

TWO-COMPONENT LASER VELOCITY METER

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ABSTRACT

A relatively inexpensive two component laser velocity meter has been assembled by extending a Dantec single component system with a few additional items. The most important of these extra items is a polarization separator. The separation of the two velocity components is achieved by producing two orthogonal sets of crossing laser beams intersecting at a single measuring point, and then polarizing each set differently.

The polarization separator takes the scattered light and feeds the detectors and electronic trackers, producing the orthogonal velocity component signals. The equipment was set up and used on the Deep Wave Flume Facility at Hydraulics Reserch, in order to gain experience and evaluate its suitability for oribital velocity measurements under waves. The work showed that for certain applications the system performed as well as more expensive two-colour systems.

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1.

Over the past decade the emphasis on water velocity measurements in model studies at HR has tended to shift from simple propellor meters to include other forms of measurement such as electromagnetic and acoustic devices. The most recent method to be examined is the Laser Velocity Meter. This has the considerable advantage of not only being nonintrusive, but_also having a measuring volume of less than 1 mm³. The first unit to be used at HR was a low power (5mW) single component system without frequency shift which meant that directional information was absent from the measurement. It was sucessfully employed for determining velocity profiles in a small annular channel used for studies of mud deposition and scour. Later a frequency shifting system was added which increased its versatility by allowing directional measurement, and in conjunction with a second similar system with a higher powered laser (7.5mW) bidirectional velocity measurements in pipes and flumes have been successfully made. (Ref 1)

However one area which the existing laser systems at HR were unable to explore was turbulent flow and orbital water velocities beneath waves. In order to successfully achieve this, it is necessary to provide at least simultaneous two component measurements eg. one vertical and one horizontal. Under this research contract for DoE it was possible at minimum cost to convert one of the existing single component systems, to a two component one. The extra parts required were paid for as part of the DoE funded research budget. The extra parts permitted the separation of the two components by polarizing the laser light and having a detector which is polarization sensitive. Some very useful experience with this new system has been obtained using the large wave flume at HR with the kind co-operation of the Maritime Engineering Department.

In order to explain the two component system in greater detail with its benefits and problems, the single component system will first be described, both with and without frequency shift, and then the extra parts required for two-component measurement will be described, with an outline of how they convert the single component system. Our experiences with the two-component system will then be described, noting both its advantages and its shortcomings with recommendations as to how these can be overcome, and the system improved. Finally suggestions for future work will be made. SINGLE COMPONENT SYSTEM WITHOUT FREQUENCY SHIFT

This basic system can be used both in differential doppler mode and reference beam mode (Fig 1).

Differential doppler mode is used where the measuring point (where the two beams cross) is clearly visible. The receiving photomuliplier optics is focussed on the crossing point. Particles travelling with the flow scatter light from the fringes produced by the two beams crossing. The scattered light is measured with a photomultiplier and the output frequency (proportional to velocity) represented as a d.c. voltage on a frequency tracker.

Reference beam mode is used where there is severe attenuation of the beam, such as in a turbid flow medium. In this case the photomultiplier is aligned co-axially with one of the beams, which is deliberately weakened. The travelling particles scatter light from the bright beam and these are mixed with the weak beam light. The frequency is again measured with the tracker.

Looking at Fig 2, the laser beam (7.5mW Helium-Neon at 633 nanometres) is fed into a beam-splitter which is capable of attenuating one of the beams (for reference beam mode), and altering polarization if necessary. Of the two beams emerging from this, one is displaced 30mm from the centre but the other is still central. To bring the other beam out 30mm in the opposite direction a beam displacer is needed. Finally the two beams now 60mm apart are fed through a lens with 600mm focal length which focuses them at the measuring point. This measuring point is then viewed by the photomultiplier, and its output processed by the frequency tracker.

This system is adequate where only the magnitude of the flow is required, but it cannot provide the flow direction. Also it is not possible to measure zero flow. As the fringes at the measuring point are stationary, the frequency of the scattered light will be zero for zero velocity. The tracker is not capable of measuring below 10% of its full scale range, which limits the lowest velocity that can be measured. 3. SINGLE COMPONENT SYSTEM WITH FREQUENCY SHIFT

> Looking at Figure 3 it will be observed that a Bragg Cell has now been placed between the beam splitter and beam displacer. This frequency-shifts one of the beams. The effect of this is to produce moving fringes rather than stationary ones, so that it is possible to obtain a single component output for the frequency tracker whatever flow magnitude and direction is present. The amount of frequency shift and hence fringe velocity is controlled by the frequency shifter electronic unit. This device has proved useful in measuring the turbulence fluctuations in one plane only in certain flow studies conducted in straight laboratory channels. With the system it is possible to measure velocities from fractions of mm/sec to metres/sec.

4. TWO COMPONENT SYSTEM WITH FREQUENCY SHIFT

The more elaborate layout necessary for two component measurements is shown in Figure 4.

The additional parts purchased in order to convert the single component system shown in Figure 3, to this two component system were

- a) neutral beamsplitter
- b) polarization separator with two filters.

For the evaluation tests the second photomuliplier and tracker were borrowed from another existing HR velocity meter.

It will be noted that the laser beam passes through the neutral beamsplitter first. This beam (B1, displaced by 30mm) undergoes no further action and is therefore unpolarized when it is directed by the lens to the measuring point. The beam which is not displaced passes through the active part of the Bragg Cell and therefore undergoes frequency shifting after which it passes through the polarizing beam splitter. In this application the plunger on the beam-splitter is pulled right out which causes the two emerging beams to be polarized at 90° to each other. The undisplaced beam B2 is offset by 30mm with a beam displacer so that all three beams emerge from the lens as shown in Figure 5. Bl is unpolarized, B2 and B3 are polarized at right angles to each other. We utilise the fringe model to describe the intersection of all three beams at the measuring point.

Bl will interact with B2 to produce fringes which are vertically polarized, and at right angles to the plane of the two beams. Bl will also interact with B3 to produce fringes which are horizontally polarised.

Since the planes of the two sets of intersecting beams are themelves at 90° to each other, this means that the fringes are also at 90° to each other but at the same measuring point . Looking at Fig 6 the system has been turned through 45° so that the fringes are vertical and horizontal. It will be observed that a particle passing through the measuring point at a small angle parallel to the horizontal fringes, will cross more of the vertical fringes in a given time than the horizontal fringes, and so the vertical fringe measured velocity component will be higher than that for the horizontal fringe.

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The system distinguishes between the two components because the vertical fringe system is polarized at 90° with respect to the polarization of the horizontal fringe sytem. By placing a polarization separator behind the photomultiplier optics the scattered light from the two sets of fringes can be separated out, each being fed to a different photomultiplier and hence to a different tracker unit, giving two separate orthogonal components. From the two components so produced it is possible to calculate the true magnitude and direction of the particle velocity.

In order to calculate the actual velocity measured, the following equation is used:

 $f_D = \frac{2V}{\lambda} \sin \left(\frac{\emptyset}{2}\right) \qquad \dots \dots \qquad (1)$

where f_D is the Doppler shift in the frequency of the scattered light. (See Fig 7).

V is the component of the velocity in the plane of the two beams and perpendicular to a line bisecting the angle between them.

 \emptyset is the angle between the beams

 λ is the wavelength of the laser light

And considering the fringe model the distance between the fringes:

$$\Delta F_r = \frac{\lambda}{2 \sin \frac{\phi}{2}} \qquad \dots \qquad (2)$$

Rearranging (1) we have

$$\mathbf{v} = \frac{\mathbf{f}_{\mathbf{D}} \lambda}{2 \sin \frac{\emptyset}{2}} \qquad \dots \dots (3)$$

In other words the velocity component perpendicular to and in the plane of the fringes is equal to the distance between each fringe multiplied by the frequency at which each fringe is crossed. (See Fig 8). If we are measuring with a single component laser velocity meter, looking at say the flow along a flume, the particle velocity direction will probably be as shown in Fig 8 (ie. horizontal and in the plane of the fringes).

However in the two component case we are interested in particle direction as well as velocity. The situation here will therefore be more complicated in that in the type of appplications calling for a two component system the angle of the particle velocity direction with respect to the fringe lines will vary, although the particle should still be travelling in the plane of the fringes. A typical example is the velocity of water under waves generated in a narrow flume, where the flow pattern is basically two dimensional. Near the bed the horizontal components predominates, whereas nearer the water surface, the horizontal and the vertical components become more equal.

Let us now analyse what happens as a particle passes through the two sets of fringes. In Figure 6 these two sets of fringes are drawn separately for clarity. A particle passes through at 20° to the horizontal. The path length for this particle between the vertical fringes will be

 $\frac{\triangle Fr}{\cos 20^{\circ}}$

where \triangle Fr is the distance between the fringes

Therefore if this particle is travelling at a velocity V then the frequency of scattered light produced will be

 $\frac{V \cos 20^{\circ}}{\sqrt{Fr}}$ from the vertical fringes = f vert.

Similarly the path length between the horizontal fringes for this particle will be

 $\frac{\triangle Fr}{\cos 70^{\circ}}$

and therefore the frequency will be

 $\frac{V \cos 70^{\circ}}{\triangle Fr} = f hor$

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Suppose the fringe spacing was 10^{-2} mm*, and the true velocity V was lmm/sec (Fig 9)

then

f vert would be $\frac{1 \cos 20^{\circ}}{10^{-2}}$

= 93.97 Hz

and f horiz would be $\frac{1 \cos 70^{\circ}}{10^{-2}}$

= 34.2 Hz

which given the fringe separation mentioned of 10^{-2} mm would indicate velocity components of 0.9397 mm/sec and 0.342 mm/sec.

* The actual fringe spacing in our instrument will be calculated later.

The true direction of the velocity can be ascertained by drawing a vector diagram. See Fig 9. (The actual direction will of course depend on the sign of each component) ie. whether it is travelling up or down in the case of the vertical component, or from left to right or right to left in the case of the horizontal component.

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The first parameter to be established is the half-angle of the intersection between the polarized and non polarized beams. Refering to Fig 5 it will be observed that the beams emerge from the lens at points on a radius of 30mm and at 90°. The linear separation will therefore be:

$$\sqrt{30^2 + 30^2} = \sqrt{1800}$$

= 42.43 mm

The focal length of the lens is 600mm, therefore the tangent of the half-angle

 $\frac{42.43}{2 \times 600}$

- .03536

At this small angle tan $\emptyset/2 = \sin \emptyset/2$

Therefore $\sin \frac{\emptyset}{2} = .0354$

This can be checked by projecting the beams over a long distance, and measuring their separation.

The laser wavelength λ = 632.8 x 10⁻⁹m

Therefore (equation 3)

$$V = f_{D} \frac{6.328 \times 10^{-4} \text{ mm/sec}}{2 \times 3.54 \times 10^{-2}}$$

or
$$\frac{V}{f_{D}} = 8.938 \times 10^{-3} \text{ mm sec}^{-1} \text{ Hz}^{-1}$$
$$= 8.938 \text{ mm sec}^{-1} \text{ Khz}^{-1}$$

The fringe separation

$$= \frac{\lambda}{2 \sin \frac{\emptyset}{2}} = 8.938 \times 10^{-3} \text{mm}$$

The output from each of the two photomultipliers is fed to a separate frequency tracker each of which has its own calibration in terms of d.c. voltage output for a given frequency input. These are calibrated using a frequency generator and it was found that one gave 10 volts d.c. only for full scale input on each frequency range, whilst the other gave 9.16 volts out for full scale input. This obviously shows the value of calibrating each part of the system and not relying on the sensitivity stated by the manufacturer. USE OF THE INSTRUMENT ON THE DEEP WAVE FLUME

6.

A two-component L.V. meter was set up in the Deep Wave Flume. This flume has thick plate glass windows on either side near the beach area, and the first thing to ascertain was whether the type of glass used would depolarize the laser light. Using a piece of polarization sensitive film it was possible to show that the correct polarization for both beams was carried through the glass. When the film was placed in the beam in line with the polarization the full strength of the beam was seen, but when turned through 90° the beam disappeared.

The laser and optics generating the three beams were mounted firmly on concrete blocks on one side of the flume. The receiving optics were clamped alongside the electronics on the other side of the flume because the back-scattered signal was too weak to use.

The laser unit was turned in its mounting until the planes of the intersecting beams were vertical and horizontal thus giving vertical and horizontal fringes. The photomultiplier (P.M.) optics were then mounted and aligned at 45° to the vertical to separate out the two polarized components. With the laser beam and the frequency shifters switched on the P.M. optics were finally aligned so that the crossing point of the three beams was in view. Fine adjustment of the P.M. optics is facilitated with an adjustable pinhole at the centre of concentric rings which enables the P.M. to see just the crossing point and not the stray light around it. The lens on the front of the optics was also adjusted to give a sharp image of the beams coming together. The intensity of the received light separated into the two P.M. tubes by polarization, was then observed by looking at the two photocurrents produced. The voltage on the P.M. tube was turned up until about 50 uA current flows.

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At this point a check was made to ascertain which tracker was sensing which fringe system and hence which velocity component, vertical or horizontal. This was done by blanking off one of the polarized beams emerging from the laser, and seeing which photocurrent dropped to zero. It was noted whilst setting up the system that the brightest forward scattered light was observed in line with the beam, and as the viewing point moved off the axis the beams became fainter. The receiving optics were therefore set up as close to the axis of the beam as possible; while still being able to view the crossing point clearly. If the beams are viewed directly on-axis, the situation becomes confused by the reflection at the glass/water interface on the flume windows.

In the flume with the wave generator switched on there were always sufficient particles stirred up in the water to provide scattering for measurement. In fact on some occasions the water was too turbid to obtain a measurement and this rather highlighted the problem of two-component measurement with a relatively weak laser (7.5mW). As velocities of the order of $\pm 1m/sec$ were expected the tracker sensitivity was set to 333 KHz full scale (equivalent to approx 3m sec⁻¹ vel). The frequency shift of 200 kHz was then applied giving +1.18 to -1.79 m sec⁻¹ coverage. (The frequency shift could only be set in steps of 100 KHz). Figures 10 and 11 show a chart record of the X (horizontal) and Y (vertical) components measured for two heights above the bed (12 and 27cm). The water level is about 45cm and the average wave amplitude about 10cm. It is quite noticeable at the higher position how much larger the vertical velocity is and how more higher frequency, shorter wavelength components are occurring. Figure 12 shows what happens as the wave generator is turned off and the wave amplitude dies down. The horizontal component is faithfully followed, but when the amplitude of the vertical component drops the tracker is unable to follow and fails to follow the velocity consistently. This is seen on the frequency tracker as the "lock" light flashing on and off indicating that the tracker is sometimes not seeing a scattered particle frequency to track.

It was found that one of the trackers appeared to require a higher level of input signal from the photomultiplier to "lock" properly. Consequently when there were insufficient seeding particles in the water, "spikes" would appear on the output signal as the system "unlocked". The less sensitive tracker which happened to be measuring the vertical component in these tests consistently gave noisier signals. This appears on the chart records as a high frequency component, but is in reality the tracker failing to lock onto the received signal.

If the water is allowed to settle completely very few particles are observed. The output from the two trackers will give a voltage corresponding to zero flow some of the time, and a spurious reading at other times. If the monitor output on each tracker is observed on a CRO, which shows the magnitude and frequency of the scattered light, the amplitude will be seen to rise and fall with time and in fact a large amplitude correlates with the periods when the tracker is following correctly. This means that there is not at all times sufficient scattered light from the measuring volume to make a measurement. In practice this could be overcome by seeding the water with suitably-sized particles, (e.g. 5 to 10 um). Several methods of seeding have been tried such as emulsion paint (which is fine particles in suspension), milk (fat particles in suspension) and Jeyes fluid which worked quite well. However these do have a tendency to settle out over windows etc. On a small scale we have tried ground aluminium powder which gave excellent results in a small perspex tank on the laboratory bench. The problem is applying sufficient seeding to a large volume of water, such as the Deep Flume, and keeping the seeding concentration high enough to obtain strong enough signals. The solution would seem to be either to have an automatic injector or simply drop some seeding material into the water occasionally. When making measurements of turbulence care must be taken to ensure that the particles are small and light enough not to significantly modify the way in which the water moves. In the situation when the water had been well stirred up by wave action, it became fairly turbid with consequent attenuation of the beams. In this situation a higher powered laser would have been very useful. The problem with the two-component system is that the frequency shifted beam already at 50% of its original strength is then split again so that the two polarized beams are only 25% of the strength of the original laser beam.

During some of the tests carried out in the Deep Flume a two component Electromagnetic Current Meter was making measurements close by, and in general good agreement was obtained between the results for the two measurement systems.

The big advantage of the laser system was its ability to measure very near the floor of the flume, which because of the hydro-dynamic effects, the E.M.C.M could not. The two component system will function well in situations where there is a sufficient number of very small particles in solution, and the optical access is via windows which do not depolarize the laser beams. The 7.5 mW laser used with the system was found to be rather weak and, apart from very small scale applications, unsuitable for back scattered measurements. In forward scatter the best signal to noise ratio was obtained by viewing the measuring point almost on axis. The bandwidth of the system is wide enough to cope easily with turbulent measurements in water and is limited by the ability of the particles to move with the water. For many applications the system will perform as well as the much more expensive two colour systems.

8. **RECOMMENDATIONS**

The existing system would benefit from a higher powered laser e.g. 15 mW or 25 mW, to make it possible to operate in the back-scatter mode. In this way measurements could be made from one side of a flume or tank.

Having shown that the equipmment purchased will produce two components of velocity satisfactorily it would be of great interest to study turbulence around some of the meters and transducers which are placed in flowing water (particularly wave flumes) at HR. This would be of particular interest with new transducers under development. The author wishes to acknowledge the help and advice given by colleagues in the Services Section at HR Ltd, in particular Mr I E Shepherd and Mr M J Crickmore. Also to the Maritime Engineering Department at HR, in particular Mr N W H Allsop and Mr A Bradbury for the use of the Deep Wave Flume and the help given in using the instrument on this facility.

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10. REFERENCES

 Practical applications of laser interferometers. HR Tech Memo 2/1983.

Figures

beam. Light from normal intensity beam is scattered by particles and viewed along weak beam PM optics must be placed coaxially with the weak PM optics can be placed anywhere provided that it can be focussed on to the crossing point and the scattered light level is sufficiently high Both beams equal intensity a) Differential Doppler Mode Attenuated b) Reference Beam Mode Norma(Laser optics Fig 1 modes Measurement









Fig 5 Geometry of beams producing 2 sets of fringes



Fig 6 A particle passing through 2 sets of orthogonal fringes







Fig 9 Reconstruction of true velocity magnitude and direction from its 2 components



Fig 10 Chart record - measuring point 12cm above bed





away

Plates

Series - Series

T.



PLATE 1 Beam generating optics



PLATE 2 Collection optics