Facilities for marine current energy converter characterization

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Abstract

The utilization of marine currents for power production offers a sustainable option to augment traditional power technologies and enhance the expansion of renewables. The marine current resource is potentially large and could generate a significant part of the European Union's electricity requirements. Before the installation of marine prototypes, specific trials are necessary to evaluate the behaviour of each system and the ability to exploit tidal or marine currents.

This paper presents experimental campaigns carried out on marine energy converter systems under METRI II program performed in the Ifremer free surface hydrodynamic water tunnel. Two of them concern horizontal axis marine current turbine systems: a “classical” pile-mounted tidal turbine concept and a fully submerged machine in deep water. The third concept is an innovative marine current and wave energy system based on Venturi principle from a submerged pipe network. The results presented provide useful information for the hydrodynamic caracterization of marine energy converter systems, their design and for the validation of numerical studies.

Keywords: Hydrodynamic, marine energy, experimental trials, flume tank.

Introduction

The utilization of marine currents for power production offers a sustainable option to augment traditional power technologies and enhance the expansion of renewables. The marine current resource is potentially large and could generate a significant part of the European Union's electricity requirements. Energy from marine currents is highly predictable making it an attractive option amongst other renewable technologies and whilst some of the technological challenges are significant model testing and sea-going prototypes have already been initiated. Many devices are designed around underwater wind turbine principles, known as a marine current turbine [1], but other systems are based on more new concepts.

Some of those systems are in a stage of concept validation for which an evaluation of the ability to exploit tidal or marine currents is needed. This ability is dependent on turbine and/or other concept performances and specific trials are necessary to evaluate the behaviour of each system before marine prototypes can be installed. The impact on the environment is also important to evaluate because changes in water surface elevation and/or seabed modification can appear.

After the first call for METRI II proposal (a European project offering a free of charge access to IFREMER Marine Environment Tests and Research Infrastructure), some marine energy converter systems were accepted for hydrodynamic tests in the Ifremer flume tank. Two of these concern horizontal axis marine current turbine systems, one from the University of Southampton for a “classical” pile-mounted tidal turbine concept [2], [3], the other one being envisaged by Tidal Generation Limited for a fully submerged machine in deep water [4]. The third concept is an innovative marine current and wave energy system developed by VerdErg Engineering Limited. It is based on Venturi principle which generates a pressure gradient used to draw water from a submerged pipe network [5].

At the end of April 2007, the exploitation of the results is not finished for the three systems but the experimental set-up, the testing programs and first results are presented in this paper. In all the cases, the experimental implications of the tests are discussed in the paper and will be presented at the conference.

1 Experimental facilities

Experimental campaigns carried out for those projects under METRI II program are performed in the Ifremer (French Research Institute for Exploitation of the Sea) free surface hydrodynamic water tunnel during the year 2007 (Fig. 1). The flume tank is 18 m long by 4 m wide and 2 m deep with a side observation window of 8 m x 2 m (this large window placed on one side of the tunnel allows users to observe the behaviour of the models during trials and to carry out video sequences). The flow turbulence is less than 5 % and the flow velocity range is 0.1 to 2.2 m/s.

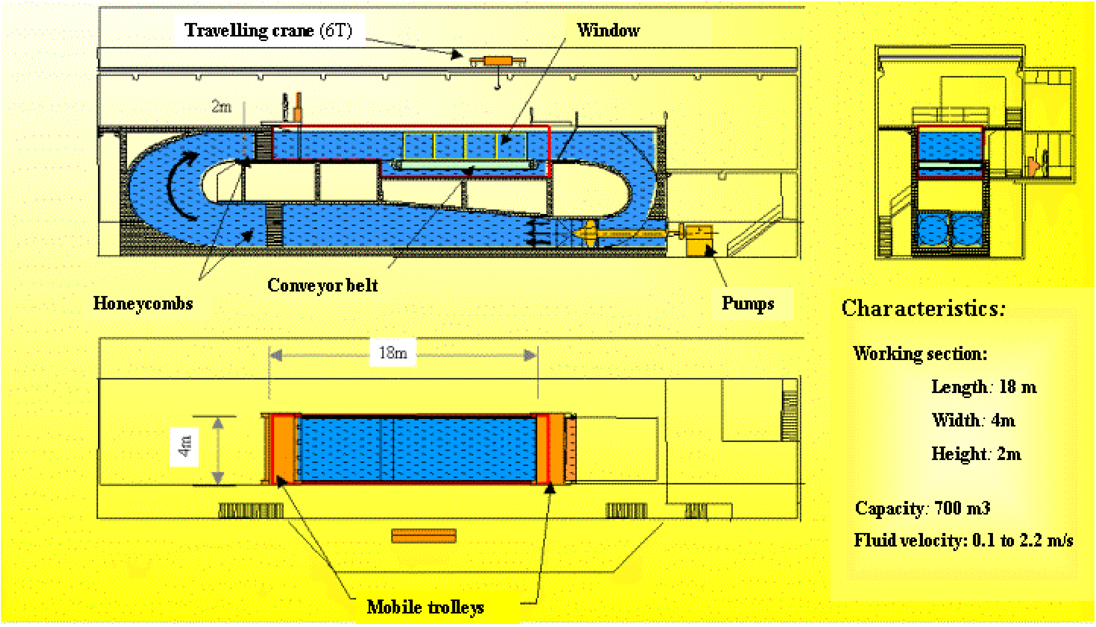

Figure 1: Ifremer free surface hydrodynamic water tunnel located in Boulogne-sur-Mer, France.

A set of instrumentation developed for force, velocity and wave measurements is available:

- 3 and 6 components load cells with a upper limit of 1500 N for forces and 1000 N for moments measurements
- two non-intrusive optical measurement devices for flow characterisation: a two components Laser Doppler Velocimetry system (LDV) for local measurement and a two components Particle Image Velocimetry system (PIV) for global information on the water flow.

The LDV system (Fig. 2) accurately measures the mean and fluctuating components of fluid velocity. Despite the low data rate obtained in some of zones being investigated, the data sets allow us to calculate turbulence parameters. The water is seeded with 15 micron diameter polyamide seeding particles and the flow velocity can be measured along vertical and/or horizontal profiles. Classical measured velocity components are: the axial component, along the x axis, and the tangential component, along y axis. This allows us to obtain the flow characteristics all around the majority of the studied devices. The third component, along the z axis, can be measured in a second time with the utilization of a 90° transmitter probe. All this would be possible by the use of a 3 axis traverse system to move the light source with an accuracy smaller than 0.1 mm.

A particular feature of the LDV measurements is that the ammount of data recorded in a given time window is strongly dependent on the local seeding conditions [6]: measurements are possible only when a particle is moving across the probe volume. Consequently, there are some regions (clean flow) where acquisitions with a relatively high data rate were possible (exceeding 50 Hz); on the other hand, close to the walls or near recirculating zones the rate falls to very low values (lower than 10 Hz).

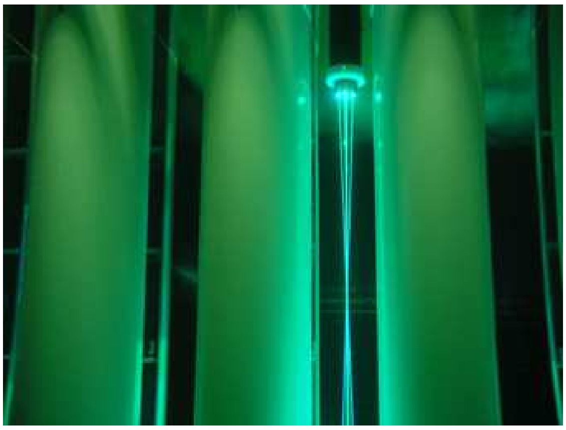

Figure 2: LDV measurement near the SMEC device of VerdErg Engineering Ltd

In order to achieve samples of data as homogeneous as possible, an inhibit method can be used and data recorded under time rather than sample length control. This technique allows us to obtain a sample length of the order of 100 seconds (that is an order of magnitude for the time window larger than the time scale of the flow fluctuations) with a number of data per sample of the order of few thousand. The long time interval allows an accurate estimate of average values, both for velocity and turbulence intensity (the turbulent intensity is generally normalised with respect to the average value of the axial velocity at the entry of the system).

The LDV system is regularly used to verify the quality of the flow in the tank. Fig. 3 and 4 give respectively the dispersion of the axial and transverse velocity around a mean axial velocity value of 1.2 m/s. These results show the good quality of the flow. Time history data can also be acquired and synchronized with, for example, power measurements in order to characterize precisely the response of the system. This kind of velocity map can also be given for the wake of any system to evaluate the flow perturbation.

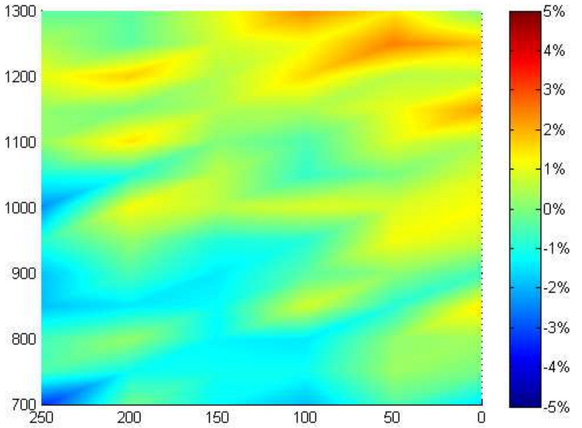

Figure 3: Map of the axial velocity for a mean speed of 1.2 m/s

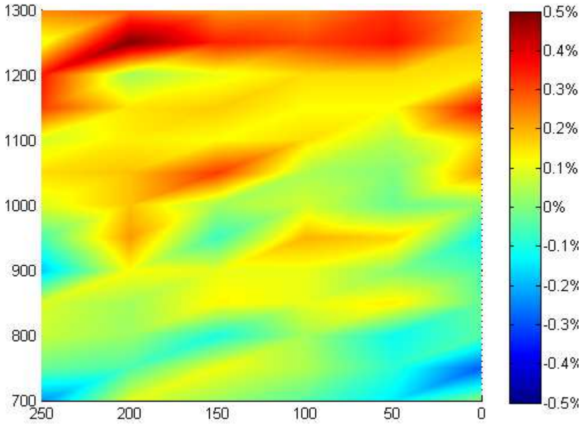

Figure 4: Map of the transverse velocity for a mean speed of 1.2 m/s

Global information can be achieved with the utilization of a PIV system. The PIV technique illuminates the seeding particles and the resulting camera images are used to analyse distances of particle group motion between images. The velocities can be obtained after dividing the distance by the elapse time of laser pulses. A Dantec 1500 PIV system with a two-chamber Gemini PIV Nd:Yag 2 x 120 mJ at 15 Hz pulsed laser can be used. The PIV images can be recorded with a HiSense 1280 x 1024 pixels^2 CCD camera, fitted with a 60 mm lens. The PIV image pairs are generally cross-correlated with a 32 x 32 pixels^2 interrogation window and 25 % overlap. The time between pulses was chosen to ensure that the maximum displacement does not exceed a quarter of the side of the interrogation area. The measurement plane is typically 260 x 220 mm^2. The vector field was evaluated by a predefined velocity magnitude and the invalid one can be replaced by the moving average method. Instantaneous velocity fields can be obtained and generally, a series of instantaneous measurements are statistically average to get the mean velocity field (see an example Fig. 5). The instantaneous and mean velocity fields and turbulence quantities are of great practical interests for marine current energy converter characterization.

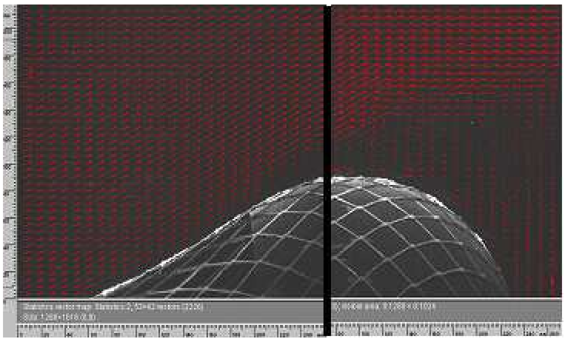

Figure 5: Example of PIV map around a cod-end

The free surface perturbations due to wake and blockage effects can be measured by a set of wave gauges and some generic flow visualization achieved by laser tomography. A set of 6 waves gauges (Fig. 6) is used for the characterization of the free surface perturbation due to the deployment of a submerged pipe network (see part 2.3).

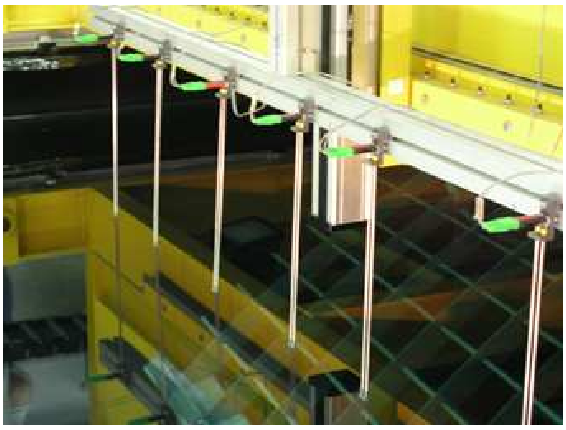

Figure 6: Set of wave gauges for simultaneous acquisition of free surface characteristics

2 Specific trials

In the following sections we present the three experimental campaigns carried out on marine energy converter systems under METRI II program performed at Ifremer. The first two concern horizontal axis marine current turbine systems: a “classical” pile-mounted tidal turbine concept and a fully submerged machine in deep water. The third concept is an innovative marine current and wave energy system based on Venturi principle from a submerged pipe network. These tesings are conducted to characterize the hydrodynamic load on the structure, the power output, the dynamic behaviour and effects on the flow.

2.1 **Fully submerged turbine** (TGL’s turbine)

Tidal Generation Limited are developing a fully submerged machine for deep water utilization. For that purpose and before the design of a 1MW tidal turbine prototype, trials on a 1/30th scale model (Fig. 7) were carried out in March 2007. The purpose of this testing was:

- to investigate the dynamic behaviour of TGL’s turbine
- to test the turbine power control strategy
- to measure the turbine efficiency
- to validate TGL’s analytical rotor modelling tool
- to investigate fault case behaviour.

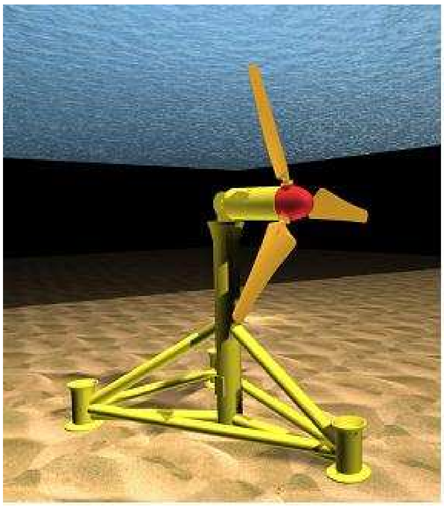

Figure 7: Fully submerged turbine developed by Tidal Generation Ltd

The model to be tested is designed to be mounted on a 6-component load cell in two configurations: *fixed upstream* and *free hinge downstream.* These two configurations are shown in Fig. 8 and 9. A 3-bladed rotor is fixed on a motor-gearbox assembly capable to provide active rotor speed control (gearbox, DC motor, ballast load, motor speed control unit). The pitch of the 3 blades is adjustable. The diameter of the tested rotor is 0.6 m, which create a blockage ratio (percentage of cross section occupied by the rotor) of the model of approximately 4%. Those configurations are tested in the flume tank at speeds ranging from 0.6 to 1.5 m/s and the turbine performance obtained over a range of rotor speed from 10 to 190 rpm and blades pitch angle from –5 to 15 degrees.

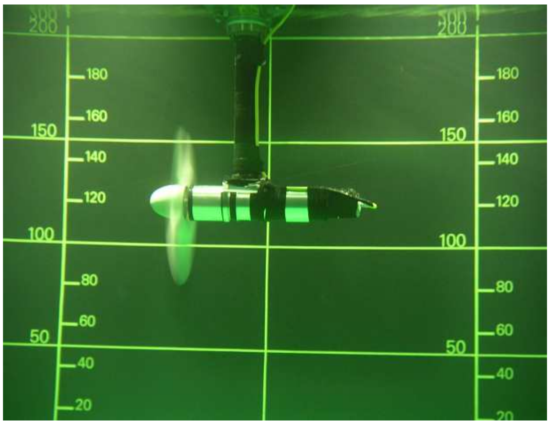

Figure 8: Fixed Upstream Configuration

Testing in the fixed upstream configuration allowed the performance characteristics of the rotor to be measured over the full range of current and rotational speeds. The mechanical torque of the turbine is given Fig. 10 in function of the rotor speed for the 4 pitch angle tested (the flow tank speed can not be given here). The maximum performance is achieved for a 0° blade pitch angle over a short range of rotor speeds (between 100 and 120 rpm). For higher pitch angles (5, 10 and 15°), the maximum performance is achieved at lower rotor speeds (respectively for 70, 80 and 100 rpm). The measured performance of the turbine over its working range of current (0.6 to 1.5 m/s) and rotational speed is within 5% of TGL’s analytical model predictions. The load predictions on the structure are also within 5% of model predictions.

Two power control strategies are tested to investigate sensitivity of turbine power output to natural turbulent fluctuations in the flow. Again close correlation is achieved with TGL’s analytical model. Sufficient data is gathered to inform the design of the control system for the full scale 1MW machine that TGL is developing, allowing fluctuations in rotor torque and power to be minimised.

Free hinge downstream testing showed that the turbine is dynamically stable across the full range of current and rotational speeds in this mounting configuration. As intended, the rotor assumed a substantially horizontal orientation when generating (Fig. 9).

Finally, the “gridloss” fault case scenario was simulated to investigate the loads acting on the turbine at full runaway. This data has helped TGL to develop an appropriate safety strategy for the full scale machine in the event of loss of reaction torque.

A picture showing the wake of the turbine is given in Fig. 11. For these tests, the wake of the turbine was observed under a laser light and a video recorded. Like this, some ventilation effects can be achieved.

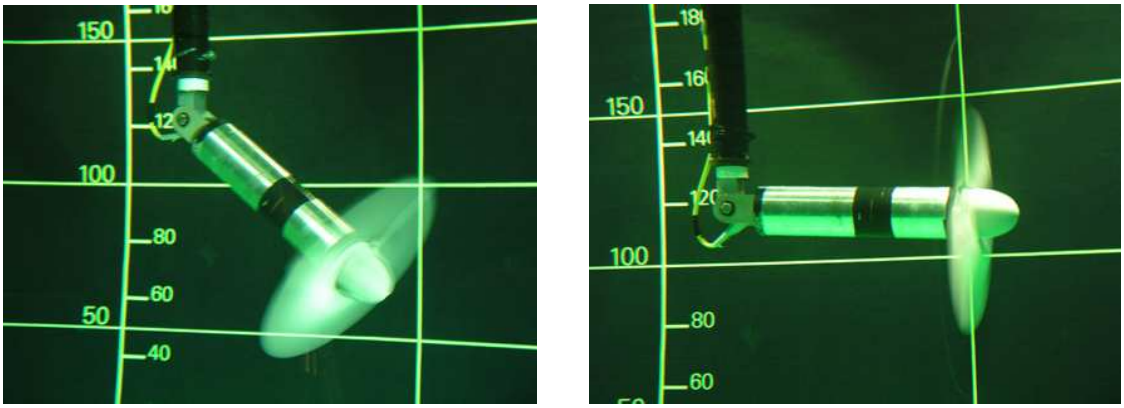

Figure 9: Free Hinge Configuration at low current (on the left) and at optimal speed (on the right)

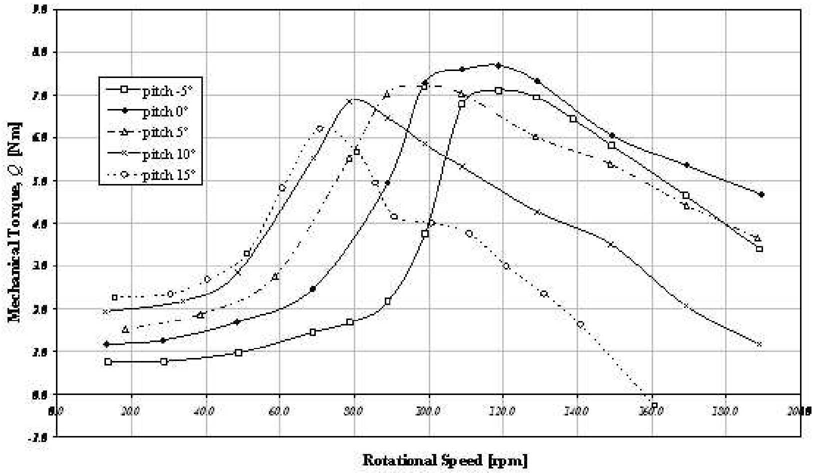

Figure 10: Measured rotor torque in the upstream configuration.

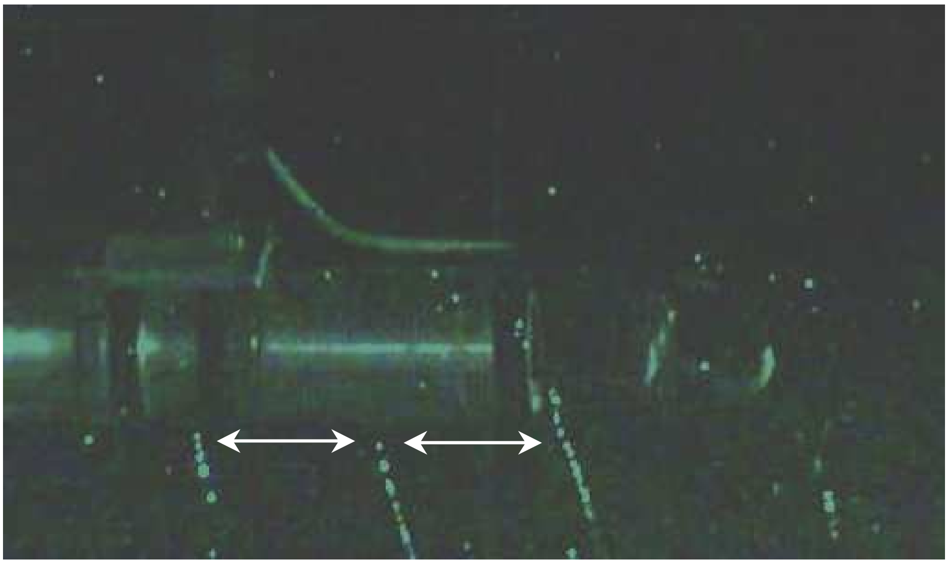

Figure 11: Wake observation at a flow tank speed of 1.5 m/s

2.2 Pile-mounted turbine (SERG's turbine)

Marine current energy conversion technology is presently at the prototype stage where single devices are deployed, or planned for installation, at isolated testing sites. In the medium term devices will be installed in arrays (Fig. 12).

As a marine current turbine extracts energy from the tidal current a wake forms downstream of the rotor. This takes the form of a gradually expanding cone of fluid that has a velocity less than the fluid that passes around the rotor. As the wake travels downstream its mean velocity increases as it mixes with free stream fluid and it is clear that the wake can recover at different rates and that it can take a long distance downstream to recover to 90% of the upstream speed.

Understanding the effect devices have on the flow is critical in determining how one device may modify both the performance of and loading experienced by another device in the array. It is one of the aims of Southampton University work to identify and investigate the parameters which govern the wake structure and its recovery to the free-stream velocity profile. Scale model testing, presented here, is being conducted to aid the development of an efficient numerical model.

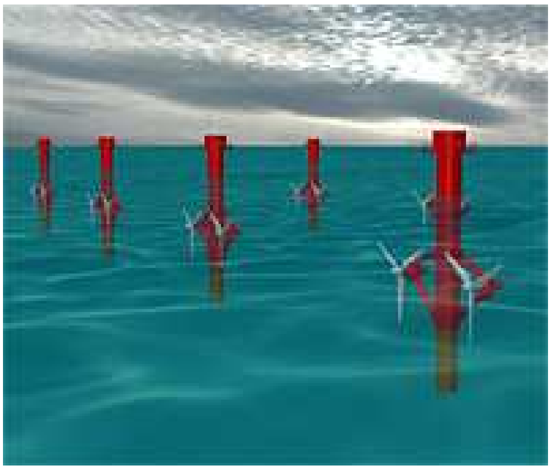

Figure 12: Array of double pile-mounted turbine

In order to increase our knowledge of those phenomenon, trials will be conducted to evaluate performance and wake effects on horizontal axis marine current turbines. The measurements of flow effects around single, multiple and rows of turbine arrangements will be used to increase the knowledge of how such devices will perform when installed in arrays or farms of several machines. Performance and flow (velocities and turbulence intensities in the wake of the system) measurements will be carried out on a 1/15 scale model of a marine current turbine studied by the University of Southampton by laser velocimetry techniques.

The first part of the trials (planned to be realize before the end of 2007) will be dedicated to measure the efficiency and the wake behind a ∅ 0.8 to 1 m horizontal axis model. Tests on twin rotor will be considered afterwards in order to investigate device spacing. At the end of the second part of the trials, we will consider a second turbine operating in the wake of the previous one. The maximum downstream distance between two single turbines will not be able to exceed eight meters.

During the testing, the global forces acting on the device for various configurations and speeds (between 0.8 and 1.6 m/s) will be measured with 6-component load cells. The flow characteristics will be measured with a 2-component laser Doppler velocimeter in the wake of the turbine. The turbine efficiency will be quantified by the measurement of the thrust and the amount of power generated by the rotor.

2.3 Submerged pipe network

The concept developed by VerdErg Engineering Limited exploits the Venturi principle for the conversion of wave and current energy into a favourable pressure gradient across orifices by channeling current and wave induced flow through an appropriately designed structure. Located underwater, this favourable pressure gradient is used to draw water from a submerged pipe network (Spectral Marine Energy Converter - SMEC). Combining multiple orifice flows to draw water from a single manifold source, the flow can be combined to produce a much larger single flow. By incorporating an appropriate impeller, the resulting mass flow may be converted to rotational torque to drive an electrical generator, Fig. 13.

Modeling to support the conceptual theory has been carried out using Computational Fluid Dynamics (CFD) and mathematical simulation but requires validation to carry the concept forward to extend technical development to engineering investigations and prototype sea trials.

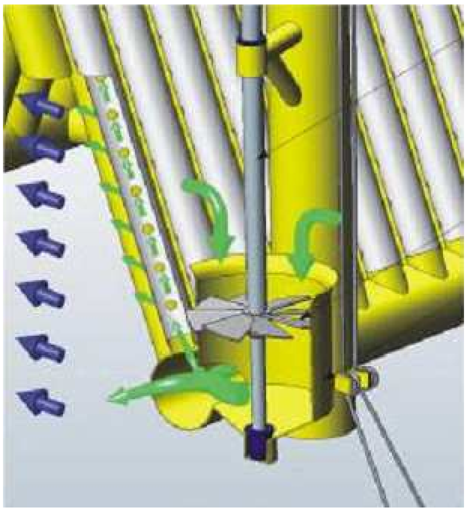

Figure 13: Flowpaths principle over the SMEC device developed by VerdErg Engineering Ltd

One of the grey areas of the numerical work was to determine the effect of the water re-entering the system from the orifice. Mainly due to energy losses and the whether it causes any turbulent areas, particularly at higher flow rates. In order to validate the real concept and the numerical results, a 1/6 scale model of an array of 4, 5 and 6 profiled tubes is used (Fig. 14).

The device (2 m width by 2.2 m height) is maintained on the bottom of the tank by a specific assembly of tubes and cables to overcome any structural failure.

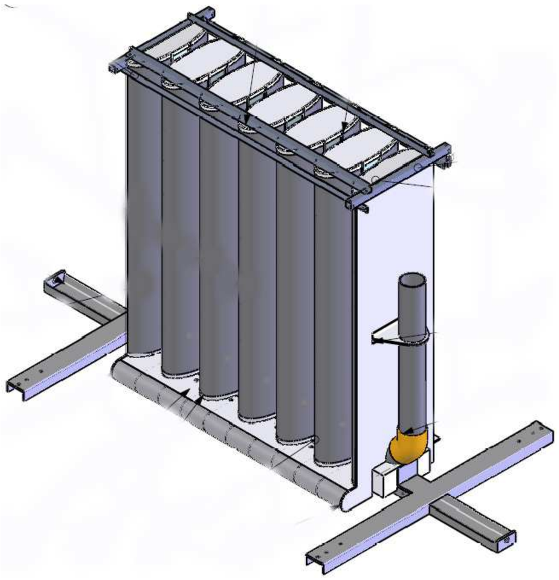

Figure 14: SMEC device of a 6 profiled tubes network with the fixing assembly

The flow characterization around the structure is carried out by laser velocimetry techniques and measurements of surface elevation with wave gauges. The pressure in tubes and the performance of the system are also measured. To achieve this aim, different part of the SMEC device is instrumented with pressure transducers to measure:

- the dynamic pressure at the leading edge of the central pipe
- the differential pressure create by the venturi
- the volume of water drawn by the device.

For the performance characterization of the system, the following test program is considered:

- trials with no orifices at different throat widths to show that the venturi tube concept works and to determine the optimum throat width over the velocity range (Fig. 15)
- once the concept of the venturi tubes is at its optimum, trials with different orifice sizes, different flow rates and different throat widths.

In order to have an idea of the characteristics of the flow to be measured, some simulations on different pipe networks have been previously carried out with the CFD software *fluent*. For these simulations, the k-ω turbulence model is used. Like in the real tank, the device is placed in the center of a 4 m width and 10 m length area. A triangular grid is carried out and the mesh is about 5 mm width close to the tubes and 50 mm width at the edges of the domain.

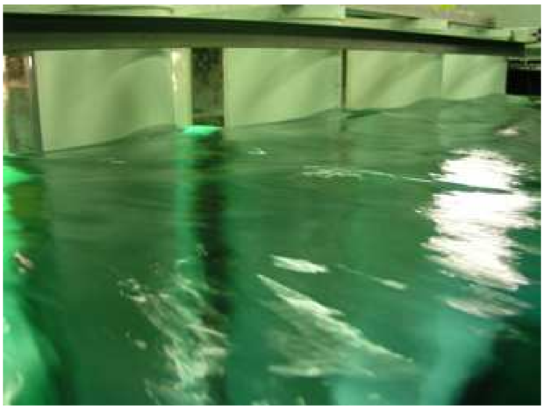

Figure 15: Flow around a 5 tubes network at a flow speed of 1 m/s

Fig. 16 shows some results obtained for an inlet flow velocity of 1 m/s on a 5 pipes network. From these figures, we can check the venturi effect of the pipe network and notice an important transverse velocity: the transverse velocity is approximately 50% of the in-line velocity at the edge of the structure (the device created here a blockage ratio of approximately 37.5 %). From these data, it is possible to determine the optimum positions of measurement.

The first results presented Fig. 17 show a relatively good comparison between numerical and experimental data of the axial velocity acquired upstream of the device. Downstream the pipes network, the comparison shows some relatively bad results, essentially due to free surface effects. These results highligth the necessity to take into account the 3D effects of the flow and particularly the free surface influence on the behaviour of the flow through the pipe network and the necessity to make 3D computation to achieve a good estimation of the performance.

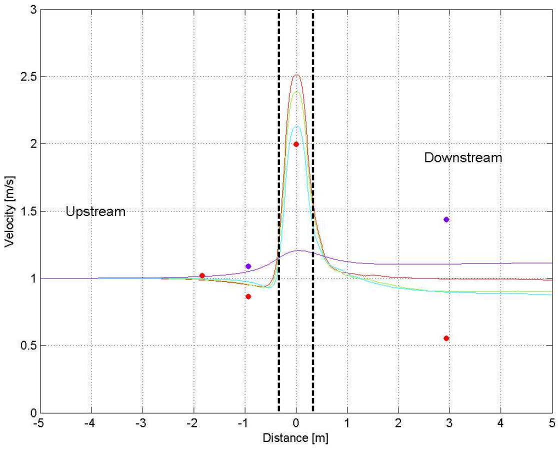

Figure 17: Comparison between numerical and experimental data of the axial velocity at 1 m/s

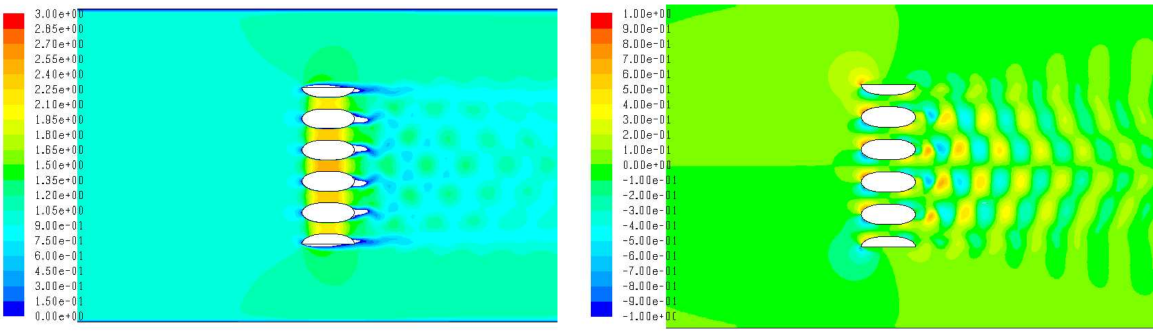

Figure 16: Contours of the axial velocity (on the left) and the transverse velocity (on the right), in m/s

Conclusion

At this date, only the trials for the University of Southampton for the characterization of wake effects on the performance of other device placed in close proximity and on the environment (free surface pertubation and seabed impact) are not achieved. For the two other projects, successful measuring of the performance characteristics of marine current energy converters have been conducted in a free surface circulation tank.

For each device, a specific assembly has been designed and a test programme carried out which provide good results and suitable data for validating theoretical and numerical methods.

In the case of a fully submerged machine for a deep water utilization the results provide here are in good agreement with the mathematical model developed by TGL. Results obtained during these trials with the free hinge configuration validate the global concept of the system for fully submerged application.

The trials for the characterization of a more innovative concept of a shaped pipe network are not completely finished but the first results give some interesting information for the validation of the concept and the numerical simulation.

In all the case, the results presented here provide useful information for the hydrodynamic characterization of three different marine energy converter systems and for the validation of their corresponding numerical studies.

Complementary trials could be carried out in the future to evaluate wave impact and turbulence consequences on device performances. To this aim, a wave generator system is in development in order to give the possibility to carry out combined trials in wave and current.

Acknowledgements

The European Union offers under the METRI II program a free of charge access to IFREMER Marine Environnement Tests and Research Infrastructure. The access is free of charge for European Research teams and for small/medium-sized companies which conduct scientific and technical studies on the behaviour of materials, equipment, sub-marine vehicle, instrumentation, physical and physico-chemical sensors… in marine environment. Prospective applicants can propose short-term projects which will be selected on the basis of scientific merit through an independent peer review procedure. The selection is on the basis of scientific merit taking into account the interest of the Community and priority is given to research teams who have not previously used the infrastructure and who are not working in countries where few such research facilities exist.

Under the METRI II program, Ifremer proposes five testing facilities which are implemented to develop, qualify, control… materials designed and used in Marine Environment, with the support of a highly qualified scientific team. These five facilities are:

- a deep wave basin (20 m depth with regular and irregular waves)
- a free surface circulation water tank (flow velocity range from 0.1 to 2.2 m/s)
- some hyperbaric testing tanks (allow the immersion simulation up to 10 000 metres) ;
- a laboratory for testing materials behaviour and structures ageing ;
- a laboratory for marine sensors evaluation and calibration (COFRAC accredited for Pressure and Temperature).

We also would like to acknowledge and thank the following people for their implication in one or all projects: J-V. Facq, B. Gaurier, D. Dodd, J. King, J. Minto, L. Myers, P. Bird, S. Chapman, D. Wood.

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