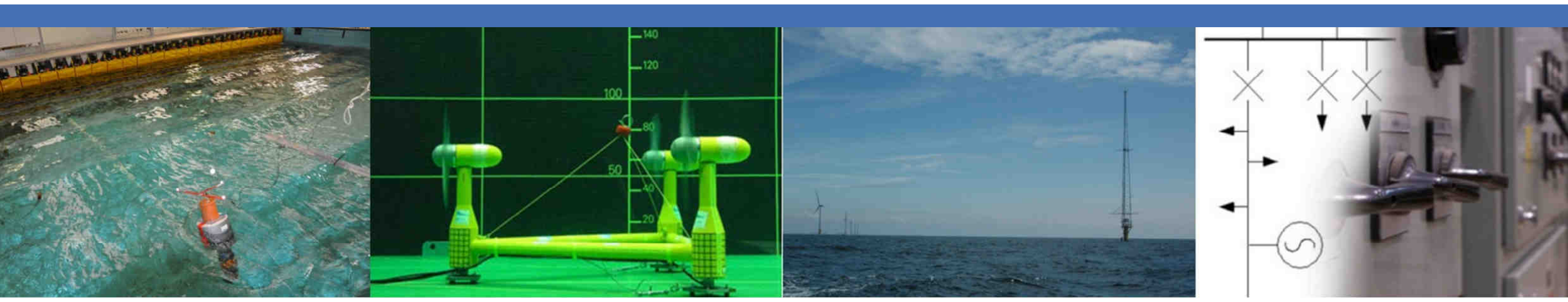
MARINET

Marine Renewables Infrastructure Network



WP4: Research to Innovate and Improve Infrastructures, Technologies and Techniques

Deliverable 4.01EC

Tank test related instrumentation and best practice

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ABOUT MARINET

MARINET (Marine Renewables Infrastructure Network for emerging Energy Technologies) is an EC-funded network of research centres and organisations that are working together to accelerate the development of marine renewable energy - wave, tidal & offshore-wind. The initiative is funded through the EC's Seventh Framework Programme (FP7) and runs for four years until 2015. The network of 29 partners with 42 specialist marine research facilities is spread across 11 EU countries and 1 International Cooperation Partner Country (Brazil).

MARINET offers periods of free-of-charge access to test facilities at a range of world-class research centres. Companies and research groups can avail of this Transnational Access (TA) to test devices at any scale in areas such as wave energy, tidal energy, offshore-wind energy and environmental data or to conduct tests on cross-cutting areas such as power take-off systems, grid integration, materials or moorings. In total, over 700 weeks of access is available to an estimated 300 projects and 800 external users, with at least four calls for access applications over the 4-year initiative.

MARINET partners are also working to implement common standards for testing in order to streamline the development process, conducting research to improve testing capabilities across the network, providing training at various facilities in the network in order to enhance personnel expertise and organising industry networking events in order to facilitate partnerships and knowledge exchange.

The initiative consists of five main Work Package focus areas: Management & Administration, Standardisation & Best Practice, Transnational Access & Networking, Research, Training & Dissemination. The aim is to streamline the capabilities of test infrastructures in order to enhance their impact and accelerate the commercialisation of marine renewable energy. See www.fp7-marinet.eu for more details.

Partners

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Sustainable Energy Authority of Ireland (SEAI_OEDU)

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Contributing Authors	Jérémy Ohana IFREMER Sylvain Bourdier ECN

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EXECUTIVE SUMMARY

Marine energy devices are still at development stage and many models are being tested in the different hydrodynamics facilities. Improving the measurements quality of these tests by exchanging between the technical staff of the Marinet partners is one of the Work Package 4 objectives.

This report is an experience feedback from Marinet tests. It was written mostly from Ifremer experience and aim to present the instrumentation techniques needed to carry out quality tank testing.

The first part reviews the typical physical parameters to be measured, gives a short description of the sensors working principle and examples of implementations. The flow measurement section starts with wind measurement and a comparison of advantages and drawbacks of different kinds of anemometers. About wave measurements, the description of the Ifremer wave gauge completes the Marinet deliverable 2.1 database. Then capacitive gauges for measuring water elevation inside the model are introduced. Afterwards the use of load cell to measure tensions in mooring lines is explained and illustrated by different Marinet project setups. Finally the motion measurements by video motion tracking are described and associated recommendations are suggested.

The second part deals with the acquisition system to record the signals from the sensors. Different configurations including adding an embedded acquisition system in the model are detailed. Synchronization issues come up with the use of several acquisitions system and are discussed here.

The third part covers the measurement uncertainty assessment. The measurement errors are calculated from the static calibration procedure. Next, the necessity of dynamic calibrations is exposed with the associated procedure and analysis.

The last chapter shows examples of generating techniques energy resources at model scale. The Ifremer wind generator with variable wind speed capabilities and some results of its characterization campaign are presented.

CONTENTS

1 INTRODUCTION

The first development phases of marine energy devices include testing in hydrodynamic facilities on reduced scale models. As described in details in the Marinet deliverable 2.5 [5] for the wave energy converters, these tests go after different objectives:

- Validation of the working principle.
- Assessment of the general hydrodynamic behaviour.
- Power Take Off performances estimation and optimization.
- Mooring system characterization.
- Validation of numerical models.

To provide quality analysis on these topics, several conditions must be met during the preparation and the carrying out steps of the tests.

The scaled model design and manufacture must consider several factors explained in details in the Marinet deliverable 2.13 [7]. Before starting the tests in the tank, the model mechanical properties must be determined accurately (mass, inertial moments, centre of gravity position). It is also the case for the scaled mooring system (lines mass per unit length, static and dynamic stiffness). The test facilities reproducing the environmental conditions must be characterized in order to apply accurate and reproducible testing conditions to the model. As the test result quality depends on the measurements quality, the choice and the good implementation of the instrumentation is a crucial point.

This report focuses on the different measurement techniques usually deployed while testing a marine energy device in a tank. For the most common physical parameters to be measured a brief description of the working principle is given and examples of implementations used for Marinet tests are shown. Then acquisition system issues are discussed and different configuration options are presented. Afterwards, static and dynamic calibration procedures, which are essential to assess measurement quality, are explained. Finally the last chapter is about wind generation techniques used at Ifremer facilities.

2 CHOOSE AND SET UP THE APPROPRIATE SENSOR

2.1 Flows

2.1.1 Wind measurements

While generating wind to apply aerodynamic forces on a model, wind properties must be determined accurately at different locations in the working volume: its direction, its average velocity and its variation around its mean value.

Wind speed can be written in the three directions as:

$$U = \bar{U} + u'$$
$$V = \bar{V} + v'$$
$$W = \bar{W} + w'$$
$$Vel = \sqrt{U^2 + V^2 + W^2}$$

With the average speed defined as:

$$\bar{U} = \frac{\sum U}{N}$$
$$\bar{V} = \frac{\sum V}{N}$$
$$\bar{W} = \frac{\sum W}{N}$$

$\overline{Vel} = \frac{\sum |Vel|}{N}$, with N as the number of samples measured

The turbulent intensity is defined as:

$$Iuu = \frac{\sqrt{\overline{u'^2}}}{\overline{Vel}}$$
$$Ivv = \frac{\sqrt{\overline{v'^2}}}{\overline{Vel}}$$
$$Iww = \frac{\sqrt{\overline{w'^2}}}{\overline{Vel}}$$

Cup type anemometers or propeller type anemometers measure the average wind speed in one direction. With such devices, even equipped with a vane, the 3D wind direction and turbulent intensity cannot be assessed. The fast variations of velocity are filtered. Hot wire anemometers are not recommended in a humid environment like a test tank. Differential pressure sensors (Pitot type) can measure fast changes in wind speed but are directional sensors. Consequently ultrasonic anemometers are the most usable solution in a lab environment. They allow a three dimensional measurement at a sampling rate up to 30Hz. They are robust and maintenance free.
At Ifremer facilities, the wind velocity can reach an average value of 10m/s. To measure turbulence at full power, the anemometer measuring range must be at least 15m/s. The sensor orientation must be adjusted carefully. Getting the wind speed map over the working surface of the wind generator can require a lot of data points. Having numerous anemometers can save a significant amount of time.

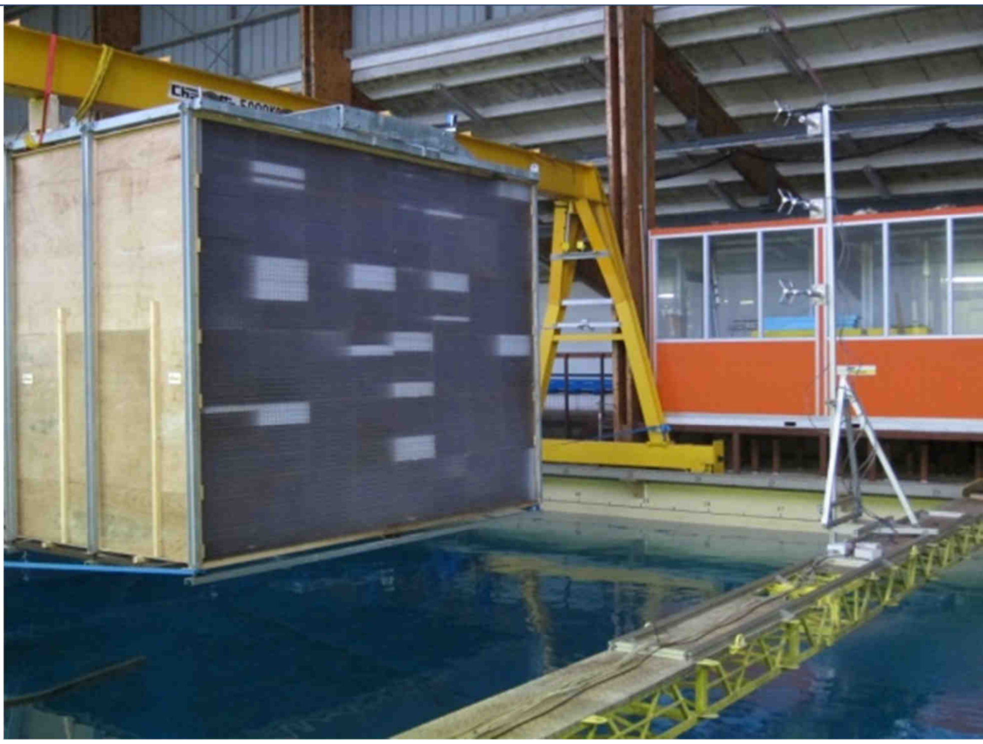


Figure 2.1: Three 3D ultrasonic anemometers (Gill Windmaster) facing the wind generator for wind characterization. Ifremer wave and wind facilities - 2013

2.1.2 Wave measurements in tank

Wave tank experiments aim at assessing system behaviour when such systems are exposed to wave loads. The waves, representing the system excitation, need to be measured accurately. Measurements should at least be done at several points upstream, downstream and inside the area of interest where the fixed or floating bodies is located. Measurements with the same wave conditions and the same gauges locations should additionally be run without any probe / model in the tank. Multiple gauges allow to examine the possible reflection phenomena in the tank, the diffraction and radiation effects and the phase shifts of the various measurement channels. Comparison of experimental data with numerical results from diffraction and radiation sea keeping methods including free surface elevation modelling can help to understand and guide the tests. Wave measuring techniques usually available in wave tanks are listed in Marinet deliverable 2.1 [4]. Developments of 3D methods for measurement of free surface area beside point measurement are being investigated; more information is available in [10].

2.1.2.1 Sensor requirements

Wave height is a dynamic physical parameter therefore the sensor ability to transfer exactly the water elevation variations to electrical variations must be carefully checked. The measuring range and the sensor bandwidth directly depend on the wave maker capacities. One criterion to define the sensor dynamic specifications can be the correct measurement of the 3rd order Stokes wave harmonics of the shortest regular wave possible in the tank. Irregular wave time series generated in the tank can also be considered. The fastest water elevation variation must be measurable in order to capture all the spectral components.

Resistive wave probes, relating the resistance measured between two metal rods partly immersed in water to the water elevation between them, are the most common sensors used in wave tanks. Capacitance wave probes become more and more used, as they present some advantages over resistive wave probes. They measure the water elevation using purely digital techniques, with no energy discharge in water and no interference with the adjacent probes. They also are not as sensitive to water temperature, allowing fewer re-calibrations, and present a faster response time.

Another type of wave gauges, servo wave gauges are now described with their technical specifications.

2.1.2.2 Servo wave gauges

A 1 mm diameter platinum electrode is servo controlled to follow the water surface, by measuring the contact resistance between the water and the electrode. This resistance depends on the electrode length under the surface.
Resistance variations are processed and used to drive a motor which adjusts the electrode's vertical position in order to keep the contact resistance at a constant value. A magnetostrictive linear position sensor is coupled to the electrode and provides the sensor analogue output voltage signal.

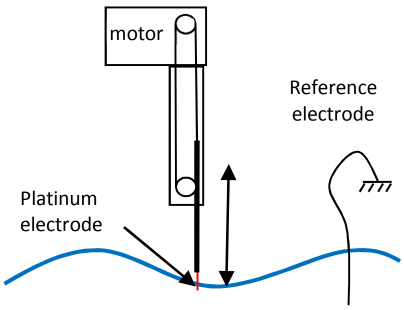


Figure 2.2: Schematic layout of servo of a servo wave gauge

Figure 2.3: 4 wave gauges in a row measuring regular waves for wave characterization – Ifremer wave tank

The technical specifications of the servo gauges used in Ifremer are for example:

- Water type: fresh or sea water.
- Full measuring range : 700 mm
- Time response : 200ms/full range
- Max speed : 5m/s
- Sensitivity : 10V/m
- Resolution : 0.1mm

The embedded magnetostrictive displacement sensor and the servo system are very stable. The sensor sensitivity does not drift and the wave gauge only needs re-calibration once a year.

2.1.3 Water elevation related to the model

Some experiments require measurement of the water elevation along the model's hull or inside the model, in an oscillating chamber or an internal tank for instance. Sensor size, weight and mounting possibilities are critical parameters for these purposes. One technical solution is to use embedded homemade capacitive gauges.

As explained in details in [4], this kind of gauge consists of one reference metallic electrode and one electrode made of a doubled thin isolated electric wire (Figure 3.14). These gauges are similar to a capacitor, the dielectric is the water for the underwater part of the electrode and the air for the upper part. The capacitance is proportional to the water elevation. The measuring part is very light, made of wires or carbon sticks for the reference electrode, as shown on fig 2.7. It can be custom made to fit the model geometry. The electronic signal processing box can be set up in the model or hung above it.

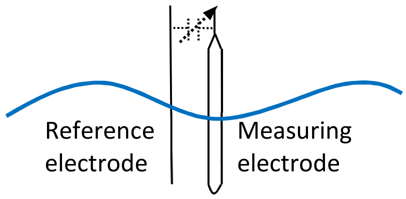


Figure 2.6: Capacitive gauge schematic layout

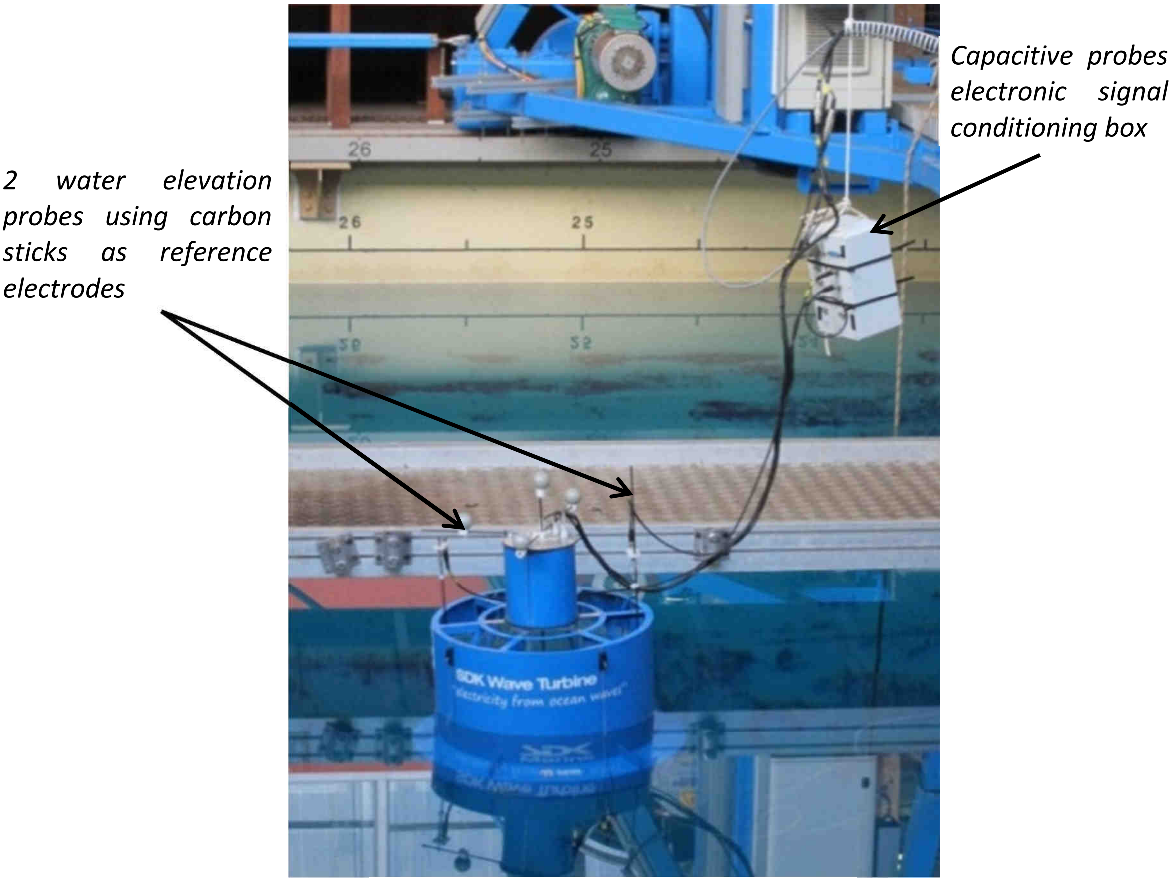


Figure 2.7: Two inside water elevation probes. SDK project – Marinet 2nd call – Ifremer Brest - 2013

2.2 LOADS:

2.2.1 Tensions in mooring lines

Estimating loads in the mooring lines is often one of the most important objectives of wave tank experiments. Tensions are usually measured by uniaxial load cells inserted in the mooring lines.

2.2.1.1 Configuration examples:

Often the mooring lines are fully under water and waterproof load cells need to be used. Figure 2.8 and figure 2.9 gives some examples of waterproof load cells used underwater:

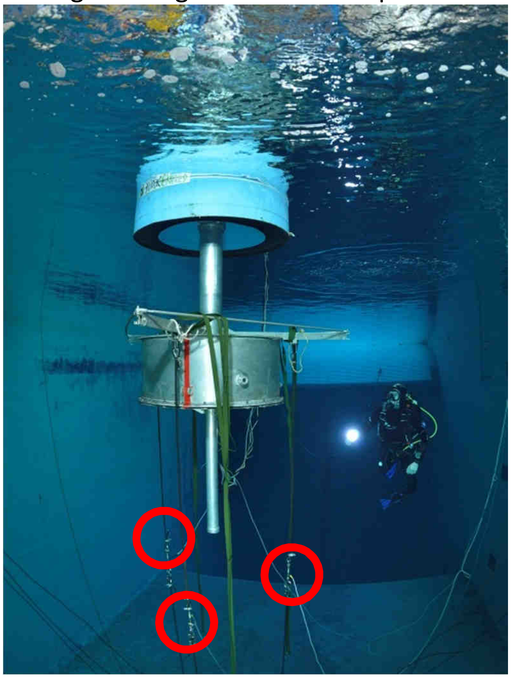


Figure 2.8: Sigma project – Marinet 3rd call – Ifremer Brest – 2014 - O. Dugornay

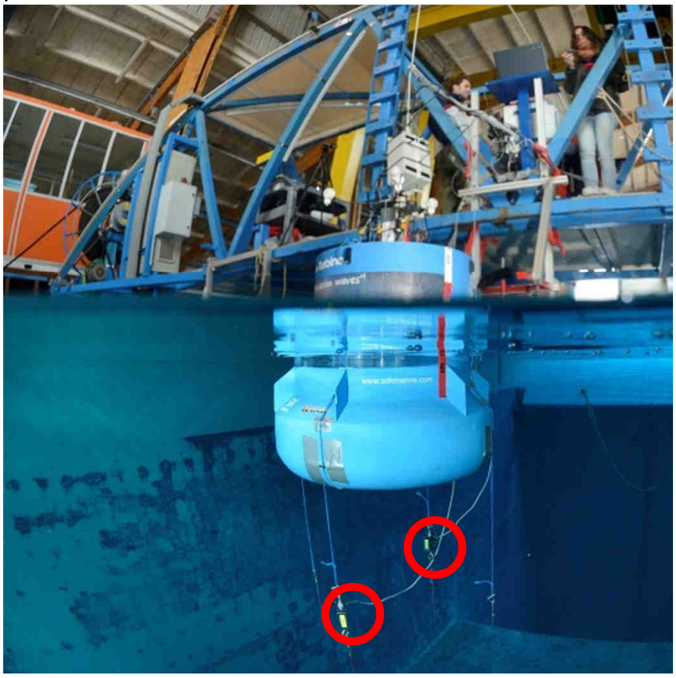


Figure 2.9: SDK project – Marinet 2nd call – Ifremer Brest – 2013 - O. Dugornay

Mooring lines can also be connected to classical uniaxial load cells set up on the model.

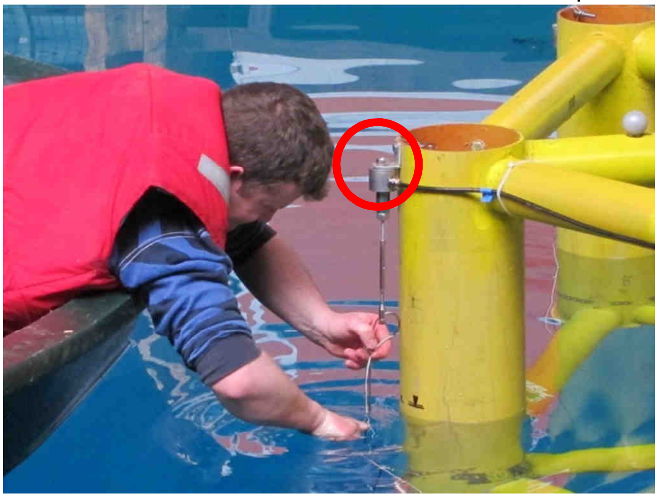


Figure 2.10: Hexwind project – Marinet 2nd call – Ifremer Brest – 2014

Another possibility for tension leg mooring systems: the mooring lines are attached to the model, go through an underwater pulley and reach at the other end a tensioning system including a load cell above the surface.

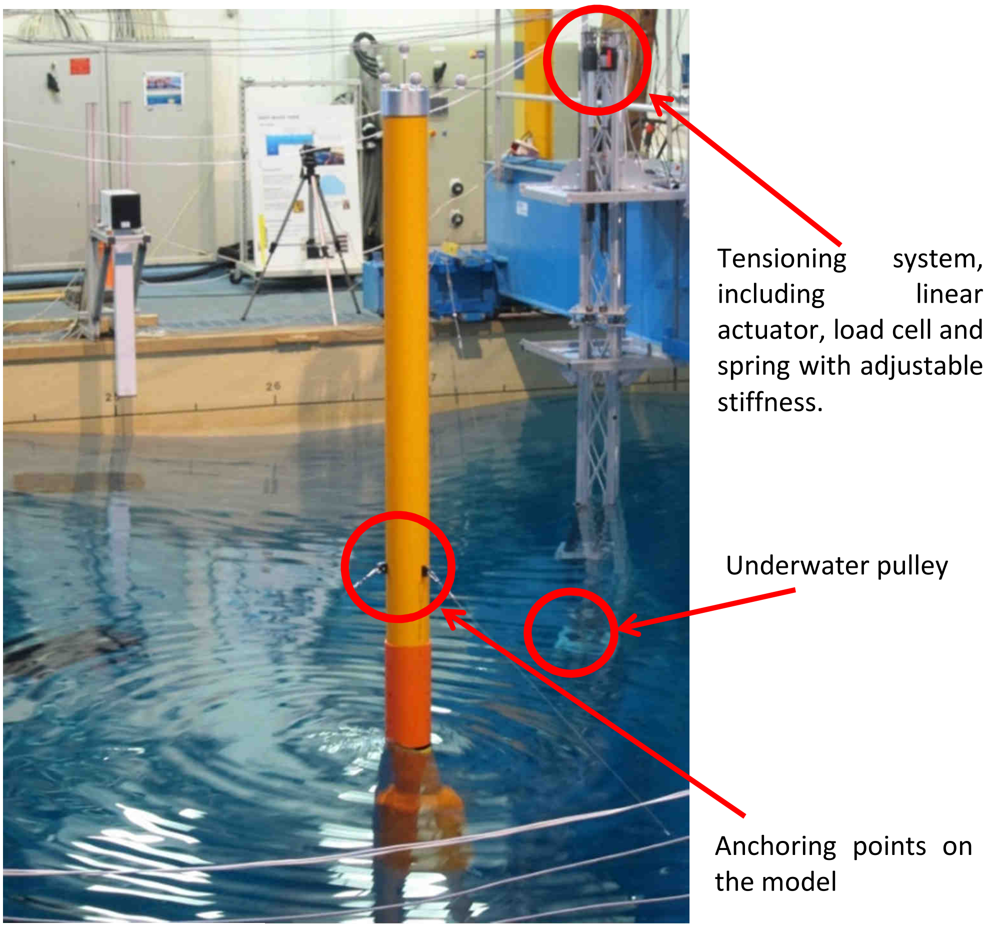


Figure 2.11: TLBTests project – Marinet 1st call – Ifremer Brest – 2014

2.2.1.2 Sensor technology:

All the presented sensors make use of strain gauges. The sensor is made of a specific deformable body which is subject to the force to be measured and consequently deformed. In the elastic range, stress and strain are proportional. Deformation and therefore force can be measured by strain gauges glued on the deformable measuring body.

Picture 2.12 shows a waterproof force sensor commonly used at the Ifremer testing tank. Its size and water tightness fit the requirements to measure tensions in a model's mooring lines. The strain gauges glued on a ring shaped deformable part are protected by a vacuum welded bellow system.

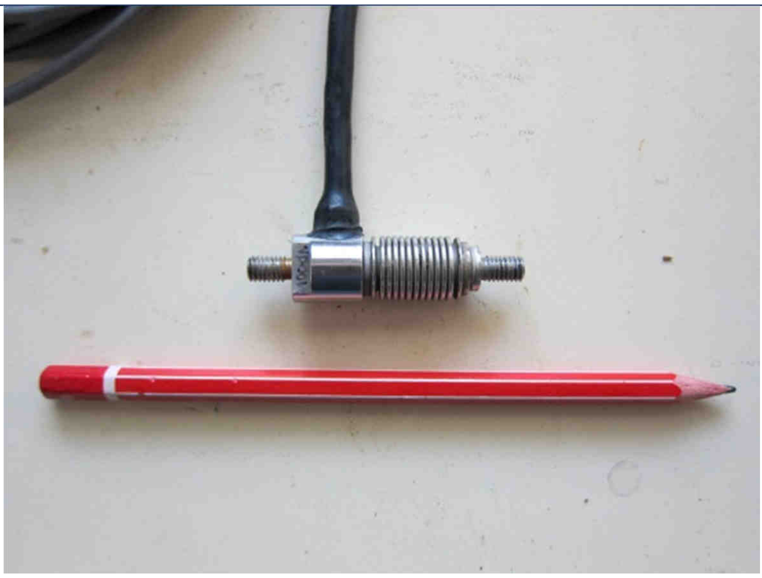


Figure 2.12: Force sensor Traction/ compression waterproof - TEI-EFE model F5070

Picture 2.13 shows a waterproof uniaxial load cell made in composite used at ECN testing facilities. The model presented here is rated at 300N. It presents the advantage of being very light (8 grams only) to minimize its effects on the mooring line. The micro amplifier integrated on the side of the sensor allows plugging this load cell directly on an acquisition board.

Figure 2.13: 300N waterproof composite load cell - ECN facilities

2.3 Motions

Video motion tracking system is often the most suitable solution to measure the model displacement during wave tank tests. The motions are left unaffected since the measuring technique is without any contact. It enables high speed 3D motion tracking of multiple points in space. Six degrees of freedom motions (surge, sway, heave, yaw, pitch and roll) of multiple rigid bodies can be captured simultaneously. The system can be synchronized with other data acquisition devices. The main provider is the Swedish company Qualisys, their motion tracking system is standard equipment in most of testing tanks [8].

2.3.1 Description

Reflective markers are mounted on the body to track and several cameras are set up around the tank. The overlapping part of their fields of view represents the working volume where the motions can be tracked. After a calibration procedure, the system locates each camera. Then 3D positions of the markers are calculated by triangulation with the 2D data from each camera.

2.3.2 Configuration examples

The following pictures show different configurations used during the Marinet tests in Ifremer's wave tank. Depending on the body to track, its size and the markers fastening possibilities, markers can be fixed directly on the model or with a custom made "ready to use" carbon stick frame.
Figure 2.13 shows a complex configuration setup used for Wavenet Albatern project trials. The wave energy converter to be tested was composed of 15 floating bodies connected to each other. Each element was tracked as a rigid body, with surge, sway, heave, yaw, pitch, roll measurements. Fifteen frames made of carbon sticks and four light markers were built and mounted on the model. Six motions tracking cameras were deployed to track the 60 markers in a large working volume.
To avoid confusion between bodies, the distances between markers must be different for each one; they all have to be unique. With randomly adjusted distances between markers we only had confusion between 2 or 3 couples of bodies. After modifications of these, the system managed to track the 15 bodies without any problems.

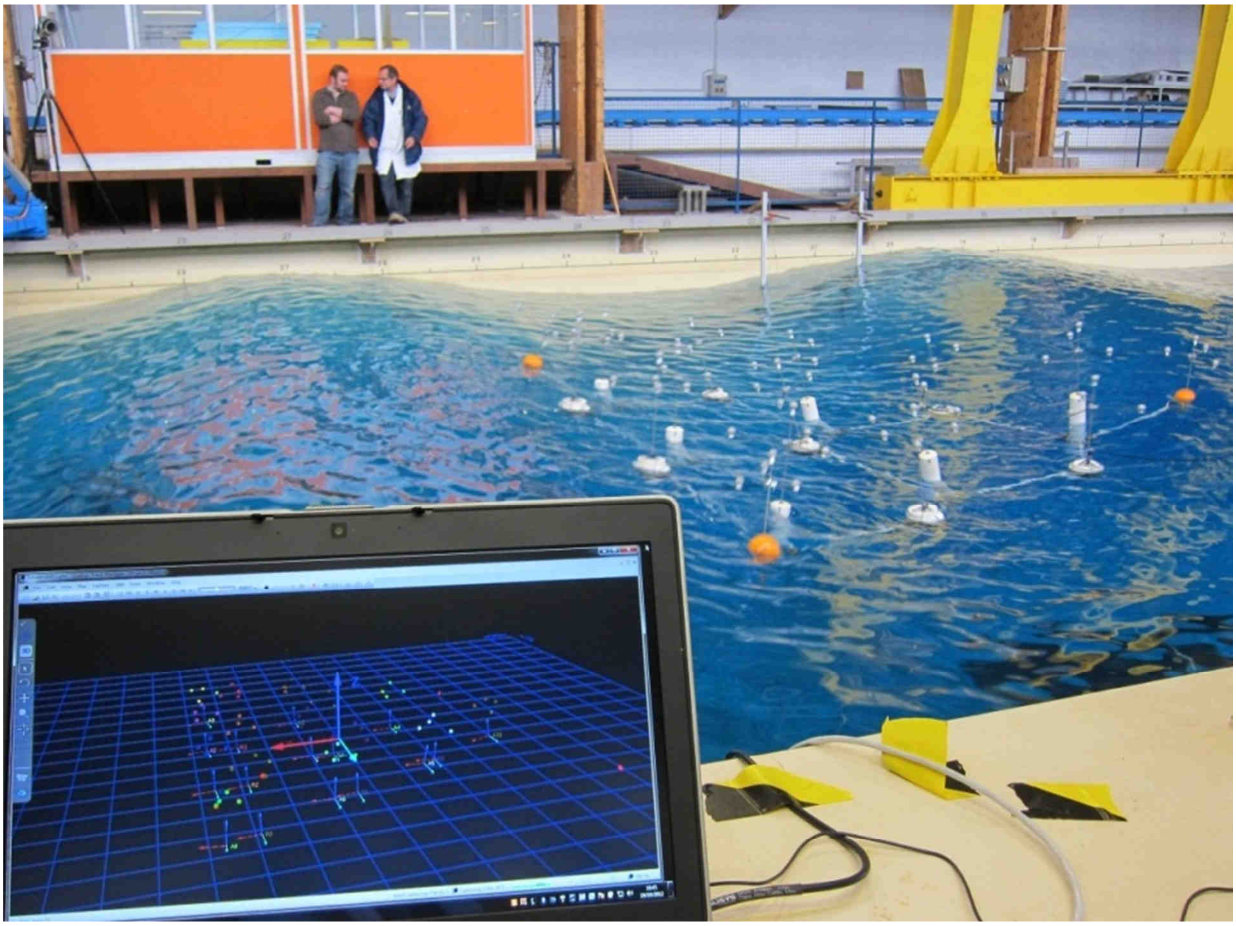


Figure 2.13: 15 connected floating bodies being tracked with a 6 Qualisys cameras system. WaveNet-Albatern project – Marinet 1st call – Ifremer Brest - 2012

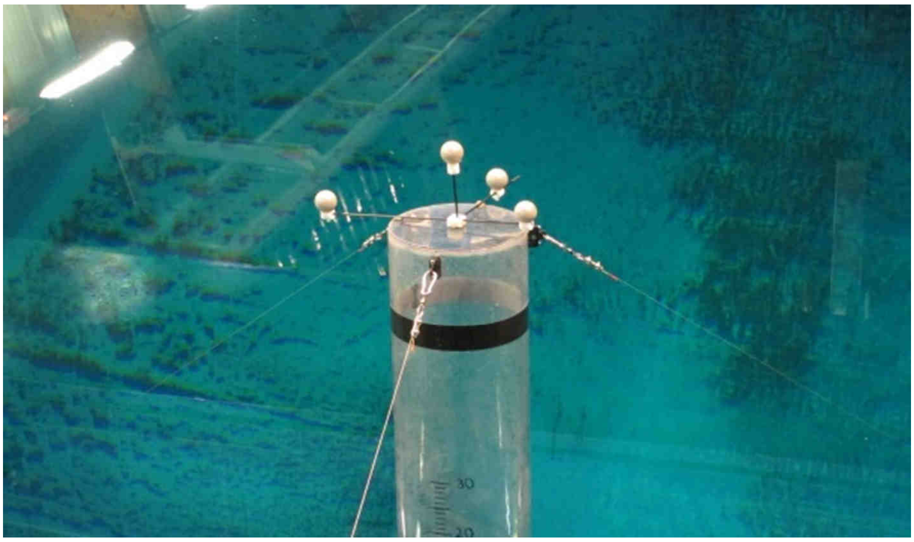


Figure 2.15: One tensioned legs buoy with 4 light markers on a carbon stick frame. TLBTests project – Marinet 1st call – Ifremer Brest - 2013

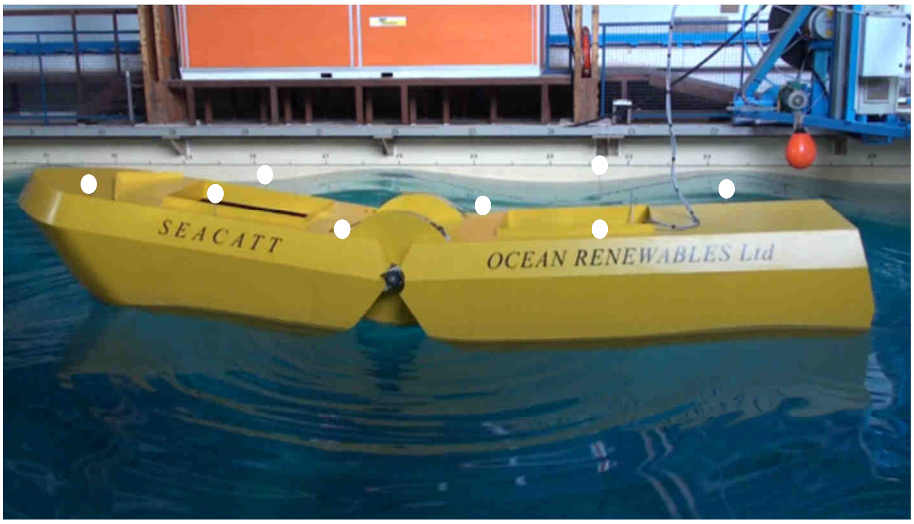


Figure 2.14: 2 connected floating bodies with threaded markers fixed on the model. SeaCatt project – Marinet 2nd call – Ifremer Brest - 2013

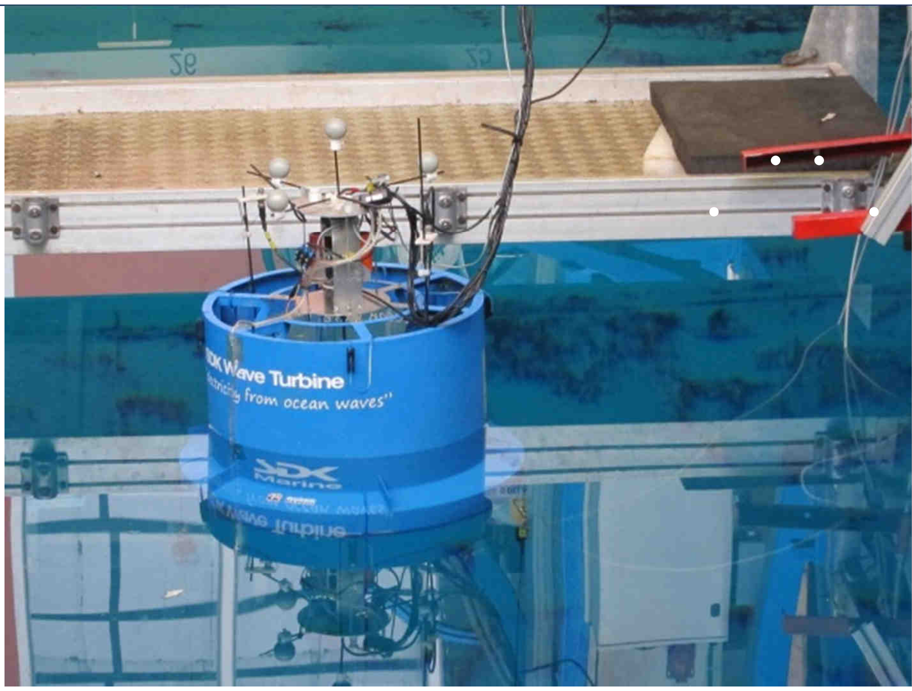


Figure 2.16: Tensioned legs buoy with 4 light markers on a carbon stick frame. SDK project – Marinet 2nd call – Ifremer Brest - 2013

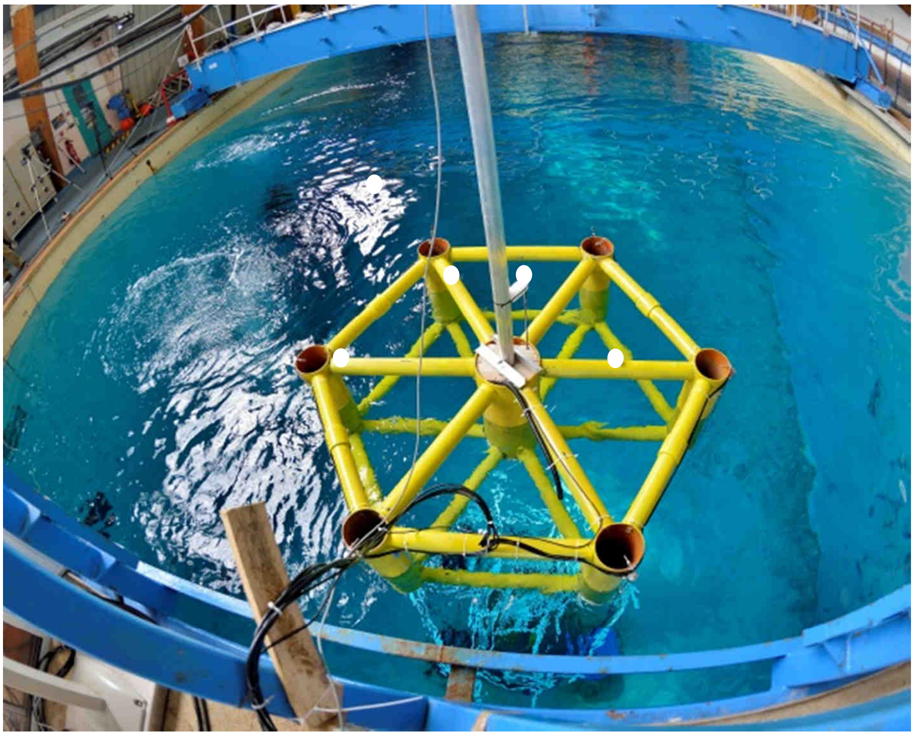


Figure 2.17: Tensioned legs buoy with 4 threaded markers fixed on the model. HexWind project – Marinet 2nd call – Ifremer Brest - 2013

2.3.3 Markers installation

Two kinds of markers can be used. Passive markers only reflect light back onto the cameras, while active markers emit infrared light. Those latter are easier to track, but they need some kind of power supply.

The size of passive marker shall be chosen depending on the distance from the camera to the model. In most of the wave tanks, this distance is bigger than seven meters and the usual marker diameter is 40 mm. Two kinds are available, light markers (7 grams) to be fixed with double face tape and heavier markers (40 grams) with M8 threaded holes. Accuracy in the motion measurements requires accuracy in the markers positioning on the model. Therefore the use of M8 threaded markers is recommended and the M8 fixing points should be planned when designing the model. Four markers are usually used per rigid body. The rigid body coordinate system associated to the model is located at its center of mass in order to dissociate different motions like sway and roll for instance.

It can be noted that reflective surfaces can cause problems with the motion tracking system. Transparent and very smooth surfaces are then not advised.

Constraints to be followed for a simple definition of the rigid body to track:

- Two markers define an axis (n°1 and n°2 define the x-axis on the drawing).
- Three markers define a plane (n°1, n°2 and n°3 define x-y plane on the drawing).
- One marker is out of the plane defined by the three first markers and it is just above the center of gravity at a known height (n°4 on the drawing), or at least at a known x-y-z position from the center of mass.
- The distance between two markers must be different from any combination between two other markers.

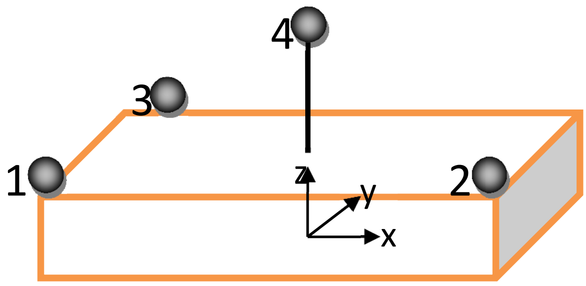


Figure 2.18: easy marker set up

2.3.4 Camera installation:

To capture the 3D motion of one moored floating body, a simple three camera set up is enough. A few things to keep in mind while setting up the system:

- Angles between two camera axis are at least 60°
- Cameras are not at the same height
- Camera tripods are firmly fixed to the ground to avoid any displacement which could affect the calibration and consequently the measurements quality.

2.3.5 System accuracy

The absolute accuracy of the motion tracking system is not easy to assess as it requires knowing the exact position in a global reference coordinate system. Another way is to measure the relative accuracy related to another object, not to a global coordinate system. This can be done by measuring the distance between two markers fixed at each end of a stick with a known length. The stick is moved around in the calibrated volume during the measurement.

Document [3] indicates a relative accuracy under +/-1mm (2σ) for a volume large enough to capture the motions of a human, which is the same order of magnitude as the working volume for a typical testing tank experiment.

2.3.6 System resolution

For a motion tracking system, the resolution corresponds to the smallest detectable motion. An easy way to assess the resolution of the system is to measure the position of an unmoving marker. The stable position is affected by noise. This noise magnitude defines the level under which a motion cannot be detected, which is therefore the smallest detectable motion.

For a typical set up as previously described, the resolution given in [3] is below 0.1mm (2σ).

3 FROM THE SENSOR SIGNAL TO THE DATA FILE

The data acquisition system must measure all channels synchronously at a given sampling rate, often 100Hz for typical wave tank experiments. For each test, it provides a measurement file containing the test parameters, and a column for each measurement channel.
As mentioned above, 100Hz is often used in typical wave tank experiments, but larger acquisition rates of the order of 1-2 kHz can be used in specific tests, for example to capture wave impact pressures and associated loads. For each test, the recorded file should provide the test parameters, and a column for each measurement channel. For detailed information about this, refer to [11].

3.1 SYNCHRONIZATION

Synchronization can be achieved by using analog output sensors and acquiring all analog signals with a single data acquisition system. While using additional measurement systems, like motion tracking system or embedded data acquisition, a trigger signal must be used to ensure synchronization. The trigger signal can be a digital signal (rising or descending slope) that sets off the acquisitions on the different systems. Then each system acquires signals or images at its own internal clock rate. Regarding the current electronics capabilities, a 100Hz sampling rate is relatively slow and the possible errors induced by the internal clock rate differences can not lead to significant time shift between two acquisition systems. However a stricter approach would consist in having a 100Hz square trigger signal controlling each sample and each image acquisition.

3.2 TYPICAL ACQUISITION SETUP

In most of the cases, a PC with a USB connected acquisition device is set up on the tank side or on the bridge. It acquires all signals to be recorded, as those coming from wave gauges, anemometers, and load cells. A widely used supplier is the American company National Instruments. They provide the hardware equipment for data acquisition and the associated graphical software developpement environment LabVIEW®.

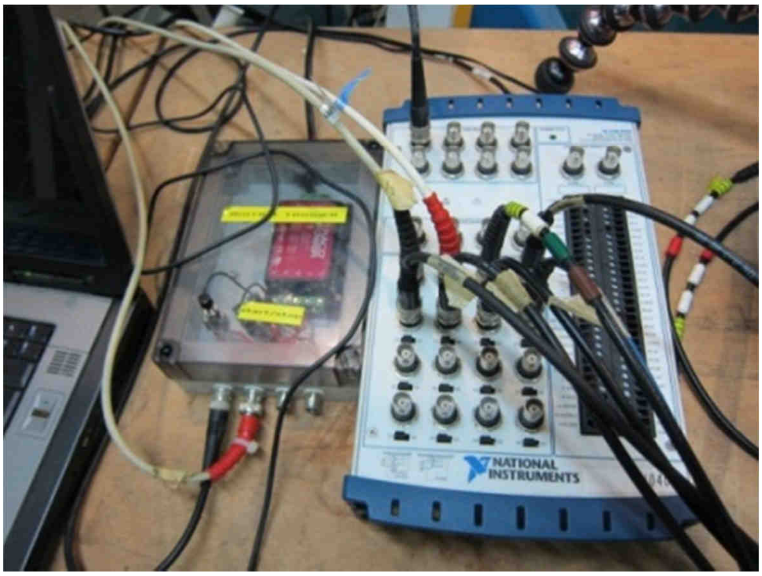


Figure 2.19: National Instruments NI-USB-6229

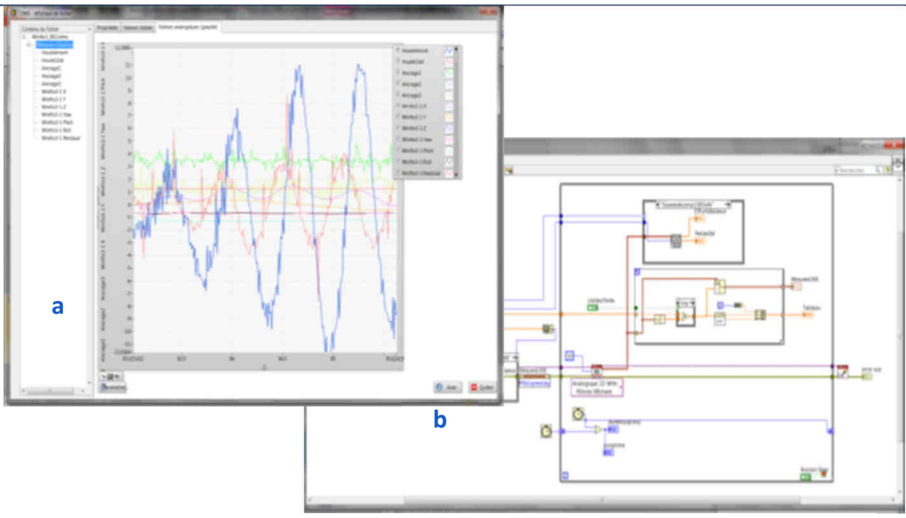


Figure 2.20: Example of Labview® interface (a) and its block diagram (b)

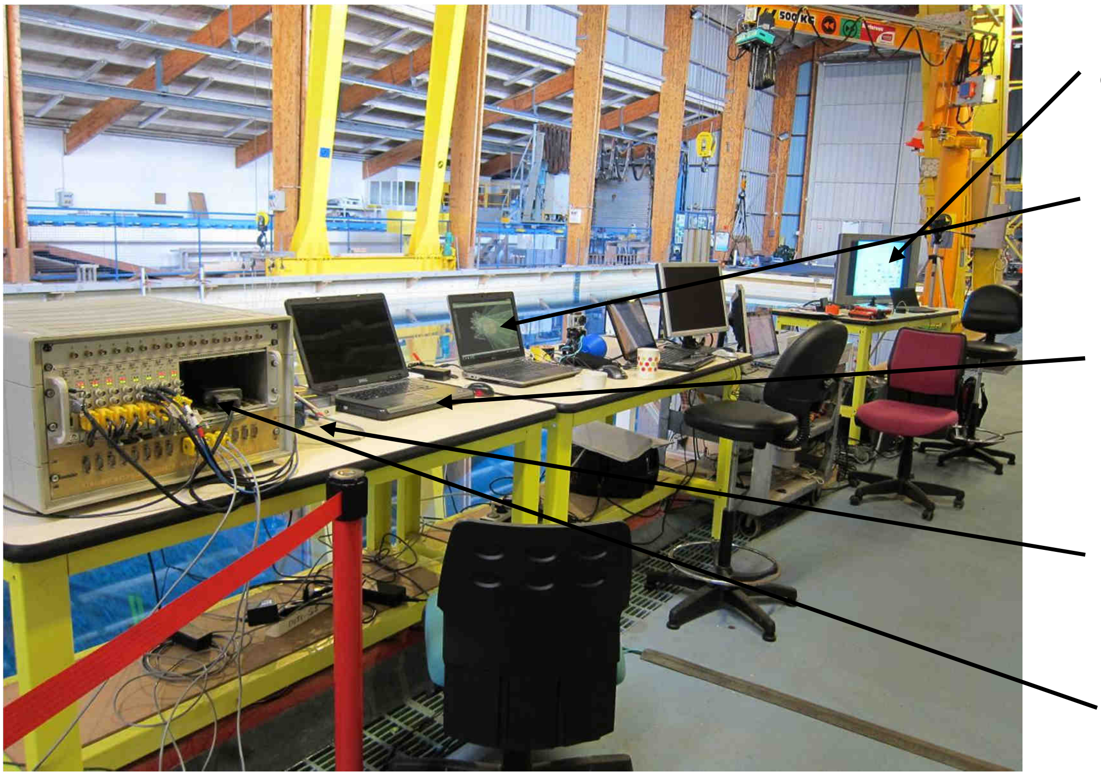


Figure 2.20: Example of acquisition setup on the tank side. Wavenet project – Marinet 1st call – 2013

3.3 EMBEDDED ACQUISITION SETUP

The model can be equipped with sensors like load cells, pressure sensors, capacitive water elevation gauges, torque and rotation velocity sensor for the generating shaft… These sensor signals can be transmitted to the data acquisition on the bridge or on the tank side by cables. To transmit the signals in good conditions, shielded cables are recommended. However a particular attention must be paid to the number of cables and their mechanical behavior to minimize their influence on the model's motions. Moreover some sensors deliver low level signals and the cable length between the sensors and the associated amplifier or data acquisition system has to be minimized in order to preserve the signal quality. Therefore in some particular cases an embedded data acquisition system is needed.

Using an embedded data acquisition system, the main issue is the synchronization of the measurements on the model, the measurements on the tank side and the motion tracking system. So far, the onboard acquisition system is connected to the land based system by a single light cable for the trigger signal. Other options like optical triggering using the motion tracking cameras IR flashes are considered but not implemented yet. Wi-Fi connection enables communication between the embedded and the tank side systems. Data is not streamed from the model during the tests because any communication loss could lead to data loss. It is preferable to have a data logging option for the onboard signals and to send them to the main computer after each test. Data from the land based acquisition system, from the model sensors and from the motion tracking are then merged, displayed and saved on a safe network backup disk.

Designing a model with embedded acquisition system involves specific constraints. Space and weight of the electronics and the batteries must be taken into account in the model weight and balance assessment. The battery autonomy must fit a test day at least. It is recommended to have a water detector and a temperature sensor in the electronic container. Following figures show two different Wi-Fi communicating systems to be set up inside a model.

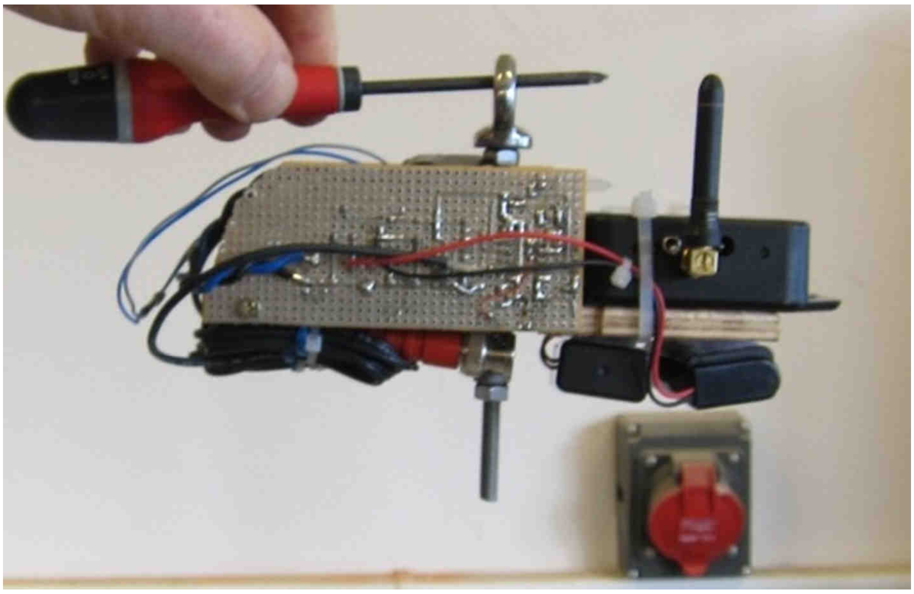


Figure 2.22: Example of µStrain VLINK implementation – Ifremer Brest - 2012

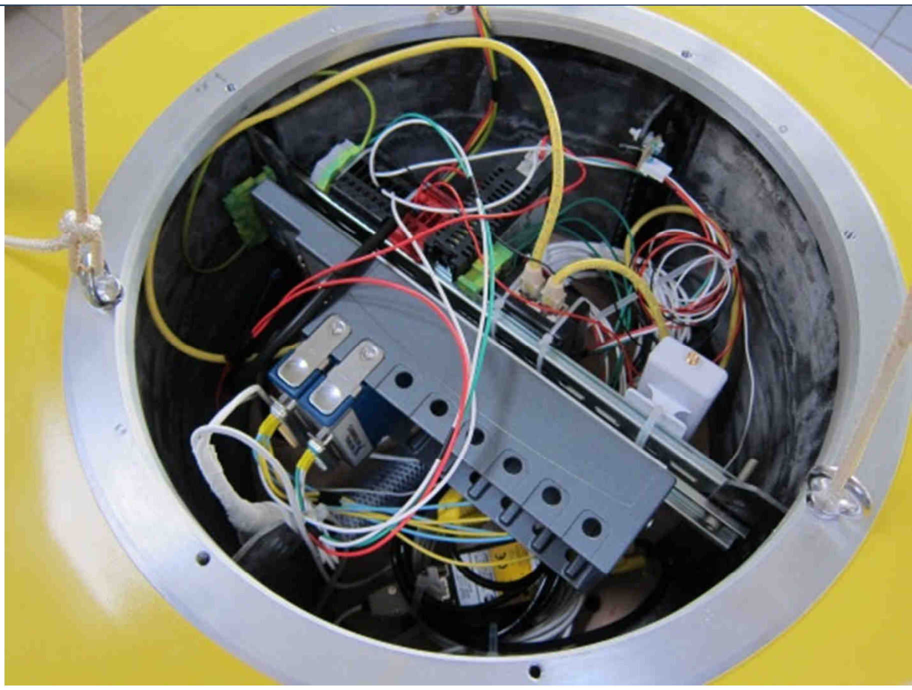


Figure 2.21: Example of NI Compact RIO implementation inside a model – Ifremer Brest - 2012

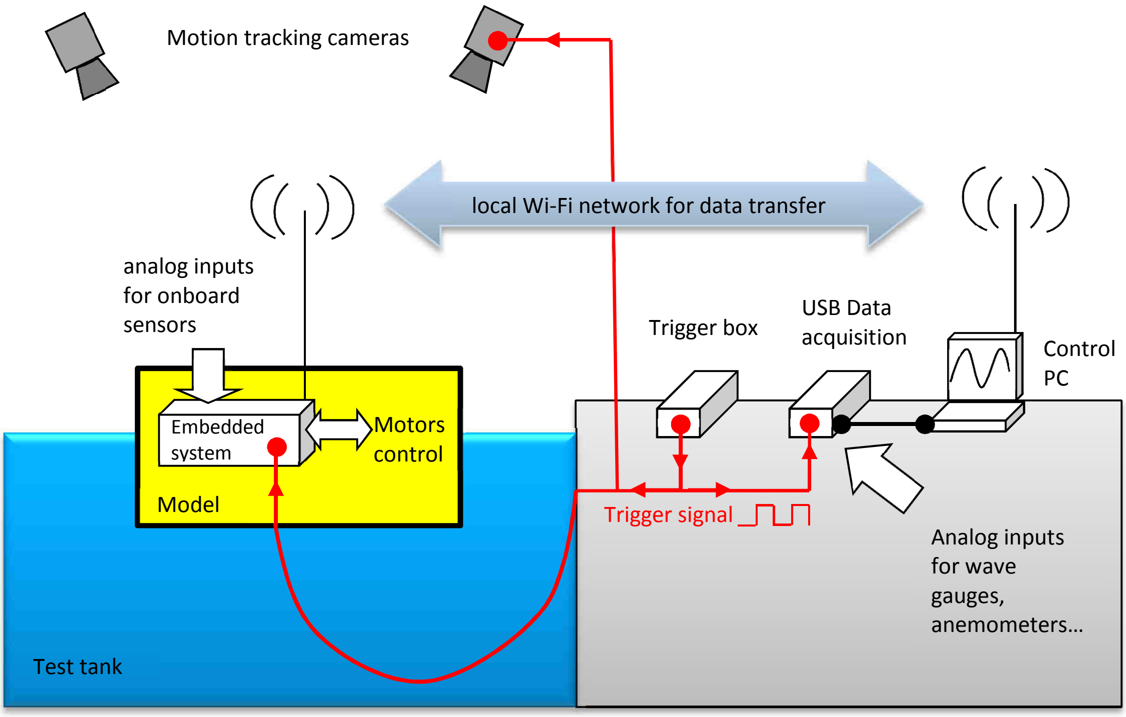


Figure 2.23: schematic diagram of embedded acquisition setup

3.4 CABLING RECOMMENDATIONS

Electromagnetic fields from any electrical actuator, power conditioning device, power cables, etc. can interfere with the measurement signals and degrade its quality. Shielded cables correctly grounded are required. Moreover, wave generator, wind generator, carriage motors and their variable speed drives can induce electrical parasites on the grid which can affect the instrumentation and the low energy measurement signals (in the mV or µA range). Therefore it is recommended to connect all the measurements related devices through an insulation transformer for power supply. Electromagnetic compatibility rules have obviously to be respected.

4 KNOW YOUR MEASURING SYSTEMS

4.1 ERRORS ASSESSMENT BY STATIC CALIBRATION

The following calibration recommendations mainly come out of two reference documents from ITTC Procedures and guidelines. Document [1] gives work instructions to calibrate force sensors, to assess the different sources of errors (linearity, hysteresis, repeatability, influence of the temperature, creep, stability of sensitivity). Methods for the evaluation of instrument calibration uncertainties are described in [2]. These guidelines are used for static calibration of any kind of sensor (load cell, wave gauges, pressure sensors, capacitive water elevation probes…). In particular, they recommend that:

- The sensors are calibrated before and after each test campaign in order to detect any possible damage during the tests.
- A traceable reference with known uncertainty is used for the calibration. It can be certified calibrated masses for load cells or a reference displacement sensor regularly checked by a certified metrology laboratory.
- Several cycles of loading and unloading of the sensor are performed, with five to ten equally incremented data points within the measuring range.
- Each data point corresponds to a 3 second acquisition time at 100Hz.
- For each data point, the mean value is used for errors linear regression and errors calculations.
- For each data point, the standard deviation is checked as a measure of the instrument noise.
- A linear regression analysis is carried out with all the acquired data points to determine the slope, intercept and residual.
- Errors are calculated with the following formulas:

Linearity:

$$L = \frac{\Delta\theta_L}{\theta_n} \times 100 \ \ (\%FS)$$

Hysteresis

$$H = \frac{\Delta\theta_H}{\theta_n} \times 100 \ \ (\%FS)$$

Repeatability

$$H = \frac{\Delta\theta_R}{\theta_n} \times 100 \ \ (\%FS)$$

where:
θ_n: Sensor output

$\Delta\theta_L$: Maximum value of the deviation between the mean advance calibration curve and the straight line of two mean end points.

$\Delta\theta_H$: Maximum value of the deviation between the return mean calibration curve and the advance one.

$\Delta\theta_R$: Maximum value of the deviation of the sensor ouput for each reference point

Examples of static calibration results can be found in appendix 1.

4.2 DYNAMIC BEHAVIOR CHARACTERIZATION

In a wave tank experiment, the physical parameters to be measured are not static but dynamic. Therefore attention must be paid to the sensor ability to transcribe the physical phenomenon variations into electrical variations without loss of information. To really be thorough, all the sensors should be tested dynamically. However having a traceable reference with known uncertainty for dynamic calibration is not easy. Force sensors can be calibrated with a reference spring associated to transition stage and a reference position sensor. Pressure sensors can be calibrated with a special pressure generator reference device.

Force sensors installed onboard moving bodies experience acceleration and measure the inertia component of the sensors. Dynamic calibration or at least evaluation of the active mass of the sensor should be made prior to trials and inertia force components be removed from the total force signal. This aspect is the most important for multiple axis force sensors for which forces and moments may be influenced by the motions (angles and accelerations). Associated situations are both sensors on board floating bodies measuring mooring or connection forces or PTO forces and sensors measuring loads in the case of forced motions for instance with a hexapod.

Practically we only apply the following procedure for the wave gauges and the capacitive water elevation probes. The sensor follows the surface of water in a jug moved by a vertical translation stage. The sensor output is compared to the jug motion measurement. The jug motions are measured by a reference magnetostrictive displacement sensor set up on the vertical translation table. This reference sensor is checked by a certified calibration laboratory every year.

The water jug describes a vertical sinusoidal monochromatic motion. 93 period/magnitude combinations are chosen in the working domain of the wave gauge, which depends on the wave maker capacities.

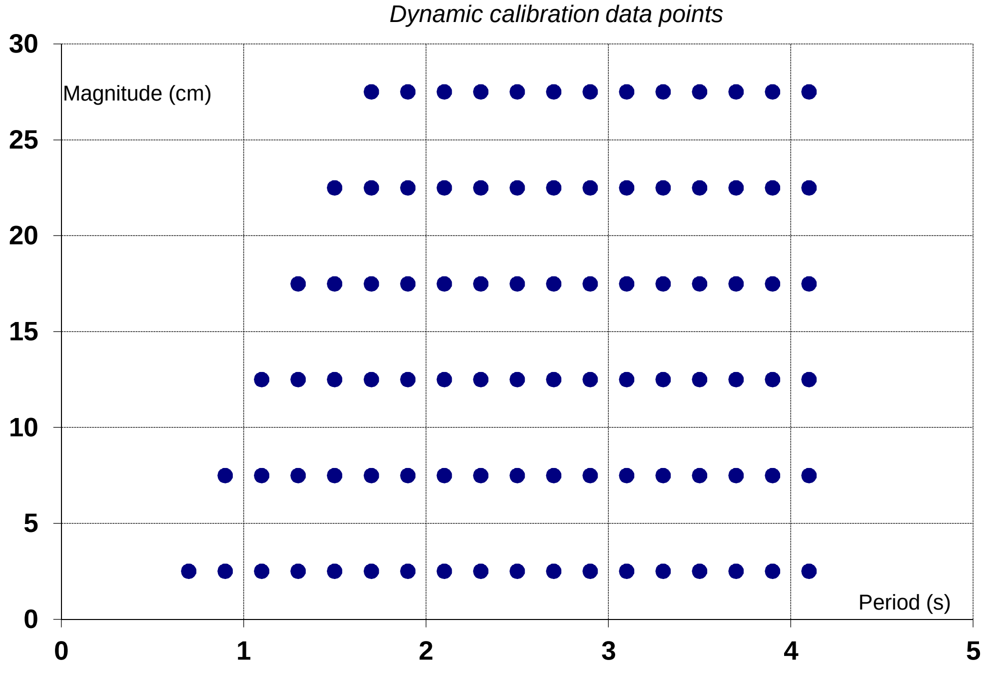


Figure 2.4: Period-Magnitude couples used for calibration

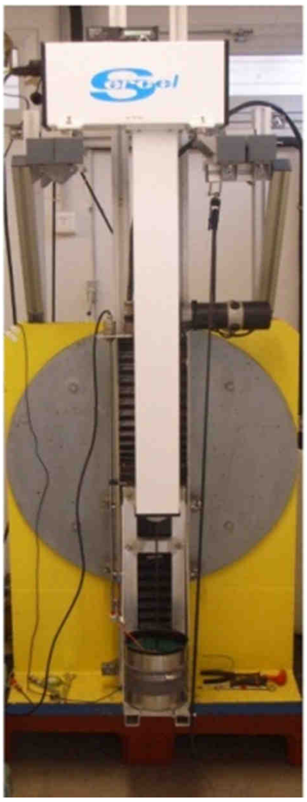


Figure 2.5: calibration tests bench

A data acquisition system connected to a PC measures the signals from the wave gauge and from a reference at 100Hz. Each test contains a starting ramp, ten periods at full amplitude and an ending ramp.
The calibration signals analysis is similar to the regular wave tests analysis. For the selected time interval, a discrete Fourier transform is calculated and the amplitude spectrum is displayed. The signals are decomposed in 3rd order Fourier series. And the stability is assessed by calculating the Fourier coefficients through a one period long window which slides to the signal end. Example of dynamic calibration results can be found in appendix 1.

5 ENVIRONMENT AND RESOURCES GENERATION

5.1 WIND GENERATION

Wind energy, harvested with floating offshore wind turbines, represents a promising part of marine renewable energies. Numerical models, simulating loads on floating structures due to waves, currents and wind, are being developed and need validation through comparison with physical model tests. For this reason, numerous hydrodynamics facilities add wind generation to their wave basins.

While constant wind generation provides the proper tension in the mooring system, the variation of the wind spectrum about its mean value may be significant for the response of a floating structure, as it influences the damping of the structure dynamics and its slow drift oscillations, especially at its natural periods. This chapter presents the wind generator systems used at the Ifremer wave basin and at ECN.

5.1.1 Technical Descriptions

The Ifremer wind generator is an open jet blower type with twelve axial fans of 1 m diameter, arranged in three rows of four fans. It has a constant rectangular cross section with an outlet of 4.3 m x 3.2 m (width x height). The flow generated by the axial fans passes through a main flow straightener, a mesh screen and finally a honeycomb-like section with rectangular cells, in order to minimize the swirl and lateral/vertical mean velocities. The wind generator is hung from a gantry crane to not interfere with the generated waves passing underneath. Figure 5.1 shows the wind generator installed over the wave basin.

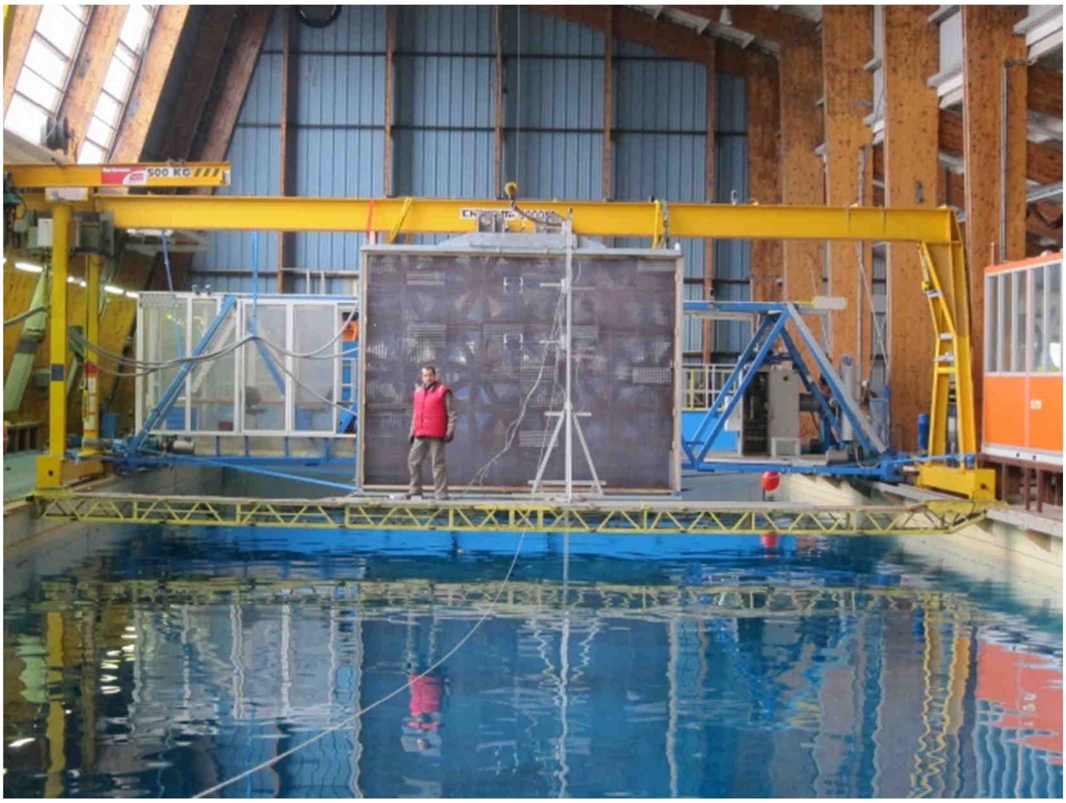


Figure 5.1: Wind generator at Ifremer wave basin

ECN's wind generation system was built in 2012 in order to study a floating wind turbine [9].
Because axial fans generate a swirling flow, creating high turbulence intensity and inhomogeneity, this system was designed using centrifugal fans. Eight centrifugal fans, with a nominal power of 18.5kW, are used by pairs to blow into four 1m-diameter ducts going to the 2.8mx2.8m outlet. Due to the transition of the flow from four circular ducts to a square outlet, a convergent shape is added to the outlet to get a homogeneous flow. A honeycomb and a 40% porous screen are also used to decrease non-axial components of the flow and create losses. The losses insure that the ducts are slightly over-pressurized and kept inflated. The maximum wind speed that can be obtained with this system is 15m/s.

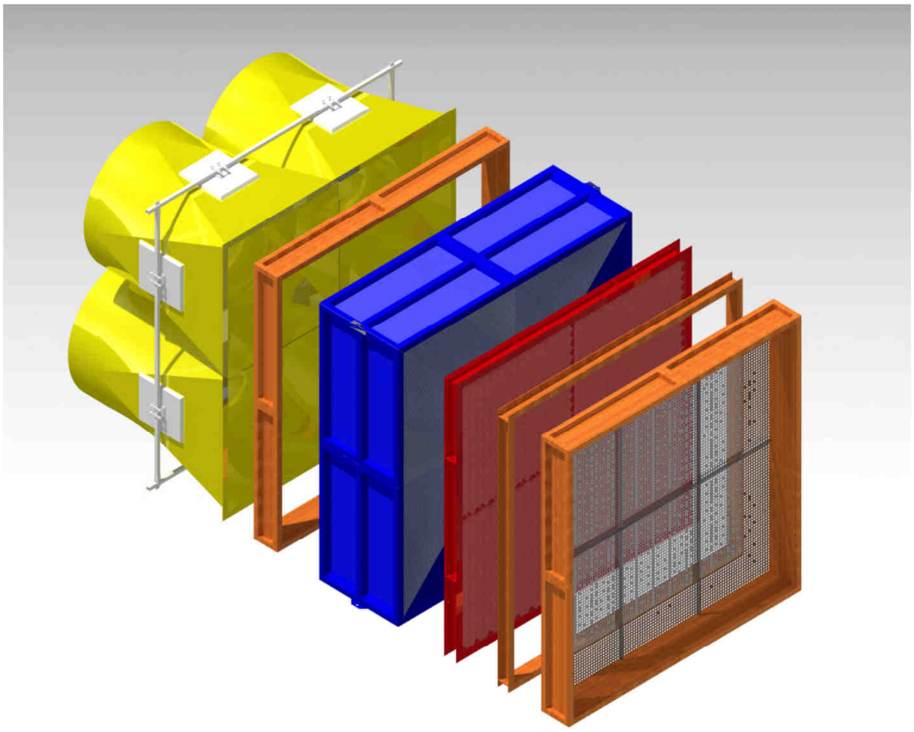


Figure 5.2 Scheme of the outlet of ECN wind generator, with in blue the convergent, in red the honeycomb and in orange the porous screen.

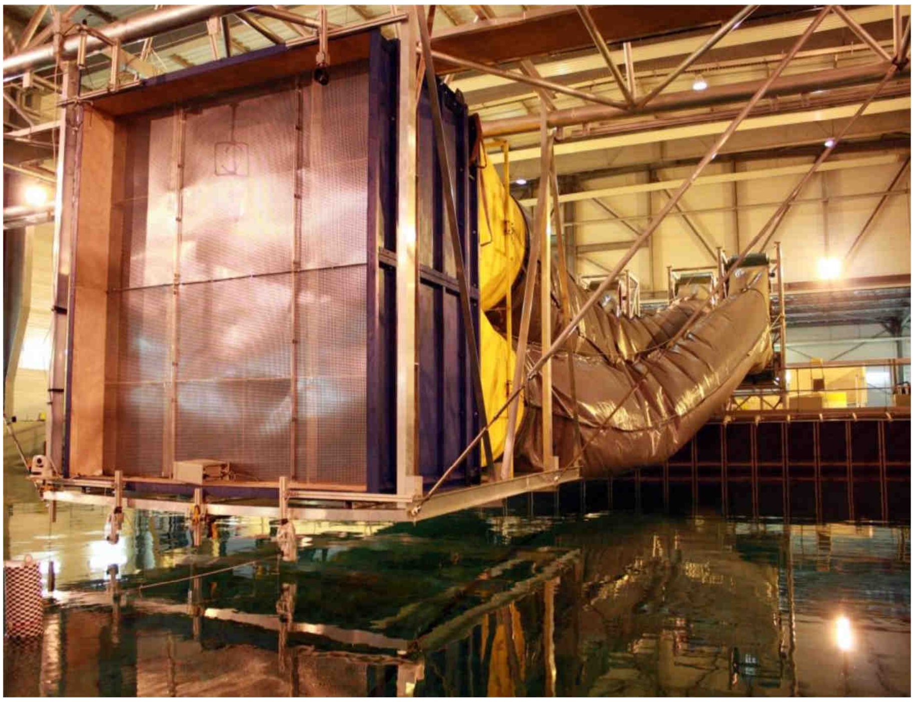


Figure 5.3: Picture of ECN's wind generation system over the wave tank

5.1.2 Constant wind speed measurements

The surface of wind available for testing a model, the wind velocity homogeneity, the turbulent intensity over this area and the velocity decay with the distance characterize the wind generator's capability. Numerous tests, with different constant wind speeds at different locations over the working volume are carried out to assess these parameters. Each measurement lasts a few minutes to let the flow settle and avoid transition effects.

Figure 5.4 displays the 169 measurements points collected at 3m after the Ifremer wind generator outlet. The small circles represent the measurement locations and the big circles represent the fans. The spatial sampling is finer along the outlet borders in order to define the useable area. The maximum wind velocity of about 10 m/s can be obtained for a usable area of about 3.7 m x 2.7 m (width x height) at this distance from the wind generator with turbulence intensities of about 5 %.

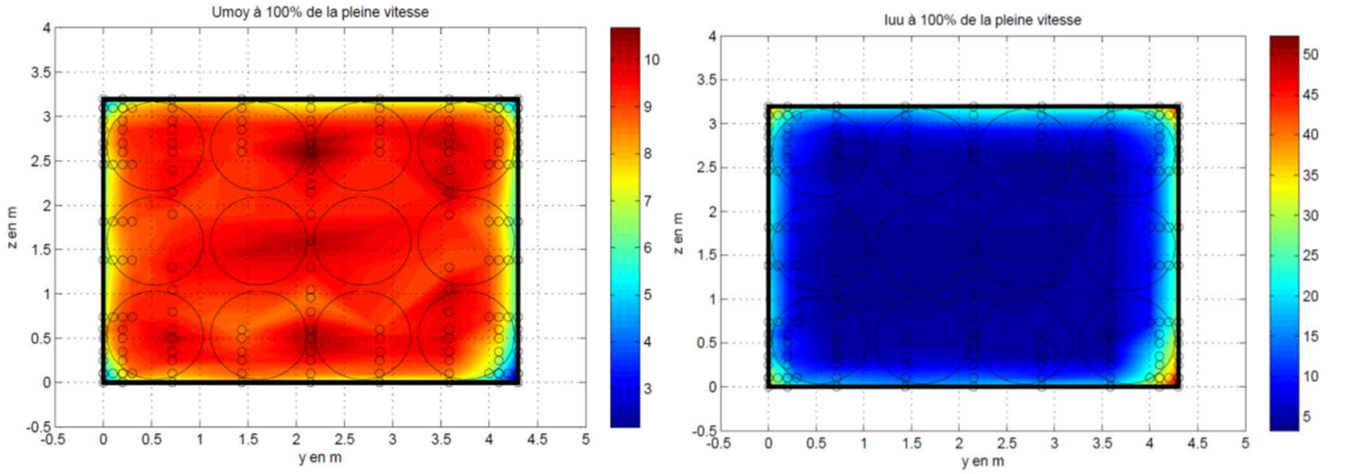


Figure 5.4 left: Ifremer axial wind velocity map U*mean*(m/s) 3m after the outlet at maximum power. Right: Corresponding turbulent intensity.

Figure 5.5 shows the ECN wind generator map of average wind velocity and turbulent intensity at 2m after the outlet, for a wind speed of 8m/s. The 102 measurement points are represented with black crosses. The blue circle is the duct section and the black lines correspond to the convergent element.

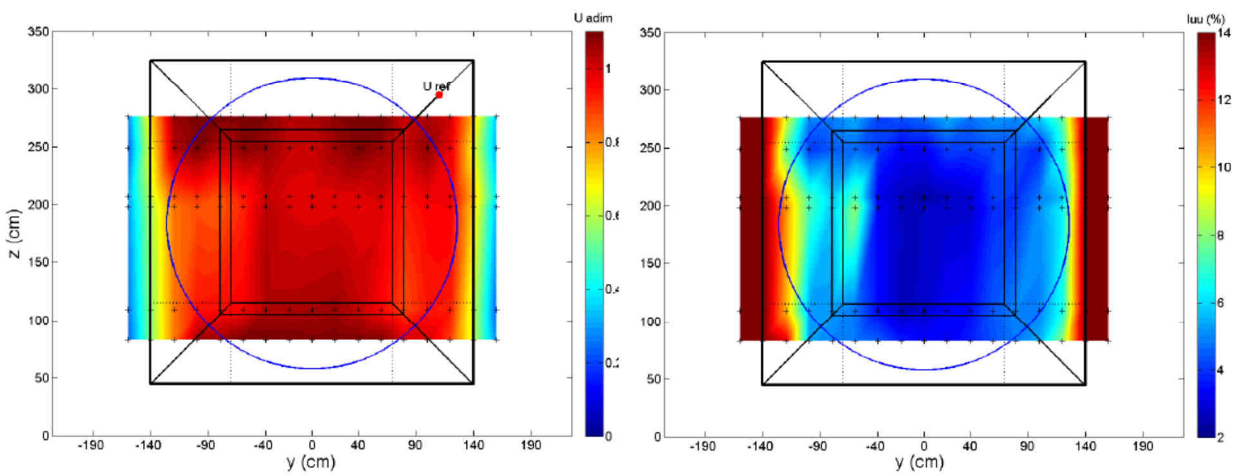


Figure 5.5: ECN maps of average wind velocity and turbulence intensity in the vertical plane 2m after the outlet, for a wind speed of 8m/s

5.1.3 Gradient wind speed measurements and variable wind speed measurements (wind spectra)

Ifremer wind generator can control each row of fans separately; vertical wind velocity profiles can be simulated with the wind velocity U (constant) depending on the height above the free surface (see Figure 5.6).

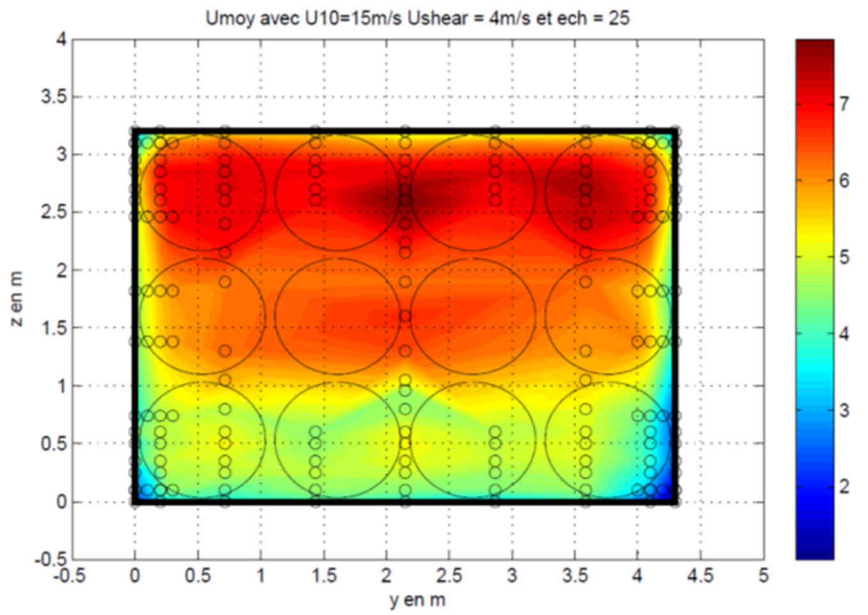


Figure 5.6: Ifremer axial sheared wind velocity map

Time domain wind sequences with variable wind speeds can be generated according to characteristics of reference wind spectra. This is done by inverse Fourier transformation of the complex wind amplitude spectrum from the frequency to the time domain. Several tests were conducted at model scale with different mean wind velocities and friction coefficients. Figure 5.7 for Ifremer and 5.8 for ECN show a comparison between the measured wind velocity U(t) and the target time series (left), and a comparison between the obtained wind spectrum and the theoretical target spectrum (right).

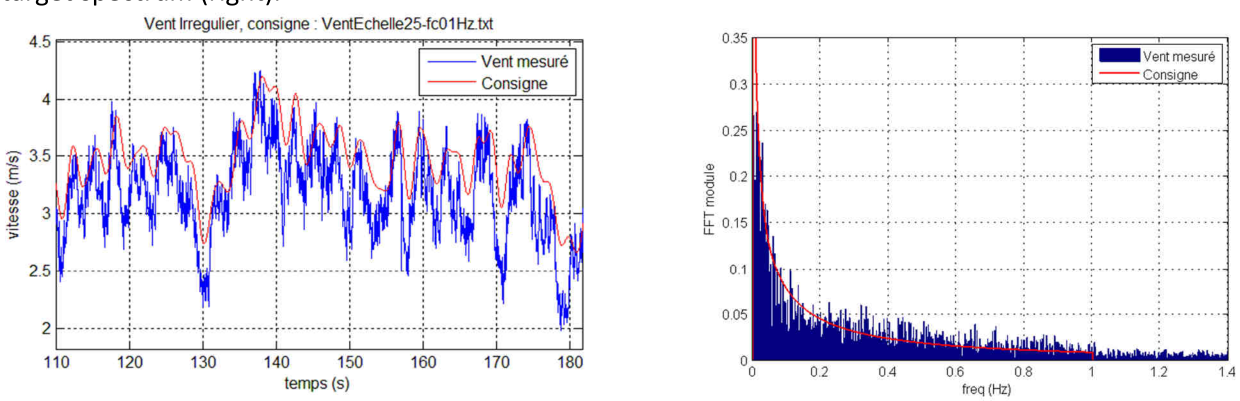


Figure 5.7: Ifremer variable wind velocity 3m after the wind generator; measured (blue) vs target(red); left: time series comparison, right: amplitude spectrum comparison

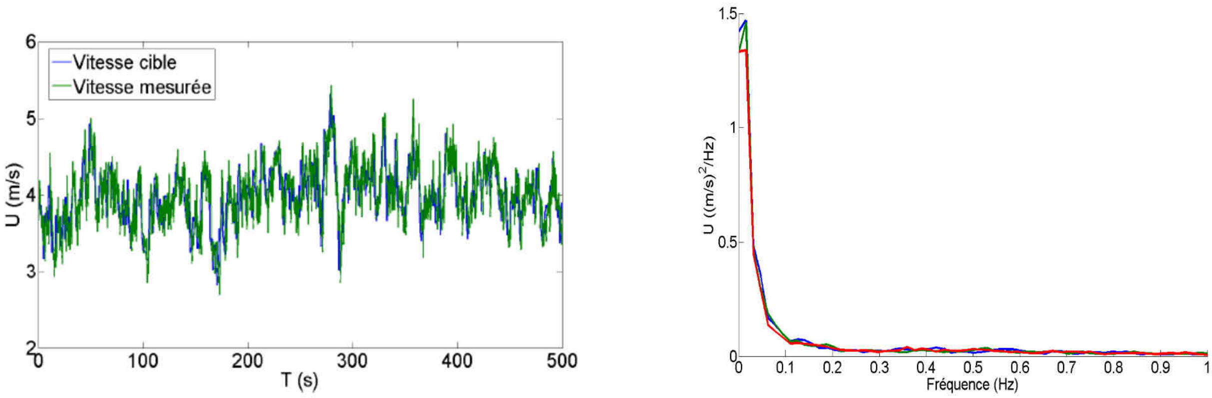


Figure 5.8 left: Target (in blue) and wind speed measured (in green) 2m downstream the outlet of ECN's wind generation system. Right: Wind spectra showing the repeatability of the low-frequency varying wind.

In both cases, the wind speed can be varied to reproduce a target variable wind speed, by controlling the frequency of the blowers. Usual and user-defined wind spectra can be then reproduced with a very good accuracy

5.2 WAVE GENERATION

The reader is invited to refer to the Marinet deliverable 2.12 “Collation of wave simulation methods”.

6 CONCLUSIONS AND RECOMMENDATIONS

In a marine renewable energy project, running tests in a hydrodynamic facility is a necessary step which must be prepared carefully. Particular attention has to be paid to the measurement quality which is a crucial point.

The appropriate sensors have to be chosen and implemented correctly. This report lists examples of setups used for Marinet transnational access project. Each facility and model is unique so these solutions may not be exactly reproducible but provide a database of working implementations.

Then the synchronization and acquisition possibilities have to be studied. The knowledge of the presented working setups can help the user to choose the most adapted solution for his project. In the process of carrying out quality measurements, the static and dynamic behaviour of the measuring systems must be known by verifying the measurement data with calibration procedures.

Finally the test quality also depends on the facility ability to reproduce energy resources and environment conditions. Wind generation is characterized by wind velocity maps at different distances, turbulent intensity maps, and irregular wind reproduction.

7 REFERENCES

[1] ITTC (2002) Recommended Procedures and Guidelines - 7.6-02-09 - Sample work instructions – Calibration of load cells.

[2] ITTC (2008) Recommended Procedures and Guidelines - 7.5-01-03-01 – Uncertainty analysis - Instrument calibration.

[3] Berlander, M (2012) - Qualisys technical note – QTECH1010 v2.0 2012/08/08 – Accuracy and resolution of a motion capture system.

[4] Marinet deliverable 2.1: “Wave instrumentation database”.

[5] Ohana J., Le Boulluec M., Peron E., Klinghammer C., Tancray A., Mansuy E., Open jet blower type wind generator with variable wind speed capability for physical model testing of offshore structures. Proceeding of Coastlab14 conference, reviewing in progress.

[6] Marinet deliverable 2.5 EC: “Report on instrumentation best practice”.

[7] Marinet deliverable 2.13: “Collation of model construction methods”.

[8] Qualisys (2014). Website. www.qualisys.com

[9] Courbois, A., “Etude expérimentale du comportement dynamique d’une éolienne offshore flottante soumise à l’action conjuguée de la houle et du vent », PhD thesis, Nantes, 2012

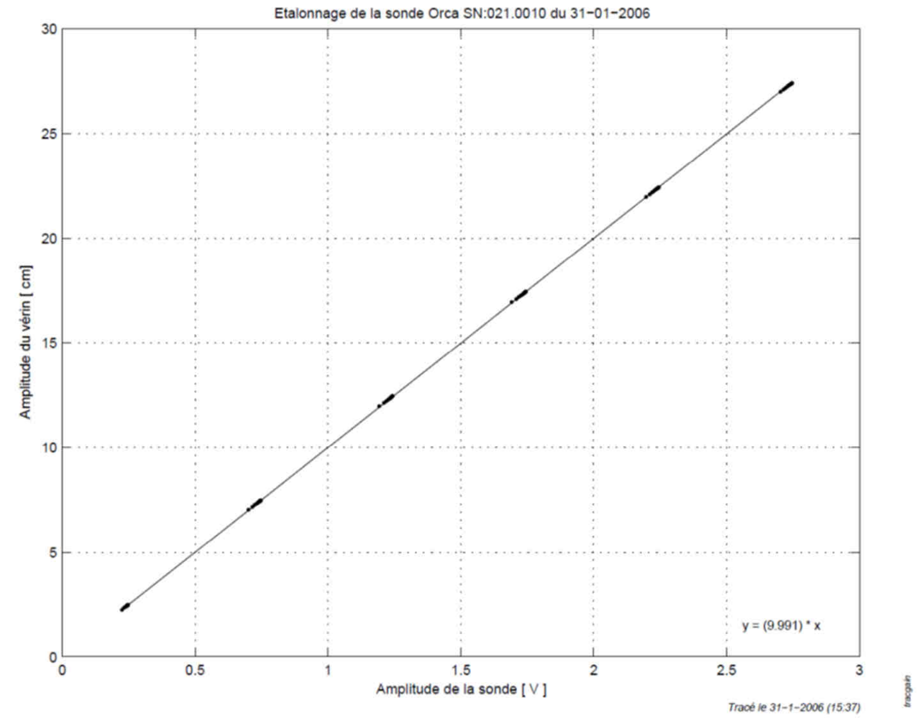
[10] Marinet deliverable 4.05: “Report on non-intrusive wave field measurement”

[11] Equimar deliverable 3.4; “Best practice for tank testing of small marine energy devices”.

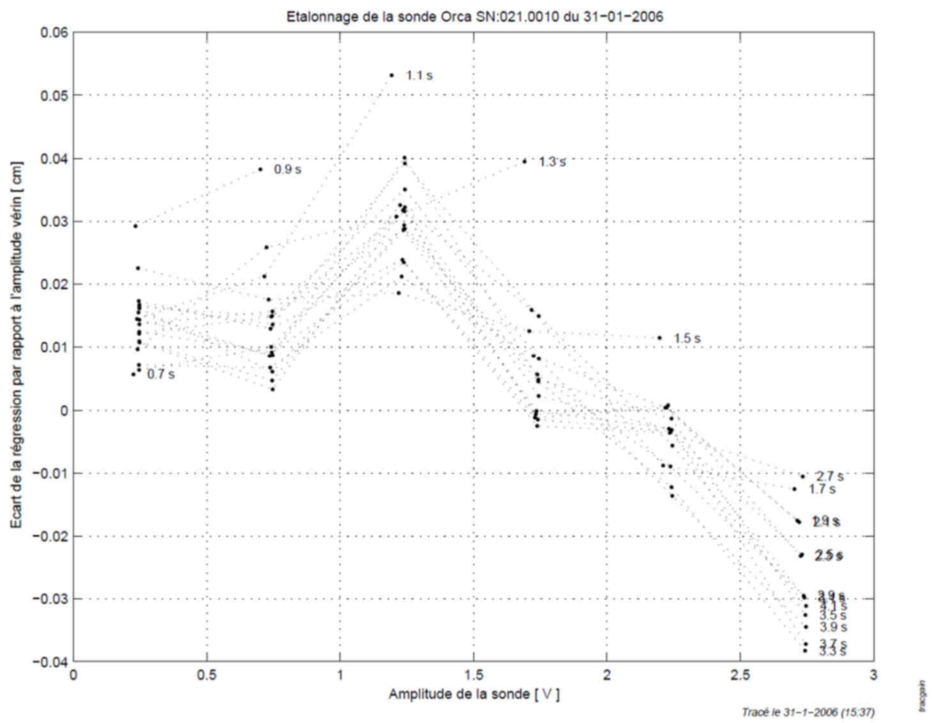
8 APPENDICES

1- Example of wave gauge dynamic calibration results

Vertical motion amplitude vs wave gauge output voltage



Difference between vertical motion and linear regression vs sensor signal magnitude and period

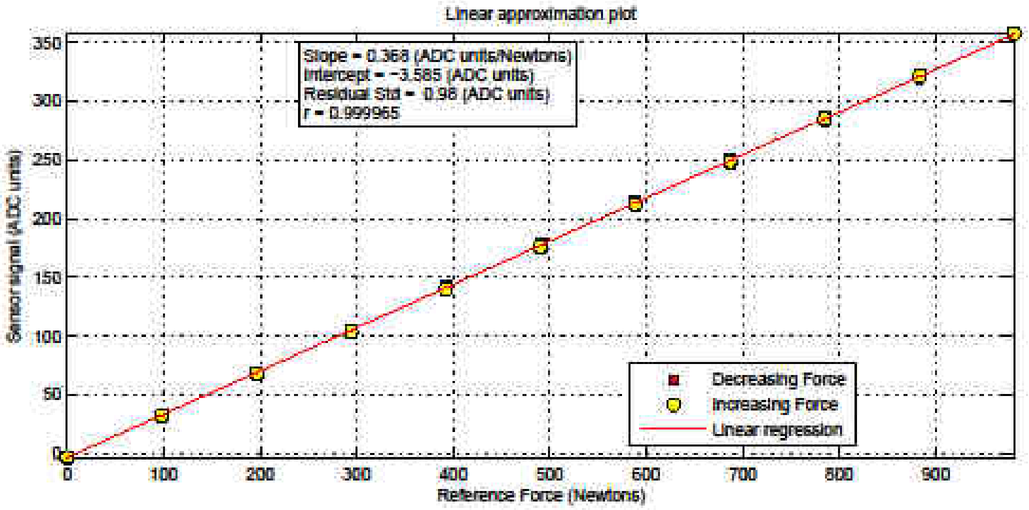


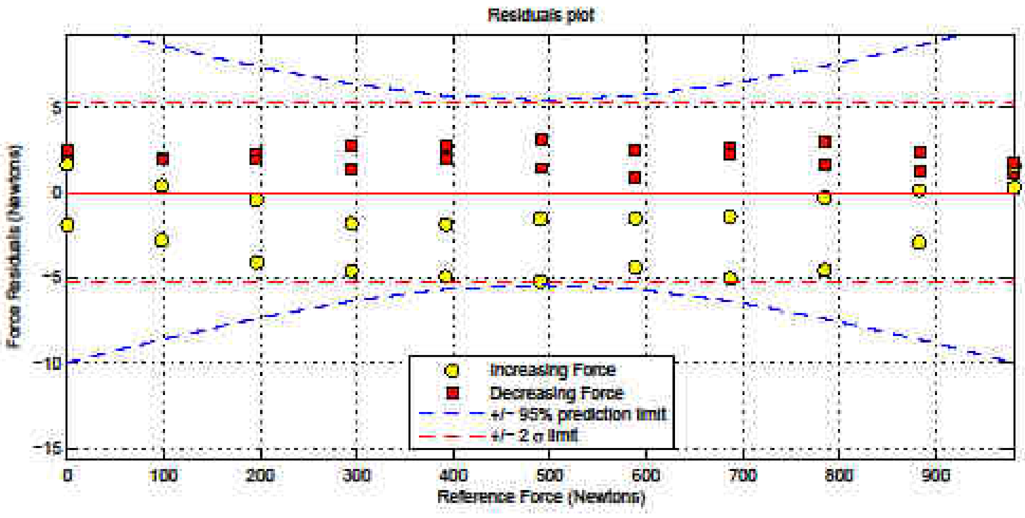
2 - Example of load cell static calibration results

STATIC CALIBRATION REPORT

Sensor name: Mooring3
Type: Force
Manufacturer: TEI EFE
Model: f5070
Serial number: 76722 – ref: BL-F051
Full Range: 1000 Newtons

Calibration reference standard:
10kg standard masses n°G131317 to G131326
Acquisition device: NI 6229 – ref: I040
Ampli: Syminex – ref: E238
Number of points: 11
Number of cycles(advance & return): 2





Sensitivity = 2.717 (Newtons/ADC units)
Linearity = 0.54 (%FS)
Hysteresis = 0.88 (%FS)
Repetability = 0.86 (%FS)
Noise = ...(%FS)

Residual Std = 2.658 Newtons
Coverage factor = 2
Expanded uncertainty = 5.32 Newtons

Calibration by J. Ohana – Ifremer – RDT/DSM – 6-Feb-2014

Reference documents:
[1] ITTC (2002) Procedures and Guidelines – 7.6-02-09 – Calibration of load cells.
[2] ITTC (2008) Procedures and Guidelines – 7.6-01-03-01 – Uncertainty analysis.

Ifremer