Mocean WEC: Next-level Hydrodynamics and Engineering

WES Novel Wave Energy Converter Stage 2 Project

Public Report

Mocean Energy Ltd

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1 Project Introduction

The Mocean WEC is a hinged raft that differs radically in shape from the classic symmetric twin-pontoon configuration. During the course of the NWEC 2 project, Mocean developed the design of a 100kW version of our WEC, referred to as the ***M100***.

The M100 geometry has two slender tubular hulls either side of the hinge, with the key innovation being two sloping, deeply-submerged plates at the fore and aft ends of the WEC, which are 3 times the width and depth of the tubular hulls. Overall, the forward section is twice the length of the aft. The combination of the asymmetrical sections and the submerged plates delivers performance that is 3 times greater than the classic hinged raft.

The project team comprised:

- Mocean Energy (MOE): Project lead and management, numerical, physical, and cost modelling
- Blackfish Engineering (BFE): Structural design, industrial best practice, system integration, project management
- Bathwick Electrical Design (BEDL): Magnetic geared generator PTO
- Supply Design (SD): Power electronics for PTO
- Ecosse Subsea Systems (ESS): Marine operations
- Industrial Systems & Control (ISC): Control system

2 Description of Project Technology

The Mocean WEC is a hinged raft, two floating bodies connected by a hinge parallel to the wave crests. The wave excitation forces, and the bodies' dynamic responses, cause a relative motion between the bodies about the hinge. Power is extracted via a power take off (PTO) system built into the hinge.

The key innovation is in the shape of the WEC. The M100 has two slender tubular hulls either side of the hinge and two sloping, deeply-submerged plates at the fore and aft ends of the WEC, which are 3 times the width and depth of the tubular hulls. Overall, the forward section is twice the length of the aft. The depth to which the submerged nose and tail plates reach below the still water surface is significant, and they act as upside-down flaps, so that the device is like a cross between a hinged-raft WEC and a floating-flap WEC.

By being different sizes and asymmetric in shape, the component bodies of the Mocean WEC induce a coupling between modes of motion due to inertial, hydrostatic, added mass, and damping forces. Motions in heave, surge and pitch cause a flex about the hinge. There is a strong resonant response that can be tuned to the wave frequency of interest. This tuning of the response is complex and, so far, has been accomplished implicitly using the numerical geometry optimisation suite. The combination of the asymmetrical sections and the submerged plates deliver a performance that is 3 times greater than that of the classic hinged raft.

The WEC geometry also provides significant survivability benefits. The sloped nose always stays submerged: the WEC dives through steep waves, and no portion of the structure ever leaves the water, so that wave slamming does not occur. Finally, the rotational PTO system means that mechanical end-stop collisions are highly unlikely.

3 Scope of Work

The goal of NWEC Stage 2 was to develop a new high-performance WEC geometry and progress it to a viable, fully functioning WEC design that can produce electrical energy when installed in a suitable wave site. Each work package was directed to improving the design by iteration, to produce an end design that addressed the WES target metrics, with an overriding emphasis on the real-world engineering and operations that will be required to get a functioning WEC to sea.

The main activities of the project were:

- Further develop the numerical optimisation suite to incorporate non-linearity and better model costs. The use the optimisation to create a final optimised version of the geometry to inform the engineering.
- Design, build and wave-tank test scale models that embody the main features of the revised WEC design, and incorporate as many of the structural features as possible.
- Create the detailed engineering design of a full-scale WEC.
- Specify at a detailed level the PTO components: the magnetic gear and generators, the power electronics and the high-level control.
- Clarify the marine operations that will be required to deploy, retrieve and maintain the WEC.
- Carry out a reliability study that will identify the main failure modes and repair & maintenance strategies.
- Evaluate the capital cost and LCOE of the WEC incorporating uncertainty and assess the WEC design outcomes with metrics.
- Create a Front-End Engineering Design of a large-scale prototype suitable for building in a Stage 3 project, to be deployed and tested at sea.

4 Project Achievements

Numerical Modelling

One of the biggest successes of the project was our geometry optimisation, in which programmatically generated geometries were assessed for performance with a numerical model and costed with a parametric cost model. Some of the reasons for its success were that

- We carried our an early-in-the-project iterative validation of the numerical model against tank tests and identified key nonlinear behaviours.
- Nonlinear behaviours were accounted for using the so-called Spectral WEC model.
- Engineering considerations were included early in the geometry definition.
- Cost of both the structure and the PTO were included.

This resulted in an optimal geometry that had 80% increase in energy yield per mass, used 1/3 of the torque for a given power rating compared to our NWEC Stage 1 WEC. Also, the numerical predictions agreed well with the wave tank performance.

There were however aspects that we gave little consideration in the geometry optimisation and that later turned out to be important (and could be incorporated in future optimisations): 1) the influence of the mooring, 2) towing behaviour, 3) wave directional spreading, and 4) the complexity of structure-structure interfaces.

Physical Modelling

We built 2 high-fidelity physical models of the M100 geometry: a 40th scale model with a free hinge used for survival tests, and a 20th scale model with a motorised hinge and a hull load cell used for performance testing and validation. This approach was successful in allowing us to test both performance and survival waves.

In the 20th scale model, space and weight constraints prevented us from using a dedicated torque sensor to assess the hinge dynamics for power calculations. Instead, we calibrated the hinge model motor to infer torque from current and found the motor to be very reliable at this.

3D printing was used extensively in both models where model-structural loads were low particularly to create complex shapes. The 40th scale model was made almost entirely from 3D printed parts. Lead times for 3D printed parts were excellent. However, the drawback of these parts is that despite our best effects to seal them, some water absorption occurred effecting the model mass, and they had to be dried out.

The biggest challenge in the model programme was that the fabrication of aluminium model parts was severely delayed, and the extent of the delay was not communicated with us by our fabricator. This delayed the tank testing which had knock on effects on numerical modelling and engineering.

Cost Modelling

For the cost modelling we used a Bill of Materials (BOM) with quotes for major cost items, which was in contrast to the parametric costing used in Stage 1. For different items, we applied different learning rates to assess future costs, and we also considered uncertainty by applying a distribution to each item and running a Monte Carlo simulation.

We considered a variety of metrics for assessing progress against our Stage 2 targets. The metrics we found more useful include: Annual Energy Production (AEP)/mass, PTO torque/rated power, and nondimensionalised capture width (CW). However, some were more difficult to use; for example: structural cost/rated power is affected by the costs basis for the structural material and the level of detail applied to the structural analysis. In Stage 1, we used an optimistic cost per tonne of steel and performed a high-level structural analysis, while in Stage 2, we used a more realistic cost per tonne of steel and applied a more detailed structural analysis. Also, it is important to keep in mind that if metrics are not non-dimensional they are affected simply by the scale/size of the machine.

Prime Mover Design

The design of the prime mover (hull structure, layout, and ancillary systems) was carried out to a sufficient level of detail to show the viability of the system.

A realistic structure was developed and analysed. However, we found the structural analysis of wave loads to be challenging, including the definition of load cases and the transfer of the hydrodynamic loads from the hydrodynamic model to the FEA model. We were not able to analyse a satisfactory load case for extreme waves.

Structure-structure interfaces proved challenging to implement, such as the connection between the tubular hull and the wave channel.

A buoyancy, trim, ballast analysis was carried out, which was vital to the WEC layout, but was also challenging to do with a hinged system.

PTO

For the PTO, we worked with a WES PTO project called PECMAG, which is developing a magnetically-geared, power-electronics based PTO. This proved very positive: the PECMAG team had a novel solution and they were focused on and knowledgeable about wave energy.

Reliability

We carried out a reliability study which included the development of a FMECA and the use of an O&M model. Both the FMECA and the O&M model were difficult to use in an absolute sense, i.e. to get realistic values for reliability. However, they were very useful tools for understanding how reliability affects costs and identifying design changes that could be made at early stages in order to achieve better reliability.

Marine Operations

All major marine operations were consider including lifts, towing, and installation. This was important as operations such as lift have step changes in cost depending on the mass of the WEC and help to identify thresholds for design. Another major outcome (which was confirmed in towing tank tests) was that as-designed the WEC needs to be towed slowly. This obviously affects the costs and the weather windows for operations. Future work is needed to address this.

Stage 3 Planning

The final third of the project was dedicated to developing an engineering design and test plan of a scaled sea-going prototype for NWEC Stage 3. It was essential to start this development during Stage 2 so that a reasonable proposal can be made for Stage 3. One of the biggest challenges of the design is that due to budget and schedule constraints of the Stage 3 project, a full scale WEC cannot be constructed, and the waves at EMEC Billia Croo are too large to effectively test performance at smaller scales. However, a half-scale design has been developed along with an appropriate strategy for performance testing at this scale.

5 *Summary of Performance against Target Outcome Metrics*

Performance

The Mocean WEC combines high energy yield with small size, owing to the unique geometric shape which induces a high excitation force per unit mass, and cross-coupling between modes of motion. There was excellent agreement between the numerical model and the physical scale model, giving confidence that the hydrodynamic design methods and the optimisation process can continue to be used to refine the design and improve performance still further.

While an initial target rating of the WEC was set to 100 kW, the geometry-cost optimisation independently determined this to be the optimal size for the wave climates considered. It also should be noted that 100 kW is a nameplate rating, the power electronics can handle power peaks of 300 kW, and so average powers above 100 kW can be sustained in energetic seas.

Survivability

The Mocean WEC has high inherent survivability. The PTO has infinite rotation – it has no end-stops. The hinge rotation is limited by the interference of the two hulls, but only in the very largest seas is this limit approached. The countermeasure adopted is a damped compliant rubber fender that absorbs and dissipates the residual kinetic energy of the moving sections.

Overtopping reduces the hydrodynamic loads on the structure. This load-shedding feature also has the benefit that the machine does not have to have an uneconomically high generator peak rating and so will deliver a higher capacity factor.

Neither the nose nor tail of the WEC was observed to leave and re-enter the water even in the largest focussed waves or irregular seas, nor did any air gap appear beneath the hulls. Therefore, the risks of slamming damage in extreme waves are negligible. Roll stability is excellent.

Reliability

The Mocean WEC has just two bodies and a single hinge with a non-contact magnetic gear, permanent-magnet generators and solid-state control electronics. There is a low number of moving parts, thus contributing to improved reliability. Redundancy is provided by using multiple generators and modular electronics. The WEC is self-referenced, with a highly compliant mooring that has a resonance period much longer than typical wave periods and so generally decoupled from wave-frequency loading

The bearing systems are relatively simple, operating in a single degree of freedom (pitch). Integrated bearing/seal modules have been designed that are easy to install, remove and protect against the marine environment; they should deliver a reliability and life that meets or exceeds the current ‘best in class’.

Affordability

Metrics show major improvements from NWEC1:

- 1/3 the PTO torque required per rated power,
- 80% increase in the energy production per mass.

An LCOE was obtained using a statistical process that took account of uncertainty by specifying a range of values for each of the contributing factors; this yielded a mean estimate of £174/MWh in an energetic wave climate (such as those around many oil and gas sites in the North Sea) and an optimistic cost of just £124/MWh at the 95% confidence bound.

The all-electric PTO is conceptually simpler than alternatives such as hydraulic systems and more efficient: mechanical power is converted directly to electrical power, without an intermediate step. We believe that the total cost of an electric PTO will likely see excellent and ongoing performance-to-cost improvements because of the ever-increasing penetration of large wind turbines into the utility electricity market which drives generator design and power electronics, likewise the growth of the electric car market which has huge potential to drive down the cost of battery storage. Better batteries will improve load matching and provide reactive power for complex controls, in turn delivering large performance gains.

A major cost element is that of the offshore operations required for deployment and maintenance. Creating a WEC that is towable and can be installed with commonly used platform mooring operations results in significant cost savings. Furthermore, the smaller size for the same power output allows much less expensive boats to be used and improved reliability will reduce maintenance, also lowering costs.

6 Recommendations for Further Work

We see 3 key steps toward a commercial wave energy:

1) Build and test a scaled sea-going prototype (as is planned for NWEC Stage 3). The aims are to:
    a. demonstrated viability of the concept,
    b. learn lessons about the build, operations, and performance of the system which can be used in future engineering designs, and
    c. raise private investment for further technology development.
2) Carry out another engineering design iteration, which will incorporate all of the lessons learned in NWEC Stages 2 and 3. We showed an 80% improvement in performance and a 66% reduction in required PTO torque between Stage 1 and Stage 2. We believe we could show a similar level of improvement with another iteration of geometry optimisation and engineering design.
3) Build and test a full-scale, next-generation WEC.

7 Communications and Publicity Activity

International Patent Application No. PCT/GB2017/050548

Initially filed in the UK in March 2017, our first patent has reached the international PCT stage and its application has been published (https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2017149302). Subsequent national patents were applied for on 1 September 2018 in the US and Europe. The patent describes the sloped nose and tail geometry as it applies to our hinged raft, and we believe it will protect our core design.

UK Patent Application No. 1714358.7

In September 2017, we filed another UK patent application, which as of 6 September 2018 was filed at the PCT level but has not been published yet. This patent describes further the physical behaviour of our geometric features, including their application to other types of WECs and as floating breakwaters. We believe this patent will protect our IP more broadly and create licensing opportunities for us.

8 Useful References and Additional Data

The Mocean website (www.moceanenergy.com) has some publicly available information on the technology.

Our NWEC confidential summary report (D11) also contains a useful summary of the project and technology.