Non-intrusive flow velocity measurements in pressurized pipe with orifice

Nicolas J. Adam[1], Giovanni De Cesare[1] and Anton J. Schleiss[1]

[1] Laboratory of Hydraulic Constructions, Ecole Polytecthnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

Orifices are hydraulic devices producing pressure drops or head losses in pipes ways. Flow velocity measurements at the upstream of orifices allow understanding the effect of given flow field on head losses, while downstream measurements provide information of orifice jet stability. The placement of an UVP sensor in the flow disturbs the surrounding velocities and thus the results. The research therefore focuses on the implementation of a non-intrusive velocity measurement using an UVP sensor located outside the pipe. A seeding method is needed to improve the signal quality and accuracy using hydrogen bubbles produced by electrolysis of the flowing water. Firstly, this research shows the flow velocities in the orifice jet, at the upstream and downstream of the orifice. Logically, the average jet velocities are higher than upstream or far downstream flow velocities. Then, pressure recordings show the asymmetry behavior of head losses for the tested orifice. Finally, the power spectra analysis of the pressure and kinetic energy at the same location are compared and show a slightly higher decrease of energy for kinetic energy. The results highlight that further experiments should be perform with higher acquisition frequency.

Keywords: Orifice, non-intrusive velocity measurement, pressurized pipe

1. Introduction

Orifices are hydraulic structures used to produce head losses [1] or to evaluate the discharge flowing through [2]. They can be used to throttle surge tanks in high head power plants to manage extreme water level during mass oscillations [3]. A better understanding of these structures involve identifying main geometry parameters and their effect on the head losses produced by the orifice and the orifice jet flow.

Flow field measurements could highlight flow natural frequencies. Furthermore, the power spectra analysis of pressure and kinetic energy are compared showing discrepancies and giving feedbacks of used acquisition parameters. This research shows preliminary tests of a bigger experimental campaign. The main goal of these studies is to have a better understanding of velocity fields around an orifice and their consequences on the produced head losses.

At end, the knowledge improvement of relation between head losses and flow field should lead to decrease the design duration of an orifice geometry for a given pair of head losses (in flow directions AB/BA shown in Figure 2).

2. Laboratory installation

2.1 Experimental set-up

The experimental set-up at the Laboratory of Hydraulic Constructions (LCH) in Lausanne is shown in Figure 1. The main part of the set-up, where an orifice (Figure 2) is placed at the middle, has an inner diameter, D, equal to 0.216 m and a length of 4 m while the water supply and restitution of the set-up have a diameter of 0.150 m.

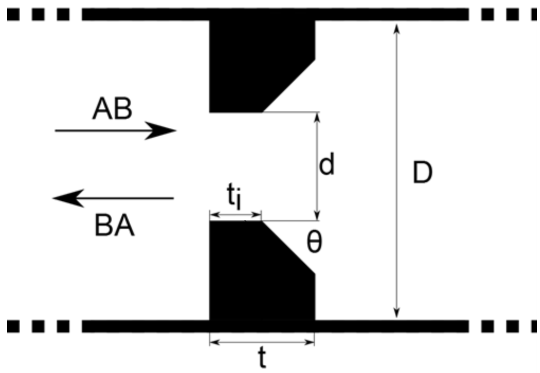


Figure 2: Tested orifice whose geometrical parameters are d/D = 0.5, t/D = 0.4, t_i/D = 0.2 and $\theta = 45°$

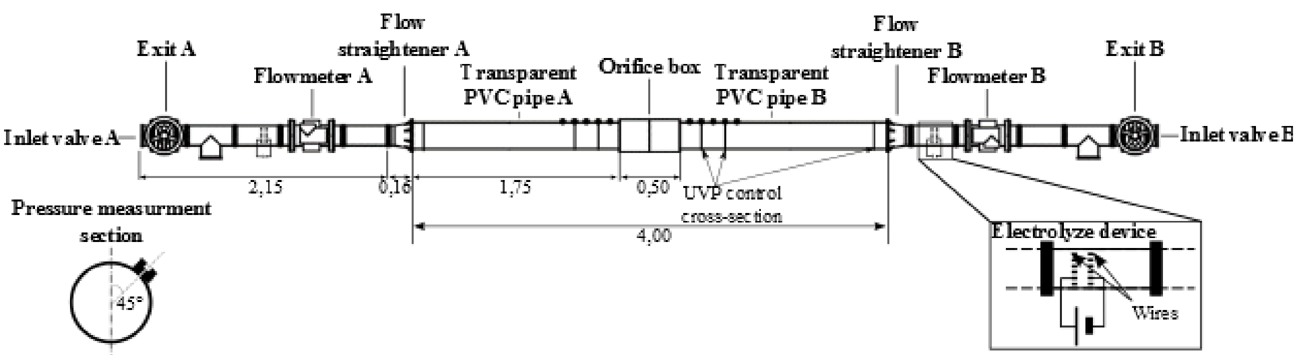


Figure 1: Physical set-up

2.1 Measuring instrument

Pressure are recorded in one point tilted 45 degrees to the pipe top (Figure 1) using 6 piezo resistive pressure sensors (Keller - series 25 with an acquisition rage between -0.1 to 0.5 bar). The acquisition frequency is 500 Hz and number of sample is 262’144 (2^{18} samples). It allows performing frequency analysis from low-frequency to high-frequency (until 250 Hz). Three discharges are tested to evaluate the pressure drop through the orifice: 10, 20 and 30 l/s.

Flow velocity profiles are evaluated by using ultrasound. For each flow direction, 1 upstream cross-section and 3 downstream cross-sections are tested (2 in the orifice jet and 1 at the end of the 0.216-meter pipe A 20-degree angle with the vertical is introduced in order to evaluate longitudinal velocity. The UVP transducer (emitting frequency 2 MHz) is placed outside the pipe avoiding any perturbations of the flow by the transducers (Figure 3). The number of sample is 16’384 (2^{14} samples) for the same duration as pressure acquisition. The sampling frequency is 22 Hz. Only one discharge is tested for the velocity profile measurements, 20 l/s.

The discharge is recorded with two electromagnetics flowmeters: ENDRESS-HAUSER – PROMAG 50 W.

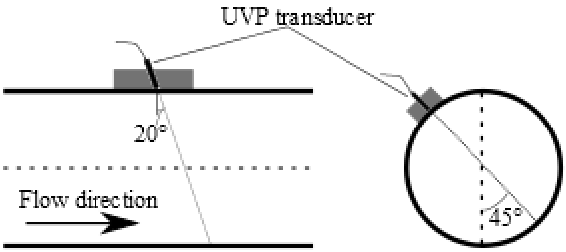
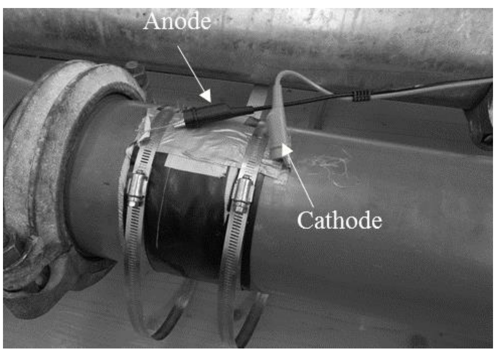


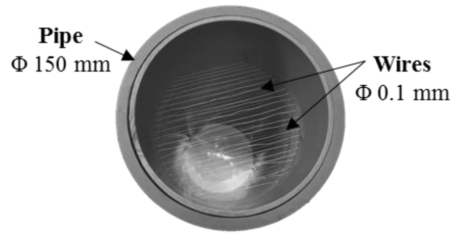
Figure 3: Installation of UVP Transducer (Longitudinal and cross-sectional view)

2.2 Non-intrusive seeding

The quality of the signal is improved by introducing hydrogen seeding with an electrolyze device in the upstream pipe (Figure 1). The hydrogen is created by electrolysis of water between two racks of wires (whose diameter is 0.1 mm) connected with a DC electrical power source (Figure 4). A steady 30-volt voltage is applied between the anode and cathode (Figure 4). As discharges, from 10 l/s to 30 l/s, flow through the experimental set-up, the characteristic flow velocities are between 0.55 and 1.75 m/s in the upstream pipe.



(a)



(b)

Figure 4: Electrolyze device (a) Inner device with two racks of wires; (b) Electrical connections outside of the pipe

3. Velocity profile

Velocity profiles are evaluated for a discharge of 20 l/s on different cross-sections as shown in Figure 1.

According to Figure 5, the following observations can be made:

- The upstream velocity profile is disturbed and asymmetric showing that upstream flow conditions are not optimal.
- This high velocity core decreases along the pipe axis (1.35 m/s at +1.97 D and 0.76 m/s at 2.89D). Far away the orifice, the velocity profile recovers standard turbulent profile for pipe flow.
- There is a trough in the jet mean velocity profiles. Further experiments should be performed to confirm or reverse this behavior.

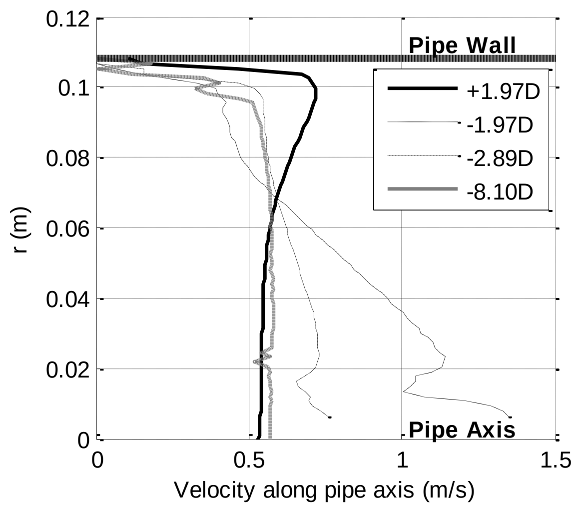
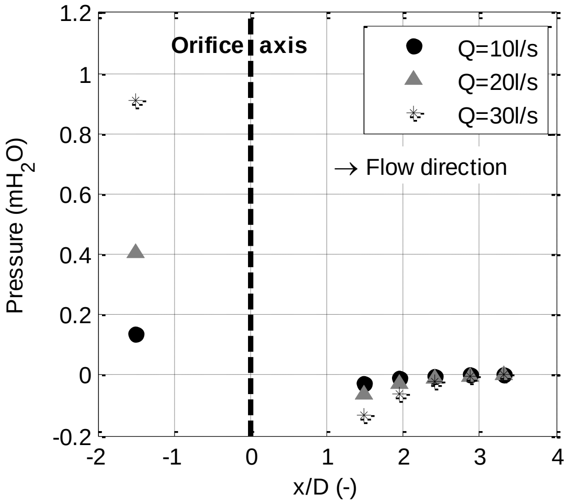


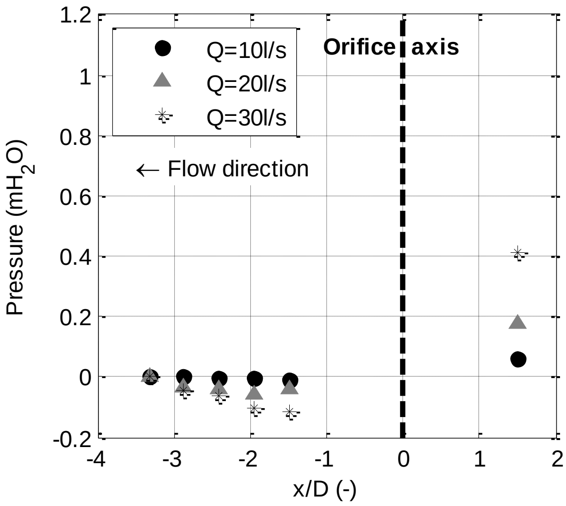
Figure 5: Flow velocity fields along the pipe axis on the half upper section of the pipe for BA flow directions

4. Pressure drop through orifice

According to [4,5], the pressure drop is proportional to the kinetic energy of the flow in the pipe. Turbulent head losses, which are independent of Reynolds number, are ensured if the Reynolds number in the pipe is higher than 10^4. This condition is satisfied for the lower discharge (1.2×10^4). Note that the downstream pressure is set artificially to 0 mH_2O in order to compare pressure for all discharges. Figure 6 and Table 1 show that the pressure drop increase with a higher discharge. In the same time, the pressure drop in the jet increase as well. While the discharge is three times larger, the global pressure drop is almost seven times larger.



(a)



(b)

Figure 6: Pressure drop across the orifice (Figure 2) for three discharges for (a) AB and (b) BA flow directions

Table 1: The global pressure drop, ΔP, between upstream and downstream of the orifice and the additional pressure drops due to the high velocities jet, ΔP_{jet}, with the downstream pressure

Q (l/s)	AB		BA	
	ΔP_{jet} (mH_2O)	ΔP (mH_2O)	ΔP_{jet} (mH_2O)	ΔP (mH_2O)
10	-0.131	0.908	-0.113	0.414
20	-0.063	0.407	-0.040	0.180
30	-0.025	0.135	-0.011	0.060

Figure 7 shows that the global pressure drop is proportional to the kinetic energy in the pipe. Furthermore, the global pressure drop is almost 55% smaller when the streamlines are contracted with a slope approach (Figure 2 and flow direction BA). The head loss coefficients (which is the ratio between the global pressure drop and the kinetic energy in the main pipe) is 27.4 for AB flow direction and 12.2 for BA flow direction.

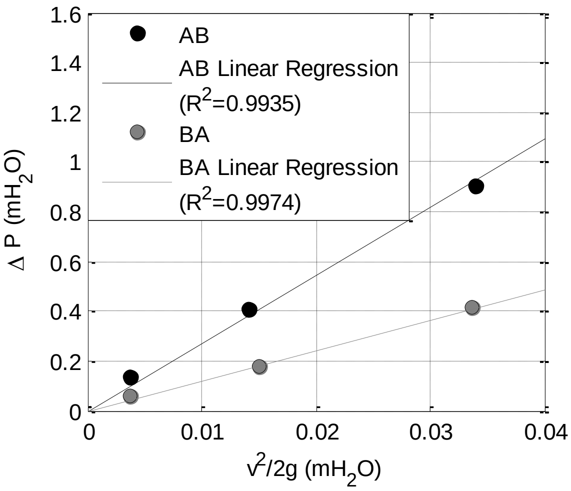


Figure 7: Pressure drop across the orifice (Figure 2) as a function of the kinetic energy in the main pipe

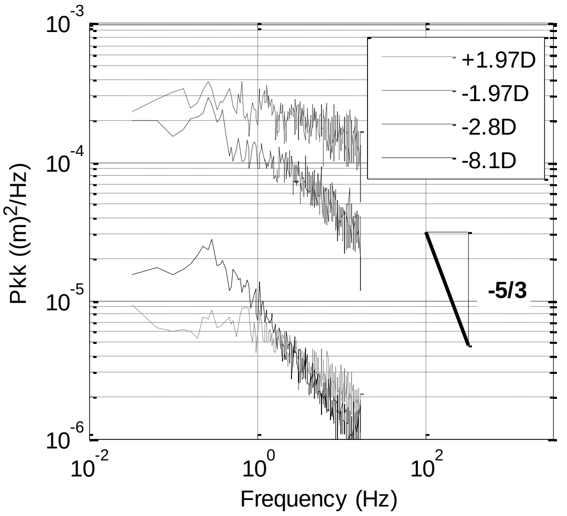
5. Power Spectrum Analysis

The power spectral densities for pressure and velocity fluctuations are determined using Welch utilities. For both pressure and velocity power spectrum analysis, the window length is equal to 1024 samples. Thus, there are 16 windows for the velocity power spectrum and 256 for the pressure. A similar comparison between powerspectral densities for pressure and velocity fluctuations has been performed in [6].

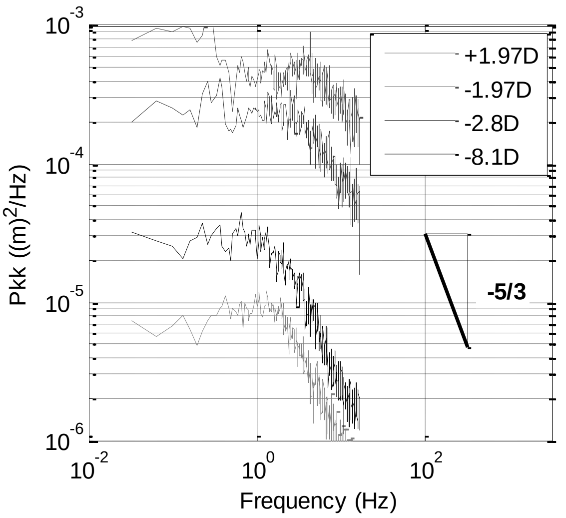
5.1 Kinetic energy

Figure 8 (a) shows the power spectrum of the velocity 5 mm away from the pipe wall while Figure 8 (b) shows the power spectrum on the pipe axis. These observations can be made:

- The energy of kinetic energy fluctuations increases after flowing through the orifice. At the end of the downstream pipe, the energy of fluctuations decreases to the same level as upstream the orifice.
- In the orifice, a natural frequency seems to appear at 0.2 Hz. However, the recording duration was not sufficient to cover accurately this frequential area.
- The energy cascade slope of kinetic energy near the wall is smaller than the typical turbulence slope of -5/3. However, this difference is higher in the jet area than upstream of the orifice (+1.97D) or further downstream (-8.1 D).
- The energy cascade slope of kinetic energy on the pipe axis is more or less equal to the typical turbulence slope -5/3.



(a)



(b)

Figure 8: Power Spectrum using welch tools for the kinetic energy upstream and downstream of the orifice for flow direction BA: (a) 5 mm away from the pipe wall; (b) on the pipe axis

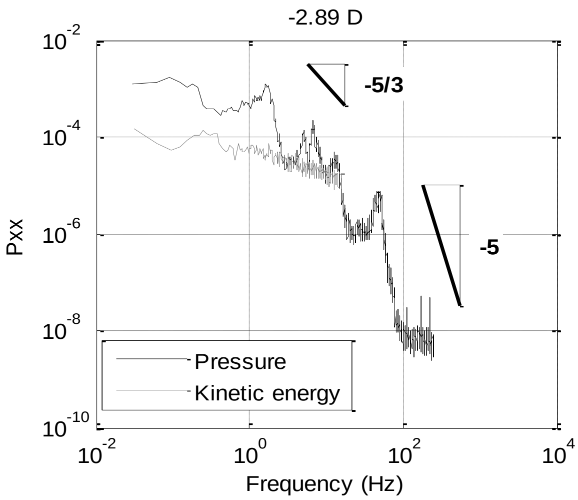


Figure 9: Comparison between power spectra of velocity and pressure at the downstream of the orifice (x = -2.89 D) for flow direction BA (5 mm away from the pipe wall)

5.2 Comparison with pressure power spectrum

Figure 9 compares the power spectra of the kinetic energy close to the pipe wall and the pressure recorded as detailed in Figure 1. The decrease of energy is smaller for the kinetic energy. The average slope of the pressure energy cascade is in good agreement with the theory. However, there are at least two big steps of energy in the pressure power spectrum (13 Hz and 48 Hz).

6. Conclusion

Orifices are useful to throttle surge tank. A better understanding of the flow behavior produced by different geometry would allow to shorten the duration of the design step during a refurbishment of a high head power plant.

The pressure drop produced higher head losses when the section restriction is sudden than when the restriction is progressive with an angle introduction.

Finally, the power spectra of kinetic energy and pressure show different behaviors. The slope of energy casacde is slightly higher for the kinetic energy. Further experiments should be performed with a higher acquisition frequency for the velocity recording in order to increase the accuracy for high frequencies.

The orifice seems to produce a jet core where velocities are higher than in the surrounding areas. Furthermore, it seems to have a characteristic frequency close to the pipe wall.

References

[1] F. Hachem, C. Nicolet, R. Duarte, G. De Cesare, and G. Micoulet, “Hydraulic Design of the Diaphragm’s Orifice at the Entrance of the Surge Shaft of FMHL Pumped-storage Power Plant,” *Proc. 35th IAHR World Congr.*, 2013.

[2] B. Standard, “Measurement of Fluid Flow by Means of Pressure Differential Devices Inserted in Circular Cross-Section Conduits Running Full,” *Part*, vol. 2, pp. 5167–2, 2003.

[3] J. Giesecke, S. Heimerl, and E. Mosonyi, *Wasserkraftanlagen: Planung, Bau und Betrieb*, 6., aktualisierte und erw. Aufl. Berlin: Springer Vieweg, 2014.

[4] R. D. Blevins, “Applied fluid dynamics handbook,” *N. Y. Van Nostrand Reinhold Co*, vol. 1, p. 568, 1984.

[5] I. Idel’cik, “Mémento des pertes de charges singulières et de pertes de charges par frottement [Handbook of singular and friction head losses],” *Eyrolles Paris*, 1969.

[6] M. Pfister, R. Duarte, M. Müller, and G. De Cesare, “Cavitation risk estimation at orifice spillway based on UVP and dynamic pressure measurements,” in *Proc. of the 8th International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engineering, 8th ISUD*, 2012, pp. 137–140.