LDV Measurements in Turbulent Open-Channel Flow

Objective

The experiment demonstrates the use of non-intrusive Laser Doppler Velocimetry (LDV) technique for velocity measurements and illustrates methods of acquiring data in conjunction with a computer-based data acquisition system. The practical flow used for this demonstration is a fully-developed open-channel flow. Finally, the experiment gives a glimpse of the manner in which the mean and turbulence characteristics of this practical flow are presented and analyzed in the literature on the topic.

Apparatus

The experiment is conducted in the 30-meter-long, 0.91-meter-wide and 0.45-meter-deep glass sided flume is given in Figure 1. Well finished concrete covered the flume's bed. The water is recirculated by two 7.5-horsepower variable speed, motor-pump units located beneath the tailbox of the flume. The flow is returned to the headbox of the flume via two 0.25-meter-diameter pipes. For damping large scale turbulence and secondary currents the entrance flow is conditioned by means of a honeycomb flow-straightener consisting of a stack of 0.20 m long tubes and a floating wood grid displaced just downstream of the straightener. The flume discharge can be adjusted coarsely by selection of the pump speed while for finer adjustments butterfly valves in the suction lines of the pumps were employed. Orifice-meters on the return pipes are used for discharge calculation (resolution 5×10^{-5} m^3/s). The flume is supported by a central pivot and four synchronized motor-driven jacks so that the bed slope can be adjusted without interrupting the flow. Precisely leveled steel rails for the instrument carriage, mounted atop the flume walls provide the reference frame for elevation relative to a plane tilted at the flume slope. The slope of the bed can be measured by means of a dial gauge and a point gauge at the downstream end of the flume. The slope of the water surface is measured using eight piezometers spaced at 3.048 m intervals, fitted to the invert of the flume, and connected to a bank of glass manometer tubes. A vernier with a resolution of 0.3 mm is used for measuring water levels in the piezometers. Linear regression of the eight measurements yields an average water surface slope for which the propagated uncertainty is estimated to be 2.4×10^{-9}.

The test section is located at 19 m from the channel entrance. Water surface elevations for this section are obtained from piezometer measurements and a point gage mounted on the instrument carriage referenced to the same zero value. A digital thermometer located in the test section measured water temperature.

The LDV system used in the present work is a two-component, He-Ne-laser-based as shown in Figure 2. The specifications of the main components of the LDV system are presented in Table 1.

The dual-beam LDV system with the three-beam arrangement, as illustrated in Figure 3, has the common beam polarized at 45°, while the other two beams are polarized in the vertical and horizontal directions, respectively. Thus, two components of velocities, along the two edges of the triangle from the common beam, are measured, using the polarization as the separation criterion. The common beam is frequency-shifted using a Bragg cell arrangement so that reversed velocities can be measured.

The photodetectors receive the mixed light given by scattering particles, i.e., “environmental” dust contained in the tap water, passing through the measurement volume (MV). The analogue voltages from the photodetectors represents the inputs for the data acquisition system (DAS). DAS contains the signal processors and a personal computer (486 processor) for data processing and storage. With respect to the operation principle, the processors, IFA 550 (TSI), are combinations of frequency tracker and counter type signal processors. During processing the signals are filtered, the frequency information is extracted for both channels (processors) after a validation algorithm is performed, and finally the signal is digitized and transmitted to the computer. The fine adjustments needed to obtain good signal quality (visibility, low noise level, good data rate) are monitored by using an oscilloscope. Subsequent data processing using the manufacturer software (Flow INformation Display - FIND) provides mean and turbulence characteristics computed using the measured instantaneous velocities.

Procedure

(a) Check the open-channel flow conditions: flume entrance conditions, waviness of the free-surface in the channel, stability of the piezometer readings, cleanness of the wall and water in the test section.

(b) Check the connections of the LDV components and turn the system on.

(c) Activate FIND icon from the Windows screen and select the Data Acquisition Menu.

(d) Check the LDV system’s optical and electronical settings using the following menus
- Processor Setup Screen
- Optics Configuration

(e) Control and adjust, if required, the Doppler signals’ quality by concomitantly using the Hardware Diagnostics Screen and the Realtime Histogram Screen. The Doppler signals should appear on the oscilloscope as a series of short, random bursts caused by particles passing through MV. LDV requires “no calibration” but step (e) is crucial for obtaining accurate and sufficient recorded information.

(f) Precise the name and the location of the recorded files using the Data Files Management Screen

(g) Activate the Acquire Data Menu (F2) Screen. Specify the conditions and the location of the measurement within the series, and press <F2>, again, for taking data. Repeat step (g) to take next measurements. Use ESC key to return to the Main Menu of the FIND software.

(h) Data processing is performed by the use of Statistical Analysis Program. First specify using the Data Files Management Menu which are the files to be processed. Then, by activating the Statistical Display Screen the results of interest for the present experiment are computed and displayed.

Plots

1. Mean velocity profile in dimensional coordinates (U vs. h or y/h)
2. Mean velocity profile in wall coordinates (u^+ vs. y^+)
3. Normalized Reynolds stress profiles ($-\overline{u'v'} / u_*^2$ vs. y/h)
4. Normalized turbulence intensities (u'_{rms} and v'_{rms} vs. y/h)

Tabulate all the measured data (including the bulk flow parameters).
Select two methods at your choice for the computation of the friction velocity, u_*, (see Nezu and Rodi, 1986). Document the selection of the friction velocity used in the plots.
Write a report.

References

Nezu, I. and Rodi, W. (1986). "Open-Channel Flow Measurements with a Laser-Doppler Anemometer," *J. of Hydr. Engrg.*, ASCE, 112(5), 335-355.
White, F.M. *Viscous Fluid Flow*, 1974, McGraw-Hill