ON THE DESIGN OF A CIRCULATING WATER CHANNEL FOR THE BRAZILIAN NATIONAL INSTITUTE OF METROLOGY – INMETRO

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Abstract: Circulating water channels provide a controlled flow environment in which a wide variety of experiments may be conducted. The Fluid Dynamics Metrology Division of INMETRO - Brazil, has designed a circulating water channel that is particularly suited to the characterization of flow phenomena. The facility was designed to conduct research on general flow phenomena with liquids as those related to environmental management and pollution control, turbulence and velocity measurements, flow meters calibrations, among others. In this paper, major issues related to the design of the water channel for INMETRO are discussed. In particular, CFD analysis of the performance of the flow conditioning devices installed and its relation to the velocity distribution along the working length are presented. Also, the feasibility of using the superconducting magnetic levitation technology to drive the movable bridge is discussed.

Keywords: circulating water channel, flow visualization, numerical simulation.

1. Introduction

The Fluid Dynamics Metrology Division - DINAM of INMETRO (the Brazilian National The fluid Dynamics Metrology Division (Dinam) of INMETRO, the Brazilian National Metrology Institute, is responsible for providing traceability related to fluid flow measures. Nowadays, it has two laboratories, the Fluid Velocity Laboratory and the Liquid Flow Laboratory. Dinam not only executes calibrations, but also develops experimental and theoretical researches, and also deals with computational simulations on fluid flow.

The success in modelling a complex flow can depend strongly on the sophistication level of the experimental techniques applied to the measurements, as well as the kind of apparatus that is chosen to perform such measures. Frequently, experimental investigations dealing with turbulent external flows are made in wind tunnels or water channels. A water channel can be used in several applications, such as in flowmeter calibration, cavitation analysis, corrosion in turbine vanes, investigation on dilution processes, pollutants dispersion, efficiency of waste water dispenser, drag reduction, etc. At Dinam's fluid velocity laboratory, two wind tunnels, two rigs for air jet flow and three rigs for multi-phase flow are part of its main installations. In addition, a water channel was designed and so soon will be set in this laboratory.

When studying a certain fluid dynamics phenomenon, the need for describing the whole velocity field and other flow characteristics demands the use of different kinds of measuring techniques, in order to increase the quantity and also to improve the quality of acquired information related to such phenomenon. So, Dinam has acquired state-of-art instrumentation, as PIV (Particle Image Velocimetry), LDA (Laser Doppler Anemometry), Shadow Sizing, Hot Wire Anemometers, besides traditional instruments as Pitot Tube.

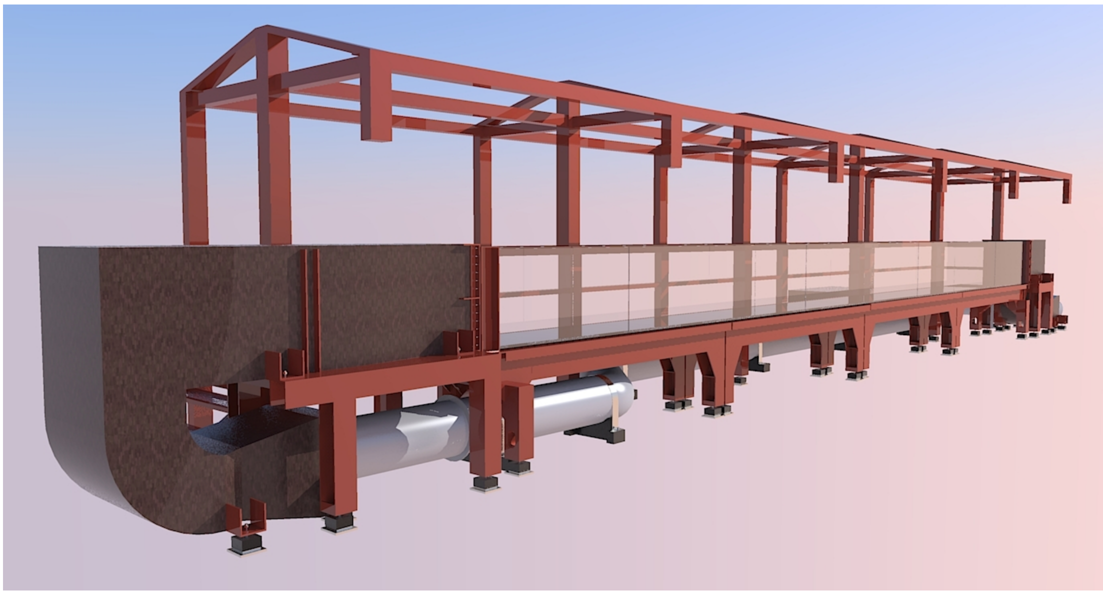

Figure 1: General arrangement of the circulating water channel.

The possibility of using all these tools is fundamental for investigating in more detail diverse phenomena on fluid flow. Sometimes, for getting more benefits from using optical techniques such as PIV for flow visualization, the constructive aspects of the experimental apparatus where the optical instrument will be applied play an important role. In this direction, the water channel of INMETRO was designed. It is an innovative concept and its use is quite advantageous when compared to traditional water channels. The characteristics of such water channel are shown in this work, as follows.

2. Facility Description

The circulating water channel designed is a horizontal type channel that operates in a closed circuit. A self-contained concept was adopted for the system configuration, where pipe, pumps, reservoirs and all its fittings are incorporated (Figure 1). The channel has an opening to the atmosphere cross-section of 600 mm wide by 600 mm deep with a total length of 12.0 m. The dimensions of the working cross-section and length are the key features of a water channel. The selection of the channel dimensions is a problem related not only to functional requirements, but also to its physical size and weight and the costs involved in its construction, operation and maintenance. The limited space available at the Fluid Velocity Laboratory imposes severe constraints to the installation of a large channel. Then, the dimensions of the water channel represent a compromise between the functional requirements and the available space.

Traditionally in water channel construction, large panels of glass mounted on side metal frames are fixed on a rigid bed. In order to allow fully conditions of flow visualization, an innovative design concept was developed to INMETRO's circulating water channel. The working length of the channel is fully built by thick glass panels mounted over two box type girders (Figure 2). Glass panels are mounted using a silicone-based adhesive. All the required side support is also made of glass profiles. Stiffeners are deployed parallel to the dominating dimension of the channel. All the stiffeners are conveniently installed at the upper and the lower part of the glass panels to provide maximum visibility. The supporting structure was manufactured in an aluminum alloy and was designed to guarantee a high degree of rigidity to the channel.

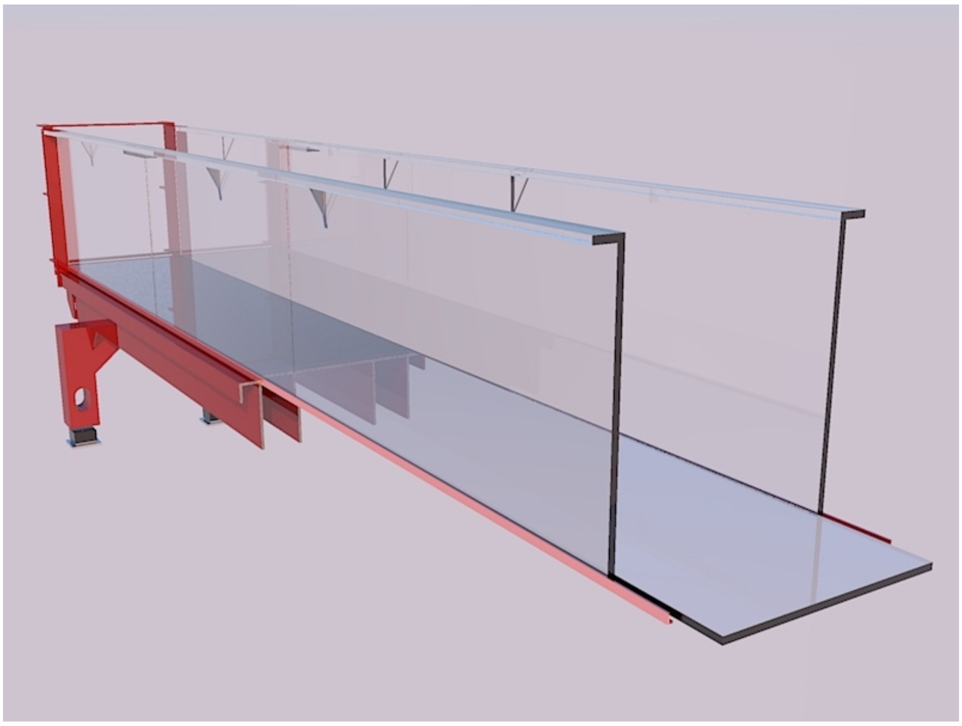

Figure 2: Detailed view of the glass panels and the supporting structure.

The major drawback with this new concept is that the established calculations for the design of water channels expect each glass panel to be supported all around its perimeter. Also, technical literature gives no indication of safety factors for the glass thickness for such an uncommon all glass design concept. The variability of the strength of glass due to limitations of the manufacturing process means a suitable safety factor must be used when calculating glass thickness. In order to assure the constructive feasibility of the proposed channel configuration a comprehensive stress and deformation analysis was performed. The results obtained indicate that the maximum von Mises stress (4.2 MPa) is well under the typical tensile strength of standard glass (19.3 to 28.4 MPa). The safety factor commonly used in aquarium/channel design is about 3.8, so the proposed configuration has a minimum safety factor, at least, 20% higher than the usually acceptable values. The results indicated also very low deflection magnitudes of the order of 0.1 mm.

Since there is no metal frame, the structural integrity of the channel relies also on the strength of the silicone holding the glass panels together. In order to verify the performance of the silicone-based adhesive, a specific experimental procedure was specially developed to determine the strength of the joins. The experimental procedure consists basically of a tensile strength test that will be used to verify if the joins are able to accept the same stress level calculated for the glass panels.

Another important issue is that glass has a much lower coefficient of linear expansion than aluminum. The length of the channel (12.0 m) is too long to rely only on the elasticity of the sealing layer as a mean to take up the forces generated between the glass and metal. The solution adopted was to split the supporting structure in two pieces. The two pieces are fixed at one end and free to move axially over a sliding bed plate at the other end. As an alternative to reduce to a minimum the stresses imposed on the sealing layer, the channel should be built and stored at a temperature similar to that which it will run at.

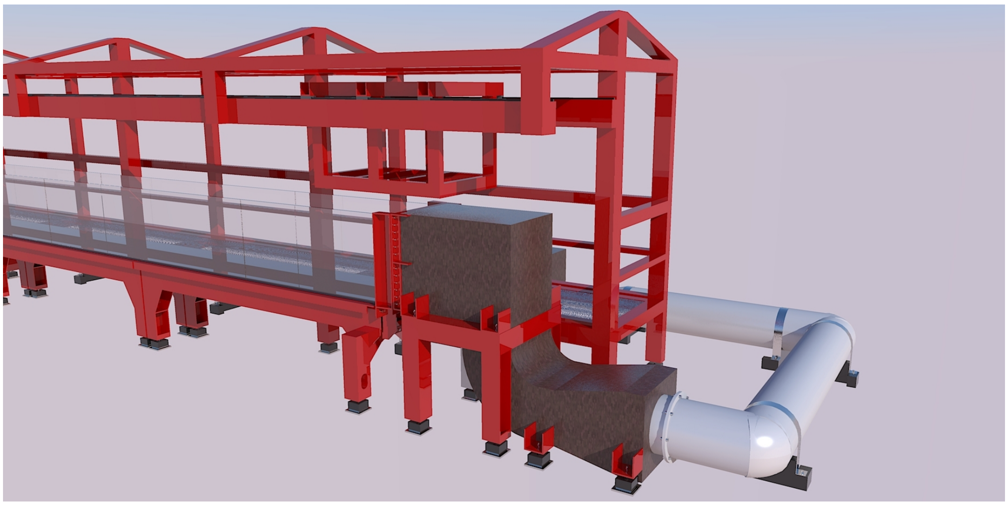

Figure 3: Detailed view of the movable bridge.

The facility is equipped with a 25 kW centrifugal pump, drawing water through 400 mm pipes made of thermoplastic material. The pumping system is capable of producing a maximum flow speed in the working section of 0.5 m/s. In order to reduce the water disposal to a minimum, a set of reinforced fiber glass tanks is installed to store the water during maintenance procedures. The channel is equipped at the inlet with a 2:1 contraction section carefully designed to provide suitable flow conditions at the working section. In defining the geometry of the inlet contraction special attention was given to the problem of wave generation at the free surface.

The channel is equipped with a movable bridge that spans throughout the channel length for ease and versatility in mounting instrumentation and models. The moveable bridge is also capable of towing models (and/or required instrumentation) up to 250 kg of load, with a maximum speed of 0.5 m/s. The movable bridge is suitable for measurements under low velocity conditions, for which it is particularly difficult to impose a laminar flow regime on the test rig. Instead, the fluid is kept stationary while the sensors move at a pre-defined speed. In some situations it is even desirable to combine the forced flow with a moving measurement system in order to attain a specific dynamics.

Concerning the driving system of the movable bridge, among the several possibilities, a linear motor actuator was chosen. In this application the traversing distances have to be traveled smoothly and precisely. A synchronous linear motor is well suited for the task for it has all the qualities of a synchronous direct drive such as high precision, outstanding dynamic response, the absence of a need for maintenance, a high force density, robustness and low energy losses. Additionally, the advances in power electronics and microcontrollers have eliminated most of the control difficulties. The linear motor will have a mobile short primary fixed on the movable bridge. The stator will receive a three-phase winding driven by a frequency inverter. A magnetic circuit excited by permanent magnets and placed along the rail will interact with the stator,

The driver characteristics are:

- Rated propulsion force: 250 N;
- Maximum propulsion force at acceleration: 500 N;
- Rated speed: 0.5 m/s;
- Rated voltage/frequency: 200 V (three-phase) / 5 Hz.

Instead of mechanical bearings, superconducting magnetic bearings will be employed. By means of superconducting magnetic levitation, the movable bridge should acquire a very smooth movement assuring a minimum mechanical interference on the measurements. Two lines of NdFeB magnets, one in each track, will interact with the YBCO ($YBa_2Cu_3O_7$) pieces inside the movable bridge. For the YBCO become superconducting it must be kept at a temperature near 93 K. This can be accomplished with two cryostats for each track. Been mechanically connected they grant more stability to the movable bridge movement.

3. CFD Analysis of the Performance of Flow Conditioner

The quality of the velocity profile at any cross section of the working length is the major concern in the hydraulic design of a water circulating channel. A uniform velocity profile along the working length represents a mandatory requirement for obtaining reliable and representative experimental data in any flow measurement facility. Even by establishing such a simple requirement, the generation of acceptable flow patterns in a circulating water channel is not a trivial task at all. Usually, limited space available impose severe constraints to design a circulating water channel with the required length to achieve fully developed flow conditions at the working length. The installation of flow conditioners is, therefore, essential for obtaining velocity profiles of acceptable quality.

The design of the flow conditioner of the INMETRO's circulating water channel requires very special attention. Due to severe space limitations, the flow conditioner must be designed to perform both tasks of flow direction conversion and velocity homogenization. Hence, the performance of the flow conditioning device installed and its relation to the velocity profile along the working length was numerically investigated by means of computational fluid dynamics (CFD) techniques.

The description of the flow properties based on RANS equations (*Reynolds-Averaged Navier-Stokes Equations*) represents a consolidated alternative for engineering analysis (Gan and Riffat [1], Erdal [2], Frattolillo and Massarotti [3]). The equations governing the problem were solved using the well known code ANSYS CFX, release 12. The code solves the Reynolds averaged Navier-Stokes equations (RANS) through a finite volume approach. The solution procedure is based on a fully implicit discretization of the governing equations. In the present work, the well-known eddy viscosity model SST (Shear Stress transport) $\kappa-\omega$ Based Model was adopted for the computation of the turbulent properties. The Volume of Fluid (VOF) method was adopted for the simulation of free surface flow.

The $\kappa-\omega$ model considers that the turbulent viscosity, ν_τ, is related to the turbulent kinetic energy, κ, and the turbulent frequency, ω, through the expression

$$\nu_\tau = \kappa/\omega \qquad (1)$$

The $\kappa-\omega$ based model formulation has become very popular over the last few years for its apparent superior performance for the treatment of near wall conditions. The $\kappa-\omega$ model does not require the introduction of the typical non-linear dumping functions present in the $\kappa-\varepsilon$ model and, for this reason, should be more accurate and robust.

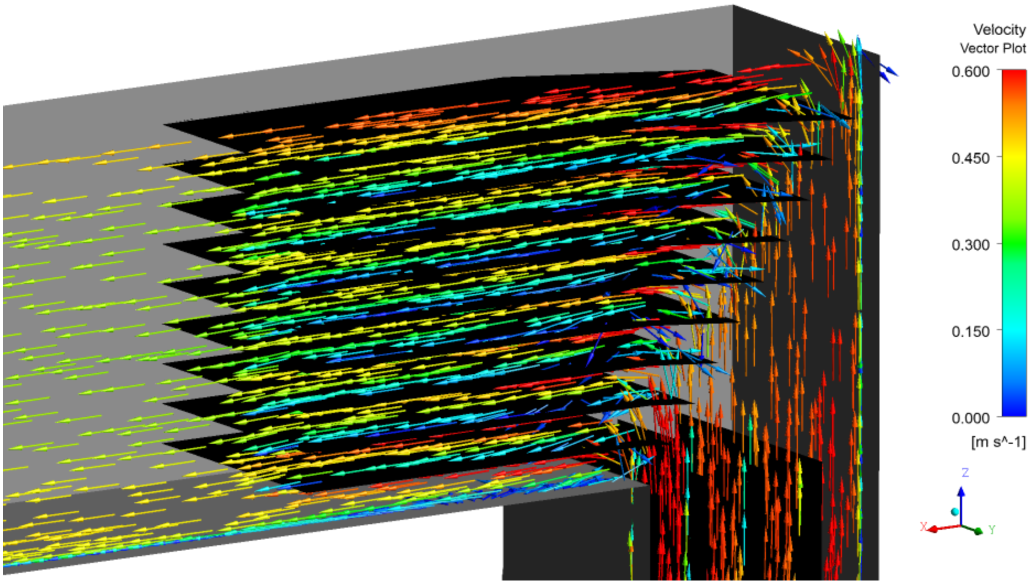

Figure 3: Detailed view of the flow inside the flow conditioner.

The numerical evaluations of the performance of the flow conditioner were conducted considering steady state flow conditions based on representative 3D geometrical models of the channel developed in full scale (1:1). Considering the geometrical complexity of wire screens, only the first stage of the flow conditioner was represented. The first stage consists of a set of parallel plates that is designed to perform the conversion of the flow direction and to act as the first velocity homogenization device. A non-uniform grid was adopted for discretization of the flow domain. Extensive grid-independence tests were performed resulting in a final non-uniform, body-fitted mesh with 800k tetrahedral/prismatic elements. The mesh was particularly refined in the near wall region so as to completely resolve the inner turbulent and viscous sub-layers.

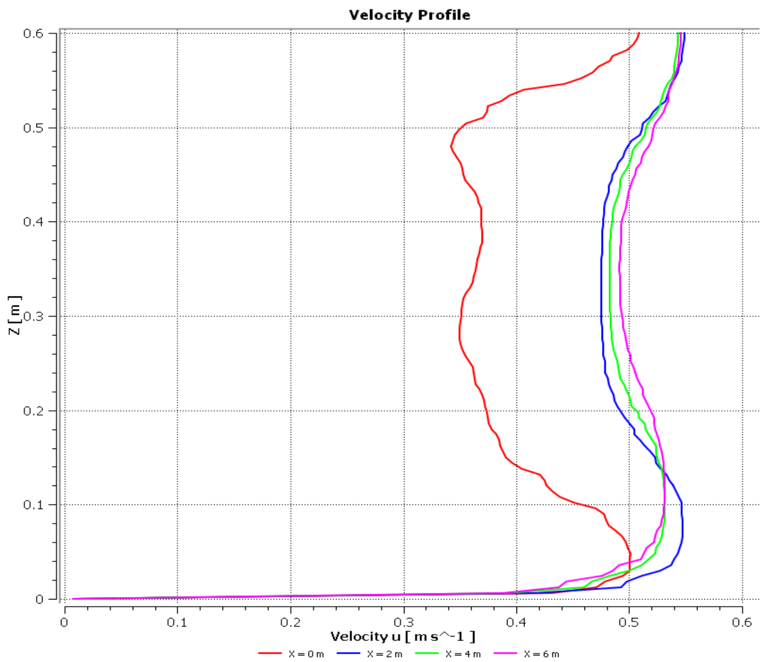

Figure 4: Development of the velocity profile along the water channel.

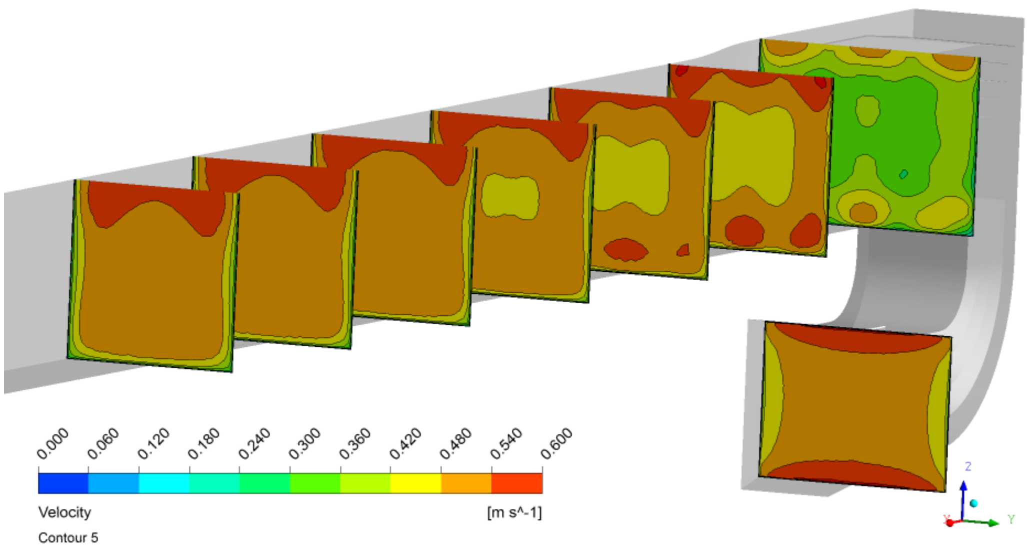

Figure 5: Development of the flow along of the water channel.

In Figure 4, a detailed view of the flow inside the flow conditioner is shown. As can be seen, flow recirculation appears immediately after the inlet of the flow conditioner. This behavior is a consequence of the high angle of incidence of the flow upstream of the flow conditioner. The effect of the flow recirculation on the performance of the flow conditioner is quite remarkable. It can be observed that the length of the flow conditioner is large enough to allow the reattachment of the flow. It represents a desirable effect since it contributes to obtain a high level of uniformity for the velocity profile downstream of the flow conditioner. The negative effect is that a higher length imposes higher values of pressure drop. So, the definition of the length of the flow conditioner is a compromise between the desirable level of uniformity for the velocity profile and the pressure drop imposed to the flow.

Figure 4 shows the development of the velocity profile along the water channel. As can be seen, the velocity profile already shows an acceptable pattern 2.0 m downstream of the contraction section. It can also be noted that the velocity distributions at 4.0 m and 6.0 m are quite similar, showing only minor variations along the profile. This result indicates a good performance of parallel plates as a first stage of a flow conditioner. It can be expected to achieve an even higher level of flow uniformity with the installation of wire screens downstream of parallel plates. In Figure 5, a sequence of contour plots illustrates the development of the flow along of the water channel.

4. Conclusion

In this paper, an innovative design concept developed to INMETRO's circulating water channel was presented. The major issues related to the constructive feasibility of the proposed channel configuration were discussed. In addition, the results of a detailed investigation of the hydraulic performance of channel were presented, showing that the concept adopted for the design of the flow conditioner allows the generation of velocity profiles of acceptable quality along the working length. Also, the feasibility of using the superconducting magnetic levitation technology to drive the movable bridge was discussed.

5. Acknowledgments

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6. References

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