Azura Full-Scale Design

2018

Test Plan for Wave Tank Testing Fall 2017

Northwest Energy Innovations

3/5/2018

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1. INTRODUCTION

This document describes wave tank tests that will be performed on a 1:15 scale model of the commercial scale Azura wave energy converter in the fall of 2017. These tests will be performed at the Harold Alfond W2 Ocean Engineering Laboratory at the University of Maine - Orono (UMO). The primary objective of these tests will be to collect data that will use to predict full-scale device performance at the U.S. Navy's Wave Energy Test Site (WETS) near Kaneohe Bay, Hawaii. These tests follow earlier wave tank tests that NWEI performed at the UMO facility in April 2017 using an earlier version of its design. During those tests a limited number of broadband irregular wave cases were run to validate NWEI's WEC-Sim simulation model of its design; that simulation model has since been used to optimize performance of the current Azura design.

2. OBJECTIVES

1. Record data in a single broadband irregular wave case that can be analyzed to produce experimental Relative Capture Width (RCW) and Response Amplitude Operators (RAOs) with respect to wave frequency for the scale model of the Azura preliminary full-scale design. The resulting RCW and RAOs will be used to confirm validity of the NWEI WEC-Sim model of the full-scale design.
2. Collect data in irregular waves that can be used to predict full-scale device performance at the U.S. Navy's Wave Energy Test Site (WETS) near Kaneohe, Hawaii.

3. TEST ARTICLE

The test article will be a 1:15 scale model of the NWEI full-scale device. See Figure 3-1 for a CAD rendering of this model. This tank model is described in detail in the NWEI document "Wave Tank Model Specification", which is included in Appendix A of this document.

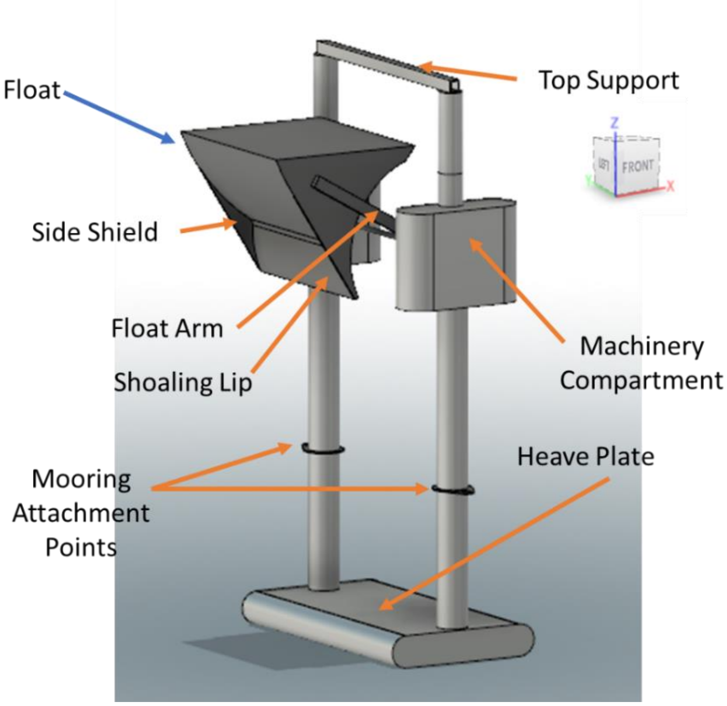


Figure 3-1 Rendering of NWEI tank model

4. TEST FACILITIES

Testing will be performed at the Harold Alfond W^2 Ocean Engineering Laboratory at the University of Maine Advanced Structures and Composites Center in Orono, Maine. Basic information about this facility is described below; further information is provided at the following web site: https://composites.umaine.edu/key-services/offshore-model-testing/.

Table 4-1 Harold Alfond W^2 Ocean Engineering Laboratory details

Length	30 m
Width	9 m
Max depth	4.5 m
Wave period range	0.5-5 s
Max wave height	0.8 m

This facility is equipped with a high-performance rotating wind machine over a wave basin. The wave basin has a 16-paddle wave generator at one end, a beach at the other end, and an adjustable floor.

5. SCHEDULE

NWEI has budgeted for seven days of wave tank calibration followed by nine days of test setup, wave tank testing, and removal. The expected timeline for these tests is shown in Figure 5-1. Three days is allocated for tank model setup after tank calibration is complete, followed by five days of tank testing and a day to remove the setup. Tank model setup includes instrumentation and data acquisition setup, testing, and troubleshooting, and running test wave cases to verify correct operation. Center of gravity and moment of inertia tests will be concurrent with the tank model setup. Hydrostatic tests to verify waterline and tilt of the tank model float and hull will be conducted prior outside the wave tank, prior to these tests.

One day is included in the schedule for extreme wave testing. Extreme wave testing is an option to be decided on as budgets are established.

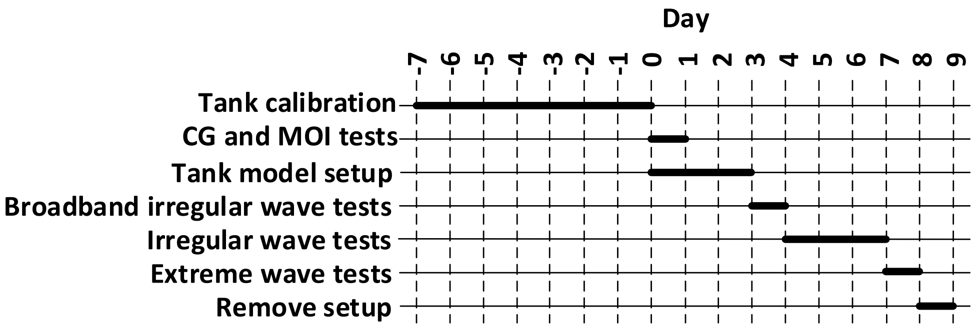


Figure 5-1 Timeline for Azura Fall 2017 wave tank tests

6. TEST SETUP

The tests setups described in the following subsections will be used for the test procedures described in Section 7.

6.1. Tank depth

The tank depth will be set to 4.5 m for these tests.

6.2. Mooring configuration

A single point mooring system will be used for these tests. Figure 6-2, Figure 6-3, and Figure 6-4 show the mooring layout. The model will be centered in the width of the tank and 12.5m from the wave maker as shown in Figure 6-1. The mooring attachment points on the tank model will be positioned vertically within the “mooring attachment zone” shown in Figure 6-3 so that mooring lines are horizontal while the device is floating statically at still water line. This mooring system successfully provided self-orientation of the tank model during NWEI’s April 2017 tank tests so that the float was always parallel to incoming unidirectional seas.

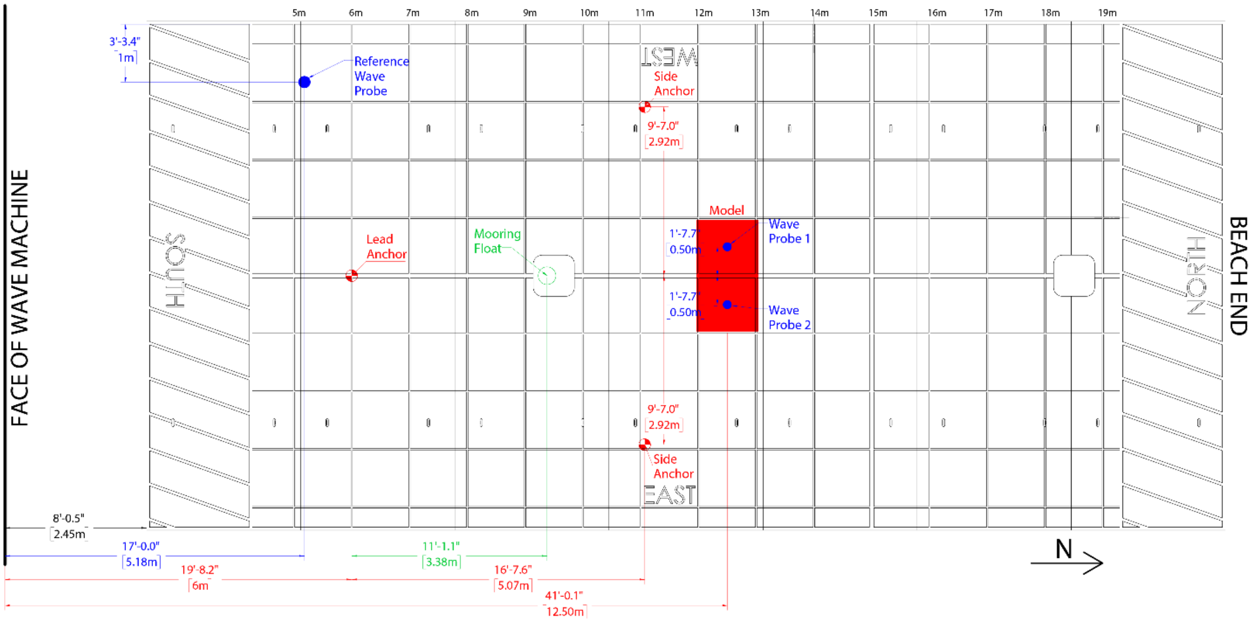


Figure 6-1 Mooring and Model Layout in W2 Basin

6.1. Anchor weights

The anchor weights shall be 500 lb or greater for the anchor in line with the wave direction and 200 lb or greater for the two side anchors.

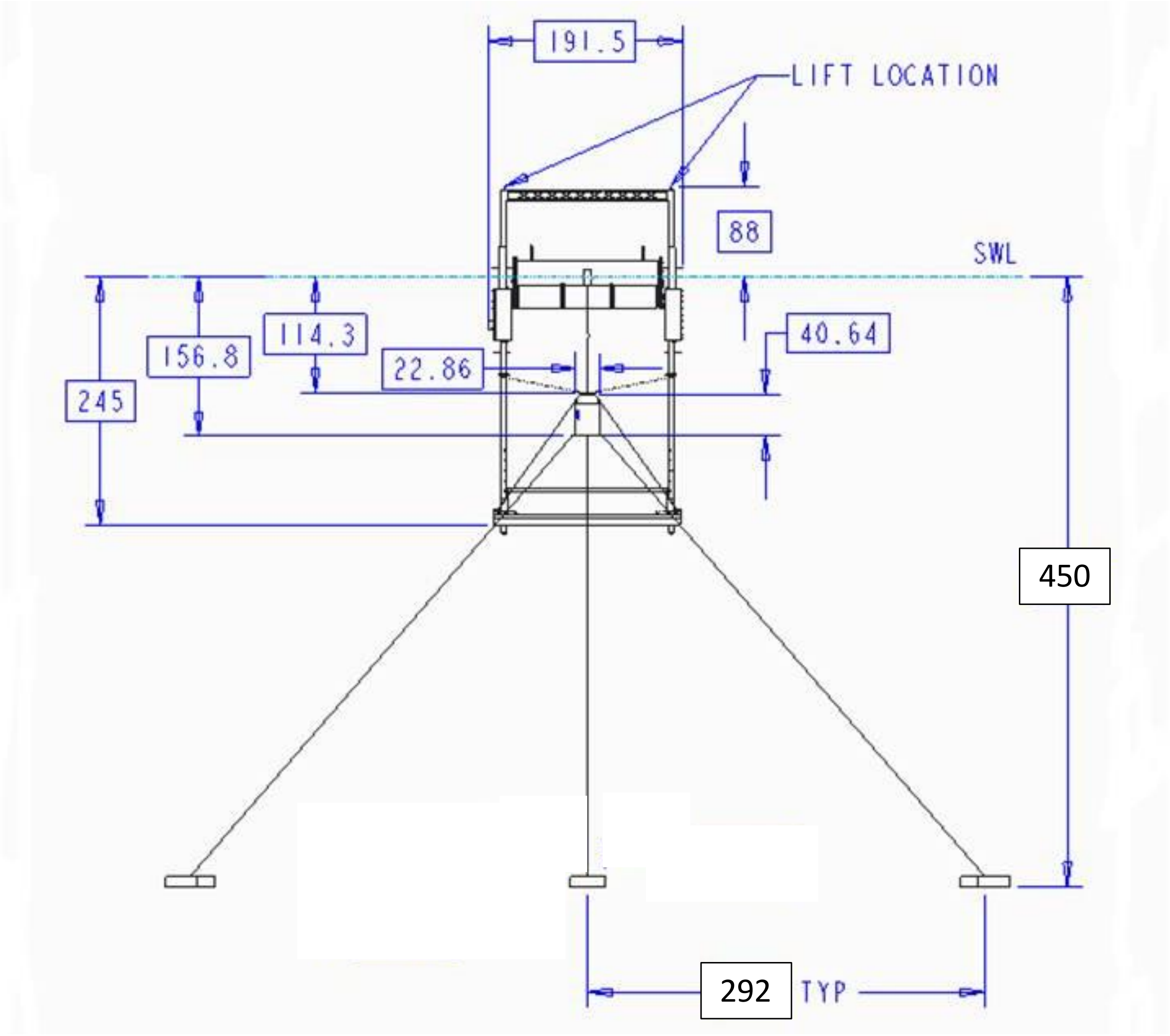


Figure 6-2 Mooring diagram – view from wave generator end (preliminary)

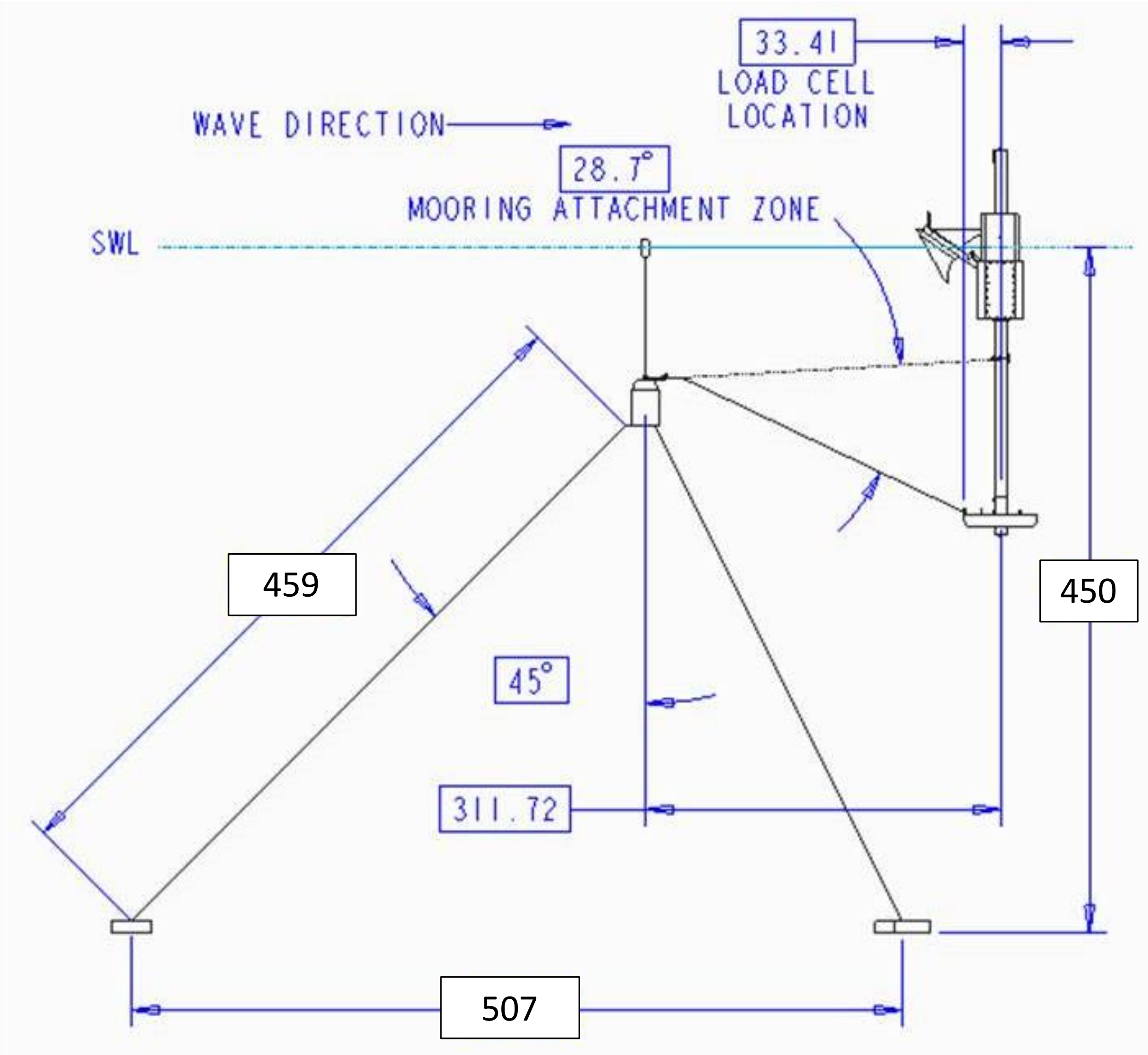


Figure 6-3 Mooring diagram – side view (preliminary)

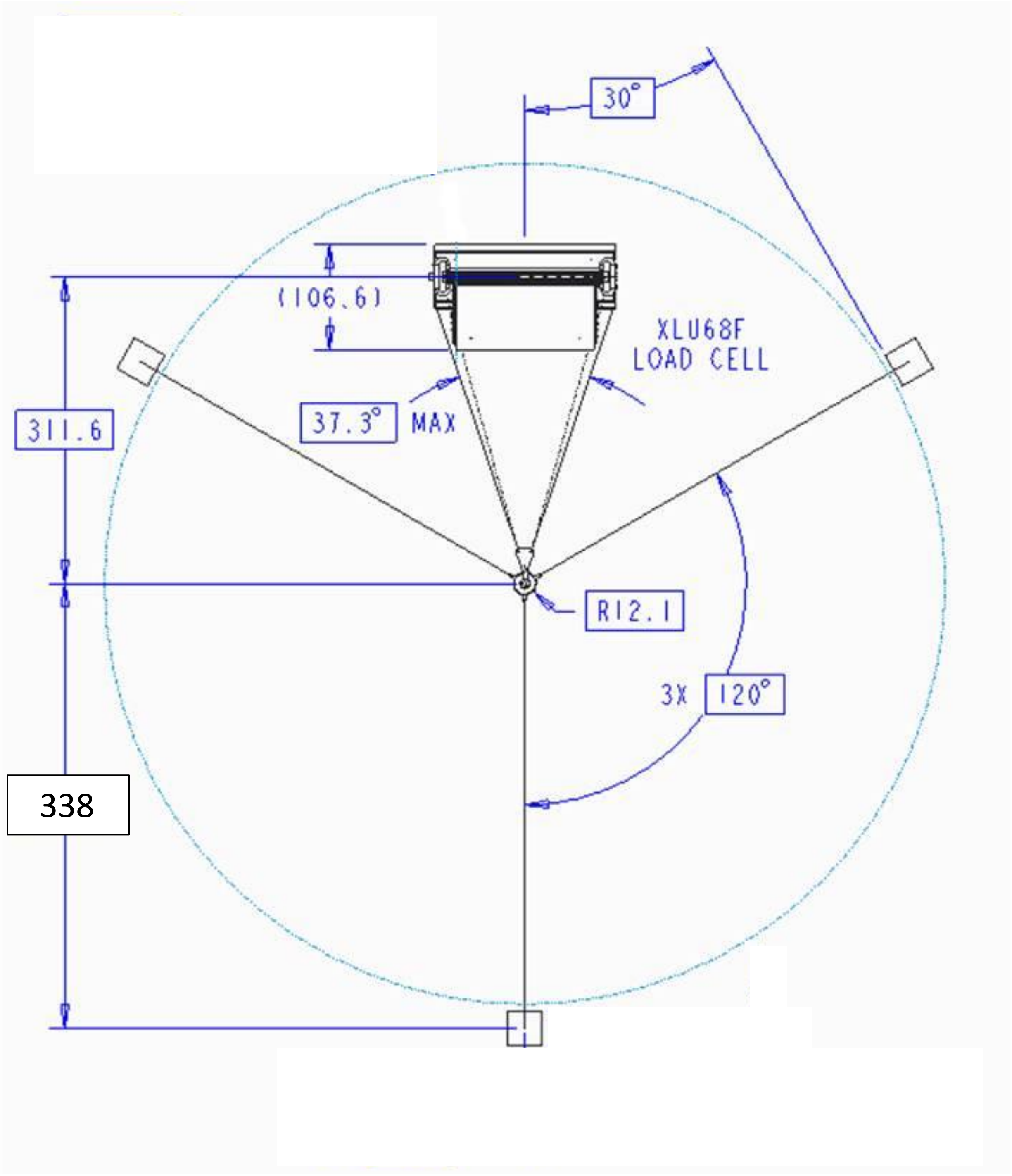


Figure 6-4 Mooring diagram – overhead view (preliminary)

6.2. Wave probe

One wave probe will be provided by the test facility to measure wave elevation at a location shown in Figure 6-1, between the device and the wave generator, during irregular wave tests. This wave probe will interface with the test facility DAS per Section 6.3.

6.3. Data acquisition

Three separate data systems will be used for this test:

1. A NWEI Speedgoat controller will be used to collect float arm torque, speed, and angle data. The data sampling rate will be 250 Hz. This controller will also include control algorithms that will produce the torque command for the motor drives that interface with the PTO generators.
2. Wave probe data will be recorded by UMO at a sampling rate of 128 Hz.
3. Motion tracking data will be recorded by UMO at a sampling rate of 100 Hz.

In addition, NWEI will use a National Instruments CompactRIO (cRIO) controller to interface with the torque sensing load cells and the generator encoders in the PTO tank model. The cRIO controller will include strain gage and encoder input modules for this purpose. The cRIO controller will provide real-time analog outputs for float arm torque, speed, and angle that will be input to the NWEI Speedgoat controller. Data will be recorded by the Speedgoat controller and not the cRIO; the cRIO will be used to reduce processing on board the Speedgoat controller and to eliminate the need for Speedgoat encoder and strain gage input modules.

A common time synch signal that will transition high at the beginning of each test run and transition back low at the end of the test runs will be recorded by each data system during the test.

A list of data acquisition channels that will be recorded during the test is shown in Table 6-1, and a diagram of the NWEI Speedgoat and cRIO controllers is shown in Figure 6-5. Additional hydraulic simulated signals recorded during the hardware in the loop tests are shown in Table 6-2. Recorded hydraulic simulation signals from hardware in the loop tests.Table 6-2.

Table 6-1 Data Acquisition Channel List

Measurement	Sensor PN	Sensor Mfr	DAS	Notes
Float arm 1 torque	NA	NA	NWEI Speedgoat	Custom Strain Gages on motor drive shafts.
Float arm 1 torque				
Shaft angle	TBD	TBD	NWEI Speedgoat	Encoders interface with cRIO digital input module; encoder on one side monitored and other is a spare
Shaft speed				
PTO control setting	NA	NA	NWEI Speedgoat	Damping or simulated hydraulic pressure setting; produced by Speedgoat
Motor Current 1	AB50A100	Advanced Motion Controls	NWEI Speedgoat	Motor current sense from motor drive
Motor Current 2	AB50A100	Advanced Motion Controls	NWEI Speedgoat	Motor current sense from motor drive
Port Water Alarm			NWEI Speedgoat	Water intrusion alarm
Stbd Water Alarm			NWEI Speedgoat	Water intrusion alarm

Measurement	Sensor PN	Sensor Mfr	DAS	Notes
Wave elevation		Edinburgh Designs	Test facility DAS	Resistance based wave probes
Wavemaker Enable	NA		NWEI Speedgoat and Test Facility DAS	The signal that enables the wavemaker. This signal was recorded across both DAS for time syncing of data files.
Surge pos. hull	Test facility Qualisys motion tracking system		Test facility DAS	
Sway pos. hull				
Heave pos. hull				
Roll pos. hull				
Pitch pos. hull				
Yaw pos. hull				
Surge pos. float				
Sway pos. float				
Heave pos. float				
Roll pos. float				
Pitch pos. float				
Yaw pos. float				

Table 6-2. Recorded hydraulic simulation signals from hardware in the loop tests.

Measurement	Notes
Hydraulic Pressure	Pressure drop across motor
Hydraulic Motor Speed	
Hydraulic Motor Displacement	
Cylinder pressure	Absolute pressure in hydraulic cylinders
Hydraulic flow	Volumetric flow from cylinders
Hydraulic motor power	Power absorbed by hydraulic motor

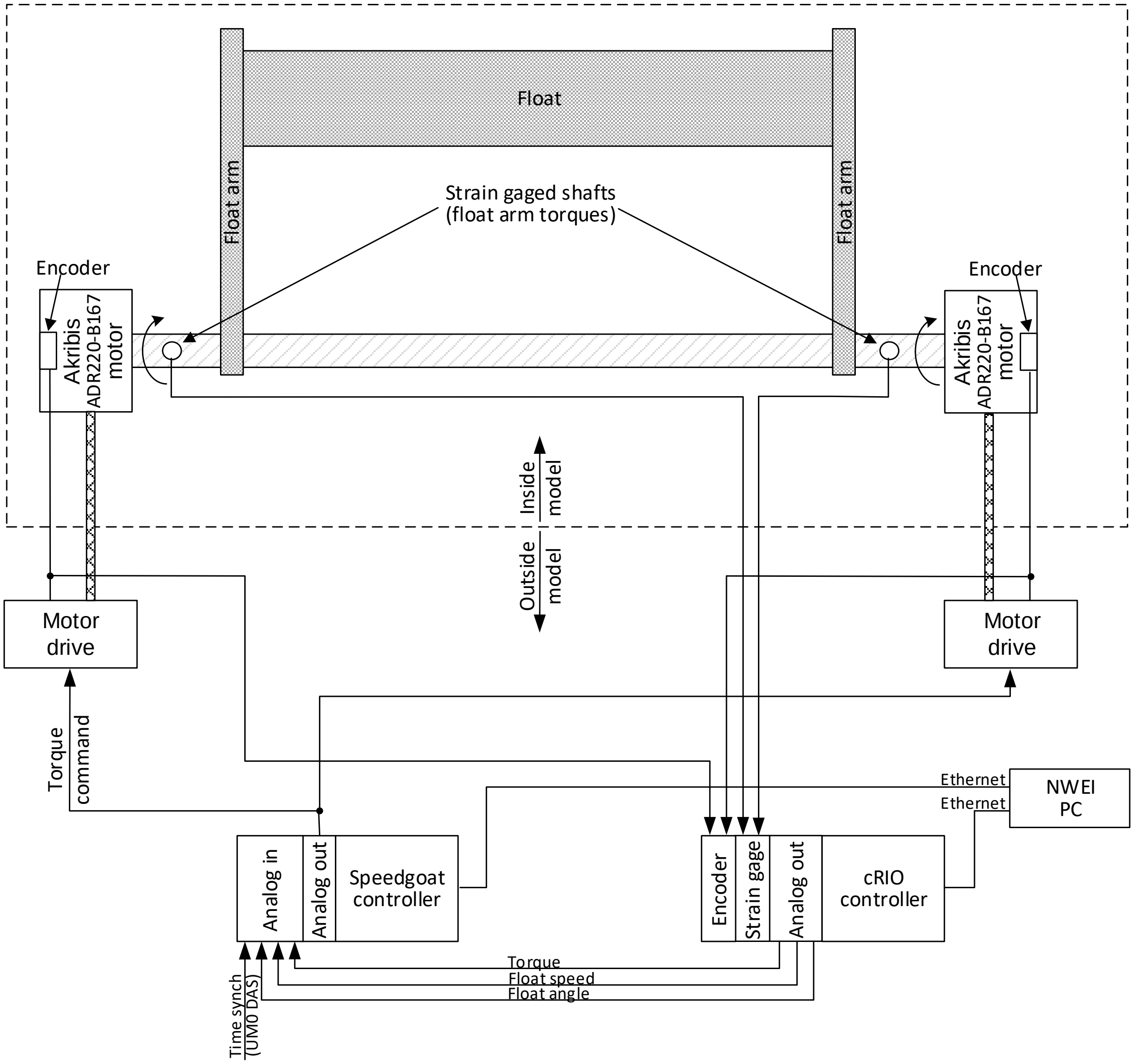


Figure 6-5 Data acquisition and tank model control for NWEI tank test

6.4. Tank model float arm torque control

Torque will be applied to the tank model float by two direct-drive permanent magnet generators that will be driven by two regenerative pulse width modulated (PWM) motor drives (see Figure 6-5). The two motor drives will be configured to control generator torques per an analog torque command from the Speedgoat controller. Equal torques will be commanded in the two PTO generators. The Speedgoat controller will be capable of providing torque commands in two alternate control modes: 1) constant damping control where torque is equal to the float speed multiplied by a damping constant, and 2) simulated hydraulic control using a hardware-in-the-loop simulation of a passively controlled hydraulic system.

7. TEST PROCEDURES

7.1. Mass measurement

The mass of the device will be measured by weighing the unit on the test facility scale. The scale has a 900kg capacity (2,000lb) and graduations of 0.2kg (0.5lb). This measurement will be made by facility staff.

7.2. Center of Gravity Measurement

The CG will be measured by test facility staff using methods outlined below.

The CG for the model will be calculated using a modified string method for irregular shape bodies. The model will be suspended using a single reflective cable and its attitude measured with the Qualisys motion tracking system to calculate the vector passing through the body's CG. The body will be hung from a different pick point for each of the three tests in order to measure the three coordinate dimensions of the CG. During each test, the Qualisys system will acquire the position of the cable and the body. Using an in-house numerical routine, the location of the cable and body will be translated and rotated to the body's local coordinate system. As shown in Figure 7-1, the CG is then defined as the intersection of the projected vectors.

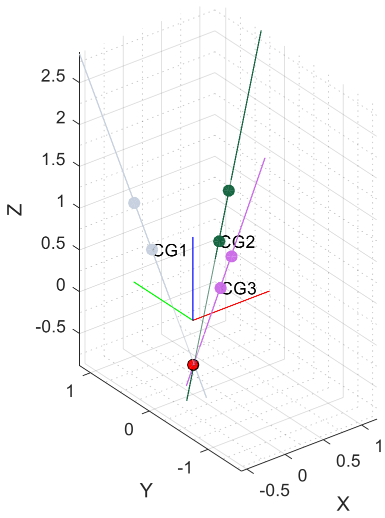


Figure 7-1: Lines are projected with respect to the part to find the center of gravity.

7.3. Moment of inertia measurement

The MOI will be measured by test facility staff using methods outlined below.

The method used to measure the system MOI about the pitch axis will be pendulum testing. In the pendulum test, the body will be hung from a cable running through the calculated CG and swung at small angles. Position data from the Qualisys tracking system will be used to measure the natural period. Then, the body inertia will be calculated using the natural period definition per Equation 1

$$T = 2\pi\sqrt{\frac{l}{g} + \frac{I_A}{mgl}}$$

Equation 1

where T is the period, l is the length of the cable to the center of gravity, g is the gravity constant, m is the mass of the object, and I_A is the MOI. Solving for I_A, Equation 2 is used to directly calculate the MOI.

$$I_A = mgl\left(\frac{T}{2\pi}\right)^2 - ml^2$$

Equation 2

7.4. Wave tank calibration

Wave tank calibration will be performed by facility staff before the tank model is installed in the wave tank. Two wave probes will be positioned at the location of the future tank model. Calibrations will be done for the target wave spectra described in Sections 7.5, 7.6, and 7.7, with random phases of each sinusoid used to reconstruct the wave field. Calibrations will be done with the repeat periods of the wave elevation time series listed in Table 7-1. Surface elevation measurements made with the wave probes for the final calibration spectra will be recorded for use during NWEI data analysis. The same wave generator settings established during these calibrations will be used to run each wave case during NWEI model testing per the procedures described in Sections 7.5, 7.6, and 7.7.

Table 7-1 Repeat periods of wave elevation time series

Wave cases	Reference for spectra	Repeat period
Broadband	Figure 7-2	15 min
Irregular	Table 7-3	15 min
Extreme event	Table 7-4	1000 waves

7.5. Broadband wave test

Testing will be performed with the single broadband wave spectrum shown in Figure 7-2. Testing will be repeated with the tank model PTO control configured with each of the three damping settings listed in Table 7-2 (no testing of hardware-in-the-loop hydraulic control will be performed in broadband waves). The following test sequence will be used for these wave runs

1. Set model damping target setting #1 (this will be done via Speedgoat controller).
2. Start data acquisition systems. Record start time, wave spectra, and damping setting.
3. Start wave generation; wait until tank settles to desired condition (< 1 min).

4. Operate for 30 minutes (two repeat periods with identical wave elevation time series).
5. Stop data acquisition.
6. Repeat steps 1-5 for the remaining target damping settings.

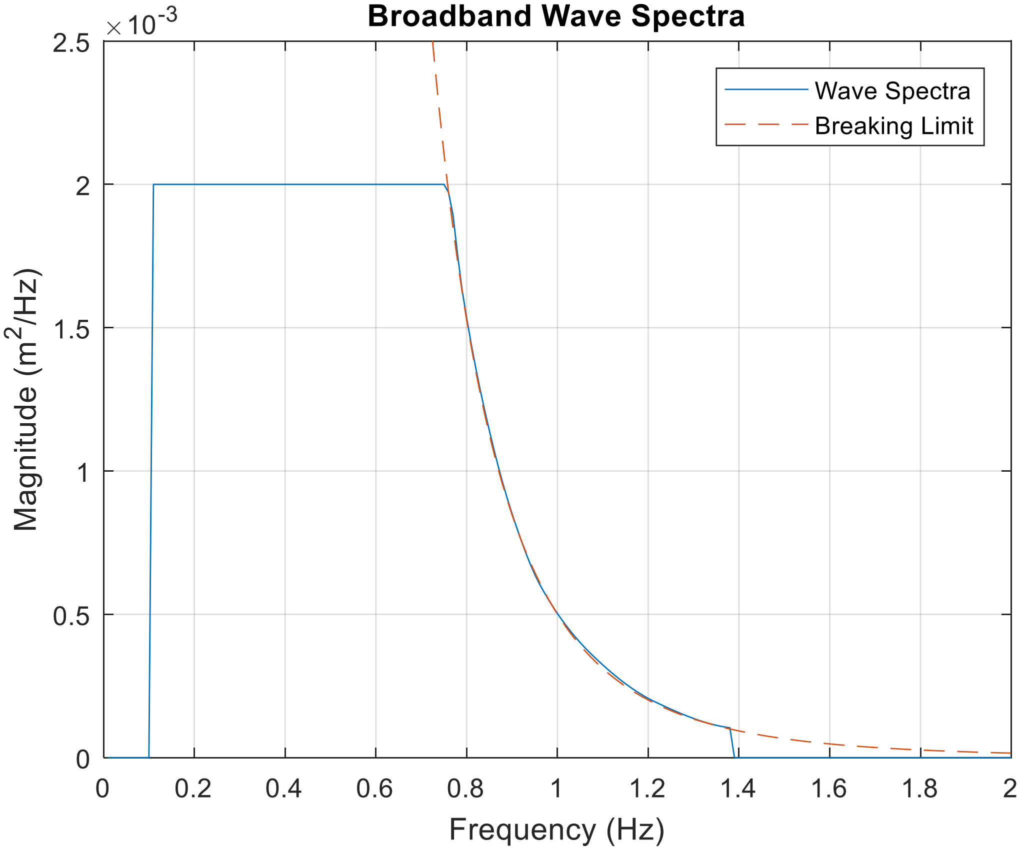


Figure 7-2 Target wave spectrum at tank scale for broadband irregular wave run

Table 7-2 Target damping values for broadband wave tests.

Damping case	Damping value (Nms/rad)
1	200
2	400
3	550
4	700
5	0

7.6. Irregular wave tests

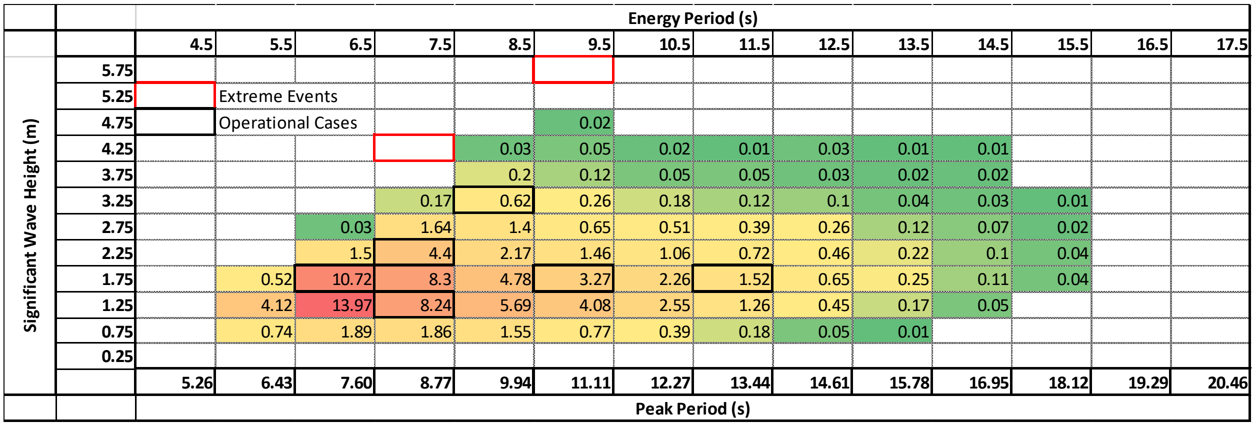
See Table 7-3 for a list of irregular wave cases that will be run. The Azura model will be tested with both ideal damping and simulated hydraulic PTO control during irregular wave tests. A total of six test runs will be performed for each irregular wave case, three with ideal damping and three with simulated hydraulic control. The damping settings used for each test are determined from WEC-Sim simulations predicting the optimal setting for each wave case. Seven of the wave cases will use Bretschneider spectra. Note that $T_p = 1.169 * T_e$ is assumed for Bretschneider wave spectra based on theoretical definition. The final wave case will be empirically derived from typical data recorded at the Kaneohe site with bidirectional seas, which often occur at that site due to a combination of long period swell and shorter period trade wind waves.

Table 7-3 Bulk Wave statistics for Irregular wave runs

Case	Significant Wave Height (m)		Energy Period (s)		Notes
1	1.25	0.083	7.5	1.94	Bretschneider (unidirectional)
2	1.75	0.117	6.5	1.68	Bretschneider (unidirectional)
3	1.75	0.117	9.5	2.45	Bretschneider (unidirectional)
4	2.25	0.150	7.5	1.94	Bretschneider (unidirectional)
5	2.25	0.150	11.5	2.97	Bretschneider (unidirectional)
6	3.25	0.217	8.5	2.19	Bretschneider (unidirectional)
7	2.25	0.150	7.5	1.94	Bretschneider (Spread, cos2S, S = 10)
8	1.75	0.117	9.5	2.45	Specified – Bi-directional from Kaneohe – See Figure 7-4

* Note, values in shaded cells are full scale values, unshaded at tank scale.

The significant wave heights and energy periods for the six unidirectional irregular wave cases listed in Table 7-3 were selected from the WETS 60 m berth (Kaneohe, HI) occurrence matrix provided in the Scandia report *Characterization of US Wave Energy Converter (WEC) Test Sites: A Catalog of Met-Ocean Data*. Performance of the full-scale Azura is being assessed using data from that wave site. Figure 7-3 shows how these six wave cases are distributed within the WETS 60 m occurrence matrix.



Significant Wave Height (m)	Energy Period (s) 4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5
5.75														
5.25		Extreme Events												
4.75		Operational Cases				0.02								
4.25					0.03	0.05	0.02	0.01	0.03	0.01	0.01			
3.75					0.2	0.12	0.05	0.05	0.03	0.02	0.02			
3.25				0.17	0.62	0.26	0.18	0.12	0.1	0.04	0.03	0.01		
2.75			0.03	1.64	1.4	0.65	0.51	0.39	0.26	0.12	0.07	0.02		
2.25			1.5	4.4	2.17	1.46	1.06	0.72	0.46	0.22	0.1	0.04		
1.75		0.52	10.72	8.3	4.78	3.27	2.26	1.52	0.65	0.25	0.11	0.04		
1.25		4.12	13.97	8.24	5.69	4.08	2.55	1.26	0.45	0.17	0.05			
0.75		0.74	1.89	1.86	1.55	0.77	0.39	0.18	0.05	0.01				
0.25														
Peak Period (s)	5.26	6.43	7.60	8.77	9.94	11.11	12.27	13.44	14.61	15.78	16.95	18.12	19.29	20.46

Figure 7-3 WETS 60 m berth (Kaneohe, HI) occurrence matrix with irregular and extreme wave cases highlighted

Wave case 8 is selected to represent a case that sometimes occurs at Kaneohe, where a long period swell and a wind sea both exist, creating a bimodal wave spectra. At Kaneohe, when this occurs the two modes of the spectra typically come from different directions. The specified spectra consists of two standard definitions combined, a Brestschneider spectra with H_{m0} = 0.077 m, Tp = 1.68 s, and a JONSWAP spectra with H_{m0} = 0.089 m, Tp = 3.62 s. The sea state was selected to match an observed sea state at Kaneohe. The angle between the two spectra is 60˚. A plot of the combined spectra, along with each component spectra, is shown in Figure 7-4.

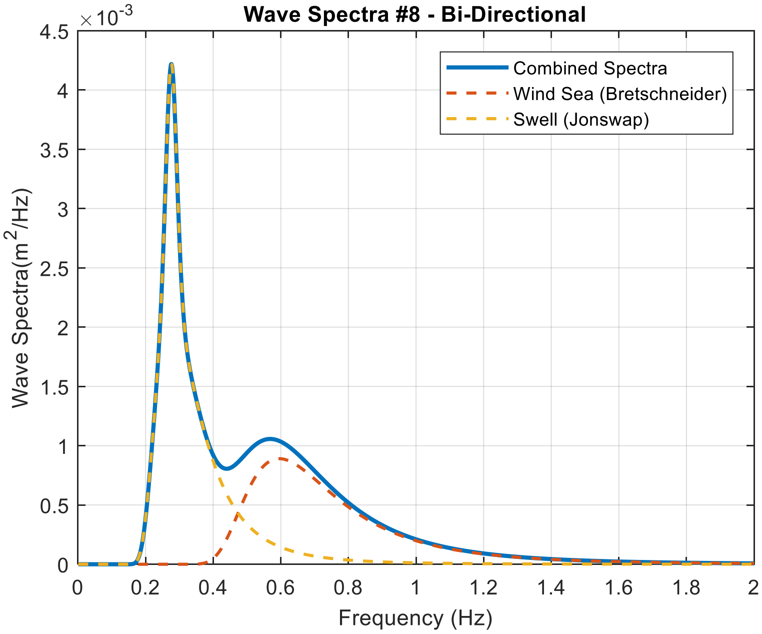


Figure 7-4. Wave case #8, the bimodal, bidirectional sea state.

The following test sequence will be used for the irregular wave runs:

1. Set model damping target setting #1 (this will be done via Speedgoat controller).
2. Start data acquisition systems. Record start time, wave spectra, and damping setting.
3. Start wave generation; wait until tank settles to desired condition (< 1 min).
4. Operate for 15 minutes (a single repeat period of the wave elevation time series).
5. Stop data acquisition.
6. Repeat steps 1-5 for the five remaining wave cases.
7. Repeat steps 1-6 until the damping value resulting in maximum output power is found.
8. Repeat steps 1-6 until the hydraulic PTO setting resulting in maximum output power is found.

7.7. Extreme wave tests

The extreme wave tests described in this section are optional tests that will be decided on as budgets are established.

See Table 7-4 for a list of extreme irregular wave cases that will be run. The Azura model will be tested with two damping values for each extreme irregular wave case (no testing of hardware-in-the-loop hydraulic control will be performed in extreme waves). The damping values for these tests will be determined from the results of irregular wave tests (per Section 7.6) for similar energy periods. For each damping value, extreme wave cases with 1000 waves will be run to simulate a full storm duration. These extreme wave conditions were selected from the WETS 60 m occurrence matrix per Figure 7-3.

Table 7-4 Bulk wave statistics for extreme event testing

Case	Significant Wave Height (m)		Energy Period (s)		Notes
1	4.2	0.28	7.5	1.9	Jonswap (Spread, cos2S, S = 7)
2	5.8	0.39	9.5	2.5	Jonswap (Spread, cos2S, S = 7)

* Note, values in shaded cells are full scale values, unshaded at tank scale

The following test sequence will be used for the extreme wave runs:

1. Set model damping target setting #1 (this will be done via Speedgoat controller).
2. Start data acquisition systems. Record start time, wave spectra, and damping setting.
3. Start wave generation; wait until tank settles to desired condition (< 1 min).
4. Operate for the full 1000 wave elevation time series (roughly 20-60 minutes depending on energy period).
5. Stop data acquisition.
6. Repeat steps 1-5 for the remaining target damping settings.
7. Repeat steps 1-6 for the two remaining wave cases.

APPENDIX A

WAVE TANK MODEL SPECIFICATION

Azura Full-Scale Design

2017

Wave Tank Model Specification

Northwest Energy Innovations

10/24/2017

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1. SCOPE

This specification describes requirements for a wave tank test model of the Northwest Energy Innovation (NWEI) Azura wave energy converter. This model will be used for wave tank testing at University of Maine Advanced Structures and Composites Wave Basin.

2. DESIGN AND MANUFACTURING RESPONSIBILITIES

The selected supplier will be responsible for both the detailed design and build of the wave tank model. NWEI will be responsible for providing the following:

1. A solid works CAD model that includes the outer surfaces of the float and hull.
2. Desired mass properties of the float and hull.
3. Specification, procurement, and system testing of the specific power takeoff (PTO) components listed in Section 4.5, prior to installation by the supplier.
4. Procurement of instrumentation listed in Section 4.6

3. REVIEW OF DESIGN

The detailed wave tank design shall be approved by NWEI before the model manufacturer begins the procurement and manufacturing process. The manufacturer shall supply a complete set of drawings, parts lists, and associated documents to NWEI for review purposes.

4. SPECIFICATIONS

4.1. Hull and float shape

See Figure 4-1 for a 3D rendering of the NWEI tank model, and see Figure 4-2 and Figure 4-3 for diagrams showing basic dimensions. NWEI will provide the selected supplier with CAD files in STEP file format defining the outer surfaces of the hull, float, spars, and heave plate as depicted in Figure 4-1. The pivot point of the PTO is located 0.333 m below the still water line.

Some dimensions can be modified slightly to ease construction. Thin parts of the float, the shoaling lip and the side shields, can be modified. The top support shape does not need to match the CAD model. The float arm dimensions do not need to match the CAD file, they should be designed to meet other requirements listed in the specification. Changes required to the machinery compartment to ensure the PTO system fits inside are permissible. The tube diameters of the spar have been designed to be imperial stock material sizes. Other deviations may be allowed with approval by NWEI.

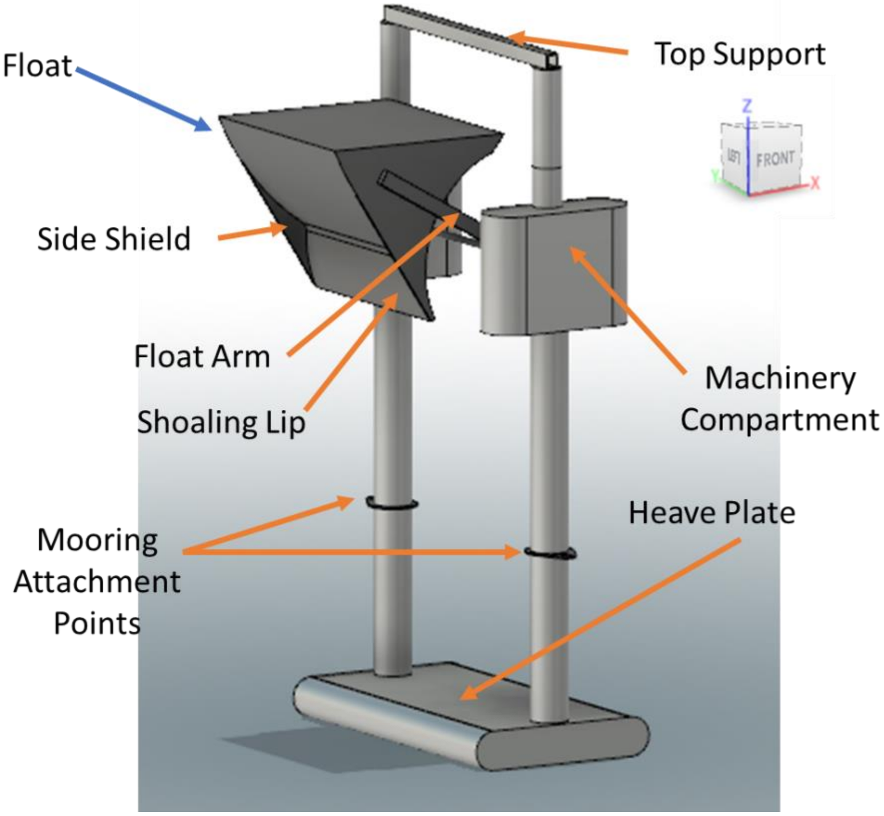


Figure 4-1 Rendering of NWEI tank model

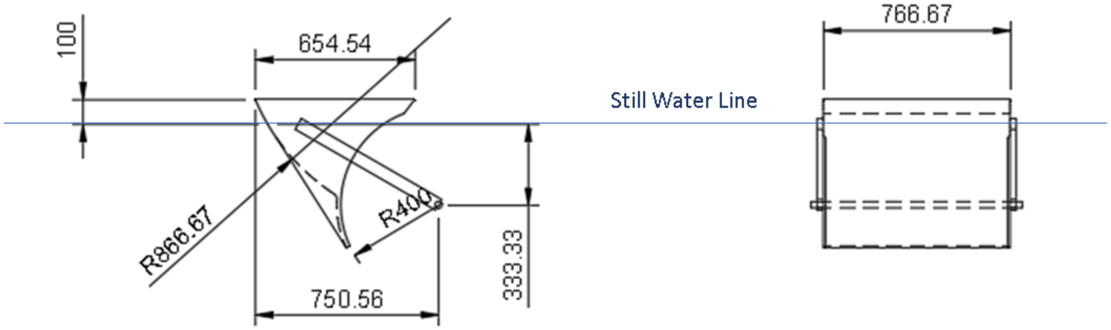


Figure 4-2 Basic dimensions of NWEI wave tank model. All dimensions in millimeters.

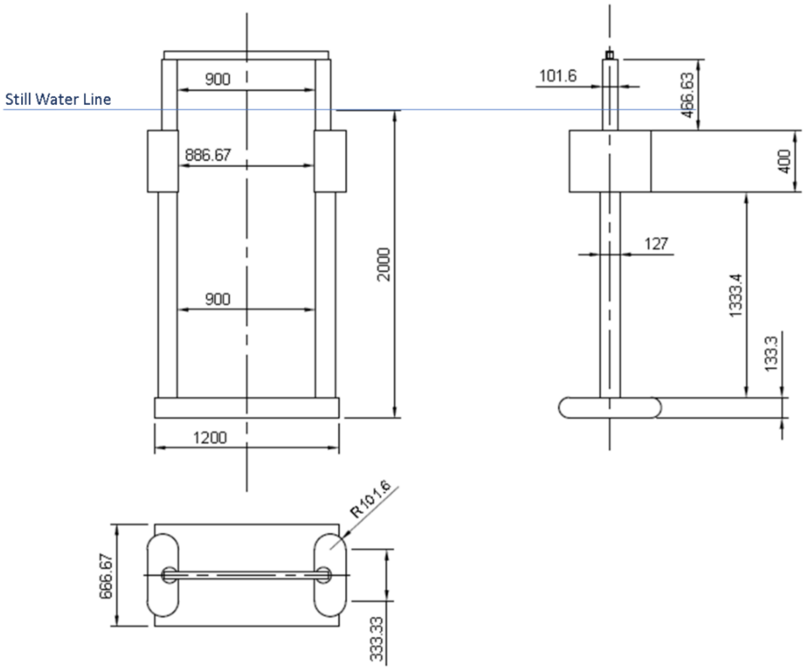


Figure 4-3 Basic dimensions of NWEI wave tank model. All Dimensions in millimeters.

4.2. Hull and float mass properties

The masses, centers of gravity, and moment of inertia around the y-axis for the spar assembly and the float alone shall be within the limits listed in Table 4-1. The three axes are defined in Figure 4-1. The water line and tilt of the completed model shall be verified in still water, and approved by NWEI. The mass moments of inertia will be measured as part of testing. An estimate of the model moments of inertia should be provided prior to testing. The order of priority of these requirements in decreasing priority are, water line, center of gravity, moment of inertia. The tolerances listed in the table reflect this priority order. Note that NWEI has done some preliminary mass estimations to determine their feasibility. Ballast water can be used to achieve the target mass properties.

Table 4-1 Required mass properties. CG Values with respect to Global Coordinate System per CAD files

Mass property	Spar Assembly	Float & arms
Mass	218 kg ± 3 kg[1]	68.6 kg ± 3 kg
CG (x-axis)	0 ± 2 cm[3]	-43.8 cm ± 3 cm[2]
CG (y-axis)	0 ± 2 cm[3]	0 ± 2 cm[3]
CG (z-axis)	-134.7 cm ± 7 cm	-11.5 cm ± 5 cm
I_{yy} about CG	125 ± 35 $kg*m^2$	No Requirement

1. *Tolerance derived from maximum still water line error of 2 cm.*
2. *CG of float should be directly above center of buoyancy.*
3. *will be checked by ensuring model floats within 3° of horizontal*

4.3. Float arm

The NWEI CAD file provided to selected supplier will include the float arm shape depicted in Figure 4-1. The float arm design can be modified depending on the material used. Deflections of the float arms shall be low enough during model testing so that float arm cannot contact the hull. Note that PTO torque is applied equally to the two float axles. The maximum expected operating PTO torque is 250 N-m.

The float arm should be designed stiff enough so that the resonant frequency of the float arm/float combination is the maximum response of the generator torque control loop. We estimate this frequency to be 50 Hz. Note that this frequency is also higher than the maximum cogging torque frequency that will exist in the permanent magnet generators (approximately 8 Hz at 10 rpm generator speed). NWEI will work collaboratively with the supplier to ensure this requirement is met.

4.4. Mooring

The supplier will be responsible for providing the mooring attachment points shown in Figure 4-1. The mooring points must be designed to slide and be clamped to any position along the two spars. The mooring points need to secure small mooring lines such as 1/8” spectra. The remainder of the mooring system beyond the attachment points will be NWEI’s responsibility.

4.5. PTO

The tank model will use the PTO design shown in Figure 4-4. This system uses two brushless generators and a four-quadrant motor drive to provide a controlled torque. Equal torque commands will always be provided to the two generators during model operation. NWEI will be responsible for purchasing the components listed in Table 4-2, bench testing the PTO system using these components prior to installation in the tank model, and providing these components to the tank model supplier. The supplier will be responsible for installing these components in the model including designing all component mounts and procuring any additional components not listed in Table 4-2. After completion of the tank model the complete, installed PTO system will be tested by the supplier at their facilities with the assistance of NWEI.

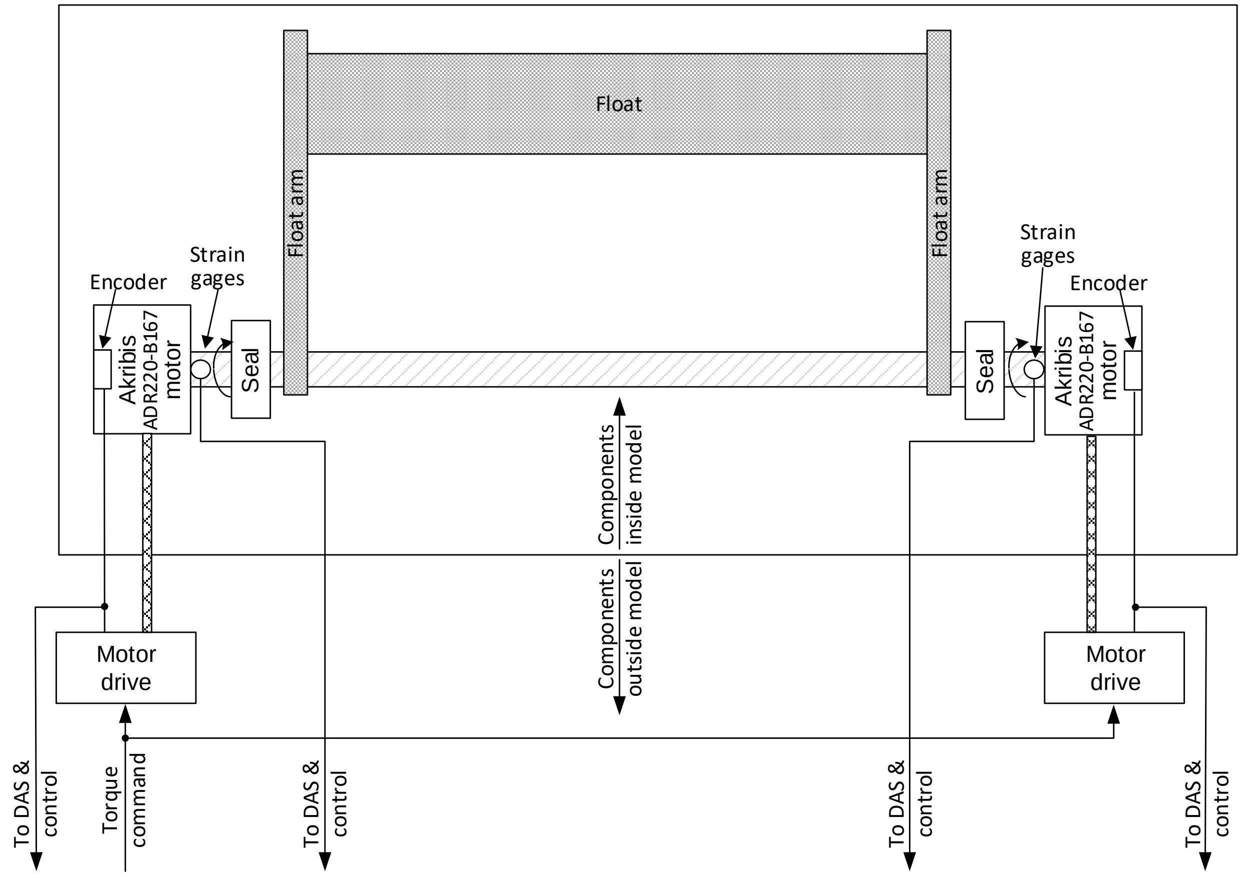


Figure 4-4 Diagram of PTO

Table 4-2 NWEI supplied PTO components

Component	Manufacturer	Part number	Notes
Motor	Akribis	ADR220-B167	Includes encoder, mass 15.6 kg each
Motor drive	TBD	TBD	External to Model

See Figure 4-5 showing the scale of the PTO components listed in Table 4-2 relative to the size of the hull. The hull shall be built with a waterproof access for each motor/generator. Mounting hardware for the motor is not shown in the model. An exploded assembly view of the preliminary PTO design is shown in Figure 4-6.

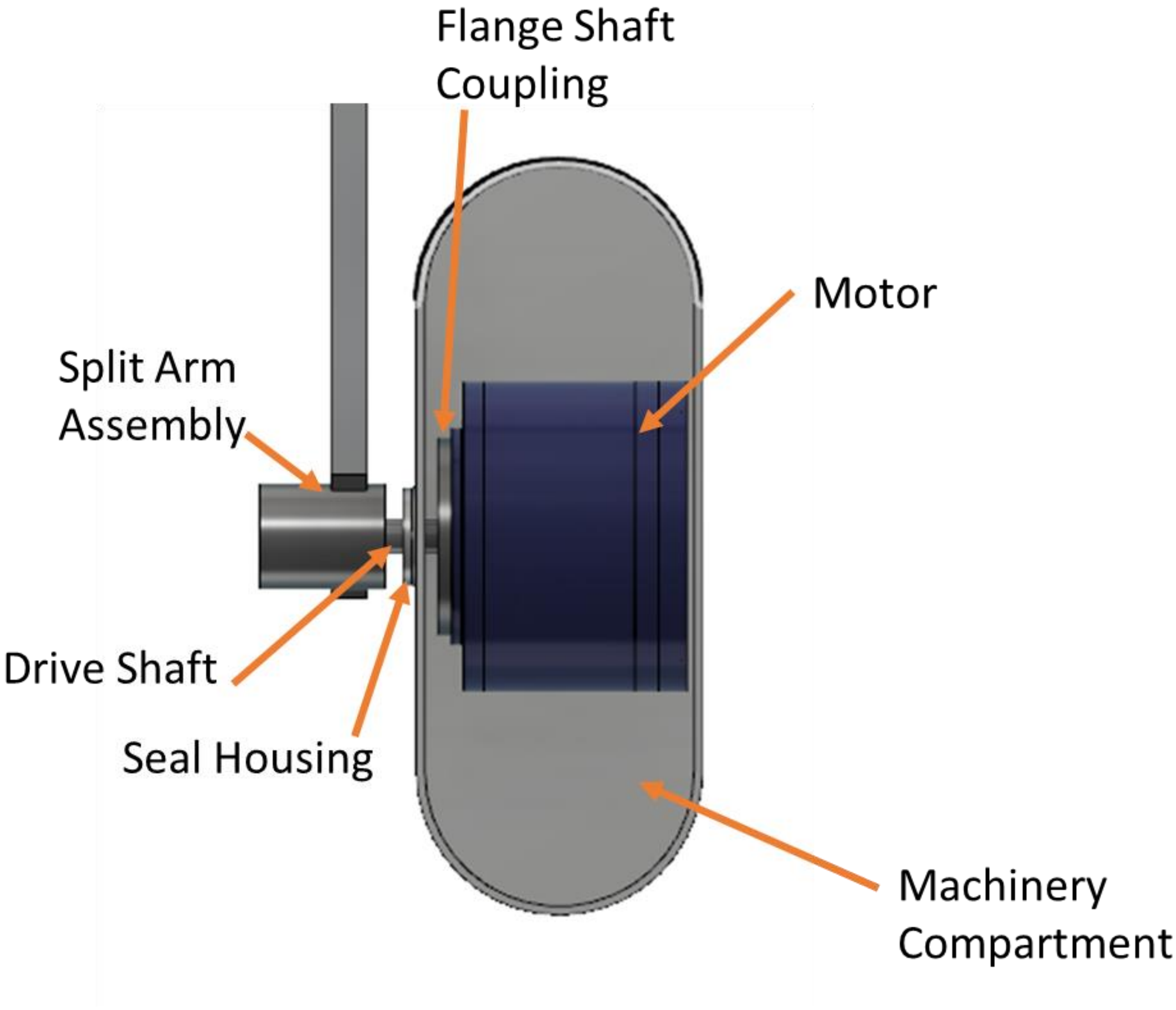


Figure 4-5 Scale of PTO components relative to hull. View is from bottom looking up, with machinery compartment bottom cut away.

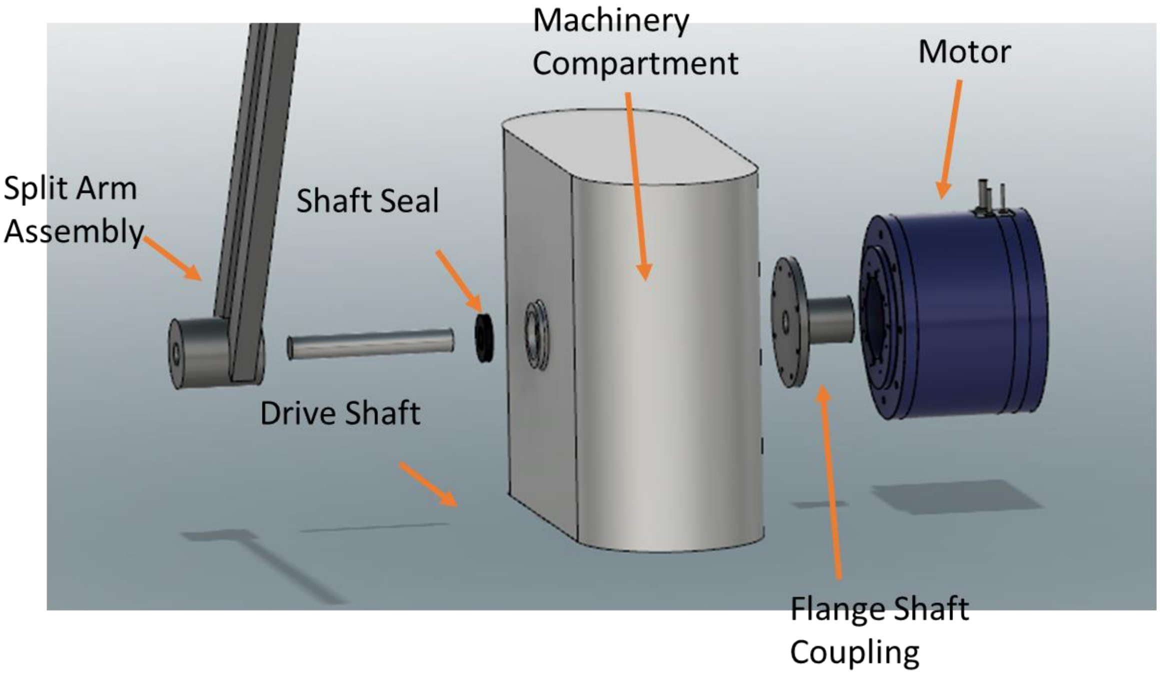


Figure 4-6 Exploded view of the preliminary PTO design.

4.6. Onboard instrumentation

See Table 4-3 for a list of the instrumentation that will be installed on board the tank model. NWEI will be responsible for specifying and procuring the components listed in Table 4-3. Mounting of these components in the tank model will be the responsibility of the supplier. The encoder and torque sensor is part of the PTO system described in Section 4.5.

The torque applied to the float by the generator will be measured by a strain gauge on the drive shaft. Installation and testing of the strain gauges will be the responsibility of the supplier. One spare drive shaft with a strain gauge installed should be supplied in case of failure during testing.

Table 4-3 Instrumentation on board tank model

Measurement	Part number	Notes
Float angle	Encoder	See Section 4.5 (PTO)
Float velocity	Encoder	See Section 4.5 (PTO)
Float shaft torque	Strain gauge on drive shaft	See Section 4.5 (PTO)
Bilge water level switch		See Table 4-4

4.7. Float axle and PTO compartment seals

The float axles will be below waterline, so seals will be necessary to keep all the onboard instrumentation and two PTO generators dry. The selection of the float axle seal will be the responsibility of NWEI. Incorporating the float axle seal into the hull design will be the responsibility of the supplier.

The PTO compartments will also require access hatches below waterline that provide access to the motors. The design of these hatches and their seals will be the responsibility of the supplier.

4.8. Bilge and bilge pump

The PTO compartments should include bilge areas at the bottom for the installation of one of the two alternate bilge pumps listed in Table 4-4, or equivalent. The bilge water sensor listed in Table 4-4 will be used to switch the pump on and either send a signal to DAS or light a bilge level indicator at the top of the model.

Table 4-4 Bilge pump and water sensor

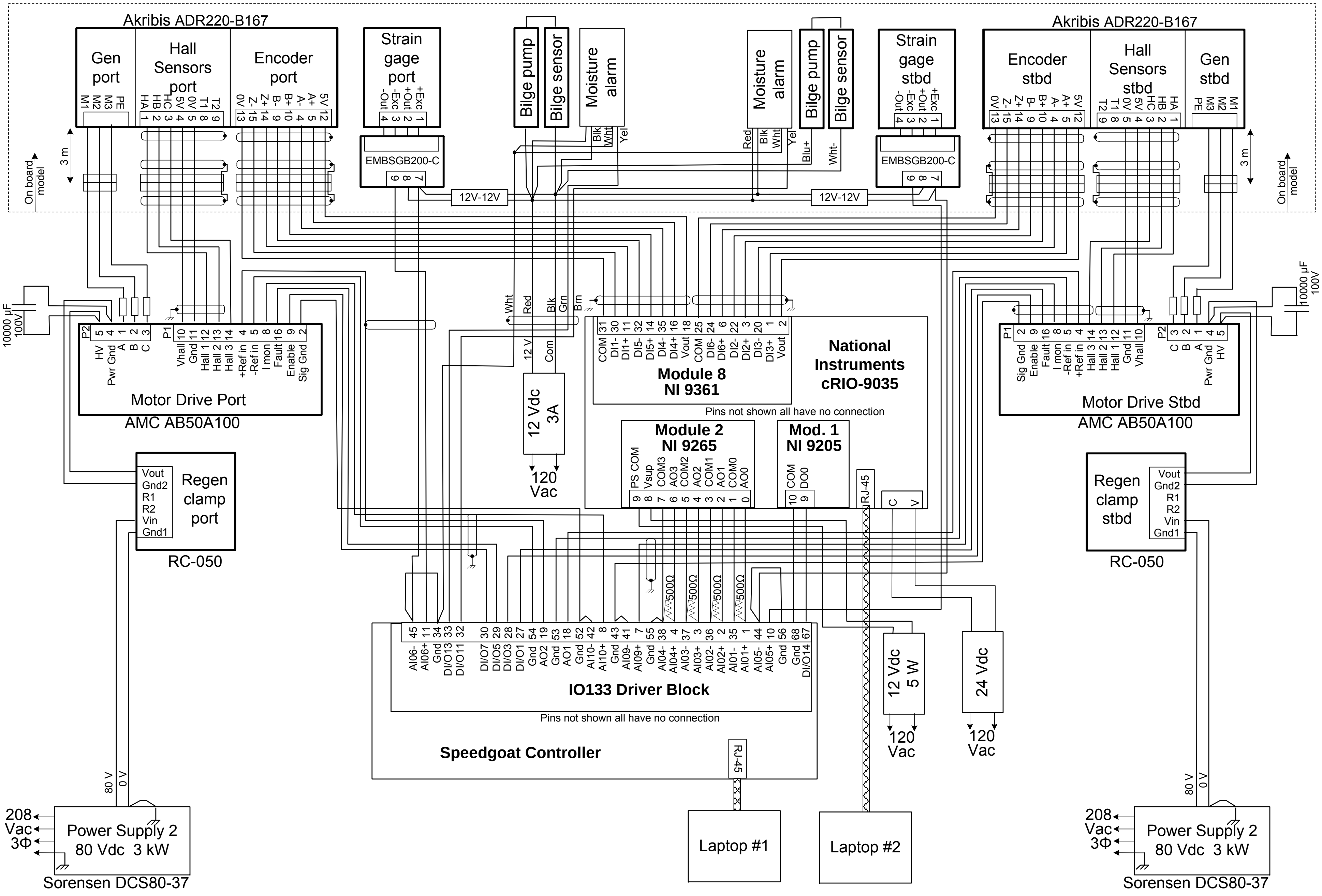
Component	Manufacturer	Part number	Notes
Bilge pump (alternate 1)	Hanperal	B01987QDKQ (ASIN)	https://www.amazon.com/Hanperal-Pumping-Submersible-Garden-Fountain/dp/B01987QDKQ
Bilge pump (alternate 2)	Cisno	CS-2469	https://www.amazon.com/Ultra-Quiet-Brushless-Motor-Submersible/dp/B01G1EGC9Q
Bilge water sensor	Ram	RAM 45	Use water sensor only (pump has insufficient head) https://www.amazon.com/Bilge-Pump-Saver-6-12V-RAM45/dp/B0006O7FNA

4.9. Lift Points

Lift points shall be provided at the top of the hull for use when hoisting the tank model out of the water. If any additional lift points are needed to experimentally measure the center of gravity, and pitch moment of inertia, of the float and the hull independently, those shall be provided.

APPENDIX B

WAVE TANK MODEL WIRING DIAGRAM



Drawn Terry Lettenmaier

Date Nov 17, 2017

AZURA WAVE ENERGY

Project

NWEI Full Scale Developement

Title

Wiring Diagram
Wave Tank Model

Sht

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