CHAPTER 118

PARTICLE VELOCITY MEASUREMENTS WITH A LASER DEVICE.

by

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ABSTRACT

A laser velocimeter has been used to measure particle velocities in a turbulent suspension in open channel flow.

Both mean and fluctuating velocity components can be determined and the system may also be used to give records of instantaneous fluid velocities.

INTRODUCTION

Fundamental to the study of those coastal engineering problems which involve diffusion processes or transport of sedimentary material by tidal currents and wave action, is the measurement of particle velocities in turbulent flow. Particles of neutral buoyancy which are small compared with the largest wave number eddies will follow the flow pattern precisely and can therefore be thought of as fluid markers In diffusion and sedimentation problems, however, the particles of interest are generally of non-neutral buoyancy and the gravity effect causes them to migrate vertically carrying them across streamlines of the mean flow. In addition to this, the fact that the inertial response of the particles will be different from that of an equal volume of fluid, will cause the particles to move relative to the fluid in accelerating turbulent eddies. Thus detailed studies must involve the statistical properties of both the fluid motion and the particle velocities.

Experimental research on these complex motions has hitherto been handicapped by lack of satisfactory instrumentation. Photographic methods have been used to measure particle movements in a Lagrangian manner but necessarily entail the laborious analysis of exhaustive data and tend to be very inaccurate Hot film probes and other conventional turbulence measuring systems, on the other hand, are extremely difficult to use in water and further do not give any indication of particle velocities

In the optical system described here, particles moving within a prescribed measuring volume cause a signal to be produced which has a frequency directly proportional to their velocity and thus the Eulerian

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statistics of their motion can be determined. Fluid velocities can be measured by using extremely fine grain neutral buoyancy tracer particles, assumed to have a negligible influence on the flow.

OPTICAL MEASURING SYSTEM

Optical Configuration. Light from a small laser (here 1mW helium-neon) is spread and collimated by two cylindrical lenses L_1 and L_2 and the parallel beam is then split by a mask M containing two small square apertures of size a and spacing b (figure 1).

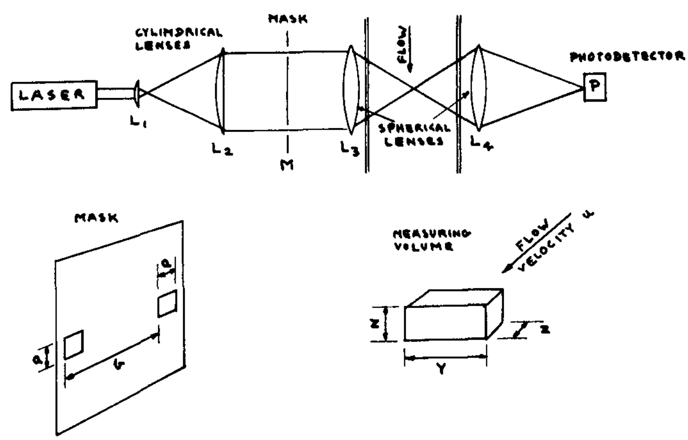

Figure 1. Optical layout.

A spherical lens L_3 is then used to bring the two beams to a focus at the required measuring point in the flow, a further spherical lens L_4 being used to image to focus on to a photodetector P.

Interference of the two beams causes a fringe pattern to be formed within a small volume at the focus and as particles move through this volume with velocity u, small patches will move across the image observed by the photodetector causing a signal of frequency

$$f_1 = \frac{b}{\lambda L} u \qquad \text{where} \begin{cases} \lambda = \text{wavelength of laser light} \\ L = \text{focal length of lens } L_3 \end{cases}$$

i.e. proportional to velocity.

Measuring Volume Although the fringes die away gradually to infinity, the measuring volume at the focus from which significant signals are produced can be taken as being approximately of size Z x Z x Y where

$$Z = \frac{\lambda L}{a} \quad \text{and} \quad Y = \frac{\lambda L^2}{ab}$$

This should be chosen so that   is greater than the diameter of the largest particles.

SIGNAL ANALYSIS

Frequency Domain The simplest method of analysis, illustrated in figure 2, is to feed the photodetector output directly into an analogue spectrum analyser and integrate the output with an R-C circuit The spectrum, which can be recorded on an X-Y plotter, then represents the probability distribution of velocity for particles in the measuring volume

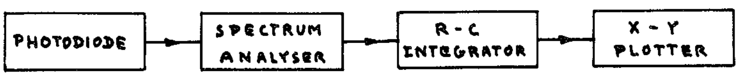

Figure 2. Frequency domain system

Ambiguity in the frequency measurement will occur here due to the finite number of fringes, but the magnitude of this can be predicted by taking the Fourier transform of the input signal giving

$$\text{r m s. ambiguity} = \frac{a\, f_1}{\sqrt{6}\, b} \quad .$$

This should normally be of order 1% of f_1 for negligible error in velocity measurement i.e $\frac{b}{a} = 40$

The details of this analysis have already been published (ref 2) but it is assumed here that the spectrum analyser used gives the modulus of the Fourier components of the signal i.e. the frequency spectrum, rather than the power spectrum This is the case with nearly all commercial spectrum analysers It is also worth noting that the band width of the spectrum analyser should be small and the sweep rate long.

Figure 3 shows a typical spectrum obtained in a small flume.

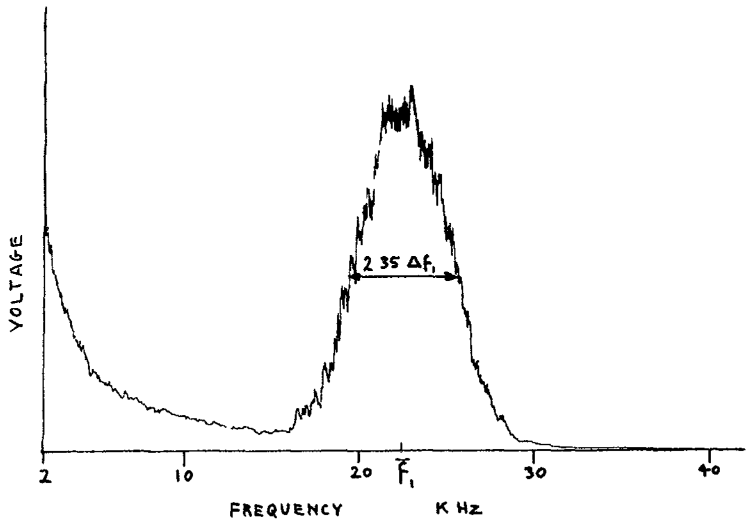

Figure 3. Spectrum of signal from photodetector.

Velocity Cross-Correlations The technique of rotating a hot-wire probe relative to the mean flow direction, or alternatively using an 'X' probe, has been used extensively for the measurement of Reynolds stresses in wind tunnels In the same way the fringe pattern in the laser flow-meter can be rotated relative to the optical axis to give cross-correlations of particle velocities Referring to figure 4, let us consider a mean velocity $\bar{u}$ with fluctuating component u' in that direction, the fluctuating component perpendicular to $\bar{u}$ being v' .

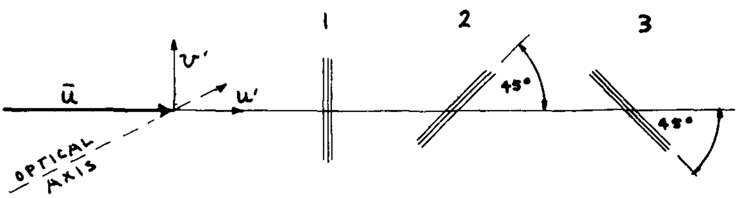

Figure 4. Alignment positions of the fringes.

Take the constant of proportionality for conversion from frequency to velocity as K i e with the fringes in position 1 the mean frequency (see figure 3) will be

$$\bar{f}_1 = K\,\bar{u}$$

If the r.m.s. width of the spectrum is Δf_1 then the r m s velocity fluctuation is

$$\sqrt{(\overline{u'^2})} = \frac{1}{K}\,\Delta f_1$$

It can then be shown (Ref 2) that by measuring the r m s spectral widths Δf_2 and Δf_3 from recordings taken in positions 2 and 3 i e at $+45^0$ and -45^0 to the mean flow direction, the transverse velocity fluctuation $\sqrt{(\overline{v'^2})}$ and the cross-correlation $\sqrt{(\overline{u'v'})}$ can be found from

$$\sqrt{(\overline{v'^2})} = \frac{1}{K}\sqrt{(\Delta f_2^2 + \Delta f_3^2 - \Delta f_1^2)}$$

and

$$\sqrt{(\overline{u'v'})} = \frac{1}{K}\sqrt{(\Delta f_3^2 - \Delta f_2^2)}$$

For most practical purposes it will be satisfactory to assume that the velocity probability distributions are Gaussian whence the width at half the height is equal to 2 35 Δf, as indicated in figure 3

Time Domain Analysis If the system is to be used to record velocities of tracer particles in the fluid then it is possible to construct the electronics in such a way that a continuous signal, proportional to the instantaneous velocity is obtained This will be called the 'time domain' method and the essential elements of the circuitry are shown in figure 5 More details are given in reference 1

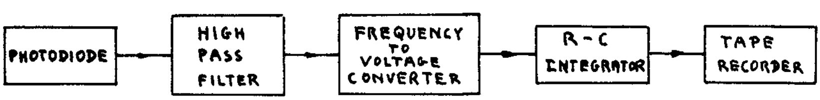

Figure 5. Time domain system

Firstly, the signal produced by the photodiode contains unwanted low frequencies produced by the total amount of light cut off as particles move across the observation volume, together with the noise caused by the passage of particles across points in the beam outside the observation volume. These frequencies are eliminated with a high-pass filter and a frequency-voltage converter is used to give an output signal proportional to the rate of zero crossings

Even if the fluid velocity were absolutely constant, the signal from the frequency-voltage converter would contain small fluctuations due to the finite number of fringes, the r.m.s. value of this fluctuation being equal to $a/(\sqrt{6}\,b)$ times the mean value. These can be damped before recording by using an R-C integrator, thus improving the resolution, but the integrating time should not be so long as to damp fluctuations due to velocity changes

PRELIMINARY RESULTS

Some preliminary results using the 'frequency domain' method are illustrated in figure 6 for the motion of glass spheres of diameter about 0.075mm in steady free surface flow. The velocities in the direction of mean flow were recorded in a channel 5cm wide with a measuring volume of size z = 0 4mm , Y = 1 cm These show the characteristic fall off in mean velocity and increase in r m.s. velocity fluctuation towards the bed

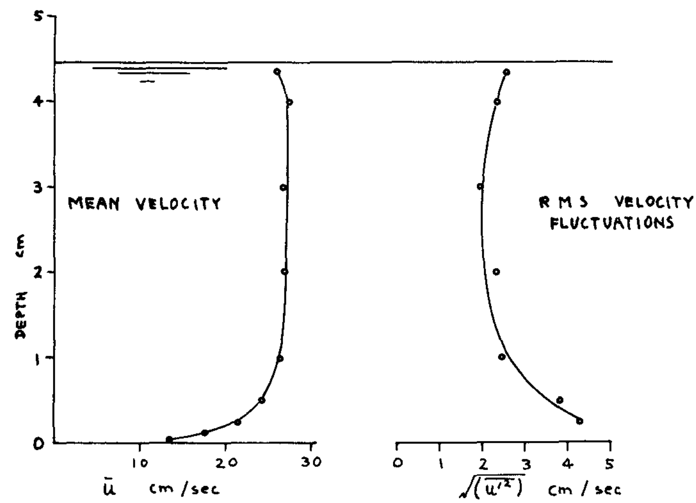

Figure 6 Particle velocities in open channel flow

At present the system is being adapted for measurements in a flume of 1m width and it is hoped that it will be possible to make simultaneous measurements of velocities and particle concentrations

POTENTIALITIES OF MEASURING SYSTEM

The system described would seem to fulfill the main requirements of a coastal engineering laboratory Both fluid velocities and velocities of larger suspended particles can be measured with precision and to within a fraction of a millimeter of a wall The instrument is directionally sensitive and rotation of the fringe pattern will give transverse velocity components and cross-correlations

REFERENCES

1 Greated C, 1970 Journal of Physics E Sci. Instrum Vol 3, Pp 158-160

2 Greated C, 1970 Journal of Physics E Sci Instrum Vol 3, Pp 753-756