Wave tank experiments of a floating, tidal-stream energy device

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ABSTRACT: Model experiments for the MTG (Modular Tidal Generators) have been conducted at the Ocean Basin of the COAST Laboratory of University of Plymouth. The twin-hull concept of the MTG was tested. The tidal turbine was supported by the platform with two floating hulls. The turbine was modelled as a porous disc. Both fixed and floating (with mooring) tests were conducted. This paper reports the model experiments set-up and some preliminary results are presented and discussed.

1 INTRODUCTION

Tidal stream energy is highly predictable and is now on the verge of being cost competitive with some of the more mature renewable industries like offshore wind. However, the levelised cost of energy (LCOE) is still too high and a major concern for the tidal stream industry is the shortage of appropriate development locations (and, therefore, market for the supply chain to invest in) (Greaves & Iglesias, 2018). A number of floating tidal stream concepts are being developed in order to reduce the cost of installation and increase the number of potential deployment sites (by eliminating the depth and bathymetric constraints). The Modular Tidal Generators (MTG) concept aims to take this idea further by utilising modularity and standardised components to produce an inexpensive floating tidal stream solution that can be easily manufactured, deployed and maintained with minimal requirements on skilled personnel.

Figure 1 shows the design of the full scale device of the prototype of the two hull version of the MTG. The twin-hull device consists of two cylindrical demi-hulls to provide buoyancy for the platform, the supporting frames positioned in between the demi-hulls to hold the turbine. The four mooring lines are controlled by the winches on the deck of the platform. There are walkways on the deck for the operational personnel activities. As part of the MTG concept development, a series of 1:12 scale physical experiments have been undertaken in the COAST Laboratory at Plymouth University. The scaled model includes the floating, twin-hulled platform, four-point mooring (catenary) system and a porous disk representing of the horizontal axis tidal turbine (HATT). Initial tests are conducted based on the environmental conditions (waves and currents) at the proposed deployment site of a full scale prototype in the Fal estuary. Further tests are performed to investigate the effect of wave excitation on the platform and to compare with the assumptions made during the structural design of the device. Measurements from the experiments include the 6 DOF motions of the platform, mooring line tensions and thrust and moments on the turbine model. The paper outlines the set-up and programme of experiments and presents some initial results of the tests.

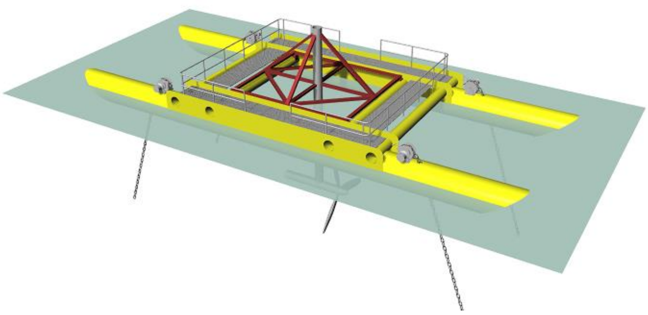

Figure 1. Prototype of the MTG device.

2 MODEL EXPERIMENT SET UP

2.1 *Facilities*

The model experiments were carried out at the Ocean Basin of the COAST Laboratory of University of Plymouth (Figure 2). Length and width of the basin are 35m and 15.5m, respectively. The basin has a movable floor and the water depth for the experiments was 1m. Waves were generated by 24 individually controlled hinged flap absorbing paddles. A convex absorbing beach was installed at the opposite end of the basin. The current was generated by a recirculating system.

Figure 2. The Ocean Basin in the COAST Laboraatory the University of Plymouth

2.2 *Model*

The model was manufactured with scale ratio of 1:12. The geometry of the underwater part of the model is similar to that of the full scale device. The above waterline part including deck layout were simplified. The two demi-hulls (two cylinders) were made of plastic tubes, the supporting frames are of aluminum tubes. The cross beams and the ballast weight inside the demi-hulls were selected such that the mass, CoG position and radii of gyration of the model were scaled from the full scale device. Figure 3 shows the model, which consists of two cylindrical demi-hulls, vertical and horizontal supporting beams for the turbine and the porous turbine model. The porosity of the disk is 50%. The main particulars of the model are listed in Table 1.

Table 1. Main particulars of the MTG model.

Item	Model	Full scale
Overall Length (*m*)	1.667	20.00
Diameter of hull (*m*)	0.102	1.219
Beam of platform (*m*)	0.620	7.438
Draft with turbine (*m*)	0.067	0.807
Displacement (*kg*)	17.36	30*000*
VCG* (with turbine, *m*)	-0.064	-0.767
Mooring line mass (*kg/m*)	0.300	43.20
Diameter of turbine (*m*)	0.333	4.000
Moment of inertia for roll (*kg.m^2*)	0.961	19927
Moment of inertia for pitch(*kg.m^2*)	2.220	46034
Moment of inertia for yaw(*kg.m^2*)	2.887	59865

* from still water line

2.3 *Measurements*

The model motions were measured by an optical tracking system. Waves and current velocities were measured by using resistance type wave probes and current flow meters, respectively. A 6-aixs load cell was used to measure fluid loadings on the model hull when it was fixed. The capacities of the load cell are 125N for Fx and Fy, and 250N for Fz; capacity of Mx, My and Mz are all 25N.m. Accuracy of the load cell is ±0.1%. Three single axis load cells were used to register the fluid loading on the turbine. The capacity of the single axis load cell is 22N and its accuracy is ±0.15%. Four load cells were used to measure tensions on the four mooring lines. Videos (including under water video) were recorded during the experiments and digital still photographs were taken.

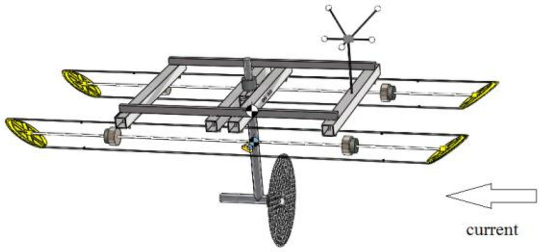

Figure 3. The MTG model for the test.

3 MODEL TEST PROGRAMME

3.1 *Fixed tests*

The model experiments consist of two groups: fixed and moored model tests. The fixed model tests were designed to measure wave/current loading on the platform and turbine models in various wave/current conditions. The model was fixed with a vertical column mounted with the gantry above the basin, the 6-axis load cell was located at the CoG position of the model and connected the model with a vertical column (Figure 4).

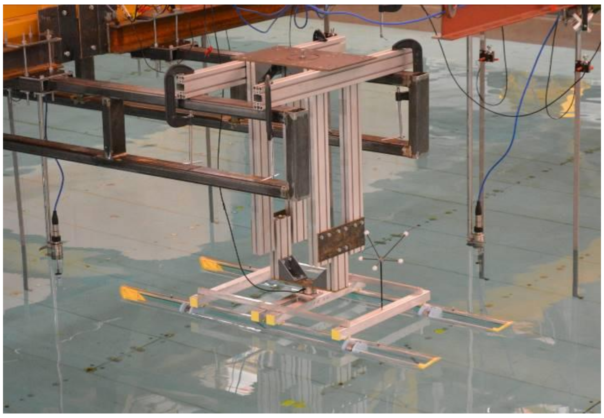

Figure 4. The fixed model test showing the 1:12 scale model in the Ocean Basin at the COAST Laboratory, University of Plymouth, Plymouth, UK.

When testing with the turbine present, the hydrodynamic loading on the turbine was also recorded. The test matrix for the model fixed cases is listed in Table 2.

Table 2. Test matrix for fixed model

Test No.	Turbine	current* (m/s)	wave
F1	No	0,0.28,0.56,0.84,1.12	No
F2	No	0,0.28,0.56,0.84,1.12	Regular
FT1	Yes	0,0.28,0.56,0.84,1.12	No
FT2	Yes	0,0.28,0.56,0.84,1.12	Regular

* current velocity at the centre of the turbine, full scale.

3.2 *Mooring tests*

Four catenary mooring lines were used for the platform in its floating condition, with two at the bow and another two attached at the stern of the twin hull. The angle of spreading mooring lines with *x*-axis (longitudinal direction) was 30 degrees. The weight of the mooring line chain in water is 37.7kg/m and the water depth is 12m in full scale.The static profile of the mooring lines (front view) is shown in Figure 5.

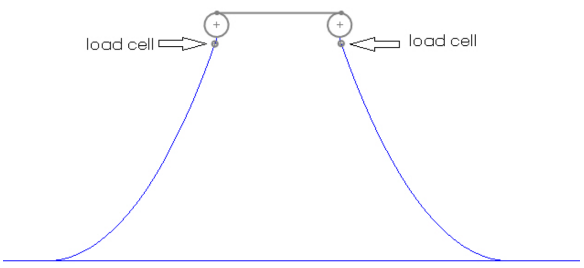

Figure 5. Static profile of the mooring line (front view).

Table 3. Test matrix for moored model

Test No.	Turbine	current* (m/s)	wave
M1	No	0,0.28,0.56,0.84,1.12	No
M2	No	0,0.28,0.56,0.84,1.12	Regular
MT1	Yes	0,0.28,0.56,0.84,1.12	No
MT2	Yes	0,0.28,0.56,0.84,1.12	Regular
MS1	No	0,0.56	Irregular
MS2	Yes	0,0.56	Irregular

* current velocity at center of the turbine, full scale.

The chain used for the mooring lines in the experiments is 4mm galvanized short link chain. Tests for the platform with and without the turbine were carried out.
The experiments were conducted for various combinations of waves and current, and for both regular and irregular waves. The test matrix for the moored model is shown in Table 3

4 RESULTS AND DISCUSSIONS

The objectives of the experiments are to inform the design and deployment of the MTG prototype and provide validation data for a fully nonlinear coupled numerical model developed at University of Plymouth to model entire floating tidal turbine systems (Ransley et al, 2016). Detailed results will be disseminated in future publications. Some of the preliminary results are presented here.

Figure 6 shows the wave loading on the turbine in the longitudinal direction, *fx*, for the fixed model tests. The loads were non-dimensionalised by $\rho g \gamma A a$, where γ is the porosity rate (50%), A is area of the disk (m^2), a is amplitude of the incident waves (m), ρ is density of water (kg/m^3) and g is acceleration due to gravity (m/s^2). Results of two test cases are shown, one with current of velocity of Vc=0.56 *m/s* (full scale) and another case without current. It can be seen that the hydrodynamic loading on the turbine is much higher for the case with current than that of wave only, due to the combined action of wave and current. The wave frequency, ω (*rad/s*), is non-dimensionalised by $\omega' = \omega\sqrt{(L/g)}$, with L length of the model (m).

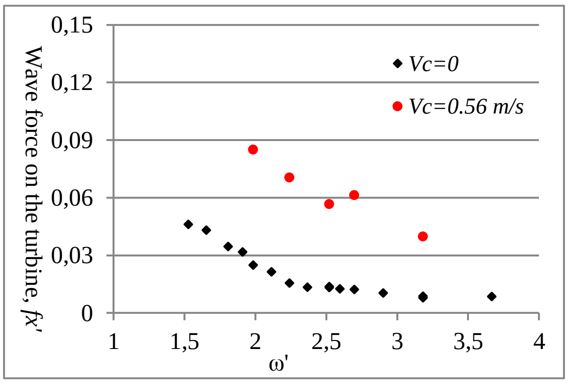

Figure 6. Horizontal force on the turbine in regular waves.

Figure 7 shows the model from the tests with the turbine present in its moored condition. As mentioned previously, motions of the platform model were measured via an optical tracking system and the mooring line tension was registered via load cells at the top end of each mooring line. The mooring line was of catenary type with uniform weight along the line. The weight and static profiles of the mooring lines were modelled in the experiments (Faltinsen, 1990).

Figure 7. Test of the platform with turbine in moored condition.

Figures 8 and 9 are the pitch and surge motions of the platform with the turbine present in moored condition, respectively. The surge amplitude was non-dimensionalised by the amplitude of the incident wave; while the pitch amplitudes were non-dimensionalised by the slope of the incident waves. These results demonstrate the effect of current on motions of the platform. It can be seen that both pitch and surge motions are smaller than those of the test without current. This is mainly due to the increased damping of the turbines with the combined interaction of waves and current. Another reason is that the catenary mooring system changed its equilibrium position under flow current, the restoring coefficients increased as well.

Figure 10 shows tensions for the mooring line at the port side of bow in regular waves.

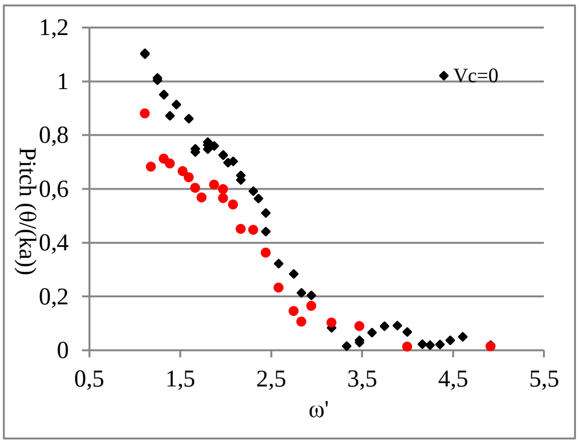

Figure 8. Pitch RAO of the platform with turbine in regular waves.

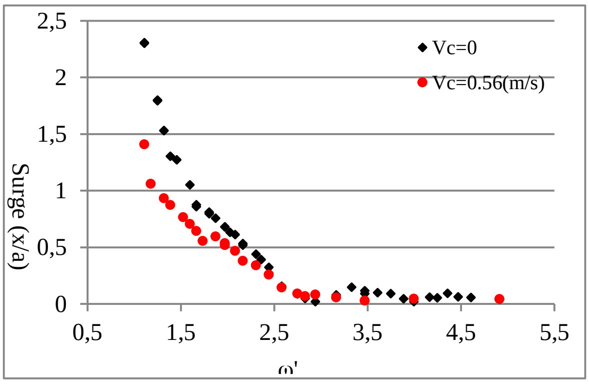

Figure 9. Surge motions of the platform with turbine in regular waves.

One case is for the platform with turbine and another is for the platform only. There was no current in this case. The tension amplitudes are non-dimensionalised with $\rho gLDa$, where D is diameter of the demi-hull of the platform (m). It is observed that the effect of the turbine on the mooring line tension is limited for the model tested in waves only (no current) condition.

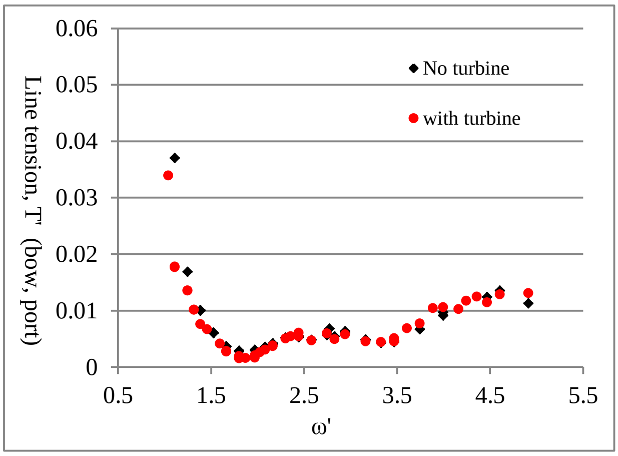

Figure 10. Tension of mooring line at port side of bow of the platform in regular waves without current.

5 CONCLUSIONS

Wave tank experiments have been conducted for the twin-hull version of the Modular Tidal Generators platform to verify the performances of the design and provide validation data for the numerical simulations. Observation and preliminary results of the experiments show the feasibility of the initial design of the floating system. The results show that wave loading on the turbine will increase under tidal condition, and the turbine acts as a motion stabilizer in tidal streams (reduce motions of the platform), while there are little differences for the mooring line tensions of the platform with and without the turbine in wave only conditions. Further process and analysis of the experimental data will be carried out, and results to be compared with field measurement during the prototype deployment and numerical predictions.

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REFERENCES

Faltinsen, O. M., 1990. Sea loads on ships and offshore structures, Cambridge University Press, UK.

Greaves, D., Iglesias, G., 2018. Wave and tidal energy, John Wiley & Sons Ltd, UK.

Ransley, E. J., Brown, S. A., Greaves, D., Hindley, S., Weston, P., Guerrini, E., Starzmann, R., 2016. Coupled RANS-VOF Modelling of Floating Tidal Stream Concepts, Proceedings of the 4th Marine Energy Technology Symposium (METS), Washington, D.C., USA.