Infrastructure Access Report

Infrastructure: IFREMER Deep Seawater Wave Tank

User-Project: SigMAR Tests 2013
Sigma Wave Power Plant MARINET Tests 2013
Sigma energija d.o.o.

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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 aim of the initiative 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

Ireland
University College Cork, HMRC (UCC_HMRC)
Sustainable Energy Authority of Ireland (SEAI_OEDU)

Netherlands
Stichting Tidal Testing Centre (TTC)
Stichting Energieonderzoek Centrum Nederland (ECNeth)

Denmark
Aalborg Universitet (AAU)
Danmarks Tekniske Universitet (RISOE)

France
Ecole Centrale de Nantes (ECN)
Institut Français de Recherche Pour l’Exploitation de la Mer (IFREMER)

Germany
Fraunhofer-Gesellschaft Zur Foerderung Der Angewandten Forschung E.V (Fh_IWES)
Gottfried Wilhelm Leibniz Universität Hannover (LUH)
Universitaet Stuttgart (USTUTT)

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National Renewable Energy Centre Ltd. (NAREC)
The University of Exeter (UNEXE)
European Marine Energy Centre Ltd. (EMEC)
University of Strathclyde (UNI_STRATH)
The University of Edinburgh (UEDIN)
Queen’s University Belfast (QUB)
Plymouth University (PU)

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Wave Energy Centre – Centro de Energia das Ondas (WavEC)

Spain
Ente Vasco de la Energía (EVE)
Tecnalia Research & Innovation Foundation (TECNALIA)

Norway
Sintef Energi AS (SINTEF)
Norges Teknik-Naturvitenskapelige Universitet (NTNU)

Belgium
1-Tech (1_TECH)
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David Volk | Mile Dragic  
Milan Hofman  
David Volk | Final |
ABOUT THIS REPORT

One of the requirements of the EC in enabling a user group to benefit from free-of-charge access to an infrastructure is that the user group must be entitled to disseminate the foreground (information and results) that they have generated under the project in order to progress the state-of-the-art of the sector. Notwithstanding this, the EC also state that dissemination activities shall be compatible with the protection of intellectual property rights, confidentiality obligations and the legitimate interests of the owner(s) of the foreground.

The aim of this report is therefore to meet the first requirement of publicly disseminating the knowledge generated through this MARINET infrastructure access project in an accessible format in order to:
- progress the state-of-the-art
- publicise resulting progress made for the technology/industry
- provide evidence of progress made along the Structured Development Plan
- provide due diligence material for potential future investment and financing
- share lessons learned
- avoid potential future replication by others
- provide opportunities for future collaboration
- etc.

In some cases, the user group may wish to protect some of this information which they deem commercially sensitive, and so may choose to present results in a normalised (non-dimensional) format or withhold certain design data – this is acceptable and allowed for in the second requirement outlined above.

ACKNOWLEDGEMENT

The work described in this publication has received support from MARINET, a European Community - Research Infrastructure Action under the FP7 “Capacities” Specific Programme.

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EXECUTIVE SUMMARY

Sigma Energy develops (for years) a novel type of wave energy converter (Sigma WEC). It is a point type wave power plant which transforms, by original mechanical PTO system, vertical motion of circular floating buoy due to waves into the electric energy. Several innovative solutions covered by international patent licences have been applied on the present version of the power plant.

During two weeks of testing of scaled Sigma WEC model in Ifremer deep water wave tank, Brest, the device motions (heave, pitch and surge of floating buoy, surge of the tower), the loads in transmission system, generator shafting and mooring lines, were measured. This was done in calm water (free decay tests) and in regular and irregular waves of different wave height and different wave period. Generator loadings and system of generator control varied, and the device configuration changed during the experiments. Altogether, more than 130 tests were performed. Excellent collaboration with the Infrastructure stuff, as well as their help during the testing and the subsequent analysis is very much appreciated by the User Group.

Detailed analysis of measured results showed that the tests were very successful:

- The experimental data was found reliable and repeatable, not covered by large friction or scale effects,
- Very good agreement with the numerical prediction was found, and
- Generally, favourable behaviour of the model in waves with reasonably high power production was observed.

The experiments also enabled the assessment of losses in mechanical PTO system, which could not be predicted with proper accuracy by the numerical analysis. These losses were incorporated into numeric prediction programs, and considerably increased their precision.

The model was connected to the electrical grid during the experiments. It may be interesting to note that a symbolic amount of wave generated electrical energy was actually used by the French public electrical network.

Prior to the MARINE tests, the Sigma power plant had reached the stage 1 of the development plan – the concept validation. The two weeks testing of scaled model in Ifremer deep water wave tank, Brest, made the crucial advances: it is believed that Sigma WEC development reached now (in full) the stage 2 – the design validation.
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1 INTRODUCTION & BACKGROUND

1.1 INTRODUCTION

Sigma Energy, in association with number of R&D institutions, develops (for several years) a novel type of wave energy converter covered by international patent licenses. It is a point type wave power plant which transforms, by original mechanical PTO system, vertical motion of circular floating buoy due to waves into the electric energy (see attached “Images”, at the end of this application).

Since the first patent application, a broad numerical analysis of the device has been accomplished, covering motion of the buoy and its support, the power production and its optimization, dynamical loads, structural analysis, etc. These results give relatively complete numerical simulation of the short term and long term performance of the device in realistic seaway. On that basis, and on the basis of already performed experiments (Montenegro coast 2008-2009, MARINTEK, Norway 2010, ETRA laboratory, Slovenia, 2011, Aalborg wave tank, Denmark, 2013), it is believed that the device fully accomplished the stage 1 of the Development Plan – the concept validation.

In spite of the tests accomplished, the experimental validation did not follow adequately (mostly because of financial reasons) the broad numerical modelling of power plant performance. Therefore, as the next step of the plant development, it was crucial to perform thorough, large scaled wave tank tests and experimentally validate the design. For such challenging task, Sigma Energy gained the support of Call 3, MARINET Project.

During two weeks of testing of scaled Sigma WEC model in Ifremer deep water wave tank, Brest, the device motions (heave, pitch and surge of floating buoy, surge of the tower) and the loads in the transmission system and generator shafting and mooring lines were measured. This was done in calm water (free decay tests) and in regular and irregular waves of different wave height and different wave period. Generator loadings and system of generator control were varied, and the device configuration changed during the experiments. Altogether, more than 130 tests were performed. Excellent collaboration with the Infrastructure stuff, as well as their help during the testing and the subsequent analysis is very much appreciated by the User Group.

Detailed analysis of measured results showed that the tests were very successful:

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The model was connected to the electrical grid during the experiments. It may be interesting to note that a symbolic amount of wave generated electrical energy was actually used by the French public electrical network.

Prior to the MARINET tests, the Sigma power plant had reached the Stage 1 of the development plan – the concept validation. The two weeks testing of scaled model in Ifremer deep water wave tank, Brest, made crucial advances: it is believed that Sigma WEC development reached now (in full) the Stage 2 – the design validation.
1.2 DEVELOPMENT SO FAR

1.2.1 Stage Gate Progress

<table>
<thead>
<tr>
<th>STAGE GATE CRITERIA</th>
<th>Status</th>
</tr>
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<tbody>
<tr>
<td><strong>Stage 1 – Concept Validation</strong></td>
<td></td>
</tr>
<tr>
<td>• Linear monochromatic waves to validate or calibrate numerical models of the system (25 – 100 waves)</td>
<td>✓</td>
</tr>
<tr>
<td>• Finite monochromatic waves to include higher order effects (25 –100 waves)</td>
<td>✓</td>
</tr>
<tr>
<td>• Hull(s) sea worthiness in real seas (scaled duration at 3 hours)</td>
<td>✓</td>
</tr>
<tr>
<td>• Restricted degrees of freedom (DoF) if required by the early mathematical models</td>
<td>✓</td>
</tr>
<tr>
<td>• Provide the empirical hydrodynamic co-efficient associated with the device (for mathematical modelling tuning)</td>
<td>✓</td>
</tr>
<tr>
<td>• Investigate physical process governing device response. May not be well defined theoretically or numerically solvable</td>
<td>✓</td>
</tr>
<tr>
<td>• Real seaway productivity (scaled duration at 20-30 minutes)</td>
<td>✓</td>
</tr>
<tr>
<td>• Initially 2-D (flume) test programme</td>
<td>✓</td>
</tr>
<tr>
<td>• Short crested seas need only be run at this early stage if the devices anticipated performance would be significantly affected by them</td>
<td>✓</td>
</tr>
<tr>
<td>• Evidence of the device seaworthiness</td>
<td>✓</td>
</tr>
<tr>
<td>• Initial indication of the full system load regimes</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Stage 2 – Design Validation</strong></td>
<td></td>
</tr>
<tr>
<td>• Accurately simulated PTO characteristics</td>
<td>❓</td>
</tr>
<tr>
<td>• Performance in real seaways (long and short crested)</td>
<td>❓</td>
</tr>
<tr>
<td>• Survival loading and extreme motion behaviour.</td>
<td>❓</td>
</tr>
<tr>
<td>• Active damping control (may be deferred to Stage 3)</td>
<td>❓</td>
</tr>
<tr>
<td>• Device design changes and modifications</td>
<td>❓</td>
</tr>
<tr>
<td>• Mooring arrangements and effects on motion</td>
<td>❓</td>
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<tr>
<td>• Data for proposed PTO design and bench testing (Stage 3)</td>
<td>❓</td>
</tr>
<tr>
<td>• Engineering Design (Prototype), feasibility and costing</td>
<td>❓</td>
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<tr>
<td>• Site Review for Stage 3 and Stage 4 deployments</td>
<td></td>
</tr>
<tr>
<td>• Over topping rates</td>
<td></td>
</tr>
<tr>
<td><strong>Stage 3 – Sub-Systems Validation</strong></td>
<td></td>
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<tr>
<td><strong>Stage 4 – Solo Device Validation</strong></td>
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<td><strong>Stage 5 – Multi-Device Demonstration</strong></td>
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1.2.2 Plan for This Access

As could be seen from the Stage Gate Criterion Table, the Sigma wave power device reached, before the MARINET tests, Stage 1 – Concept Validation. The plan of the access was to perform large model scale measurements in Ifremer deep water wave tank, and reach Stage 2 – Design Validation.

The following measurements were planned (see Fig. 1.1)

1. Vertical motion – heave of the buoy ($\zeta_b$)
2. Horizontal motion – surge of the buoy and the tower ($\xi_t$)
3. Rotation – pitch of the buoy ($\psi_b$)
4. Rating of electric generator ($n_G$)
5. Torque on the generator shafting ($M_G$)
6. Force in transmission system ($F_t$)
7. Tension forces in three mooring lines ($Q_1, Q_2, Q_3$)

Referring to the criteria identified as ‘planned for this project’, it should be stressed that the mechanical PTO system was constructed as accurate as it was possible in the scaled model of the device. Sophisticated electronic system of generator control was designed and applied. Changes in mooring rope distances were planned, as well as the changes in direction of the device in respect to waves. The maximal waves which could be generated in the wave tank would be applied to check the device survivability.

It was planned to perform very detailed analysis of the measurements, to check, validate and (perhaps) improve the numerical prediction of the device performance. It was also hoped that the general behaviour and the power production of the device would prove the high expectations indicated by numerical analysis and the previous experiments. As said, it was planned that, by tests in Brest wave tank and their analysis, the Stage 2 of the device development – the Design Validation would be reached.

2 OUTLINE OF WORK CARRIED OUT

2.1 Setup

The Sigma WEC model used for testing in Ifremer deep water basin, Brest was scaled 1:18 compared to the full size device. In that way, the largest regular waves which could be generated (wave height 0.5 m) would simulate the waves of 9 m. The largest irregular waves (significant wave height 0.28 m) would simulate the irregular waves of 5 m significant height. If a smaller model was used, the more extreme survivability conditions could be simulated, but the tests would be more influenced by the scale and dry friction effects.

The model was equipped with the following instrumentation:

- Optical sensors on the floating buoy, to measure its 6DOF motion;
- Optical sensor on the top of the tower, to measure the motion at that location;
- Load cell mounted at the top of the toothed rack, to measure the transmission force;
- Load cells in three tendons, to measure the tension force in mooring lines;
- Torque and speed sensor on the generator shafting, to measure the rating and torque of the generator.

In addition, two wave gages were used to measure the generated waves.

![Fig. 1.1. The major parts of the model, with characteristics values to be measured.](image-url)
The Ifremer supplied the instrumentation for motion measurements (Qualisis System), and the load cells for transmission force and mooring force measurements. The Sigma used its own sensors for generator rating and generator torque measurements.

The instrumentation layout enabled the measurements of heave, pitch and surge motion of the floating buoy, and heave and surge motion of the tower. Actually, it also enabled simple cross-checking, as the heave and surge motion of the buoy and tower should be the same. Additionally, it gave the opportunity to check possible (but unfavourable) roll or sway motion of the buoy, and the tower inclination.

In addition to the load measurements, the instrumentation layout enabled the assessment of mechanical power. The power could be calculated as a product of generator rating and torque on generator shafting, but also as a product of vertical velocity of the toothed rack and the transmission force.

So the instrumentation enabled all the planned measurements, and flexible cross-checking of the obtained results.

The model of the device prior to the testing, with the installed optical markers, is presented in Fig. 2.1.

### 2.2 Tests

During the ten days of testing of Sigma WEC model in Ifremer deep water basin, Brest, the following tests were performed:

- Free decay tests (calm water tests) of heave, pitch and surge of the floating buoy;
- Tests in regular waves of floating buoy motion, loads in transmission system, loads in mooring ropes, and output of the generator;
- Tests in irregular waves of floating buoy motion, loads in transmission system, loads in mooring ropes, and output of the generator.

The tests were performed:

- With two different spacing between the anchors;
- With engaged and disengaged generator;
- In the case of engaged generator, active generator control was applied, and several different generator loadings investigated.
- In some tests, different concepts of active system control were applied, searching for the optimal solution.

The tests in regular waves were performed on four different wave heights. These waves would be named here as small, medium, large and extreme regular waves. Three different wave periods were used: short, medium and long regular wave period.

The tests in irregular waves were performed with three different significant wave heights, referred here as small, medium and large irregular waves. Again, three different wave periods were used: short, medium and long irregular peak wave periods.

Altogether, including the unsuccessful tests, and the tests for checking the instrumentation, 135 tests in calm water, regular and irregular waves were performed.

Compared to the plans, just one important part of the testing could not be performed. Namely, the intention was to rotate the device in respect to waves, to check the influence of the wave direction on the mooring forces. These tests had to be cancelled because lack of time.

There were no serious problems during the testing. The signals were found clear and repeatable, the collaboration with Ifremer stuff was excellent, and the only real problem was the shortage of time to perform all the tests planned.
2.3 RESULTS

As said, more than 130 tests were performed on calm water (free decay tests), on regular, and on irregular waves. Different wave heights and wave periods were used, different generator loading and control system, and different spacing between the anchors. From numerous experiments, as typical examples, the results from one of free decay tests (buoy heave for zero generator loading), from one regular wave test and one irregular wave test for constant generator loading, are presented in Figures 2.2, 2.3 and 2.4, respectively. The regular and irregular wave test present large waves $\zeta_w$, with associated (measured) buoy heave $\zeta_b$, tower surge $\xi_t$, generator rating $n_G$, generator torque $M_G$, forces in mooring lines $Q_1$, $Q_2$, and transmission force $F_t$.

Fig. 2.2. Typical free decay test. Buoy heave with zero generator loading.

Fig. 2.3. Typical test results in regular waves.
2.4 ANALYSIS & CONCLUSIONS

The test analysis included:

- Analysis of free decay tests, giving the natural frequencies of heave and pitch motion of the floating buoy, and the natural frequency of surge motion of the support.
- Analysis of regular wave tests, which gave the RAO values for three distinct wave frequencies. Also, the power captured by the device was obtained. Actually, the power was calculated from the numerical tests in two independent ways:
  a) From the measured vertical velocity of the floating buoy, and the force transmitted by toothed rack,
     \[ P_m = v_L \cdot F_t \], and
  b) From the measured generator rating and torque on the generator shafting,
     \[ P_m = \omega_G \cdot M_G \].

These two powers correspond to the different locations along PTO system, and gave the deeper insight into the losses along the transmission. Further, by dividing the obtained powers by the corresponding wave power, the Capture Width Ratio (CWR) was evaluated.
- For irregular wave tests, the Fourier analysis of the signals was performed, and the corresponding spectrums of waves, motions and loads were obtained. Then, the transfer functions (RAOs) followed from the formula.

Fig. 2.4. Signals obtained in 600 s of typical irregular wave measurements.
where \( \omega \) is wave frequency, \( S(\omega) \) is obtained spectrum of motion or loads and \( S_w(\omega) \) the corresponding wave spectrum. Finally, the obtained scattered RAO functions were smoothed by the moving average method. Similar to the regular wave analysis, power of the device was calculated in two different ways: as a product of vertical buoy velocity and the transmission force, and as a product of generator rating and the corresponding generator torque. From these results, the corresponding Wave Capture Width in irregular waves was obtained.

Generally, the experiments performed in Ifremer deep water basin were found very satisfactory. Three main results support such belief:

- Reliable experimental data not covered by or scale effects,
- Very good agreement with the numerical prediction, and
- Generally favourable behaviour of the model in waves with reasonably high power production.

Prior to the tests, there was doubt if the large dry friction or scale effect could cover the results of the test analysis. The doubts were based not only on the theoretical considerations, but on some previous testing as well. Namely, in the preceding tests in Aalborg wave tank with a smaller (1:35 scaled) model, some large discrepancies were found, manifested as very different transfer functions of the buoy heave in waves of different height. The transfer functions in larger waves were considerably higher than in smaller waves. This typical dry friction (or scale effect) behaviour caused, in some cases, the extrapolation of the results to the full scale device practically impossible.

In the tests performed in Brest wave tank, some differences in transfer functions obtained from the tests in irregular waves of different height were found, also. However, as could be seen from the comparison presented in Fig. 2.5, the differences were reasonably low, and could be recognized as typical Keulegan-Carpenter effect: the transfer function in smaller waves were found higher. So, they did not imply the scale effect, and could be safely extrapolated to the full scale device.

Comparison of the tests to the previous numerical prediction was also found very satisfactory. The computer program developed by Sigma Energy simulates the motion and loads of the WEC model, as well as the power produced. It does that in regular and irregular waves, for different device configuration, and different generator loading\(^*\). The program, however, could not predict damping in the mechanical transmission system with the proper accuracy.

The model tests gave the opportunity to find such loses, so enabled their incorporation into future numerical predictions. There are two ways to get the damping from the analysis of experimental results:

- From the free decay tests of the buoy heave, if the zero electrical loading is applied on the generator;
- From generator torque and rating on generator shafting (measurements in waves), in the case of zero electrical loading on the generator.

It is interesting that the common procedure from the free decay tests did not give the reliable results. Namely, it was found that damping coefficients followed from the decay tests considerably depend on the motion amplitudes, confirming already mentioned Keulegan-Carpenter effect (as could be seen from e.g. Fig. 2.2). So, the unconventional

\(^*\) More detailed explanation of the computer program developed by Sigma Energy was given in the Application for MARINET 4th Call.
approach, from the power (found as product of generator rating and torque on the generator shafting) was found more useful.

The comparison of transfer functions of buoy heave obtained from test analysis and from numerical prediction, for constant generator loading, is presented in Fig. 2.6. The comparison of mechanical power on generator shafting, obtained from the test analysis and from the numerical prediction, as function of generator loading, is presented in Fig 2.7.

The presented results prove that, if mechanical transmission losses found by the experiments are properly incorporated into numerical prediction, excellent agreement between the tests and the numerical calculations are obtained.

Finally, the comparison of tower surge transfer functions obtained from test analysis and from numerical prediction is presented in Fig. 2.8. It shows also that, for the wave frequencies over 2 rad/s, there is very good agreement between the tests and the numerical calculations.

Concerning the general behaviour of the device, it was found very adequate, fully in accordance with the previous numerical prediction. The WEC tower stayed practically vertical thought-out the motion, with acceptable small surge. The floating buoy heaved and pitched in the proper way, so that there was no slamming, and acceptably low deck wetness was observed. The only problem accounted was the danger of slacking of the mooring lines in high waves, when (deliberately) the anchor distances were over-reduced.

The power production of the device was also found satisfactory. In Fig. 2.9, it is presented in the form of Capture Width Ratio, which is the ratio of the power measured on the generator shafting and the associated wave power

\[ CWR = 100 \cdot \frac{P_m}{D \cdot P_w} \]
where $D_b$ is the float diameter, and $P_w$ is wave power per unit of wave crest. In case of irregular waves, the wave power is calculated according to the well-known formula

$$P_w = \frac{\rho g^2}{64\pi} \cdot 0.9 T_p h_s^2,$$

where $\rho$ is density of water, $g$ is gravitational acceleration, $T_p$ peak wave period and $h_s$ significant wave height. Some of the obtained results are presented in Fig. 2.9. They show that the dimensionless parameter CWR depends on the generator loading, and could reach (for the optimal loading) some 25%. In the cases where the advanced system of generator regulation was applied, the parameter CWR was increased up to 30%. This seems very promising for the small scaled model used. On that basis, an additional effort will be given do increase the efficiency by the further optimization of system control.

The results and analysis given in this report present just a small portion of the data measured during the tests, and the outcomes of the test analysis. For instance, the analysis of the buoy pitch, transmission forces and moments, tension forces in mooring lines and phenomenon of slacking, are not presented here. However, all the other results do support the main conclusion given in this text, and show generally favourable and predictable behaviour of the tested model. They show the high potentials of the device, especially if further advances in control and optimization of the PTO system are applied.

3 MAIN LEARNING OUTCOMES

3.1 PROGRESS MADE

3.1.1 Progress Made: For This User-Group or Technology

Generally, the experiments performed in Ifremer deep water basin were found very valuable for the User group. Three main results support such belief:

- The experimental data was found reliable and repeatable, not covered by large friction or scale effects,
- Very good agreement with the numerical prediction was found, and
- Generally, favourable behaviour of the model in waves with reasonably high power production was observed.

The experiments also enabled the assessment of damping in mechanical PTO system, which could not be predicted with proper accuracy by the numerical analysis. These losses have been incorporated into numeric prediction programs and considerably increased the precision of these programs.

Prior to the MARINET tests, the Sigma power plant had reached the Stage 1 of the development plan – the concept validation. The two weeks testing of scaled model in Ifremer deep water wave tank, Brest, together with subsequent detailed analysis of the obtained results enabled the crucial progress: it is believed that Sigma WEC development reached now (in full) the stage 2 – the design validation.

3.1.1.1 Next Steps for Research or Staged Development Plan – Exit/Change & Retest/Proceed?

The next step in the device development (the stage 3 of the development plan) involves construction of larger prototypes, and their installation on sheltered sea sites. Sigma Energy continues the WEC development in that direction, and already did undertake steps for obtaining the financial support for the scaled prototype sea site tests.

Prior to that, another slot of tests is planned at the Ifremer wave tank with the same model, in aim to finalize the parts omitted from the present experiments, and to continue the analysis of active generator control and better optimization of the PTO system.
3.1.2 Progress Made: For Marine Renewable Energy Industry

It is quite general belief that the hydraulic transmission system is advantageous for WEC application compared to the mechanical one. Sigma Energy, unlike most of other WEC developers, uses and innovates an advanced mechanical PTO system, confident in its values. The present experiments demonstrated very favourable behaviour of the mechanical PTO system. It showed very high efficiency, and (if properly adjusted generator loading) operated smoothly, without significant vibrations, or impacts.

The comparison of scaled model tests and numerical prediction is a very delicate problem. The experiments involve scale effects, and several other potential inaccuracies, especially if small scaled models are used. The numeric prediction involves numerous approximations, which often have unclear impact on the final results. In spite of all that, the tests demonstrated (to some surprise) an excellent agreement between the results of test analysis and the numerical prediction. They proved that, if the tests and numerical prediction are done with great care and understanding, the both approaches are essential and very much complement each other. In the present case, one of main outcomes was the improvement of numerical prediction by experimentally obtained transmission damping coefficients.

3.2 Key Lessons Learned

- In spite of possible scale effects and other potential inaccuracies of the experiments on one side, and numerous approximations involved in the numerical predictions, the results of the two approaches could be in very good agreement. To achieve that, however, great care and understanding of both, the tests and the numerical calculations has to be accomplished.

- Because of strong physical interaction of buoy motion and generator performance, any change of generator loading largely influences the motions and loadings of the device. This could be very favourable, but could also have very unfavourable effects (such as large vibrations, high forces etc.).

- Proper and advanced generator power control could considerably increase the efficiency of the system. To achieve that, detailed numerical analysis has to be performed, and fine tuning accomplished in carefully prepared tests.

- In spite of general belief, the mechanical PTO system of WEC device could work smoothly, with no significant vibrations or impacts. Together with the known high efficiency, the tests demonstrated very favourable operation of such systems. To achieve that, however, very advanced system has to be constructed and great care taken on adjustment of generator loading and regulation.

- The danger of slacking of mooring lines in case of tension leg platforms (as used in the present experiments), is very real. The anchor distances in some tests were, deliberately, over reduced, and some slacking allowed. The tests showed extreme increase of the tension forces in tendons, in the first cycle after the slacking.

4 Further Information

4.1 Scientific Publications

It is planned to prepare and publish a paper, based on the test analysis and its comparison to the numerical prediction of the device behaviour. The paper would be, perhaps, presented at one of the oncoming EWTEC Conferences.

4.2 Website

Website: www.sigma-energy.si