Protocols for testing marine current energy converters in controlled conditions. Where are we in 2018 ?

G. Germain [1], B. Gaurier [1], M. Harrold [2] , M. Ikhennicheu [1], P. Scheijgrond [3], A. Southall [4], M. Trasch [1]

[1] Marine Structure Laboratory, IFREMER, 150 Quai Gambetta, 62200 Boulogne s/ Mer. France. gregory.germain@ifremer.com

[2] TOCARDO Tidal Power, Netherlands, NL. mha@tocardo.com

[3] Dutch Marine Energy Centre, DMEC, The Netherlands. peter@dutchmarineenergy.com

[4] European Marine Energy Centre, EMEC, Orkney, UK. anna.southall@emec.org.uk

***Abstract*—Certification can help to reduce perceived risks of marine energy technologies in terms of performance and structural integrity, and thus helps to attract commercial financing and make export easier. At present, a certification scheme for marine energy convertor is under development by the International Electrotechnical Commission (IEC) involving all stakeholders in a consistent way based on international consensus.**

The implementation of international standards and certification schemes are needed to accelerate marine energy technologies development. In order to improve the work already achieved and to propose adaptations and enhancement, four experimental trials are undertaken on different kind of tidal energy devices (fixed and floating horizontal axis turbine as well as undulating membrane) under the Interreg 2 Seas Met-Certified project. The first results obtained under this project in the wave and current flume tank of Ifremer are presented. The experimental set-up and protocol trials, taking into account the actual best practices and guidelines, are presented.

Index Terms—Marine energy, tidal energy, standards, certification, experimental trial, test protocol.

I. Introduction

Certification can help to reduce perceived risks of the technologies in terms of performance and structural integrity, and thus helps to attract debt financing and make export easier. At present, a certification scheme for marine energy convertor is under development by the International Electrotechnical Commission (IEC) involving all stakeholders in a consistent way based on international consensus. The implementation of international standards and certification schemes are needed to accelerate marine energy technologies development. Within the IEC, Standards are developed by Technical Committees (TC), TC 114 prepares standards for Marine Energy converters. Conformity assessment is separated from this and is managed by IECRE Marine Energy Operational Management Committee (IECRE ME-OMC).

In order to create a valuable and robust system, it is important that it is applied in the real world and feedback from experience is given back to the groups developing the specification and certification schemes.

In July 2016, the Interreg 2 Seas Monitoring Committee gave the green light to the MET-CERTIFIED project [4], which stands for Marine Energy Technologies Certification. The project aims to contribute towards the development of the specifications and certification schemes under the umbrella of the IEC TC 114 committee and the IECRE ME-OMC [14]. Stakeholders around certification, from banks and insurers to consenting authorities, end-users, test facilities and certification bodies are involved throughout this project.

Four pilot projects will be verified against the IEC TC 114 standards that are currently under development (see Fig. 1). For example, the tidal power plant in the Eastern Scheldt Storm Surge barrier will be used as a reference case in order to make recommendations for procedure adaptation.

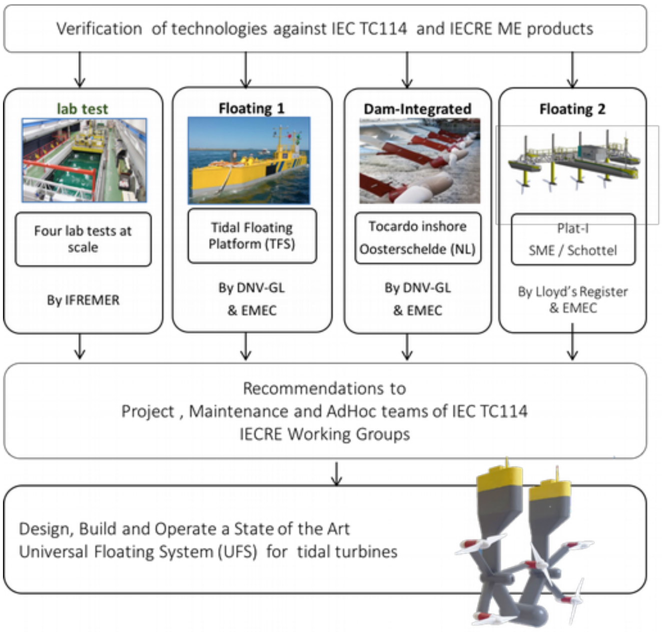

Figure 1 : Diagram showing how the various technologies are reviewed under the MET-CERTIFIED project and feed into recommendations to IEC TC 114 Technical Specifications and IECRE ME certification schemes.

By applying the standards and certification schemes on such real world projects, valuable feedback is collected to improve the IEC products. It is expected that this process will result in a robust and internationally recognised certification scheme for the sector and reduce the actual and perceived risk associated with marine energy projects [5]. This in turn will increase large investors interest, enabling the sector to deploy large marine energy projects. Technical Specifications under development under IEC TC 114 standards for Marine Energy Convertors are presented Fig. 2. MET-CERTIFIED focusses on generic specifications relevant for Tidal Energy Convertors.

Scale testing standards for controlled conditions and their use to predict performance at higher TRLs in open water constitute the final objective of this work. In this work, we focus on procedures adaptation to 62600-202 Scale testing Technical Specification. We will thus propose a hierarchy to take into account the wave and turbulence effects as well as device interaction effects in function of the technology and project progress.

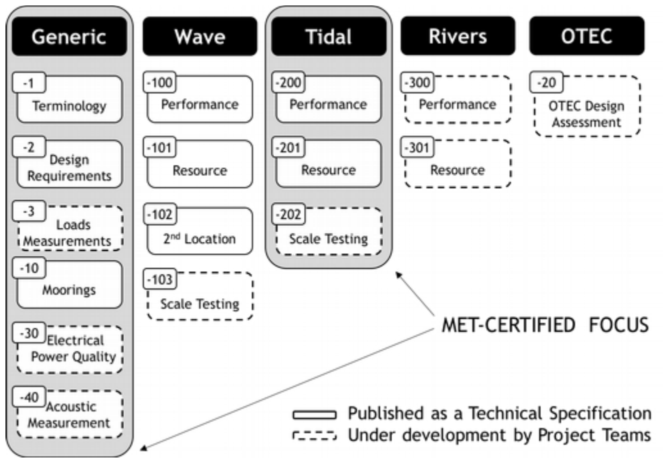

Figure 2 : Technical Specifications under development under IEC TC 114 standards for Marine Energy Convertors. MET-CERTIFIED focusses on specifications relevant for Tidal Energy Convertors.

I. Scale Testing

Prototype testing is required for a new tidal energy device certification. Therefore, tank testing at model scale [12] must be undertaken to establish the behaviour of a tidal energy converter under different kind of conditions. The availability of a controlled environment where each set of experiments can be repeated is thus highly valuable.

Due to the fact that marine renewable testing laboratories are not uniformly configured or constructed, standardisation of test practices is an important aspect for industrial development. Tank testing is primarily undertaken to establish the behaviour of a tidal energy converter at model scale and to identify the impact of different test configurations (flow and prototype characteristics) on device performance. At present there is no pan-European or worldwide consensus on appropriate test methodologies and practices to be implemented, even if procedures developed within the EC EquiMar [1] and MarInet [2] projects, have been carried out. Today, international best practice guidelines for tidal turbine testing are under development by the International Electrotechnical Commission (IEC) [3]. In order to improve the work already done and to propose adaptations and enhancement, three experimental trials are undertaken on different kind of tidal energy devices (fixed and floating horizontal axis turbine as well as undulating membrane, Fig. 1) under the Interreg 2 Seas Met-Certified project [4]. During these tests the IEC Tidal Scale testing procedures (62600-202) will be applied and evaluated for being fit for purpose, even if the IEC 62600 series of standards are currently under development. Some works have also been carried out to determine the best instrumentation and procedure to use for inflow condition characterization.

Figure 3 : Technologies planned to be tested under Met-Certified projetc (from left to right): (1) SME's Plat-O submerged platform for tidal turbines to be installed at EMEC, (2) the Eastern Scheldt Tidal power plant of Tocardo, (3) EEL Energy being tested at IFREMER, (4) TTC offshore test site.

II. Tank test protocols

Under the Met-Certified project, three experimental campaigns have been carried out to study the impact of the experimental protocol and the instrumentation used to evaluate the performances of different kind of tidal energy convertors. A three-bladed horizontal axis turbine is used as a well-known generic turbine with which it is possible to undergo some specific research trials such as turbulence [7], waves [16], impacts [15] and interaction [17] effects. A floating platform for multi-turbines deployment developed by Tocardo has been also tested in order to demonstrate the behaviour of the full concept, from the mooring lines system to the platform behaviour under wave and current solicitations. At least, an undulating membrane developed by Eel Energy [9] has been considered in order to evaluate the adequation of the classical protocols for other kind of technologies (Fig. 3 and 4). These three devices have been tested in the wave and current circulating tank of Ifremer [5].

The tank working section is 18m long by 4m wide and 2m deep. The streamwise flow velocity range is U=0.1 to 2.2m/s. The natural flow turbulence intensity (I_∞) in the tank is 15%. It can be decreased to 3% by using flow straighteners and to 1.5% by using grids and flow straighteners. A wave generator, composed of eight independent displacement paddles, each 0.5m wide and 500mm deep, can be moved between an upstream or a downstream surface position to create waves propagating with or against the current. When the wave generator is used to generate waves with the current, the turbulence level increases to 15% close to the free surface, whether there is flow straightener and grids. The system is able to generate regular and irregular waves with a frequency range between f = 0.5 and 2Hz and a maximum amplitude of 280mm with a current speed up to 1m/s. Measurements have revealed that the resulting reflection coefficient was less than 12% for all the usual wave periods and amplitudes. A side observation window of 8 x $2m^2$ placed on one side of the tank allows users to observe the behaviour of the model during trials. The tank is equipped with a Laser Doppler Velocimeter (LDV) and a Particle Image Velocimeter (PIV) for 2D flow measurements with a relatively high acquisition frequency up to 1kHz for the LDV and a high spatial resolution for the PIV.

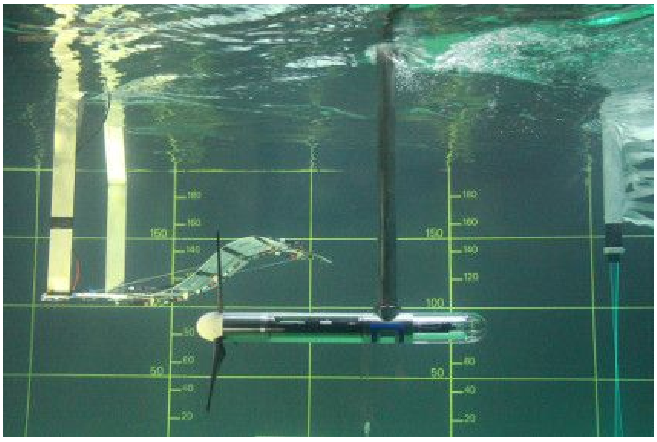

Figure 4 : Tests carried out for comparison between a generic 3-bladed horizontal axis turbine and the Eel Energy undulating membrane.

The prototype studied in this paper is a three-bladed horizontal axis turbine of 0.724m diameter. The rotor is connected to a motor-gearbox assembly consisting of a gearbox, a DC motor, a ballast load and a motor speed control unit, providing an active rotor speed control. The turbine blades are designed from a NACA 63-418 profile. The model is fixed to a mast, itself fixed to a support above the water level. Each blade foot is now equipped with a load-cell providing 5 different output channels: 2 forces (drag and lift) and 3 moments (bending and pitching moments). In addition to this new multi-component blade load-cell, the torque and the thrust applied on the main rotational axis are now measured. This water-proof sensor is positioned directly behind the blade foot and before the seals of the machine to prevent measuring the friction effects [15].
With the use of this prototype, several aspects of the protocol can be evaluate:

- Influence of the flow conditions, from a steady flow to combined wave and current conditions or a highly turbulent flow,
- Instrumentation sensitivity and geometrical representativeness,
- Wake effects with LDV and comparison with previous wake profiles,
- Upstream flow and wake measurements for each flow conditions.

III. Experimental results

Performance tests (in laboratory as well as in-situ) require to calculate kinetic energy the measurement of the upstream flow velocity, especially when the turbulence intensity is high [6]. However, to get a good accuracy this measurement needs to be synchronised with the turbine parameters (62600-200 and 62600-201).
On figure 5, two power coefficient curves obtained for an averaged velocity U = 1.0m/s and a turbulence intensity of 15% are presented. For both curves, the turbine parameters, i.e. torque and rotation speed, are the same and have been acquired during 6min, which is enough to reach the convergence. These parameters are non-dimensionalized with a velocity from flow measurement performed during 30min, previously obtained for the same conditions, and from synchronously acquired flow measurement acquired at 2 diameters upstream of the turbine. The differences between these 2 curves show a higher accuracy when both kind of measurements obtained in a synchronous way are used for the data analysis. Hence, the power curve must be considered along with flow velocity variation.

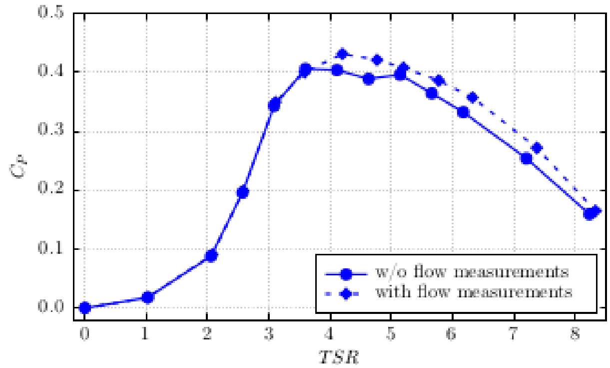

Figure 5 : Comparison of the power coefficient, non-dimensionalized with a velocity from flow measurement performed during 30min (w/o flow measurements) or from synchronously acquired flow measurement acquired at 2D upstream of the turbine (with flow measurement).

Due to the high level of turbulence, the distance between the upstream velocity measurement point and the turbine may be misleading or source of uncertainty. With a 4 diameters distance (2.8m), Medina & al. [2] studied the coherence function between the velocity and the power production of the turbine. According to this study, above 1Hz sampling frequency, no more correlation is noticed.

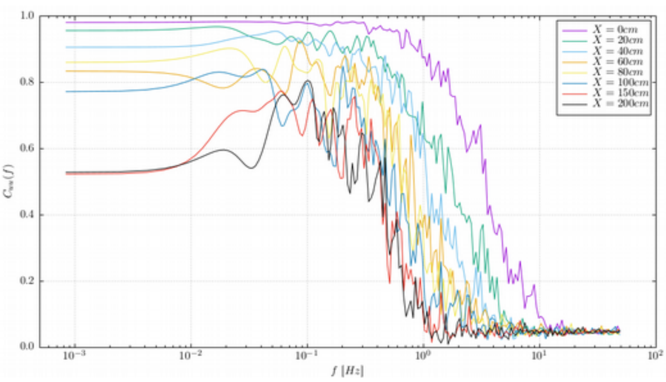

Figure 6 : Example of coherence functions in function of the distance between the flow point measurement and the turbine.

On Fig. 6 we can see the influence of the distance between the flow point measurement and the turbine: the further the flow measurement point is located from the turbine, the lower is the coherency. A particular study focus on the time and space correlation between velocity measurement and turbine parameters is presented in [12]. The instrumentation used to measure the upstream flow will be also addressed: 2 or 3 velocity components, one point with high data-rate (LDV) or vertical profile map (PIV).

The turbulence characteristics in term of iso or anisotropy, energy level and spatial repartition, effect on turbine performances must be also addressed. Indeed, Ikhennicheu & al. [8] highlight that a particular attention should be paid in presence of large velocity fluctuations, with high turbulence rate, coming from bathymetry variations. Here results are presented with a large square cylinder with aspect ratio width/height = 7. These low frequency structures, with a diameter up to the diameter of the turbine like shown Fig. 7, affect the efficiency of the turbine and the fatigue of the blades [7].

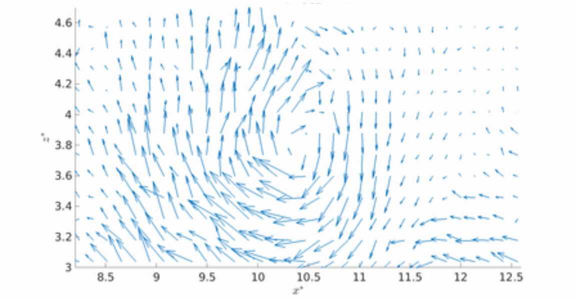

Figure 7 : Vortex detection behind a wall mounted cylinder from PIV measurements

To assess these points, the performance of the turbine, in term of classical power and thrust coefficients, should be processed. The blades bending moment coefficients should be analysed as well, in a temporal and spectral point of view. PIV measurements for upstream flow characterization must then be preferred as presented by Gaurier & al. [10] and illustrated Fig. 8.

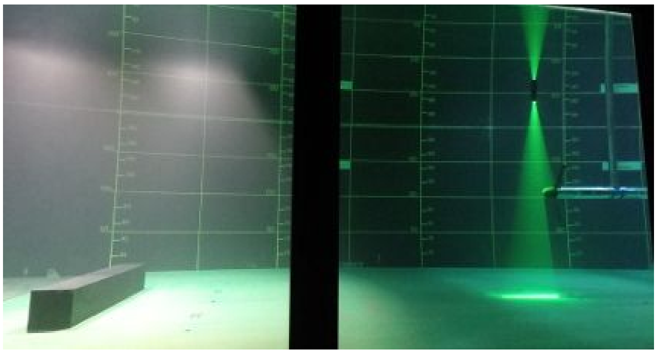

Figure 8 : PIV measurements of flow perturbations affecting the hydrodynamic loads on the turbine

From these measurements with a high spacial resolution, it is possible to study the coherency between the flow perturbations and the power production for a turbine deployed in the recirculation zone behind a wall mounted structure like shown Fig. 9.

In order to support the Tocardo development of the UFS (Universal Foundation System), it was necessary to firstly test a scale model of the structure in the controlled environment of a laboratory. A prototype was built at 1/18th scale and tested in IFREMER's 2 m deep combined current and wave tank (Fig. 10). During these tests, the behaviour of the UFS and its mooring system has been studied in a range of conditions representative of those at full-scale.

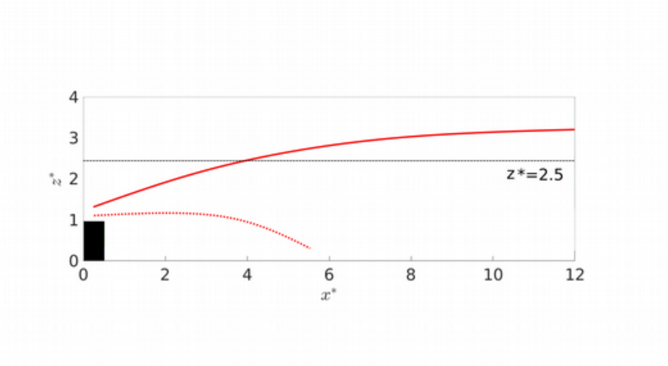

Figure 9 : Schematic representation of the recirculation zone behind a wall mounted cylinder. Dots indicate U < 0 and line U > 0.9.

It has been decided to first performed tests without rotating turbines on model scale to reduce the trials complexity for the first test stages, but with the complete mooring system. Therefore it was decided to simulate the turbines with changeable static actuator discs and strip blades, which give equivalent drag loads for conditions in which the turbines are operational and parked (survival) respectively. The operational rotors have considerably higher drag coefficients than the parked condition. Fig. 10 shows the model UFS with parked rotors.

The UFS was tested in current only conditions to evaluate platform drag without the presence of waves. Full-scale equivalent flows of up to 6 m·s^{-1} were achieved, equivalent to survival conditions. The conditions can be assumed to be quasi-static, since a constant flow velocity was maintained for each measurement run, during which the UFS held a stable position.

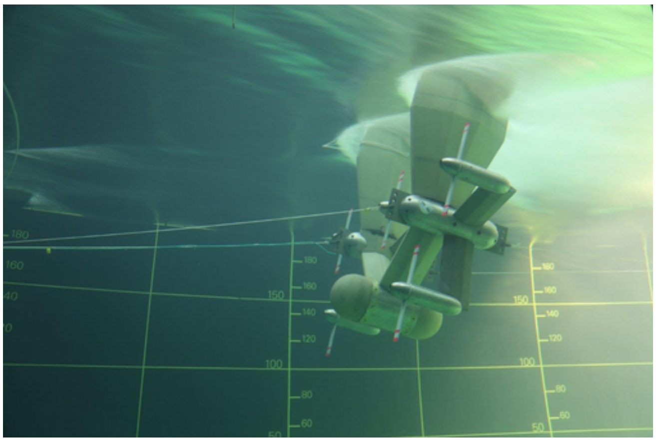

Figure 10 : UFS platform developed by Tocardo under H2020 InToTidal project.

The UFS platform was found to be stable in all conditions, showing no significant variation in position or orientation during the tests, other than the allowed surge motions. The operational rotors unsurprisingly result in greater surge motions and upstream line tensions for a given flow velocity (Fig. 11). Platform behaviour also appeared to be almost identical with respect to the orientation of the rotors.

The unsteady results did result in increased motion of the UFS, but generally this did not affect the mean platform

positions. Turbulence could occasionally, for example, create additional lift on the UFS columns and cause the platform to temporarily sway. As expected, the unsteady results did have an effect on the platform pitch, due to the lower flow velocities at the top of the water column. This caused the UFS to pitch slightly from the top towards the upstream end of the tank.
One unexpected result from these tests was the development of a bow wave at the UFS columns in high flow velocities, adding considerable wave resistance to the platform. The effect is most prominent on the pitch motions. This effect is currently not captured in the numerical model. Hence it will be necessary to add an empirical correction to account for this feature in order to accurately account for the full-scale behaviour.

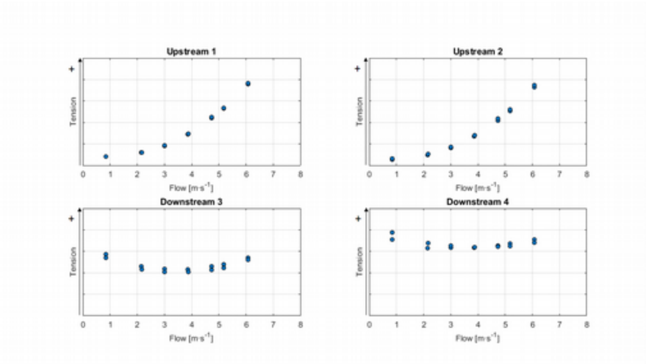

Figure 11 : UFS mooring line tensions in current

The UFS was also tested in a variety of regular and irregular wave conditions, both with and without current, like shown Fig. 12. While regular waves will not occur in reality at sea, these tests provide useful datasets that are easier to compare with numerically simulations. The maximum achievable wave heights in the tank were approximately 4 m at full-scale, and generally this decreased with increasing wave period and/or the inclusion of current. Tested full-scale wave periods ranged from 6 – 12 seconds. As with the current only tests, the UFS was tested with operational and parked rotors, both in upstream and downstream configurations. The wave conditions tested were not particularly extreme and generally the UFS comfortably pitched back in forth with each passing wave. In short period waves of 6 s, however, the platform did not have time to recover to its initial position before the arrival of the next wave.

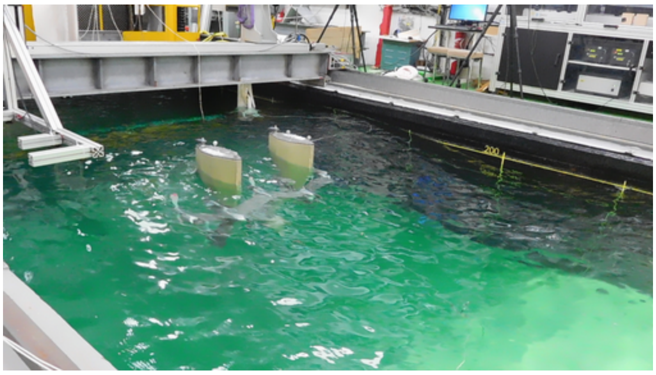

Figure 12 : PIV UFS under combined regular waves and current solicitation.

Therefore the pitch period was not equal to the wave period, but instead double the period. This behaviour has also been observed in the numerical model. The obtained datasets not only provide information on the stability of the platform in a range of wave conditions, but also the induced cyclical variations in mooring line tensions. These are directly related to the mooring line fatigue life.

PIV measurements have been performed in the wake of an undulating tidal energy converter developed by Eel Eenergy [9]. Three configurations of the converter have been tested: one un-damped case (without PTO), a low and a high amplitude damped cases with shorter cables.

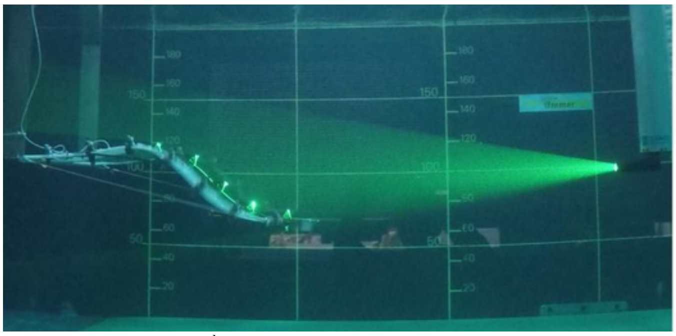

Figure 13 : 1:20 th scale prototype during PIV measurements.

Large measurement planes (616 mm × 979 mm) have been obtained during a period of 150s for each configuration. A motion tracking system has been synchronized with the PIV measurement. It enables to phase the different planes of a same wake. Phase-averaged maps of velocity variation are presented figure 13. We can notice water packs projection of positive and negative vertical velocity once an undulating cycle, each in the top and bottom parts of the tank. These areas are moving downstream at mean upstream velocity speed. They are submitted to confinement and interact with free surface and tank bottom. Indeed, one can observe more persistence of bottom perturbations, whereas upper vortices get to burst at free surface. Here, the free surface and bottom floor effects can't be neglected, even if the experimetnatl set-up represents at scale in-situ conditions (2m representing 40m water depth). This experimental database doesn't allowed easy comparison with numerical simulations.

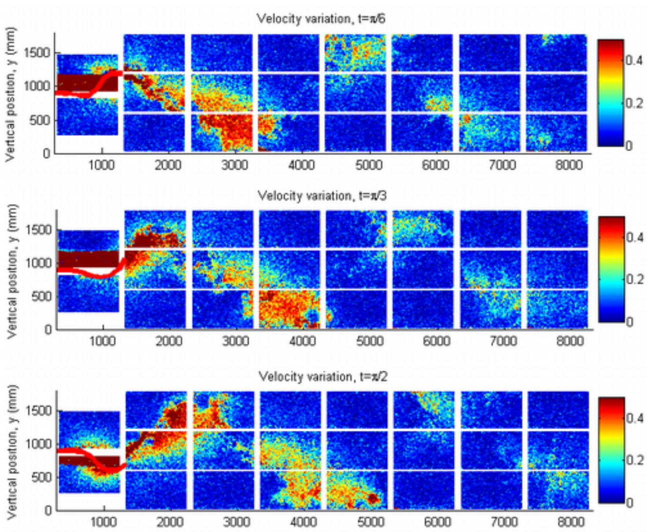

Figure 14 : Phase-averaged velocity variation map

Due to the duration of the experiments, the adjustment of PTO varied. This variation causes difficulty in the power estimation and in the junction of the planes. The PTO adjustment has been measured before and after each experiment in order to minimize the uncertainty and errors. Moreover, the trajectories of the dampers used to simulate power conversion have been re-produced in a displacement table to get precise power estimation.

Even if for classical turbine the PTO system is easier to simulate, some specific developments are still needed to be able to reproduce the good behaviour of the energy converter, from the energy caption to its transformation. As underlined by the experimental results obtained from these three test cases, the existing experimental infrastructures don't allowed to take into account all the parameters (operating conditions and device characteristics). In order to balance considerations between Reynolds scaling and Froude, we choose for the three devices a scale of 1/20. This scale factor allows:

- to overcome blockage effects with the three-bladed horizontal axis turbine for performance evaluation but also wake characterization,
- to limit the blockage effects with the undulating membrane even if the free surface and bottom floor effects can't be neglected for wake characterization. In opposite, the experimetnatl set-up represents at scale in-situ conditions,
- to study the dynamic behaviour of the UFS without any PTO system under regular and irregular waves .

IV. Conclusion

The MET-Certified project provides a unique opportunity to apply newly developed technical specifications and certification schemes in real world scale and demonstration projects. Undergoing this process has helped to raise the understanding and reduce the risk profile for the technology developers. At the same time, Test Laboratories and Certification Bodies are learning to apply the specifications in real conditions for the first time. Finally, IEC TC 114 project and maintenance teams benefit from input to improve the specifications. The feedback is provided by experts that are both partners in the MET-Certified projects as well as members of relevant project and maintenance team. It is expected that these activities result in wider acceptance and adoption of more robust international technical specifications and certification schemes. Robust certification reduces actual and perceived risks of the technologies in terms of performance and structural integrity, and thus helps to attract commercial financing and facilitate international trade, thus accelerating the adoption of innovative marine energy technologies.

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