WavePiston MK I test at Nissum Bredning

Final report

Sep 28, 2013

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Introduction

As preparation for deployment of the 1:3 scale WEC, a 1:9 scale system has been developed designed and build.

As test site for the 1:9 model the test site at Nissum Bredning was chosen. The waters at Nissum Bredning are not as energetic as waves in the North Sea. Thus, Nissum Bredning is almost an ideal location for a scaled down test to validate the future 1:3 model.

The 1:9 model was designed using the analytical tools developed for the later 1:3 model. The design takes into account the benign wave climate at Nissum Bredning, resulting in a very light and cost effective design. By surviving the wave climate in Nissum Bredning the model validates the current design approach.

By building and deploying the 1:9 scale model important experiences are gained on three different levels:

Level 1: Validation of conceptual system design

- Validation of over-all design approach and numerical models
- Validation of Force Cancellation in real waters
- Validation of deployment strategy
- Validation of mooring strategy

Level 2: System study

- System output and comparison to numerical models
- Pressure and flow of energized water feed
- Test of system handling of tidal (mooring)

Level 3: Sub system testing

- Wear of pumps and plates
- Materials and material combinations
- Effect of marine growth
- Data logging system

Due to the benign nature of the waves at Nissum Bredning, mooring as well as structural parts can be significantly downscaled. Hence, the Nissum Bredning system can be made extremely cheap. Consequently, the cost of testing in scale 1:9 at Nissum Bredning is approximately 2% of the same setup in scale 1:3 in full scale waves.

The waters at Nissum Bredding

The test location of Nissum Bredding is situated in a closed bay with no direct connection to open waters. This is advantageous for initial tests as rouge waves formed by interaction of oceanic swells will never hit the coastline.

Furthermore, the shielded waters of Nissum Bredning makes the waves very modest compared to oceanic waves, making Nissum Bredning and ideal location for scale modeling.

The flipside is, however, that Nissum Bredning has only very modest waves. Thus, the available kinetic energy in the waves is modest and expected output from devices relying on drag is only very modest in these waters.

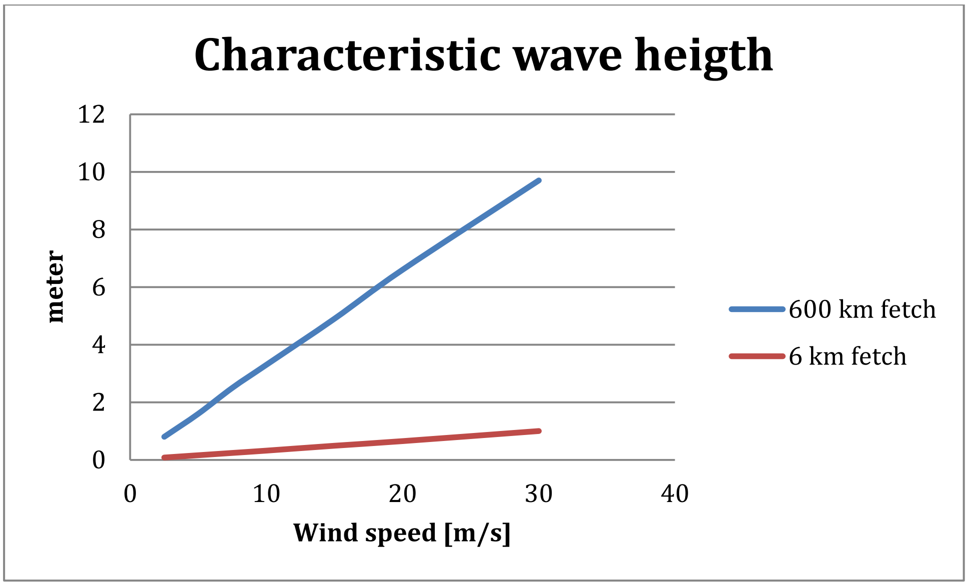

Figure 1 Calculated wave height in Nissum Bredning vs the North Sea

Assuming a Pierson-Moskowitz wave spectrum (with a peak enhancement factor of 3.3) it is possible to calculate the expected wave height in Nissum Bredning and compare this to wave heights in the North Sea. These data are shown in figure 1.

From the figure it can be noted that the expected wave height at Nissum Bredning (wind direction perpendicular to the beach) is only 1/10 of the expected wave height in the North Sea.

Thus, testing at Nissum Bredning should never be regarded as a full sea trial, but rather a model test under benign, albeit uncontrolled, conditions.

Calculated output from WavePiston system

Apart from validating design approach, mooring strategy and deployment strategy the most important purpose of the WavePiston 1:9 test at Nissum Bredning was to validate the numerical model developed by WavePiston. The numerical model forms the basis for design as well predictions of energy output, dimensioning of the system and ultimately COE for a full commercialized WavePiston system. Thus validating the numerical model will at the same time validate WavePistons COE predictions.

The numerical model show excellent correlation to the data obtained in the wave-tank at Aalborg University. By proving a firm correlation between measurements made at Nissum Bredning, measurements made at Aalborg University and the numerical model, the model is validated on both a 1:30 and a 1:9 scale and therefore most probably valid for any size system.

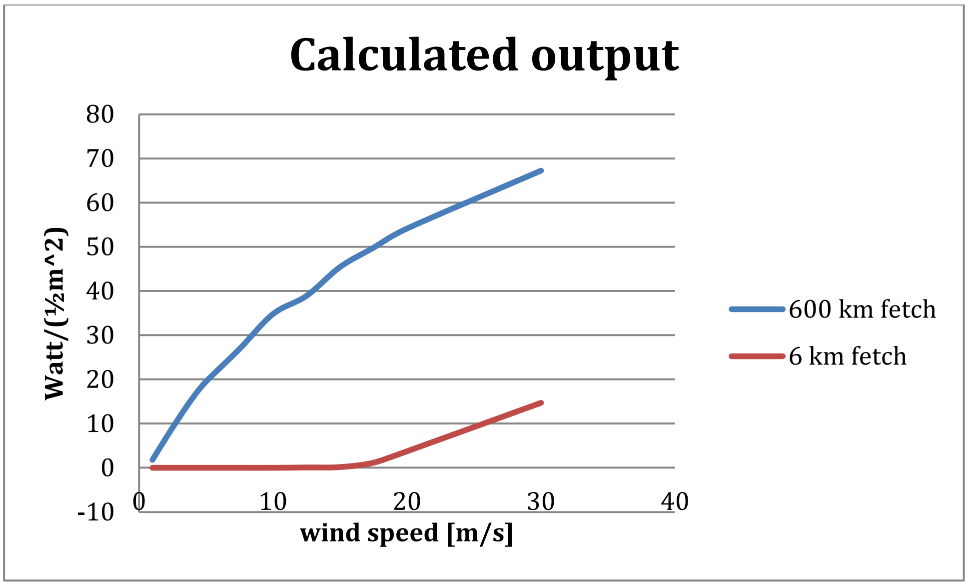

Figure 2 Calculated output from single plate on system (6 km fetch = Nissum Bredning) Output calculated as mean output over a simulated timespan of 20 minutes.

From the calculations shown in figure 2 one immediately notes that the expected output from a WavePiston system deployed in Nissum Bredning is very modest in all but the highest winds.

To understand this one has to realize that the WavePiston PTO system is based on drag induced by differences in speed between the submerged plate and the surrounding waters. There is a parabolic relation between the speed difference and the force, i.e.

$$\text{Force} = k^*(\Delta \text{Speed})^2$$

Thus, only very small forces are acting on the plates in small waves. Although the force on the plates grows rapidly with ΔSpeed the forces does not grow beyond the load bearing capacity of the system, as the plates start to move at a certain threshold, hereby keeping the system loads within manageable limits.

Another interesting feature that can be read from the blue graph in figure 2 is that the expected output from the system trails off at high wind speeds.

This is a highly advantageous characteristic, as this will allow the system to produce energy over a large range of wind speeds and therefore allow for a steady energy production in all but the calmest periods. The characteristic is very different from e.g. wind turbines where the produced energy is roughly proportional to the squared wind speed, resulting in unwanted peak loads during operation.

The reason that WavePiston energy production levels off at high wind speeds is partly due to change in wave characteristics and partly due to decreasing efficiency when the waves are large. A detailed explanation of this phenomenon is beyond the scope of this report.

When performing scale tests one has to be very careful about effects that scale disproportionally. For the 1:9 scale experiments in Nissum Bredning friction was of special concern as the force on the plates depends on the squared size of the system whereas friction depends linearly with size. Hence a 1:9 system will roughly have a friction loss 9 times bigger than the 1:1 system.

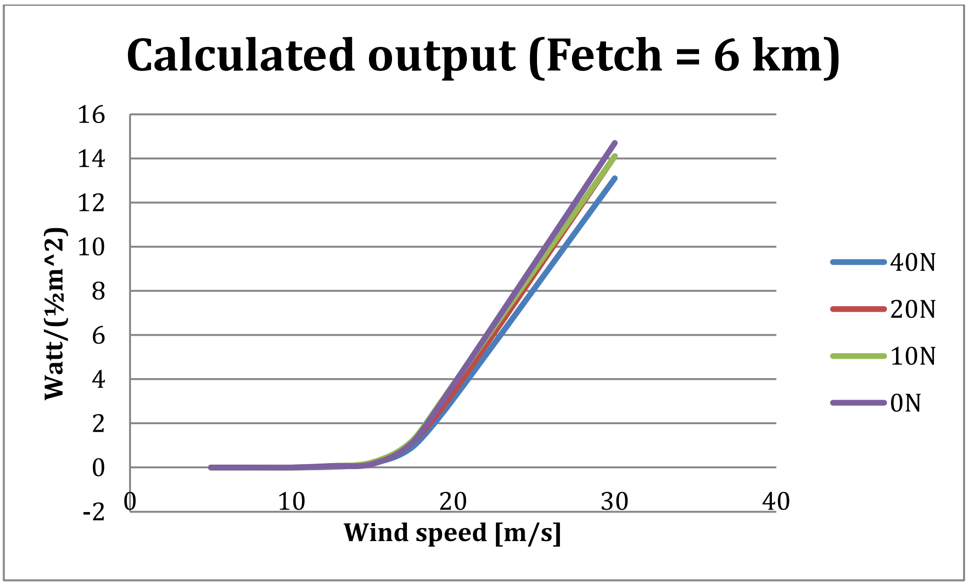

Figure 3 Output from plates having different frictions

System performance was simulated for 4 levels of friction using the WavePiston numerical model. The outcome from the simulation is given in figure 4. Quite unexpectedly the simulations indicate that friction has very little influence on the plate output.

Once again we have to turn to the relation between speed and force to understand the system behavior:

$$\text{Force} = k^*(\Delta\text{Speed})^2$$

When the wind speed picks up and the waves get high enough to start moving the plates, only a slight increase in ∆Speed is necessary to overcome the friction and move the plate.

Friction is one of the poorest understood parameters in the current model, but figure 3 suggests that friction has only a very limited influence on system performance.

All subsequent simulations are made using a guesstimated value of 20N.

Nissum Bredning - Deployment:

Figure 4 WavePiston system pre-assembled onshore prior to deployment

An important sub-goal of the test was to test the deployment strategy. The string is assembled on the beach. For the 1:3 system the individual PTO modules will be placed on rails. Rails are not nessecary for the 1:9 model as it can be handled simply by lifting it into the water. As soon as the string floats in the water, handling is completely identical to handling of the forthcoming 1:3 model.

Figure 5 The string is dragged in to the water. The system is fitted with fenders to make it neutrally buoyant

Figure 6 Deplyed system. Note the low visual profile

To collect data a computer is logging the pressure and flow and sends a data packet to the WavePiston test-server twice every hour. Data for pressure and flow is logged every second. Once every hour a high speed logging with a resolution of 0.1 seconds is made for 200 seconds. This will allow for study of sharp spikes in the water pressure.

Results - deployment:

Deployment of the WavePiston 1:9 test system was carried out using a simple dinghy, hereby fully validating that WavePiston systems are simple and easy to deploy without dedicated deployment vessels.

There is no doubt that deployment of the forthcoming 1:3 test system can be carried out using a modest size boat. Thus, it has been proven that installation cost of future WavePiston systems will be very low compared to competing wave power systems.

The data acquisition system is working according to plan, sending almost 100000 data points to the WavePiston server (located in Copenhagen) every day.

Useful data making a comparison between theory and reality is generated.

This concludes Level 1: Validation of conceptual system design

- Validation of over-all design approach and numerical models
- Validation of Force Cancellation in real waters
- Validation of deployment strategy
- Validation of mooring strategy

As all objectives above has been completed successfully and according to plans.

Measurements

After deployment of the system in February, the system has performed flawlessly, without any human intervention.

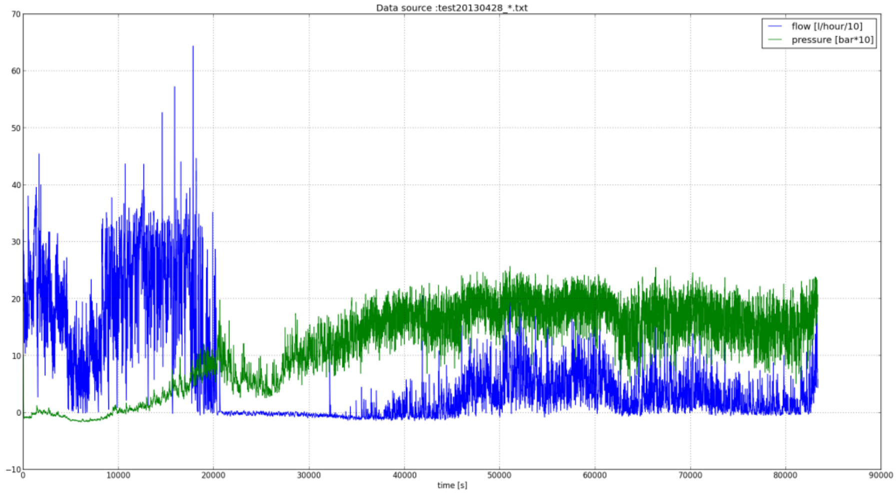

Figure 7 Raw data from measurement system. Flow: blue; Pressure: green

In figure 4 is a typical output from April 28. On the x-axis is time (in seconds), on the y-axis is flow and pressure logged by the sensors.

Note that the flow in the period from 0s-20000s apparently is high and erratic. In reality the flow is zero and the high readings is noise due to air bubbles in the flow meter.

At about t = 20000s the read flow is reduced to zero and pressure starts to build up in the system. In reality a slight flow is induced in the system at t = 20000s, hereby displacing the air bubbles and giving a clean reading of the flow.

Thus, only flow data for t > 20000s should be considered valid.

Using the valid data for t > 20000s it is now possible to calculate the mean power produced by the system by simply calculating the product of flow and pressure

$$\text{Power} = \text{Flow} \times \text{Pressure}$$

Pressure flow and calculated power for the valid period of April 28 is plotted in figure 8.

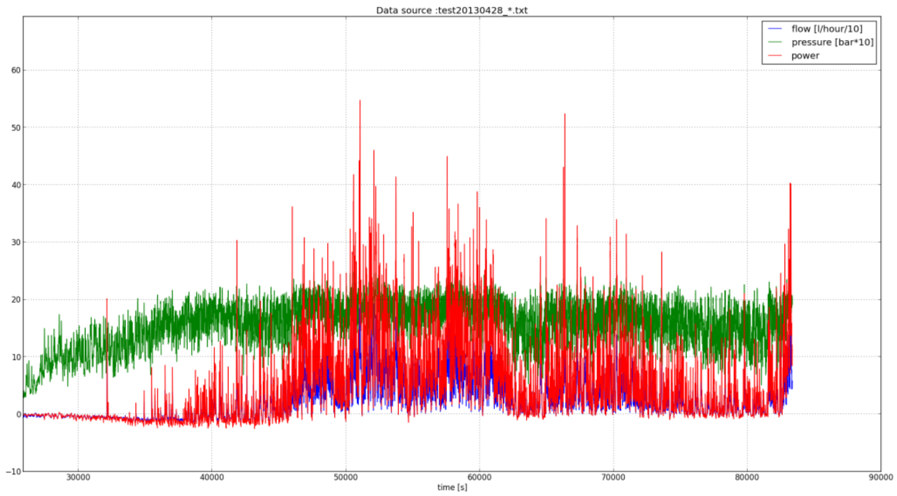

Figure 8 Flow, pressure and calculated power output from deployed WavePiston 1:9 scale system deployed @ Nissum Bredning The wind speed and direction is 18 m/s, parallel to the WavePiston string

Several interesting features can be noted in figure 8.

Before t = 35000s one can note how the pressure builds in the system due to increasing forces acting on the plates. At about t = 35000s the force on the plates overcomes the opening pressure of the relief valve on the system and flow starts to run.

Figure 9 Close up on a 30 min time interval of figure 5

When studying the close-up in figure 9 one notices that the flow is not even but rather erratic. This is due to the lack of pressure compensators on the system and due to the low amount of plates/pumps mounted on the 1:9 system.

A commercial system would consist of more plates and be fitted with pressure compensators evening out the flow to the turbine. Although the flow is not even, the data allow for calculation of the energy output, hereby measuring the performance of the system.

Measurements vs numerical model

To validate the system predicted output was compared to measured output.

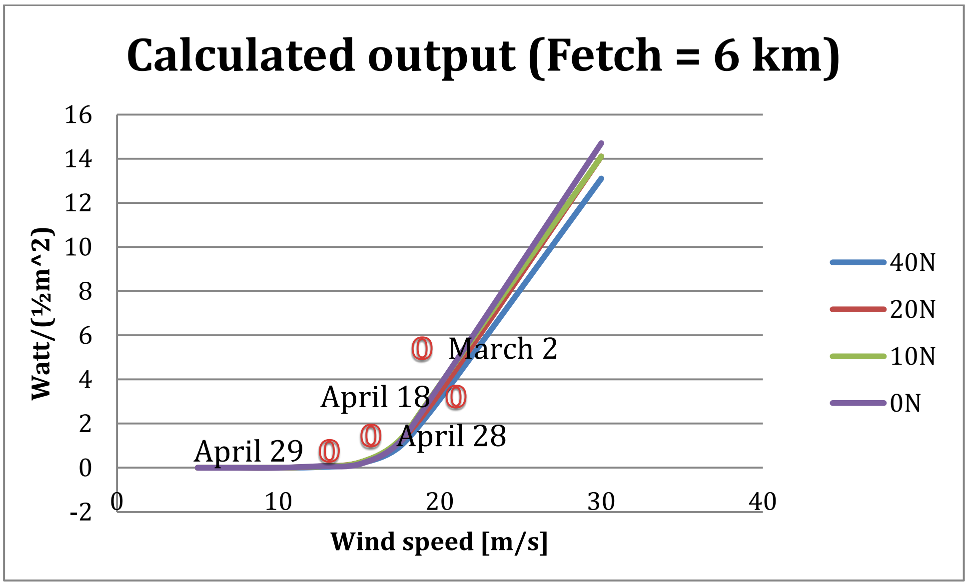

Figure 10 Comparison between calculated output and measurements for selected days with optimal wind direction (single plate) Note fetch depends on wind direction

Wind data was obtained by online data from the DMI homepage.

The measurements show an excellent correlation between predicted and measured power output for the 1:9 test system.

Date	Wind speed	Est. output [W/plate]	Wind direction	Fetch	Calculated output [W/plate]
2/3	15	5	W	6	3
18/4	20	3	SW	9	6
28/4	14	1	NW	7	0.8
29/4	12	0.25	SW	9	0.3
2/6	12	0,25	W	6	0.2

2/9	12	0,25	W	6	0.2

Results – measurements

Data has been logged continuously over a period of more than 7 months and data has been compared with simulations using the WavePiston numerical model and wind data obtained from DMI.

This concludes level 2: System study

- System output and comparison to numerical models
- Pressure and flow of energized water feed
- Test of system handling of tidal (mooring)

All the objectives in level 2 has been completed for the test system and a firm correlation between tests in the wave tank, numerical simulations and real measurements at Nissum Bredning has been established.

Marine growth

An important part of the test was to investigate if the hydraulic system would be influenced by marine growth. The test period covered the summer period and in the calm warm waters marine growth thrives very well. As the image above shows the system is cowered in marine growth. The hydraulic power take off system had no reduction in efficiency due to marine growth, but a little due to piston wear.

Wear and tear

The system was tested for 7 months and then taken up for examination. No maintenance had been done during the test period and the system was still fully functional when taken up.

We had tested a number of different materials for sealing the pistons and some of them showed sign of wear but all were still working.

The last piece of anchor chain was worn down to 2/3 of its original thickness due to movement of the buoys.

The shackle at the end of the wire showed heavy corrosion due to choice of pure grade of stainless steel.

Conclusion:

All main objectives of the Nissum Bredning test have been completed:

Level 1 and level 2 of the test programme has been completed according to plan, hereby validating the concept, the deployment strategy and the numerical model.

It should be noted that the test was executed exactly to plan and that the system works exactly as predicted, without intervention. This highlights the robustness of the concept and the level of engineering invested in the system.

Due to the small waves found at Nissum Bredning no further useful data can be obtained from this experiment. To proceed this technology further, real tests in the North Sea using a 1:3 scale model has to be carried out.

The numerical model shows a very good correlation to measured data. It is therefore firmly believed that the numerical model is perfectly suited to predict forces and power production from a scale 1:3 model to be deployed in the North Sea.

By validating the numerical model WavePiston now have a powerful tool to predict the 1:9 scale model performance in any waters without the need for cumbersome experimental work.

To complete level 3 the system will be pulled out of the water and pumps will be examined for wear, hereby paving the way for an even better performing 1:3 scale system.

Marine growth had no effect on system efficiency.

Precautions to wear and corrosion has to be taken in the next test.