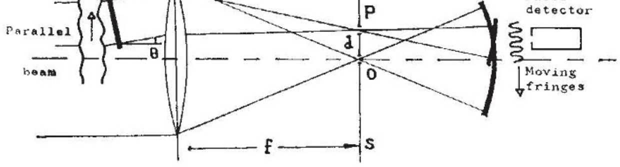

Fig. 1. Selection of Doppler-shifted light for interference. O, Optic axis; θ, angle of deflexion; f, focal length of schlieren lens; d, distance of P from reference point.

A detailed theoretical analysis, in terms of fringes moving past a small detector, which examines various practical limitations and experimental refinements, will be published elsewhere. One interesting conclusion is that sensitivity and accuracy can be improved in certain circumstances by covering the detector's aperture by a ruled grid of spacing equal to that of the fringes, or by a transparency of the fringe system photographed instantaneously.

We have tested this method experimentally in several forms, on a wide variety of experimental objects. These included moving gratings (radially ruled, 5,600 lines rotated at speeds up to about 600 r.p.m., mean track diameter of about 10 cm), ultrasonic beams generated by a quartz crystal transducer, flames (burner stabilized and made to move across the test space by a mechanical device) and dispersions of particles. In the case of the gratings and sound waves, the schlieren blind was designed to pass the +1 and −1 diffraction orders, while in the case of the flame, interference was achieved between the beam deflected through a small angle by the flame front and the undeflected beam, which was somewhat attenuated by a neutral filter, so as to match the two intensities. In each case the fringes were monitored by a photomultiplier and displayed on an oscilloscope. The range of velocities covered by these illustrations extended from a few centimetres/second to the speed of sound; the method, however, is not so limited. The accuracy of the measurement was generally limited only by that of determining the geometry of the optical system, in particular the width of the schlieren aperture in relation to its displacement from the optic axis.

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Stress Graphitization of Polyacrylonitrile Based Carbon Fibre

CARBON fibre can be made by the pyrolysis of organic polymer fibre precursors. Up to now, cellulose[1] and polyacrylonitrile (PAN)[2] have been found to produce carbon fibre of good strength and modulus. Preliminary details of the structure of PAN based carbon fibre, similar to that prepared and used by us, have been published by Johnson and Watt[3] and Badami, Joiner and Jones[4]. One of us[5] has reported that the strength of PAN carbon fibre declines when heated above 1,200° C. It is therefore of interest to report that increasing strength with Young's modulus can be obtained if stress is applied to the fibre at graphitizing temperatures.

The stress graphitization was carried out using an extensometer, mounted within a graphite resistance furnace. Torque was applied to the extensometer lead screw by a variable speed motor, driving a variable torque slipping clutch. Using this method the stress applied to the fibre was continuously variable and the stretch could