Gator: A compliant seal free hydraulic PTO

WES Power Take Off

Stage 1 Project

Public Report

Exceedence

This project has been supported by Wave Energy Scotland

1 Project Report

1.1 Project Introduction

The Gator power take-off (PTO) device is based around a novel polymer ‘spring pump’ capable of pumping significant quantities of water at moderate pressures through conventional hydro-electric turbines.

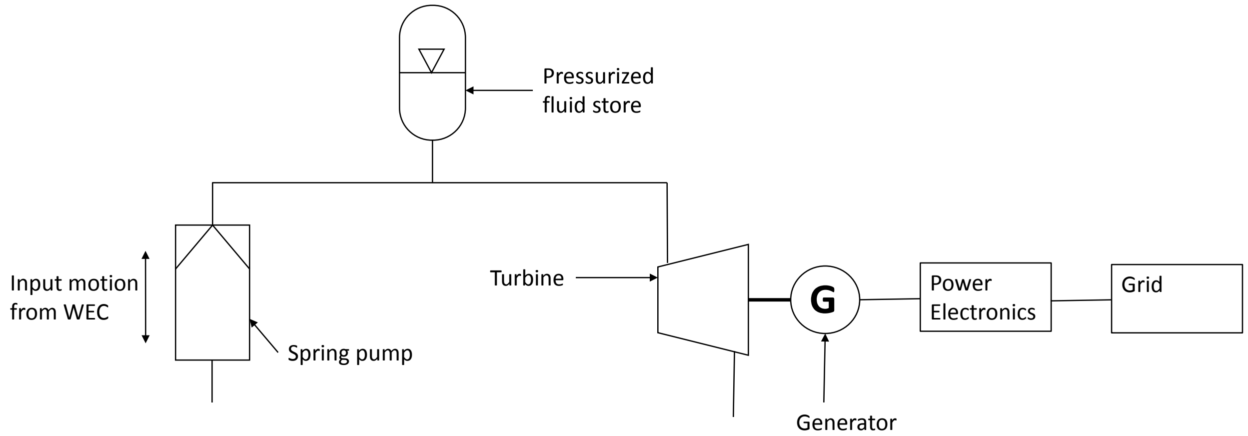


Figure 1 – Schematic of the overall Gator PTO system

Hydro-electric technology is highly efficient, cost effective and well established. Several WEC developers have tried to use it, but have run into two very significant challenges. Firstly, the life of cylinder seals pumping a water based fluid was inadequate for a commercial wave energy technology. Secondly, pipeline systems connecting the WEC to shore had significant reliability issues. The Gator PTO tackles both of these; the spring pump itself, manufactured from engineered polymer materials, needs no seals and therefore offers a truly contamination tolerant pumping device. The pump is closely coupled to the hydro-electric turbine, reducing the flow losses and the transient pipeline effects that have plagued previous shore based systems.

The key to unlocking the benefits of hydro-electric technology is the spring pump itself, and this has been the principal focus of this stage 1 PTO project.

The project team consists of Exceedence, Technology from Ideas, Pelagic Innovations, University College Cork and Strathclyde University.

The Key questions addressed by this project were:

- Affordability – particularly focused on capex and £/kW of the technology;
- Performance (energy conversion efficiency) – particularly focused of different load conditions;
- Availability (a function of reliability and maintainability);
- Survivability – especially focused on how the technology will handle peak load conditions.

1.2 Description of Project Technology

The Gator PTO utilises a novel contaminant tolerant pumping system to deliver seawater to a hydroelectric turbine. The primary element of the pump is an engineered thermoplastic elastomeric spring. Movement of the

WEC, compresses and stretches the spring delivering seawater at moderate pressures to the PTO system. Typically, the flow of water would be smoothed by pumping into a fluid store before discharging efficiently through a hydro-electric generator.

The Gator innovation is specifically in the area of taking the polymer springs already developed for mooring applications, and developing them into stand-alone PTO systems. Recent developments in the thermoplastic spring design and manufacture have enabled Tfi to push the performance boundaries around wall thickness, spring length, and fatigue to the levels required for such a solution. This has created the possibility of the spring element being used itself as a simple, non-linear, compliant, seal free, contaminant tolerant, seawater compatible, hydraulic PTO.

The key challenge to be addressed at this stage is concept characterisation and feasibility. The benefits to availability, survivability, affordability and performance are hypothesised and these need to be characterised before the technology can progress. This involves design, analysis, simulation and testing to determine the parameter ranges which deliver working solutions with LCOE potentials below £150/MWh. There is a wide range of potential operation parameters, especially around pressure and flow rates, that need to be narrowed down to a shortlist which make sense for key WEC device concepts. This WES stage 1 project will seek to answer those questions.

1.3 Scope of Work

This project contains seven work packages (WP), WP1 dealt with project management, WP2 analysed the system, WP3 simulated the Gator PTO, WP4 investigated the engineering design, WP5 conducted physical testing, WP6 conducted the LCOE modelling of the Gator PTO, and WP7 presents the final analysis and reporting of the project. The following sections present the work within the primary work packages WP2 to WP6.

1.3.1 WP2 – System Analysis

The system analysis work package assessed requirements for the Gator PTO, potential PTO architectures and some of the critical aspects affecting the major components.

Application of the Gator PTO to attenuators, point absorbers, oscillating wave surge converters and submerged pressure differential devices was investigated at a high level. This analysis suggested that it is feasible to configure the Gator PTO to suit any of these four WEC types. A point absorber (heaving buoy) was selected as a reference case for further development in WP3.

The Gator PTO pumps water (either fresh water or seawater) at pressures compatible with conventional low to medium head hydro-electric turbines. In comparison to oil hydraulic systems these pressures are low and the flow rates are high. It is implied therefore that in order to reduce flow losses and to minimize the cost and maximise the reliability of piping systems that the turbine will be located physically close to the spring pump; either within the WEC or adjacent too it.

The overall Gator PTO system comprises the spring pump, a pressurized fluid store (most likely), a turbine, generator and power electronics.

Spring pumps can be configured to provide damping on either the retraction stroke or the extension stroke, and multiple units can be arranged to take power from the WEC in both directions. It should be noted that the spring pump applies a different set of forces to the WEC compared to a hydraulic cylinder. The spring itself applies a spring force in addition to those arising from the pressurised fluid within it. Potential energy is stored in the spring that is released back to the WEC later in the wave cycle. This is an inherent feature of the gator PTO. The spring characteristic can be modified by adjusting parameters such as the wall thickness, convolute shape and material grade to generate a response that maximises the benefit to the power capture capability of the WEC. Appropriate matching of the spring characteristic to the WEC dynamics has been identified as a critical area for further investigation using numerical simulations.

Another related feature of the spring pump is that at high displacements its stiffness increases markedly, thus providing an in-built end stop functionality.

Further tuning of the Gator response to different sea conditions can be achieved using combinations of springs in series and / or parallel to maximise power capture over the full range of seas.

The turbine itself will be based on a conventional hydro-electric turbine. Several types of turbine can offer high efficiency (around 90%) over a broad range of input conditions. A Kaplan turbine will be the most versatile although Crossflow turbines and Turgo turbines could offer advantages in some applications.

1.3.2 WP3 – Simulation

This work package numerically modelled the Gator PTO system and applied it to an idealised WEC in reference resource conditions. The work package examined the interaction of the main Gator PTO components within the system and confirmed that there are no fundamental issues with integrating it with a wider range of WECs or scaling the technology.

The system was broken down into its component parts and the behaviour of each was numerically modelled. Strathclyde expanded on previous spring component models, including the range of performance parameters identified in WP2. The PTO system was then integrated into an ideal WEC device and tested to ensure that it was performing. The PTO design parameters were varied through their performance envelope, which helped understand the core design trade.

1.3.3 WP4 – Engineering

This work package considered a theoretical desired spring response curve and performance and developed a physical polymer spring shape at a suitable small scale for testing. To achieve this Tfi used its existing simulation and design tools which it developed with DuPont. Tfi set the key physical parameters related to the hydraulic fluid pumping (volume, pressure), such as the spring inner and outer diameters and convolute shape. The variable range of the other changeable parameters were explored (e.g. wall thickness, material grade, convolute radii, pitch) to match the required stress-strain response around these key physical parameters. This was an iterative process of setting initial parameters, undertaking detailed FEA or CFD simulations, making changes to each parameter and simulating the performance changes, and then choosing a new parameter set closer to the desired response. It is an accurate process which results in a final shape of the spring matching the desired response. Once the physical spring shape was determined a mould was designed and fabricated from which to manufacture the spring. The chosen manufacturing process was a plastic extrusion and corrugation process, with a thermoplastic material which can form the deep convolutes required for the pump performance. The mould was a corrugator mould consisting of multiple pieces for a mould chain. A range of springs were produced with different wall thicknesses (and therefore different response curves and max pressures). These were delivered to UCC for testing in WP5. The final part of this work package focused on investigating the engineering challenges ahead to scale the springs to the full scale required for the different WEC devices. This checked that the concept is on the correct trajectory and appropriate scale against metrics such as component size, weight, layout, interfacing, reliability, performance, efficiency, operability, survivability, manufacturability and maintainability.

1.3.4 WP5 – Physical Testing

The overall objective of this WP was to test and characterise the power performance of the Gator PTO critical concept components to reduce uncertainty and to validate high level assumptions from WP2 and WP3. The test rig used was developed by UCC and has been used for many different linear PTO tests. This work has not been carried out in Scotland as there was no calibrated rig ready to go there. UCC has worked with both Strathclyde and Tfi in the past and hence this was the lowest cost, fastest turnaround, lowest risk solution for a stage 1 test.

The Gator PTO spring pump component was investigated under a range of motions using sinusoidal waveforms. These waveforms tested and characterised the fundamental performance of the device, and highlighted any possible unforeseen problems that could adversely affect more in depth testing or possibly cause damage to the Gator PTO device. Parameters measured included, among others, loads, motion accelerations, displacement, forces, flow, and pressure. The performance of the device was determined under varying damping levels using throttle or pressure controlled valves. The device was subjected to a range of forces; the compression of the device was tested up to 70% of their length under maximum loads (20% greater than normal operating conditions).

1.3.5 WP6 – LCOE model and Market analysis

The LCOE and market analysis work package assessed the impact of the Gator PTO on Levelised Cost of Energy (LCOE) and its potential market(s).

The LCOE modelling consisted of high level assumptions to provide early indications of the overall cost benefit of using the Gator PTO. Therefore, it was important to keep as many variables as possible consistent between the modelled WEC device with a conventional PTO and the WEC device with the Gator PTO. The aspects kept the same were resource location, device, discount, structure costs, foundation/mooring cost, as well as installation and connection cost. The overall structure cost was kept similar between the two cases as the high level assumption was that WEC devices have space available to change the space envelope of the PTO device. Other simplifications were warranted such as normalising availability and efficiencies to 1. In this way the changes in PTO are isolated and the impact of the Gator on the LCOE was determined.

The LCOE modelling initially used real costs of a WEC, obtained from WES. These figures give an LCOE that are much higher than the officially quoted figures by SI Ocean and Carbon Trust. This “real cost” LCOE was used as the baseline to which the Gator was compared. By substituting the cost of the conventional PTO for the estimated cost of the Gator PTO, a much lower LCOE was achieved.

Further LCOE reductions will need to come from optimising other WEC components both in CAPEX and OPEX.

The potential Gator PTO market has been estimated according to the IEAs Blue Map on medium growth. This path shows a predicted 46 GW in Europe and 184 GW globally cumulative wave deployment by 2050.

Other potential markets for the Gator are aquaculture, buoys, shipping, floating platforms, and desalination.

This work package also briefly investigated the supply chain of the main components of the Gator PTO: turbine, accumulator and spring. The first two can be bought off the shelf and once the spring is designed to requirement, a mould is created that is reusable.

1.4 Project Achievements

1.4.1 What went well

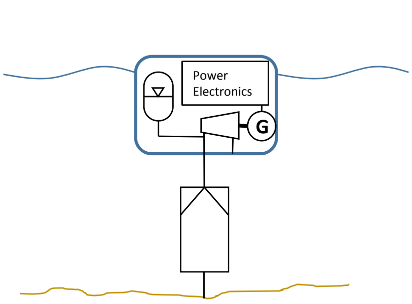
- The LCOE results for the Gator spring exceeded expectations with a much lower cost than had initially been expected. This was achieved by detailed discussions with manufacturing partners and using mature hydropower components.
- There was very good interplay and feedback from the various work packages, with the modelling and testing work packages validating and guiding the design and engineering packages. This delivered the required confidence to move the technology forward to the next stage.
- The operating range for the Gator spring and the breath of applicability were both at the upper end of expectation ranges. No significant limiting factors arose to bringing the technology forward.

1.4.2 What can be improved

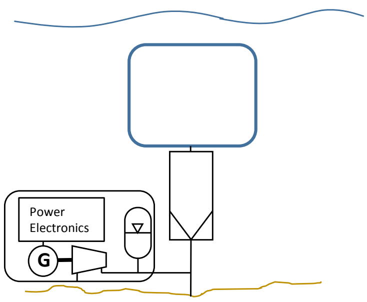
- The project was shorter than usual due to a late starting date. To keep the momentum, the project team had weekly project update meetings. The shorter period than planned limited the range of testing that was completed in the project, so testing was focussed on validating the key assumptions made in WP2, WP3 and WP4. This provided valuable system and component design feedback.
- There was not enough time allocated between milestones which put significant pressures on the team to keep the project on time. Future phases of the work need to better space the deliverable to allow for unforeseen minor delays. The number of deliverables was also quite large for such a short project and could also be reasonably reduced, resulting in fewer, but more substantial reports.
- Both the simulation work and the testing struggled with balancing the allocated time between building their tools (model and rig) and using the tools to undertake the research. More time would have helped with this and as would tighter management of these aspects of the projects. Future projects should allow more time for these tasks and clearly separate the build stages (with a working tool as a deliverable) from the research stages where the tool is used to answer the key questions it was designed for.

1.5 Applicability to WEC Device Types

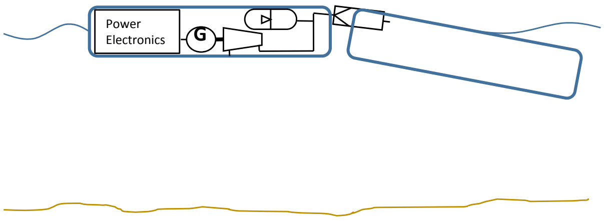
The Gator PTO can be applied to (at least) attenuators, point absorbers, oscillating wave surge converters and submerged pressure differential devices. Typical forces / torques and velocities for these device types have been assessed and used to drive the requirements for the PTO system. Some conceptual arrangements of PTOs within different WEC types are shown in figure below.



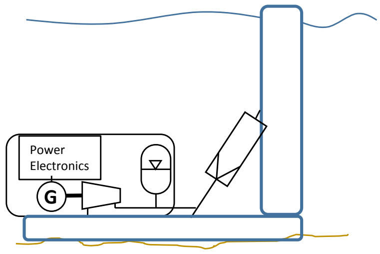
GATOR PTO located in Point Absorber or Submerged Pressure Differential device



GATOR PTO adjacent to Point Absorber or Submerged Pressure Differential device



GATOR PTO with attenuator WEC



GATOR PTO with Oscillating Wave Surge Converter

In terms of physical integration, a buoy is the easiest WEC / Gator system to envisage. Here the Gator can also act as the tether for the device, providing this functionality in addition to being the PTO.

1.6 Summary of Performance against Target Outcome Metrics

Table 1: Comparison of expected target outcomes versus actual project outcomes

Metric	Expected Target Outcome (Qualitative)	Actual Project Outcome (Quantitative)
Affordability	Lower than conventional PTOs. Show that Gator spring pump has lower CAPEX and OPEX than equivalent rating cylinder.	Gator PTO system significantly lowers LCOE as compared to a conventional PTO. Both CAPEX and OPEX are much lower compared to the baseline costs.
Performance	Show that performance is suitable for different WEC concepts, delivering flow rates at pressures which deliver power generation levels supportive of low LCOE.	Simulation shows that the PTO system can be designed to provide good efficiencies. One caveat is that it is yet unknown how the spring pump will interact with the WEC.
Availability	Show that reliability is high in comparison with conventional technology. MBTF, fatigue and lifetime.	Lifetime of the polymer spring is expected to be high. Testing of material creep is deemed insignificant and will not be a limiting factor on the lifetime.
Survivability	Show no end stop problem and ability to load shed in a designed and engineered manner.	Unlike in the conventional PTO system, in the spring pump, the stiffness of the spring contributes to the force applied by the PTO on

		the WEC. This force is not extracted or lost, but rather temporarily stored in the spring as potential energy.

1.7 Communications and Publicity Activity

The following public activities were undertaken during the project:

- Attended the ICOE conference
- Attended the WES Workshop
- Poster Presentation for WES Workshop

1.8 Recommendations for Further Work

The project team is preparing a Stage 2 application.