LASER DOPPLER VELOCIMETER

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INTRODUCTION:

The Laser Doppler Velocimeter represents a unique 'no-probe' technique of measuring the instantaneous velocity of a liquid or gas flowing in a glass-walled conduit or channel. It was developed around the year 1968 as a result of research work carried out by the National Aeronautics & Space Administration, U. S A, and some European universities.

The instrument measures the velocity at a point in the fluid flow by detecting the Doppler-shift in the frequency of the scattered light originating from minute suspended particles in the flow that cross the point of measurement defined by two intersecting laser beams. The laser source is used as it can give out a narrow, intense and truly parallel light beam of high spectral purity.

The instrument was fabricated, for the first time in India, at the I. I. T., Madras, in 1974, as part of the doctoral research programme of the writer. The unique features of this instrument are: (1) No physical probe is required; (2) Excellent spatial resolution, the measuring volume being typically 0·02 mm^3; (3) No transfer function is involved, the output voltage being linearly related to the flow velocity; (4) Very fast response to fluctuating velocities, the typical frequency response going upto 50 KHz, and (5) Measurements can be made in gas as well as liquid flows. Laser velocimeter is the ideal instrument for the study of fluid velocities close to a solid boundary.

MECHANICS OF LIGHT SCATTERING:

Consider a light beam of wave-length λ crossing a flowstream at an angle α with the direction of flow (Fig. 1). Suspended particles in the flowstream will scatter light in all directions when illuminated by the light beam. This scattered light behaves as if it originated from the moving particles and hence is Doppler-shifted with reference to the frequency of the incident light, when picked up at an angle to the beam.

It can be shown that if the scattered light is picked up at an angle θ with the direction of the incident light, the Doppler frequency shift is given by

$$f_D = \frac{V}{\lambda} \cdot \left[(\cos\theta - 1) \cdot \cos\alpha - \sin\theta \cdot \sin\alpha \right]$$

where V is the flow velocity.

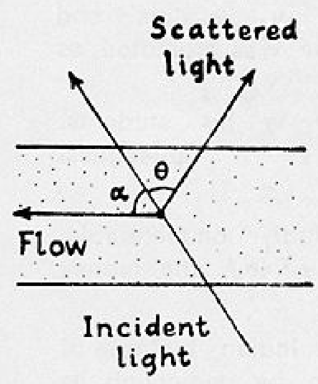

FIG.1. LIGHT SCATTERING.

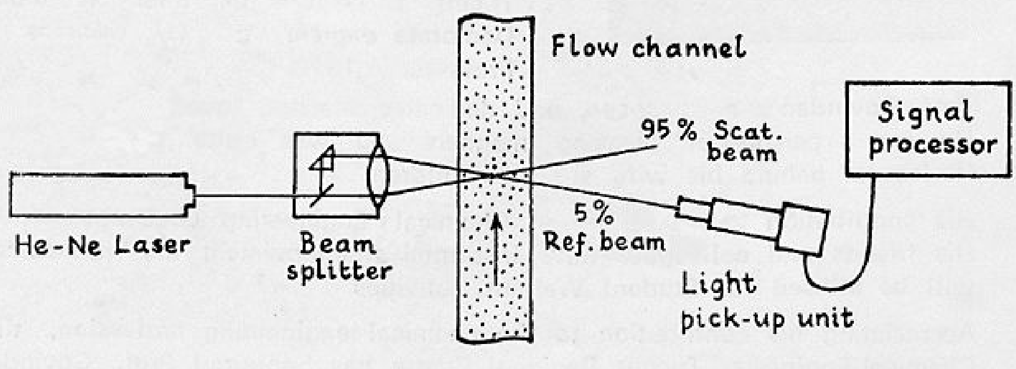

FIG.2. SET-UP IN REFERENCE BEAM MODE.

If the incident and scattered beams are equally inclined to a normal to the flow direction,

$$\alpha = 90^\circ - \frac{1}{2}\theta \text{ , and}$$

$$f_D = \frac{V}{\lambda} . 2 \sin\left(\frac{1}{2}\theta\right)$$

$$V = \frac{f_D \cdot \lambda}{2. \sin \frac{1}{2}\theta}$$

Considering a Helium-neon laser beam, (λ = 0·6328 micron) and expressing V in m/sec and f_D in MHz,

$$V \cdot 10^2 = \frac{f_D \cdot 10^6 \cdot 0.6328 \cdot 10^{-4}}{2 \cdot \sin \frac{1}{2}\theta}$$

$$V \text{ (m/sec)} = 0.317 \cdot f_D \text{ (MHz)} / \sin \tfrac{1}{2}\theta$$

If $\theta = 3.63^\circ$,

$$V \text{ (m/sec)} = 10 \cdot f_D \text{ (MHz)}$$

INSTRUMENTAL SET - UP

The instrument can be set up in either of two modes of measurement, namely, the Reference beam mode and the Interference fringe mode. Fig. 2 shows the set-up in the Reference beam mode.

The light from a 2 milliwatt Helium-neon laser is split up into a weak (5%) reference beam, and a strong (95%) scattering beam, by means of a Beam splitter. The two beams, which are equally inclined to the direction of flow, are made to intersect, by means of a lens, at the point of velocity measurement in the channel. Minute suspended particles in the flow scatter light in all directions when illuminated by the scattering beam. When this scattered light is picked up in the direction of the reference beam its frequency is Doppler-shifted.

The Light pick-up unit on the other side of the channel is so positioned, and its telescope so focussed, that it picks up the reference beam as well as the scattered light in the same direction originating from the point of intersection of the two beams. The light is focussed on to a photodiode where optical mixing takes place, giving rise to the Doppler signal at a frequency equal to the Doppler shift.

In the Signal processer unit, the frequency of the Doppler signal is converted to a voltage, which can be recorded on a strip-chart recorder. The mean value is also indicated on a panel meter.

FIG.3. LASER DOPPLER VELOCIMETER SET-UP

CHOICE OF THE SCATTERING ANGLE :

The usual range of values of the scattering angle θ is 2 to 15 degrees. In order to improve the spatial resolution of the measurement the scattering angle should be as large as possible, provided the Doppler frequency is within the range of operation of the signal processor. In the Beam splitter built by the writer, the scattering angle is adjustable and is set to 3.63°.

SCATTERING PARTICLES :

The diameter of the scattering particles should be in the range of 0.5 to 5 microns (1 micron = 1/1000 mm). Too small particles will give rise to Brownian motion, while too large particles will modify the flow field and also increase the system noise by excessive masking of the light picked up.

Fortunately ordinary tap water usually contains enough of fine suspended particles to provide adequate scattering. If necessary, the flow may be 'seeded' with a scattering medium such as talcum powder or white clay suspension in the case of liquid flows and aerosol suspension in the case of gas flows.

Even when the scattering particle concentration in the fluid is adequate, the concentration within the measuring volume may, at times, drop to a low value resulting in temporary 'drop-out' of the Doppler signal for a few milliseconds or so. The signal processor should be designed so that the occasional drop-out of the signal does not affect the measurement significantly.

DESCRIPTION OF THE EQUIPMENT :

Fig. 3 shows the layout of the Laser Doppler Velocimeter set up to measure point-velocities of water flowing in a glass-walled channel. The water flowing through the channel is collected in a sump and recirculated by a pump.

The Helium-neon laser source used is a commercially available unit. The Beam splitter, Light pick-up unit and Signal processor were designed and built by the writer. The Laser source and Beam splitter are on one side of the channel. The Light pick-up unit (Fig. 4) is on the other side of the channel. The photodiode used is a Hewlett - Packard 5082 - 4204 P.I.N. photodiode having a light - sensitive 'target area' of just 0.5 mm diameter. The Doppler signal is extracted by optical mixing at the photodiode and appears as an electrical signal at a frequency equal to the Doppler shift. The Light pick-up unit has a built-in preamplifier to amplify the weak Doppler signal.

In the Signal processor unit (Fig. 5), the signal is passed through one of a set of three sharp band - pass filters to reduce noise, and then

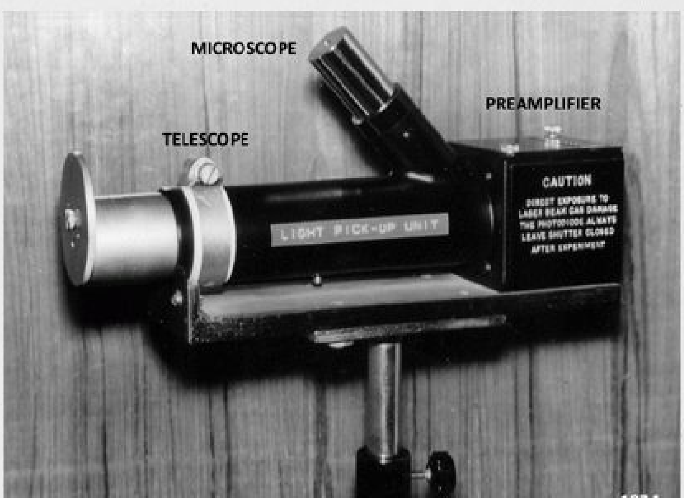

FIG.4. LIGHT PICK-UP UNIT.

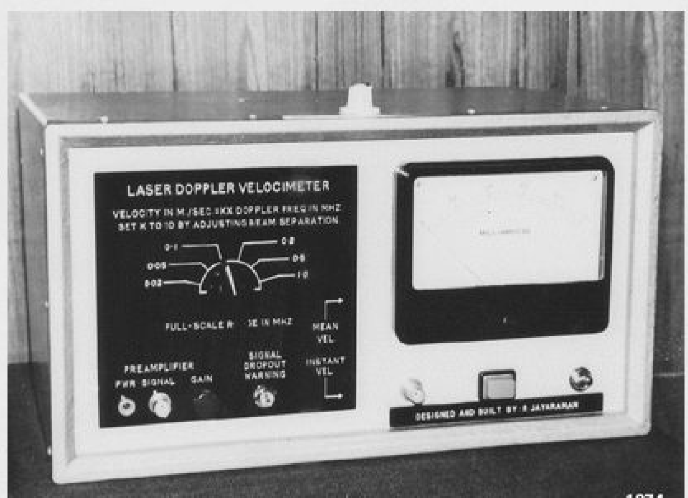

FIG.5. SIGNAL PROCESSOR.

further amplified. The frequency of the signal is then converted to a voltage proportional to the frequency by a 'diode-pump integrator' circuit. The mean voltage, averaged over a few seconds, is indicated on a panel meter, while the instantaneous voltage is available for recording on a strip-chart recorder.

The instrument has 6 measuring ranges with full-scale readings of 0.2, 0.5, 1, 2, 5 and 10 m/sec.

CONCLUSION :

Within two decades of its invention, the Laser Doppler Velocimeter has become an indispensable tool for research studies on fluid flows. Experimental studies on topics such as Velocity distribution in the boundary layer of a fluid, Turbulence studies in fluid flow and Velocity distribution in fluid jets have greatly benefited from the use of the Laser Doppler Velocimeter.

This instrument is now manufactured commercially by firms such as Thermo Systems Inc., U.S.A. and Disa Elektronik, Holland. These equipments cost over Rs. 2 lakhs and employ sophisticated optics and signal – processing techniques such as tracking filter, high-speed frequency-to-voltage converter and 'memory – hold' circuit to tide over momentary drop-out of the Doppler signal.

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