

Experimental studies toward the characterization of Inmetro's circulating water channel

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Abstract: Circulating water channels are facilities which can be used for conducting environmental metrological and engineering studies. The Brazilian National Institute of Metrology-INMETRO has a water channel of innovative design, and the present work deals with the prior experimental investigation of its hydrodynamic performance. By using the optical technique PIV – Particle Image Velocimetry, under certain condition, the velocity profile behavior in a region inside the channel was analyzed in order to evaluate the scope of applicability of such bench.

Keywords: Circulating Water Channel, Particle Image Velocimetry, Metrology, Fluid Flow Characterization.

1. INTRODUCTION

In research laboratories, water channels or flumes are benches used for fluid flow investigations or submerged bodies behavior analyses, for a variety of applications, e.g. scientific, environmental and technological areas [1]. In these facilities, by controlling operation conditions it is possible to reproduce effects of flow stratification (temperature, concentration), turbulence and boundary layer, free surface (waves generation or dissipation), among other aspects of a flow field. The performance and applicability limits of a water channel will depend on its design and internal components characteristics (flow straighteners, screens (mesh and distribution), working section details etc.) [2]. The more specific the apparatus application is, the more exigencies for accuracy on its design, building and ancillary measurement instruments to be employed.

The Fluid Dynamics Metrology Division (Dinam) of the Scientific and Industrial Metrology area of the Brazilian National Metrology Institute (Inmetro) has a Circulating Water Channel. The channel was constructed to be used in instrument calibrations and fluid flow researches. This bench was designed by the own Inmetro/Dinam researchers team [3] and it was built under rigorous specifications. Recently it was commissioned. The earliest steps towards its characterization process are object of the present work. Some aspects of the flow generated in such bench when it is free of a model testing inside are shown.

2. FACILITY DETAILS

The water channel (figure 1) is an innovative design [3]. It has long visualization side walls (12m length) which are composed by 05 monolithic glass plates interconnected by high

strength silicone. The channel floor is also made in glass, for flow visualization and measurements through the bottom. Its cross section is rectangular, 0.6 m length x 0.7 m height, and at the channel entrance an accommodation section contains straighteners (figure 2) and a space for screens insertion (when required).



Figure 1 – The Circulating Water Channel – wide glass wall.



Figure 2 – Aspect of the flow straighteners.

At the channel exit, two types of customized waves suppressors were installed (figure 3 shows one type).

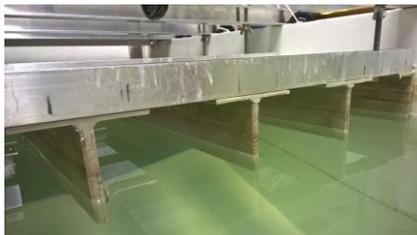


Figure 3 – Set of triangular wave suppressors.

The position of such devices can be changed according to the water column and flow rate, in order to vanish generated waves. A centrifugal pump (30 kW) drives the flow, and the maximum mean flow velocity inside the channel is 0.5 m/s (max. flow rate is 648 m³/h). An electromagnetic flowmeter (diameter 0.254 m; nominal capacity 53.6 m³/h to 1770 m³/h; calibrated in 10 points of

the nominal range) is used for monitoring the mean flow rate in the channel. Adjacent to the channel was constructed a platform, on which a unity can be driven under controlled velocity (max. 0.5 m/s) for transporting instrumentation or a model to be studied in the channel.

3. EXPERIMENTAL PROCEDURE

The main aspects of the fluid flow, as well as the water channel operation capability determination were initiated during the bench commissioning phase. After that, a flow field mapping in the central plane of a region in the test section (Figure 4), under certain conditions, was performed.

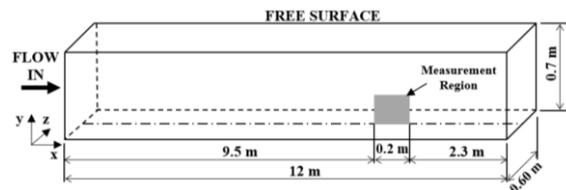


Figure 4 – Details of the channel dimensions and the measurement region.

3.1 Brief comment on the water channel commissioning process

The commissioning phase consisted of evaluating the facility under several conditions, on which we can detach: **i)** a progressive channel filling with water, in four steps of a water column of 150 mm, up to reach the maximum water column intended for working (600 mm). During all water channel filling process, the deflections of its horizontal supporting structures were monitored along the all length (12 m), and the maximum deflection was less than 1 mm (at the middle length); **ii)** the free surface behavior after the flow left the straighteners and reached the wave suppressors; **iii)** the hydraulic pump (30 kW) performance influences: operation stability (under 25% of the maximum pump motor rotation and also with partial opening of a valve positioned at the pump exit).

3.2 Brief comment on the wave suppressors acting in the flow

Before introducing the wave suppressors in the channel, a fast increase of the wave amplitude was provoked due to a pumping sudden stop or due to the water flow rate increase. So, in the characterization process, a limitation of the pump rotation was imposed, in order to avoid stationary wave generation along the channel. Then, after the wave suppressors were installed, stationary waves vanished, and so, the pump could work at rotation level close to its maximum capacity (with the highest water column intended to work in the water channel, 600 mm).

3.3 Flow characterization using the particle image velocimetry technique-PIV

The PIV technique was used in this work. It consists of a dual cavity laser source which pulses synchronized with high speed cameras (CCD or CMOS) aperture. Micro particles of reflexive material are seeded in the flow (tracer particles). When the laser sheet is inserted in the flow, such particles reflect the incident light. So, sequential images of the illuminated region are captured by the cameras (01 camera for two-dimensional measurements and two cameras for 3D stereo). By comparing the position of the particles in small regions (called interrogation window) of two sequential images captured by the cameras, and relating them to the acquisition frequency of the images (time interval), through mathematical correlations (cross-correlation or auto correlation) is possible to estimate the flow velocity (considered equal to the tracer particles velocity). A velocity field and associated information on the flow (ex. turbulence characteristics) can be mapped in this way.

The PIV system from Dantec Dynamics™ used in the present work was in 2D configuration. Basically, this system is **i)** a double cavity Nd:YAG laser (DualPower 200-15 Laser 2x200 mJ, 15 Hz, 532 nm) and **ii)** one camera CCD

Flow Sense Mk2 4M – with resolution 2048 × 2048 pixels (pixel size 7.4 μm), with 60 mm lens and glass filter high pass (cut-off at 532 nm).

3.3.1 On the measurement uncertainties estimate when using the PIV technique

The PIV system is one of the most important state of art tools employed in fluid dynamics experimental investigations. However, due to its operation principle, there are some challenger gaps to be solved by the scientific and metrological communities, related to find the best refined methodology for measurement uncertainties quantification (UQ) when using such system. The community concerning about this subject is related on what should be considered as sources of uncertainties. In this context, the main challenge faced nowadays is to find the best way for evaluating each uncertainty component, regarding the intricacy of sources. Such sources come from cameras and laser alignment, intensity and time between laser pulses, image distortions, physical to image scales (scaling magnification), tracer particle (displacement, concentration and density), mapping function, algorithm, image processing, and others. Then, not only experiment conduction way and technological resources are influence factors, but also computational and mathematical tools have impact on the uncertainty ranges, showing that PIV UQ and related uncertainty reduction is a matter that requires multidisciplinary treatment. In the last years the attention for PIV UQ have been increased [4]. There is a lot of subjects to be discussed and investigated. As interested part, last year Dinam/Inmetro has introduced in its activities the research line in such topic, including both computational and experimental focuses. For starting point of the experimental side, Dinam has been working intensively on PIV experimental procedures improvement. Nevertheless these refined procedures has not

been already implemented when the present work was developed.

The level of standard deviation of the local mean velocity (time averaged) was chosen as a parameter for the water channel hydrodynamics performance approbation, since it permits infer some about stability and the development state of the flow in the measured region. Standard deviation is a representative criterion, since it carries influences of the system alignment, software, timing, etc, besides, of course, the flow behavior. The consistency of the hydrodynamic profile was also appreciated under the basis of the physical process and the theory of fluid flow.

3.4 Measurement conditions

Table 1 summarizes the measurement conditions. In this table, the flow rate uncertainty is different for each flow rate level because the flowmeter was calibrated in several points within its nominal range. The water column was 0.6 m.

Table 2 shows the PIV system setup, which was controlled by the Dynamics Studio™ (software for acquisition and processing).

Table 1. Measurement conditions.

Mean flow rate	
Range (m ³ /h)	Uncertainty (%)
147	0.1943
207	0.1943
265	0.1943
325	0.1214
Tracer particles: silver coated hollow glass spheres; size distribution diameter: 8 to 30 μm; density: 900 kg/m ³	
Water column: 0.6m	

Table 2. PIV system setup.

Number of captured images (double frame) at each flow rate	2000
Time between laser pulses (μs)	5000 μs (at 147 m ³ /h and 207 m ³ /h); 4000 μs (at 265 m ³ /h and 325 m ³ /h).
Trigger rate	7.4 Hz
Interrogation window (pixel)	Initial: 128x128 Final: 64x64

4. RESULTS AND DISCUSSION

The water channel flow velocities profiles are shown in figures 5 to 8. The figures 5 and 6 show the velocity field for the minimum and maximum tested flow rates. U is the horizontal velocity. The maximum standard deviation value of the local horizontal velocity in the uniform region was 0.02 m/s.

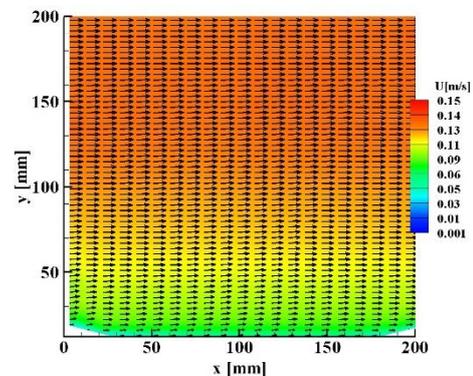


Figure 5 – Mean velocities field for flow rate 147 m³/h; (mean of 2000 captured images).

It can be observed that the vertical positions (y) in which the horizontal velocity becomes uniform are around 120 mm and 70 mm approximately, respectively.

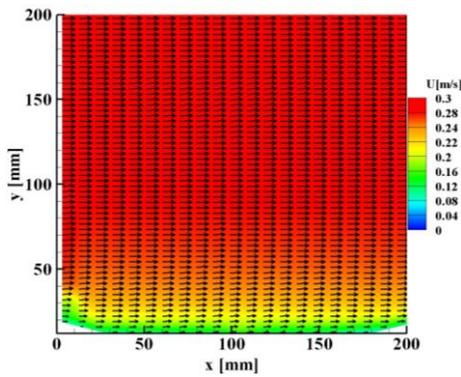


Figure 6 – Mean velocities field for flow rate 325 m³/h; (mean of 2000 captured images).

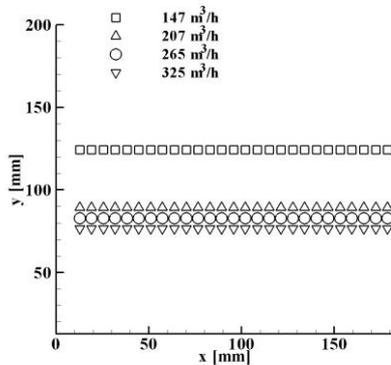


Figure 7 – Boundary layer thickness at different flow rates and longitudinal positions.

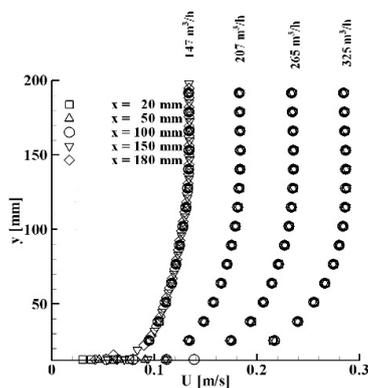


Figure 8 – Horizontal velocity (U) profile along the channel axis for different flow rates.

In figure 7, analyzing the evolution of the horizontal velocity component, can be concluded that the boundary layer thickness is almost constant, for different longitudinal positions of the flow measurement region.

The figure 8 shows the vertical position from which the horizontal velocity component does not change along the main flow direction.

5. CONCLUSION

This work shows the earliest evaluation of the Inmetro's water channel. The experimental data show a good efficacy of the wave suppressors and the flow straighteners of the bench, since the standard deviation levels for local velocities are within acceptable ranges for this kind of flow and the pattern velocity profile is according to the expected. Besides, under the tested conditions, the field flow shows typical characteristics of developed flow and there is no perceptible influence of the free surface in that flow position. It is a satisfactory finding. The complete characterization of the water channel is an experimental work that will demand long term to be finished, and the research will be continued.

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