# A new high resolution velocity and acoustic turbidity profiler for open-channels

Stéphane Fischer
UBERTONE, 1, rue de Molsheim, 67000 Strasbourg, France
(email : stephane . fischer @ ubertone . fr)

Hydraulic studies in rivers and sewers need a detailed metrology of flow and sediment transport at all spatial and time scales. We have developed an ultrasonic profiler for open-channel flows that allow high resolution measurements of velocity and acoustic turbidity in environmental and industrial applications. The system is fully integrated in a hydrodynamic box connected by an Ethernet cable. It is equipped with two transducers placed in the front for the measurement over two axes at different angles and frequencies. The electronic board is composed by a low noise analog stage for adaptive amplification and demodulation of the acoustic signal, a digital part dedicated to real time sequencing and signal processing and a low power processor that manage the data storage and the embedded web interface. This new profiler allow high speed sampling of velocity and backscattered acoustic energy profile with a high spatial resolution in sever conditions. Typical applications for this profiler are velocity measurement on river or channels, flowmetering in partially filled pipes, sediment transport studies, velocity field around submerged structures, concentration measurements.

**Keywords:** velocity profiler, acoustic turbidity, field instrument

## 1 INTRODUCTION

The Ultrasonic Velocity Profiler is one of the more efficient tools in hydraulic research and studies [1]. It is useful in accessing the main velocity field in open channel flows, and the interpretation of backscattered signal amplitude at different frequencies can lead to the concentration of suspended particles [2]. This amplitude profile can also be used to detect interfaces [3]. The good spatial and time resolution of Doppler coherent systems allows the study of turbulence [4]. Ultrasonic techniques are widely used in environmental and industrial flows due to their non-intrusive nature and their ability to work with opaque fluids.

A better knowledge of hydrodynamic processes and sediment transport in sewer systems may improve their efficiency and reduce the pollution of natural flows.

We have developed an ultrasonic profiler for open-channel flows that allow high resolution measurements of velocity and acoustic turbidity in environmental and industrial applications.

## 2 INSTRUMENT DESCRIPTION

The UB-Flow F156 (figure 1) has been designed for studies in the field of hydrodynamic and sediment transport as well as sewer diagnoses.

### *2.1 Device*

The instrument is integrated into one single immersed hydrodynamic box. It is placed along the flow, and can be oriented in order to get either a horizontal or a vertical velocity profile. It is powered and communicates through the same cable. The device is handy and compact.


Figure 1: The UB-Flow F156 profiler is equipped with 2 transducers and integrates the whole electronic and software

### *2.2 Transducers*

The device is equipped with two transducers placed at the front of the instrument.

The large band transducers are centered on two different frequencies (1.5 and 6.0 MHz) in order to match a wide range of particle sizes, beginning at 30 µm.

| Frequency | Diameter | Angle |
|---|---|---|
| 1.0 to 2.1 MHz | 20 mm | 75° |
| 4.0 to 8.3 MHz | 5 mm | 55° |

### 2.3 Electronic

The hardware is composed of three main parts : analog, digital and computing. All electronics are integrated in an immersed box and weighs less than 150 g.

The analog part is equipped with a low noise 82 dB amplification/demodulation channel. The ultrasonic emission bloc allows instantaneous power of 25 W (RMS) at frequencies going from 800 kHz to 9.25 MHz, selected by the user.

The digital part manages the ultrasonic sequencing, the data sampling and the first stage of real-time signal processing.

The computing part lies on an operating system embedded in a low power processor associated with 4 GB on board storage. This part communicates by Ethernet with any computer or smartphone accessing to the network.

The system is powered by the same Ethernet cable using the IEEE 802.3af norm (*PoE*).

### 2.4 Software

The software for data management and user interfaces is fully embedded in the device.

The web interface allow the user to configure the instrument, to visualize the velocity and acoustic turbidity profiles in real time and to download the data files.

The software allows to store instantaneous velocity and acoustic turbidity profiles at the selected sampling rate. As the software of the device is autonomous, it can collect data during a few weeks without being connected to a PC.

### 2.5 Configuration

Many parameters are modifiable to finely tune the instrument to fit the application :

- transducer selection
- emission frequency (1.0 to 2.1MHz and 4.0 to 8.3MHz)
- phase coding
- pulse duration (0.5 to 1000µs)
- number of cells (2 to 100)
- distance between cells (from 2.5 mm)
- pulse repetition frequency (up to 5kHz)
- automatic or manual amplification gain

## 3 MEASUREMENT

### 3.1 Profiling method

One of the main advantages of the pulsed ultrasonic techniques is the ability to measure from a distance without perturbation of the flow. The emission of an ultrasonic pulse in a narrow beam allows you to observe a profile which is composed of many measurement cells (or volumes) distributed along the beam axis. Thereby, the pulse is transmitted along the beam in the medium and is backscattered by the particles suspended in the flow. The echoes of the particles are received by the same transducer, the signal is conditioned, amplified, demodulated and sampled. This signal contains informations on velocity and concentration, the travel time of the ultrasound is relative to the position of the concerned particles. Thus, the windowing of the backscattered signal in several blocs leads to the profile.

### 3.2 Velocity estimation

The UB-Flow F156 uses the coherent pulse Doppler method in order to estimate the velocity. This method uses the observed phase shift of the acoustic signal in a same volume during consecutive emission-reception cycles. Each cycle generates one data sample per volume. The set of data samples coming from the same volume is called "Doppler signal" and has a frequency $f_D$ which is related to the flow velocity $v$ in the corresponding volume according to:

$$v = \frac{c \cdot f_D}{2 f_0 \cdot \cos\beta} \qquad (1)$$

where $c$ is the speed of sound in the medium, $f_0$ the carrier frequency and $\beta$ the angle between flow and ultrasonic beam.

The Doppler frequency in one volume is given by the calculation of the first order moment of the signal (samples of the complex envelope with in-phase and quadrature components). Several methods may be used for Doppler frequency estimation. The UB-Flow uses the Pulse-Pair method [5]; another approach may be spectral analysis of the signal [6]. With the Pulse-Pair method, the estimated value of Doppler frequency is given by:

$$f_D = \frac{1}{2\pi T_{PRF}} \arctan \frac{\mathrm{Im}\left(R_{xx}\left(T_{PRF}\right)\right)}{\mathrm{Re}\left(R_{xx}\left(T_{PRF}\right)\right)} \qquad (2)$$

where $R_{xx}(\tau)$ is the autocorrelation function of the Doppler signal and $T_{PRF}$ the sampling repetition period.

The coherent pulse Doppler method has been largely studied [7,8]. This method ensures good temporal and spatial resolution and low variance on velocity estimation.

### 3.3 Acoustic turbidity estimation

The turbidity of fluid is generally measured by optical techniques. This parameter is used more and more in sediment transport studies in sewers and rivers because it can be linked to the suspended sediment concentration (SSC).

The acoustic turbidity is defined as the ability of the suspended particles to diffuse an acoustic wave. It relates, in each volume, for a given emission frequency, to the turbidity ratio :

$$T_r = \frac{v_r^2}{v_e^2 \cdot \Delta t_p \cdot G_t(z)} \left( \frac{z}{R_t} \right)^2$$

where :

- $v_r$ is the reception voltage,
- $v_e$ the emission voltage,
- $\Delta t_p$ the pulse emission duration,
- $G_t(z)$ the electro-mechanical gain of the transducer in emission/reception at the working frequency, including the near field correction (modelled from the data given by [9]),
- $z$ the distance to the transducer,
- $R_t$ the transducer's radius.

This parameter $T_r$ is proportional to the backscattered acoustic intensity and compensate all the transducer and instrument effects. Thereby, $T_r$ only depends on the characteristics of the liquid (attenuation) and of the suspended particles (concentration, size, nature, form). This parameter can be used to evaluate the SSC with granulometric (*i.e.* particle size) estimation [2].

## 4 EXPERIMENTAL SETUP

Figure 2: UB-Flow F156 installed on the river Aar.

The instrument has been configured according to table 1.

It was installed on the Aar (figure 2), an arm of the river Ill in Alsace. The river is 12 meters large. The Reynolds number of the flow is approximatively $3 \cdot 10^5$. The beam is horizontal, placed 10 cm under the free surface.

Table 1: Parameters of the instrument

| Variable | Symbol | Value |
|---|---|---|
| Carrier frequency | $f_0$ (MHz) | 1.5 |
| Pulse duration | $\Delta t_p$ (μs) | 20 |
| Pulse repetition frequency | PRF (Hz) | 700 |
| Number of volumes | $N_{vol}$ | 54 |
| Time between volumes | $\Delta t_v$ (μs) | 25 |
| Samples per estimation | $N_s$ | 300 |

## 5 RESULTS

The mean velocity profile measured from the border of the river is in agreement with the observed flow.

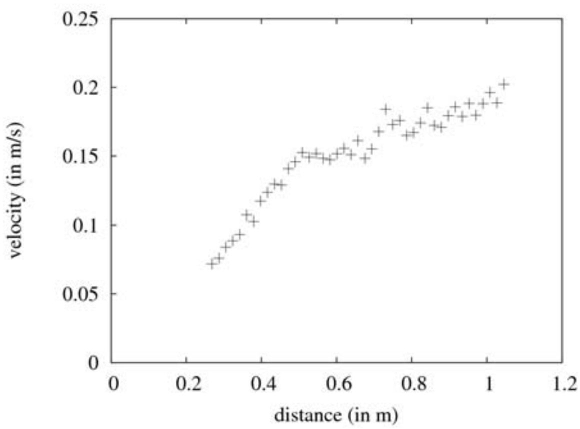


Figure 3: Mean velocity profile averaged over 133 successive instantaneous profiles

The standard deviation of the mean estimation is mainly due to the velocity dispersion in the flow.

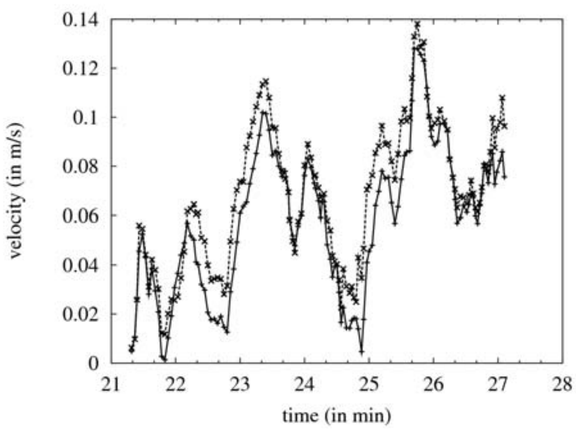


Figure 4: Evolution of the velocity in two measurement cells distant from 7.5 cm at 36 cm from the transducer.

The evolution of the velocity through the time is observed at a distance of 36 cm from the transducer and presented in figure 4.

This time series shows the large effect of the turbulence on the velocity fluctuation. The slowest velocity variation (approx. 0.01 Hz) corresponds to the energy injection frequency which is approximatively equal to the mean velocity divided by the hydraulic diameter.

The high correlation between the evolution of the velocity in the two cells distant from 7.5 cm is due to the coherence in the turbulent vortex.

The figure 5 compares the turbidity ratio $T_r$ in the same measurement cell in two different flow conditions. The first measurements have been done in low water conditions during July 2009, the second have been done during rainy conditions in December 2009.

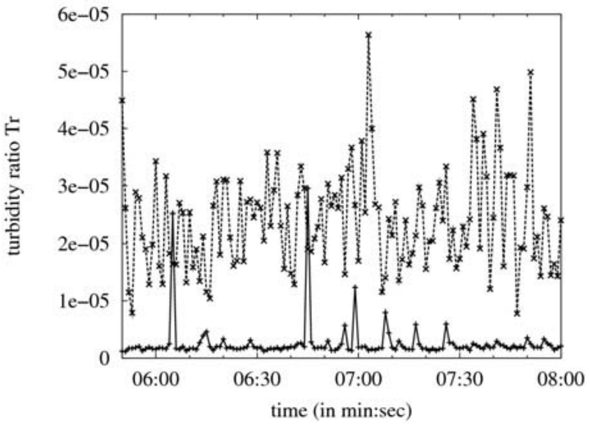


Figure 5: Evolution of the turbidity ratio $T_r$ during time in two different concentration conditions (continuous line : July 2009, dash line : December 2009)

In low water conditions the turbidity is lower and presents some random peaks. This may correspond to a low homogeneous concentration of small particles associated with the random transit of isolated particles.

In rainy conditions, the turbidity ratio is greater and presents an important variation around the mean value. This may be due to local variation of the concentration of the particles.

## 6 CONCLUSION

We have developped an ultrasonic velocity and turbidity profiler, integrated in a compact immersed device equipped with two transducers. The instrument is designed for outdoor conditions.

This new instrument offers the possibility to measure velocity and turbidity profiles in industrial or natural flows with high spatial and temporal resolutions.

## 7 ACKNOWLEDGEMENT

This work has been done with the support of the ”concours national d'aide à la création d'entreprises de technologies innovantes” from the French Ministry of Research.

## 8 REFERENCES

[1] G. De Cesare and J.-L. Boillat, Flow velocity measurements using ultrasound Doppler method - 10 years experience in hydraulic modeling, Proceedings of the Fifth International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engineering, (2006) 113-116.

[2] Abda F., Azbaid A., Ensminger D., Fischer S., François P., Schmitt P., Pallarès A. : Ultrasonic device for real-time sewage velocity and suspended particles concentration measurements, Water Science & Technology, 60.1(2009) 117-125.

[3] S. Kojima, Y. Tasaka, Y. Murai and Y. Takeda, UVP Measurement for Flows Accompanying Free Surface, Fifth International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engineering, (2006) 117-120.

[4] D. Hurther, 3-D acoustic Doppler velocimetry and turbulence in open-channel flow. PHD Thesis EPFL, (2001).

[5] Miller, K.S., Rochwarger, M.M.: A covariance approach to spectral moment estimation, IEEE Transactions on Information Theory, 18(1972) 588-596.

[6] Fischer, S. et al.: A New Velocity Estimation Method using Spectral Identification of Noise, Flow Measurement and Instrumentation. 19 (2008) 197-203.

[7] Lhermitte, R., Serafin, R.: Pulse-to-Pulse coherent Doppler sonar signal processing techniques, Journal of Atmospheric and Oceanic Technology, Vol.1(1984),NO. 4.

[8] Abeysekera S., Performance of pulse-pair method of Doppler estimation. Aerospace and Electronic Systems, IEEE Transactions, vol.34 (1998) 520-531.

[9] Pallarès A., François P., Azbaid H., Schmitt P., Fischer S., Abda F.: Acoustic characterization of sewage effluents, CFA (2006).