Testing and Expertise for Marine Energy (TEAMER) Program Support - Numerical Modeling Assistance for iProTech's "PIP" WEC Device

Cooperative Research and Development Final Report

CRADA Number: CRD-20-17303

NREL Technical Contact: David Ogden

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Contract No. DE-AC36-08GO28308

Technical Report
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Cooperative Research and Development Final Report

Report Date: April 28, 2022

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: iProTech

CRADA Number: CRD-20-17303

CRADA Title: Testing and Expertise for Marine Energy (TEAMER) Program Support - Numerical Modeling Assistance for iProTech's "PIP" WEC Device

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Water Power Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind	Totals
Year 1	$150,000.00	$154,500.00
TOTALS	$150,000.00	$154,500.00

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<u>Executive Summary of CRADA Work</u>:

Develop a time-domain, 3 degree of freedom numerical model of IProTech's PIP device, including power take-off (PTO), that can be used to develop control algorithms and establish a baseline technology performance level (TPL). This is important to IProTech because having a good numerical model allows IProTech to optimize design and control algorithms on an ongoing basis. A baseline TPL enables the PIP technology to be benchmarked against other wave energy converter (WEC) concepts, providing (i) justification (or not) for investment in wave tank model testing, (ii) identifying optimum design parameters and control algorithms for the test model, (iii) specifying test conditions and (iv) interpreting wave tank test results. An accredited WEC-Sim model of the PIP device is an essential tool for further development of the technology.

1. The development of numerical models of the PIP concept will enable iProTech to evaluate the potential performance of this concept, and to investigate how sensitive the device is to different variables within the system (e.g. hydraulic components, geometry dimensions, etc.)
2. The numerical models were developed with WEC-Sim and PTO-Sim - the de-facto industry standard WEC numerical modeling tools. A detailed model of the system's hydraulic circuit was developed with PTO-Sim. However, WEC-Sim is based on linear hydrodynamics and has several limitations; validation against high fidelity models/physical scale models would help to build confidence in the results.

CRADA benefit to DOE, Participant, and U.S. Taxpayer:

This project supported the development of a novel WEC concept that could eventually be used to supply renewable energy to U.S. electrical grids. The project utilized NREL's expertise in WEC numerical modelling and enabled the exploration of several different design variables in batch simulations. The systems response in regular waves was analyzed and several potential areas of improvement were identified–with some configurations potentially doubling the peak power performance identified in the baseline configuration. Furthermore, resonance frequencies were identified, and several parameters were identified that the system's resonance is sensitive to. These variables could be investigated further to broaden the system's response across several wave periods.

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<u>Summary of Research Results</u>:

The main outcomes of this project can be summarized as:

- Development of meshing scripts in Python to explore the device's geometry and improve its hydrodynamic performance
- Development of Python-based BEM models with the open-source code Capytaine to compute hydrodynamic coefficients (and convergence studies to identify appropriate mesh resolutions)
- Development of 2 time-domain models in WEC-Sim:
    - A simplified model with linearized PTO to rapidly evaluate the performance of different geometry iterations
    - A higher fidelity PTO model including:
        - Incompressible water coil moving inside the device's hull
        - Valve models (with cracking pressure) that open when the pressure from the water coil reaches a certain threshold
        - Hydraulic accumulators and motor to estimate power output
        - Bypass valve to decouple the water coil from the rest of the hydraulic system ("free wheeling") which can be opened and closed; opening up potential research for reinforcement learning (RL) algorithms.

Task 1: Demonstrate/handover existing numerical modelling work (and all relevant device data/required input data) and will provide existing MATLAB script for hydrodynamic mesh.

This task was the responsibility of the partner. Partner successfully transferred all necessary data as required.

The following explanation and data describe Task 2 and Task 3:

Task 2: Developing meshing scripts in Python and compute hydrodynamic coefficients with Nemoh and WAMIT

1. Using MATLAB or Python software, …using the Requestor scripts provided in Task 1 to define the geometry for the Requestors PIP device's hydrodynamic meshes…and create hydrodynamic meshes for two device sizes specified by Requestor.
2. NREL will compute hydrodynamic coefficients by using open-sourced Nemoh and WAMIT (licensed by NREL) boundary element method (BEM) codes. NREL will compare and verify the accuracy of the Nemoh results against WAMIT results. For context, WAMIT is considered the gold-standard of BEM codes and is the acronym for Wave Analysis Massachusetts Institute of Technology but WAMIT has just become the name of the software in its own sense.

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Task 3: Develop a WEC-Sim ‘idealized model’ model of the PTO of Requestor’s PIP device using NREL’s WEC-Sim software.

Geometry functions were developed in Python to define lines and arcs in 3D space, fill in the side of the PIP and extrude it along the y-axis. Cosine spacing was used to refine the mesh at the edges.

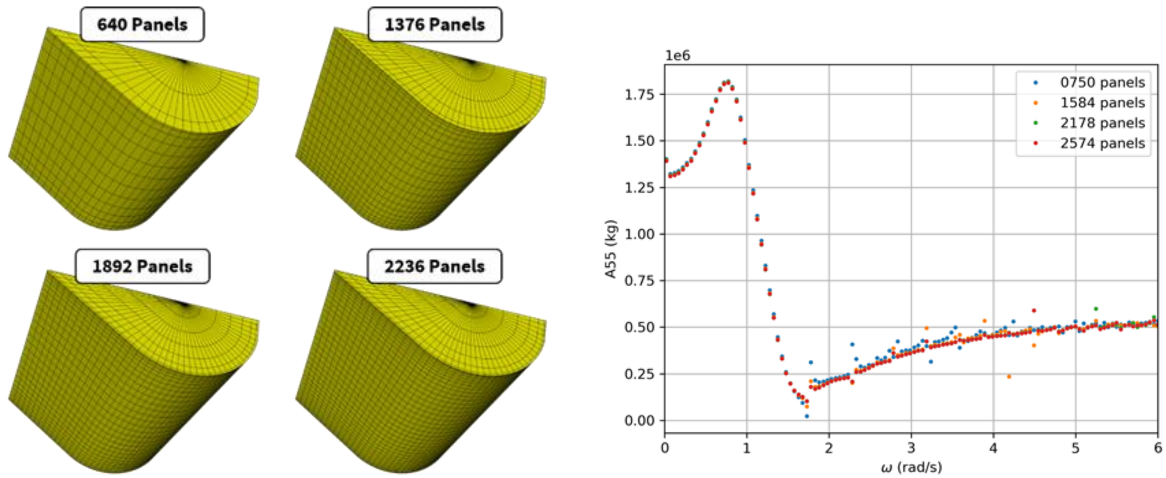

Figure 1. Different resolution PIP hull meshes (generated with custom Python scripts) and corresponding convergence study for added mass in pitch.

WAMIT was used to compute hydrodynamic coefficients for the baseline geometry but Capytaine (a Python-based fork of Nemoh) was used to investigate different geometry iterations as its easier to integrate with the Python-based meshing scripts.

A WEC-Sim model of the device was developed with a simplified, linear PTO (constant stiffness and damping), which can be used to quickly estimate the performance of the system (results from this model shown in Figures 2 and 3).

As iProTech had not previously attempted to optimize the PIP hull geometry these tasks were extended to explore how different geometry changes could influence the performance of the device. **Error! Reference source not found.**Figure 2 demonstrates how modifying the location of the PIP hull profile’s fore circle (which modifies the shape of the PIP hull’s nose) can significantly influence the power response of the device. Similarly, Figure 3 demonstrates how modifying the position of the PIP hull profile’s center circle can also significantly influence the power response of the device. The combination of these parameters should be researched in future work in order to optimize the hull’s geometry and therefore the device’s performance. Furthermore, the precise cause of the double response should be investigated; controlling the phase relationship between the water coil and the hull could lead to a broader response across wave periods.

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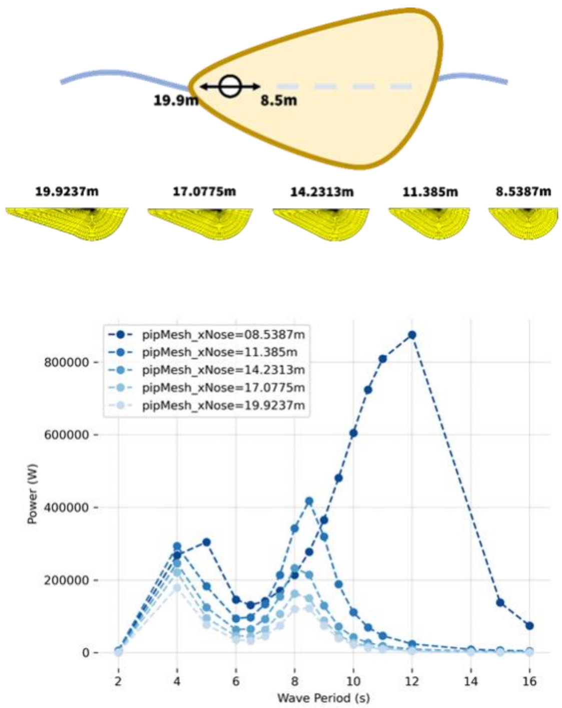

Figure 2. Modifying the PIP's nose shape and assessing the power response of the system (in regular waves).

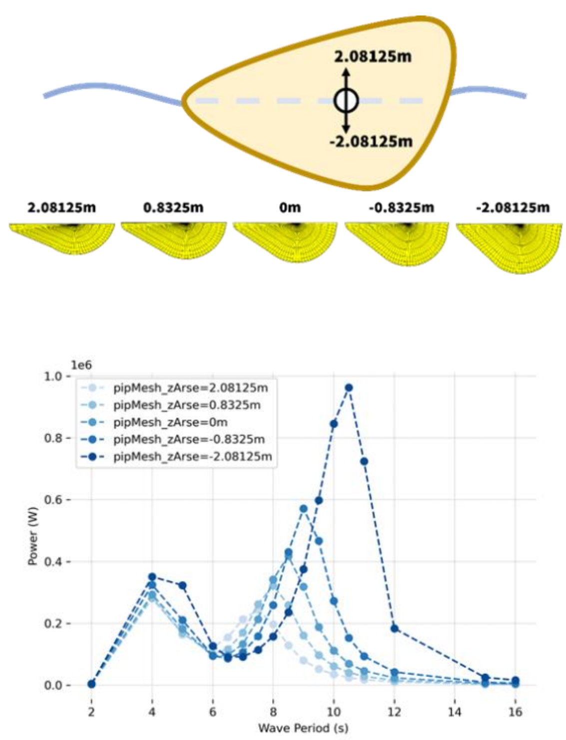

Figure 3. Modifying the position of the PIP's center circle; assessing the power response of the system (in regular waves).

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An overview of the workflow used for geometry investigations is shown in Figure 4.

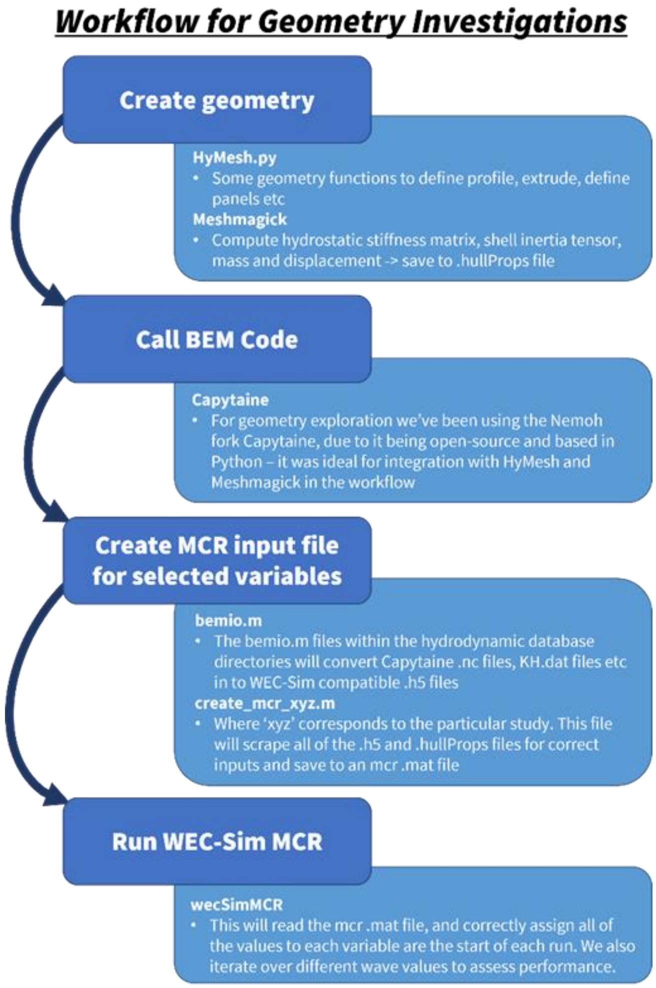

Figure 4. Workflow for geometry investigations.

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Task 4: Increase the WEC-Sim idealized model's complexity to develop a "realistic model" of PTO, starting with the Passive Control Model. If time permits after completion of passive model, NREL will advance to the Active Control Model.

To model the PIP's internal hydraulic system, a PTO-Sim model was developed and incorporated into the WEC-Sim model. This enables us to simulate cracking pressure at the end of the water coil, valves, accumulators and a hydraulic motor.

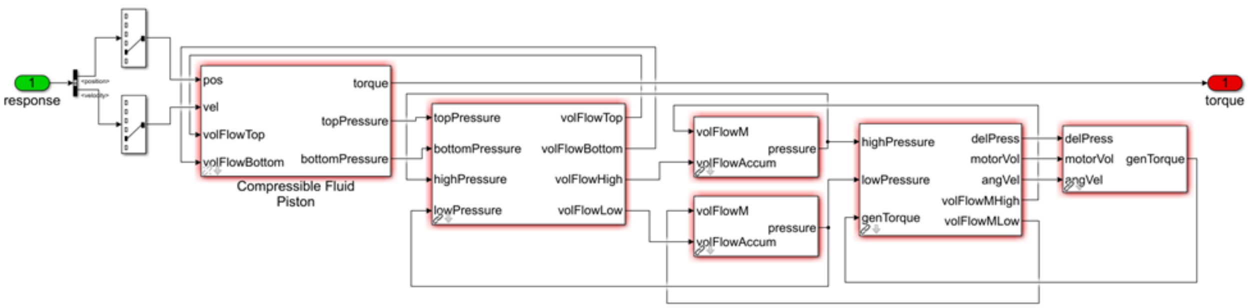

Figure 5. Hydraulic circuit components modelled with PTO-Sim. The 'Compressible Fluid Piston' block has been specifically developed to model the PIP's water coil.

The Compressible Fluid Piston block is shown in more detail in Figure 6, with blocks to compute the pressure on the main valves at each end of the coil, friction and other relevant forces on the water coil, and to compute the correct force on the hull when water is flowing out of the coil.

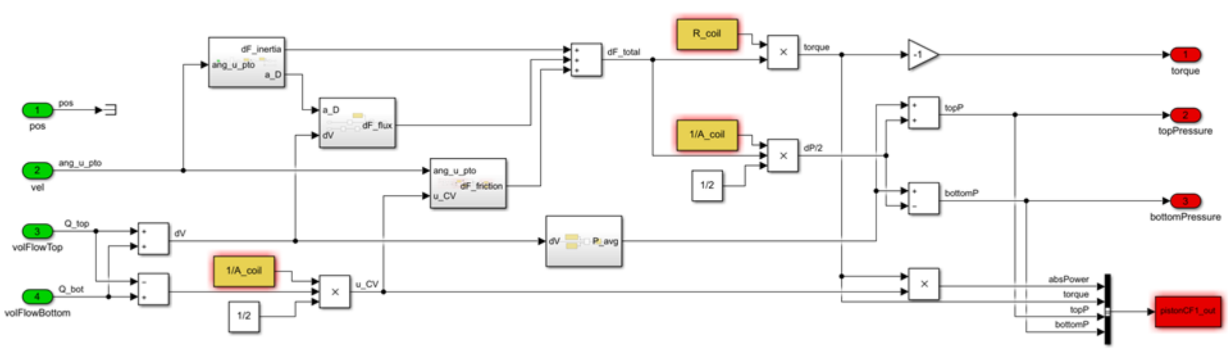

Figure 6. Compressible fluid piston block, representing the PIP's water coil.

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Results of the PTO-Sim model were compared with the linear PTO model for several damping coefficients (Figure 7).

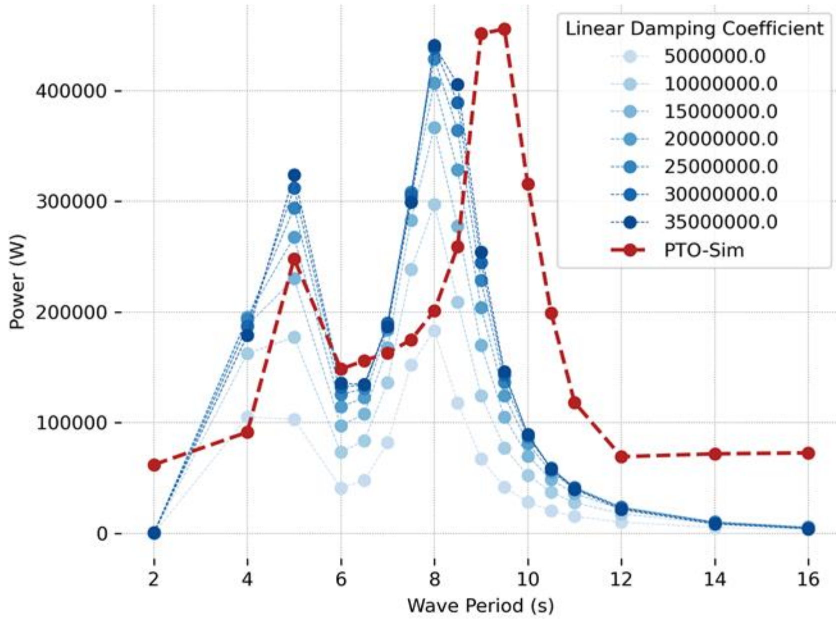

Figure 7. Comparison of PTO-Sim results with linear PTO model results for various damping coefficients.

Given the significantly different modelling approaches between the PTO-Sim model compared to just using a constant damping coefficient, the agreement between models is quite good - with both resonance peaks being captured by both models. This suggests that understanding the phase relationship between the motion of the two bodies is critical and controlling this could lead to a broader banded response, improving the system's performance over a wider range of sea states.

The first peak is seen around 5s for both models, with the PTO-Sim result corresponding to a linear damping coefficient of around 15-20e6 Ns/m. The second peak is slightly off–the PTO-Sim peak is around 9.25s, versus around 8.25s for the linear PTO model. It's not clear why exactly the more complex PTO model would shift the second resonance peak toward higher periods, but it could be due to the two bodies moving 'in-sync' up to the point at which the valve cracking pressure is reached. In other words, until the pressure on the water coil's valve is great enough to cause it to open, the water coil is locked with the hull and there is no relative motion. This could result in different inertial properties compared to the linear damping case, where the two bodies are in constant relative motion.

The final part of this task was to develop a way to control the hydraulic circuit, principally by decoupling the water coil from the rest of the hydraulic circuit and opening the valves independent of cracking pressure. The principle of this is demonstrated with a switch that decouples the water coil (Figure 8). At the moment this is just triggered at pre-determined time intervals, but we were able to demonstrate stable results. Further work is required to develop a fully-fledged RL-based controller, but the current model does provide a platform for iProTech to research RL algorithms where this valve action is considered in the action space.

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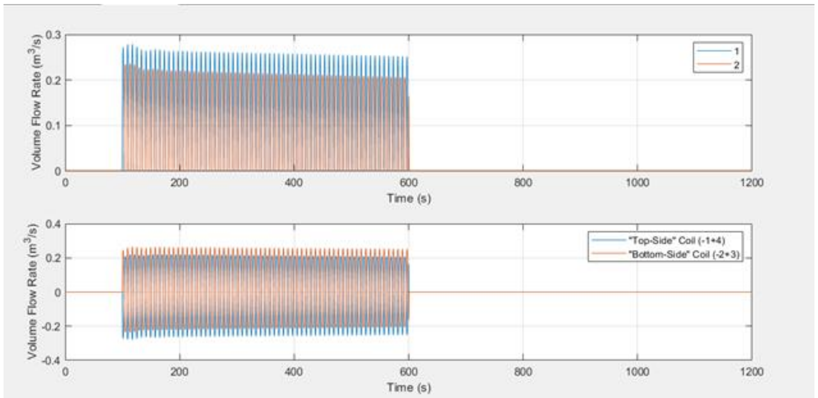

Figure 8. Demonstration of decoupling/recoupling of water coil from the rest of the hydraulic circuit.

Task 5:

This final report meets the requirement for this task.

<u>Subject Inventions Listing</u>:

None

<u>ROI #</u>:

None

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