

# Laser Doppler Velocimetry

## 1 Introduction

Laser Doppler Velocimetry is a means by which velocity in a fluid can be determined optically, and hence, without interfering with the fluid itself. The process involves measuring the Doppler shift of the laser radiation that is scattered by the moving particles. The technique was first developed in 1964 by Yeh and Cummins [1] who employed it to measure laminar water flow. Since then, numerous improvements have been made from improving the optical geometry to developing better signal-processing equipment. Correspondingly, many diverse applications have evolved ranging from measurements of turbulent systems such as aircraft trailing vortices and remote wind sensing, to techniques by which the size of particles themselves can be determined. The purpose of this lab will be to investigate the basic principles involved in laser doppler velocimetry and to apply these to some simple applications.

## 2 Theory

The experimental arrangement for the differential laser doppler velocitometer used in this lab is illustrated in Figures 1 and 2. Presently, there are two interpretations of such a system. The first is the Doppler-shift interpretation in which the scattered radiation is regarded as being composed of two beams. Optical heterodyning of the scattered radiation results in a different frequency, which is proportional to the particle velocity.

The other interpretation considers a real fringe system being created in the beam crossover region. As particles cross the fringes, the intensity of the scattered light is modulated at a rate directly proportional to the velocity. Under appropriate conditions, the governing equation, which can be derived from either of the above interpretations, reduces to

$$(1) \quad f = \frac{2v \sin \theta}{\lambda}$$

Where  $\lambda$  is the laser wavelength,  $v$  is the particle velocity and  $f$  is the signal frequency discussed above. Hence by measuring this frequency, the flow velocity can be determined. A brief description of the basic theoretical aspects of doppler velocitometry, including the development of this equation, should be included in the report.

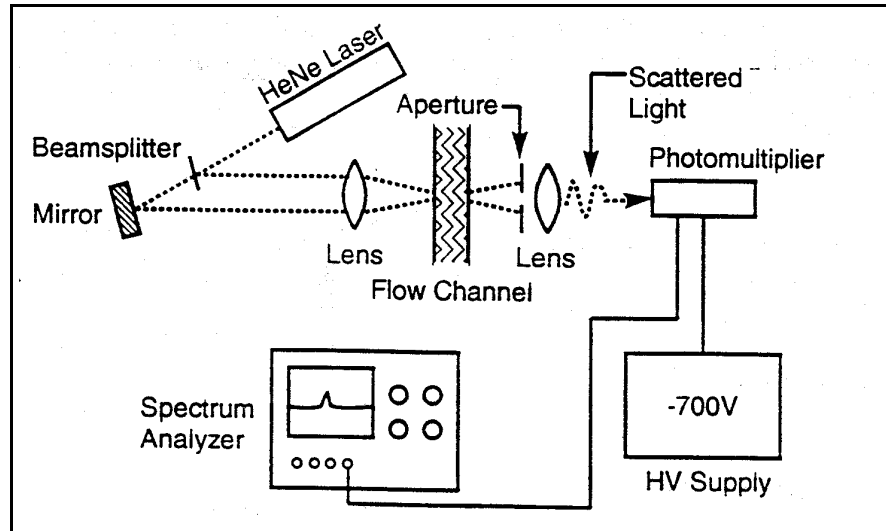


Figure 1: The optical system used for Laser Doppler Velocimetry in this laboratory.

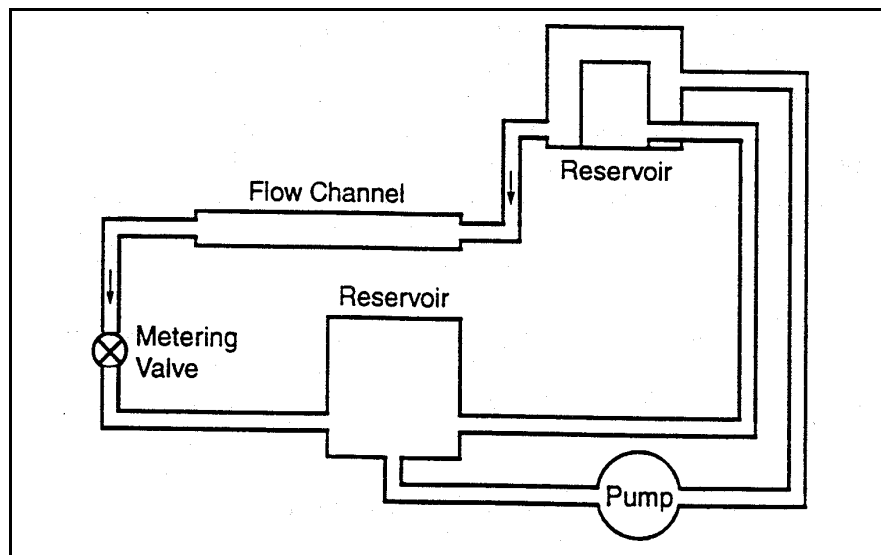


Figure 2: The flow system used in this laboratory.

### 3 Experimental

#### 3.1 Determination of Average Flow Velocity

By aligning the apparatus such that the probe region is in the centre of the flow channel, and by knowing the flow profile (see Section 3.2), the average flow velocity can be determined (remember to include the effects of refraction when determining the angle). The resultant value should be compared with that obtained by measuring the volume flow rate using conventional means. Since the flow channel cross-section is accurately known ( $1.000 \pm 0.001$  cm by  $1.000 \pm$

0.001 cm), the volume flow rate can be converted to a flow velocity. Both measurements should be made for a range of flow rates and a graphical comparison made.

Note: After the lab instructor ensured that the flow system was clean and that the distilled water had been properly filtered and de-ionized, a small amount of milk was added to the water.

### **3.2 Determination of Flow Velocity Profile**

Under proper conditions, (e.g., low Reynolds number, etc.) a parabolic flow profile should be present in the flow channel. By scanning the probe region across the flow channel, the actual flow profile can be determined. When doing this, particular care should be taken to accurately note the positions at which the measurements are made. Plot the results and compare the measured flow profile with the expected one. Account for the discrepancies by considering the different types of flow that could in fact be present in a system such as this.

### **3.3 Determination of Beam Angle Effects**

Using the same average velocity values as part 3.1, vary the beam angle (2 values) from the smallest possible to the largest possible and sketch the spectrum analyzer display for each. Show all settings, scale values, and beam angles. Discuss the effect of beam angle on bandwidth and resolution.

By relating the results of all parts, comment on the accuracy of the techniques employed in this lab. In particular, consider the effects of any assumptions or simplifications that were made in the analysis. Hence, determine the ultimate capabilities of this arrangement. Include in this discussion any design changes, which could lead to significant improvements in these capabilities.

### **3.4 Further Experimental**

This section should be completed if time permits and/or you want bonus marks and further experience with the application of laser velocimetry. In this section you will attempt to measure the actual size of the seed particles in the fluid.

#### **Procedure:**

- i) Carefully remove the square glass tube from its mount and set it aside. Now mount the glass tube connected to the plastic box with the pump where the first tube was. Fill the box with clean DI water and run the pump for a few minutes to flush the glass tubing. Drain all the water from the box and glass tube system. Refill the box with clean DI water and run the pump.
- ii) Set up the velocimeter as before and sketch the display of the spectrum analyzer. Can you see a signal? Now add a small amount of 0.05-micron powder to the water in the box. Wait a few minutes and sketch the signal showing all the scales. Note the width and

height of the signal. Now adjust the beam angle and focus to maximize your signal and re-sketch the display. Record the new beam angle.

- iii) Now add a few drops of milk to the water until the signal changes. Sketch the display noting the width and height of the signal. Given the known size of the powder and its signal can you determine the diameter of the milk particles from this data? Discuss the results and reasoning. How does the set-up alignment and beam angle effect the signal? Can this system be improved to accurately measure particle sizes?

## References

- [1] Y. Yeh and H.Z. Cummins. Localized fluid flow measurements with a He-Ne laser spectrometer. *Applied Physics Letters*, 4:176, 1964.
- [2] L.E. Drain. *The Laser Doppler Technique*. John Wiley, New York, 1980.
- [3] T.S. Durrani and C.A. Greated. *The Laser Doppler Technique*. Plenum Press, New York, 1977.
- [4] F. Durst, A. Melling, and J.H. Whitelaw. *Principles and Practice of Laser-Doppler Anemometry*. Academic Press, New York, 1976.
- [5] J.H.C. Chan. *Optical Velocimeters*. PhD thesis, McMaster University, Hamilton, 1976.
- [6] E.A. Ballik and J.H.C. Chan. Fine image technique for the measurement of flow velocities. *Applied Optics*, 12(11):2605, 1973.