Danish Wave Energy R&D

The Wave Star

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-The Wave Star-

Wave Energy Research Group
Department of Civil Engineering
Aalborg University

WAVE STAR ENERGY

The Wave Energy Research Group WERG is situated at the Department of Civil Engineering, Aalborg University, and was formally established spring 2005. It originates from the Hydraulics and Coastal Engineering Laboratory, which presents extensive experience within the field.

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Figure 8:

Artistic Impression of the Hanstholm plant, including personal plant access and control room.

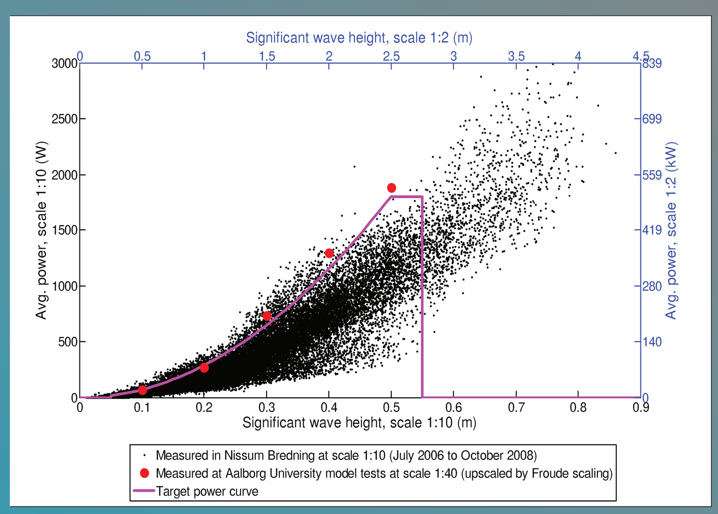


Figure 7:

Averaged P_{out} curve plotted over the significant wave height H_s (Wave Tank vs. NB). Upscaled to Hanstholms output scale.

Figure 6:

Storm protection mode. Above the water level, the white structure as a part of the lifting structure module.

Figure 5:

Commissioning of the test pilot plant at Nissum Bredning in 2007.

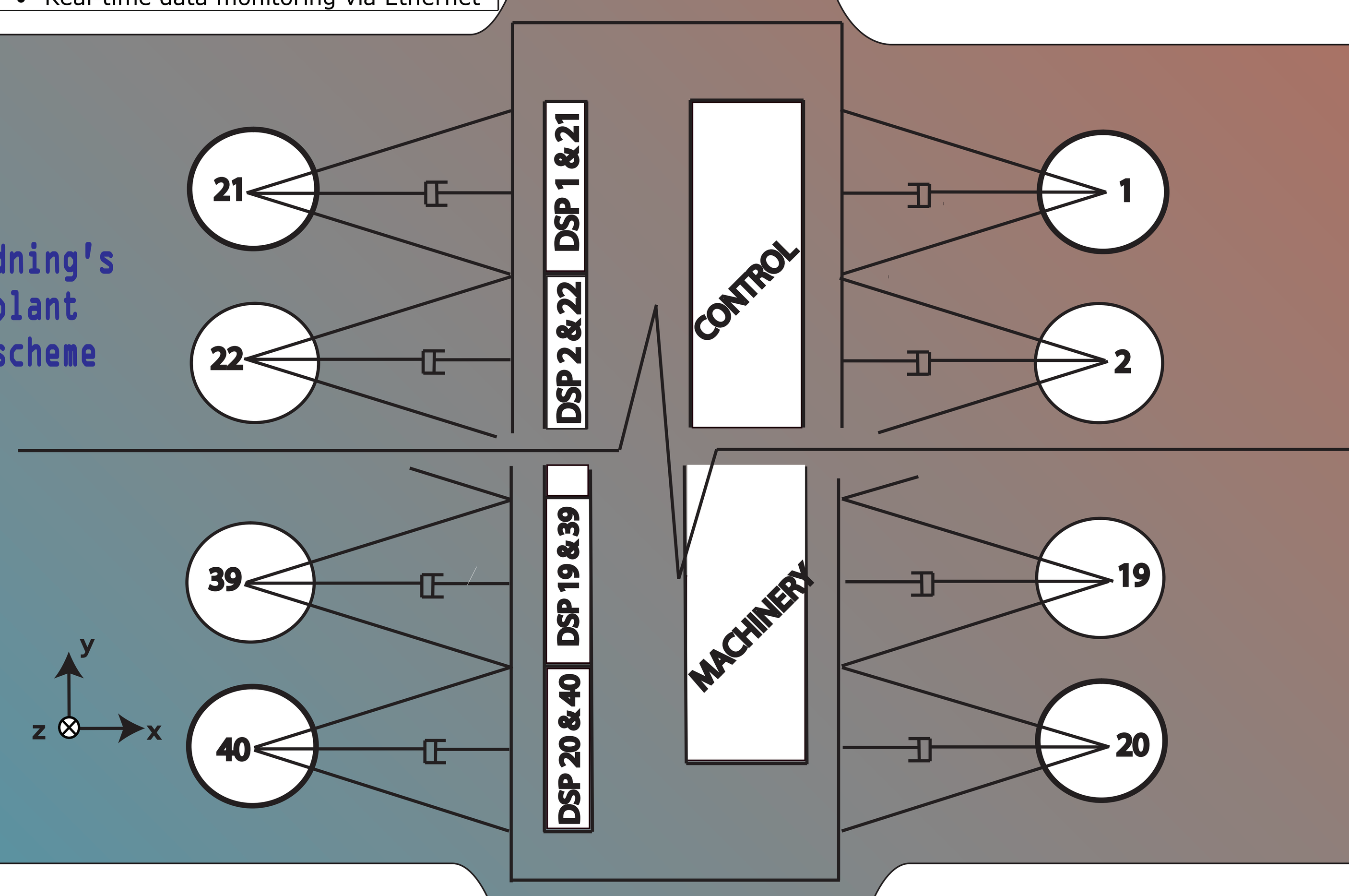
Future estimations

- Adaptability: either nearshore or offshore installation. Control to var. sea-state. Meteorological station use.
- Possible Farm integration within wind energy parks
- Life cycle:50 years(a)/unit (Checks & overhauling/10y)
- P_{out} performance:1 Gwh/year @ 6 kW/m, North Sea.

Design Portfolio

Electrical (Control room)	• Access, Manipulation of plant functions • Monitoring of main hydraulic system variables (Generator, Pump, Pipe, Valve – p, Q, T, P_{out}) • NB : DSP, LabView Monitoring for each floater pair • Hanstholm: PLC system for faster response, Alstom Grid Frequency Converter unit
Hydraulic PTO (Machinery room)	• Piston sensors (measuring $\vec{s}, \vec{v}, \vec{a}$) • High and Low Pressure Accumulator System • Auxiliary Diesel Generator unit • NB: Common hydraulic system for all floaters • Roshagen: Single hydr. system for each unit
Floaters	• BEM & FEM Simulations • Detailed Studies on the applying forces, Torques • Draft & Slamming Analysis • Full equipped measuring system ($\vec{s}, \vec{v}, \vec{a}$, floating angle, pressure & force transducers, strain gages)
Structure	• Exact position reference in every support strut
Boundaries	• Several Wave & Wind measuring units • Maintenance of single components on site possible • 10-40m shallow water
Additional Features	• Floater Buoyancy Control • Real-time data monitoring via Ethernet

Nissum Bredning's (NB) test plant top view scheme



Working principle

The Wave Star (Multi point absorber type)

Its platform is supported by two parallels of 20 fixed floaters on either side. Hydraulic pistons connect both structure & floaters. Incident waves produce the floaters oscillation. Analog to a combustion engine, the floaters motion sequence results depending on the wave direction.

- Crossing waves: produce min. dead zone without motion
- Extreme sea conditions (**storm protection mode**): Device lifted by an auxiliary generator. At NB's test plant, within less than 5 minutes, avoiding structural damage. Herefor, the floaters are held in horizontal position. For instance several floaters follow this procedure, while the rest may continue operating.

In **normal operation mode**, the buoys produce a drive moment around the bearing in the steel arm structure. This is turned into an axial motion by the hydraulic piston on the upper strut. Hydraulic pumps convert then the high pressurized fluid into electricity (Power Take-Off system).

Wave Energy

The ocean wave loads from Wave Energy can be converted through specific machinery into electricity. The variety of operating principles & machinery devices in this renewable energy field is remarkable, having arisen until the date considerably in terms of research & development (R&D). Nowadays studies evaluate it as a technology with maximum 5 years delay to Wind Energy. The World Energy Council established 2001 the world exploitable wave energy potential in 2 TW, covering 50% of the current total human consumption in Europe. The Wave Star Energy project presented here is a major step towards these goals.

Wave Star Energy history

- **2000** Tusindben invention: Hansen brothers patent
- **2003** Patent rights acquisition Per Resen Steenstrup Wavestar Energy Foundation
- **2005** 2 patents granted by EU, 4 pending
- **2006** Deployment of Pilot plant
- **2000-2008** >1000 tests done by Aalborg University

Wave Star Projects

Location: Nearshore Hellisgø, Nissum Bredning, 1:10 Scale
Structure: 24 m length, anchored nearly 4 m under water
Floater-Ø: 1 m (20/20 floater lateral configuration, scheme)
Material: Steel structure, fiberglass floaters
Full Hydraulic PTO – System (common floater supply)
P_{out} := 5.5 kW Generator (grid connected)
Deployment: 2006
2.

Location: Hanstholm , Roshage dike, 1:2 Scale
Floater-Ø: 5 m (2 floater configuration on one side)
Material: Concrete structure & floaters
Full Hydraulic PTO - System (single floater supply)
P_{out} := 500 kW Generator (grid connected)
Deployment: 2009
3.

Location: Horns Rev offshore wind energy farm, 1:2 Scale
Floater-Ø: 5 m (20+20 floater configuration)
Material: Concrete (UHPC) structure & floaters
Full Hydraulic PTO - System (single floater supply)
P_{out} := 500 kW Generator (grid connected)
Deployment: End 2010
4.

Settled in Charlottenlund, Copenhagen, Wave Star Energy is a group of currently 13 employed engineers & technicians. It is leaded by Per Resen Steenstrup and Mads Clausen from Danfoss A/S as Chairman. Covering the projects demand for installation, machine design, electronics & general simulation purposes, it is a steadily growing unit.

Contact: Per Resen Steenstrup (Director, M.Sc., M.E.)
@ http://www.wavestarenergy.com/

Figure 1:

Map on the different locations for the Wave Star Energy evolution. From Aalborg University to Skagerrak, Atlantic.

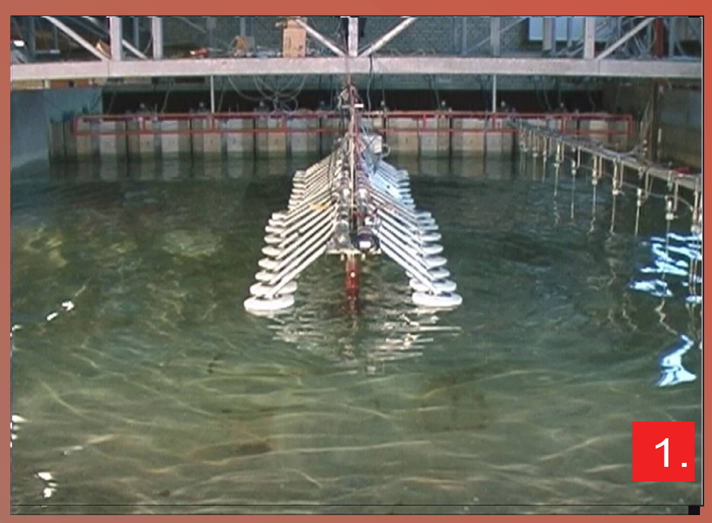


Figure 2:

Wave tank Aalborg University. 1:40 scale model tests. Subject to Torque T, mech. efficiency η & Power P_{out} analysis

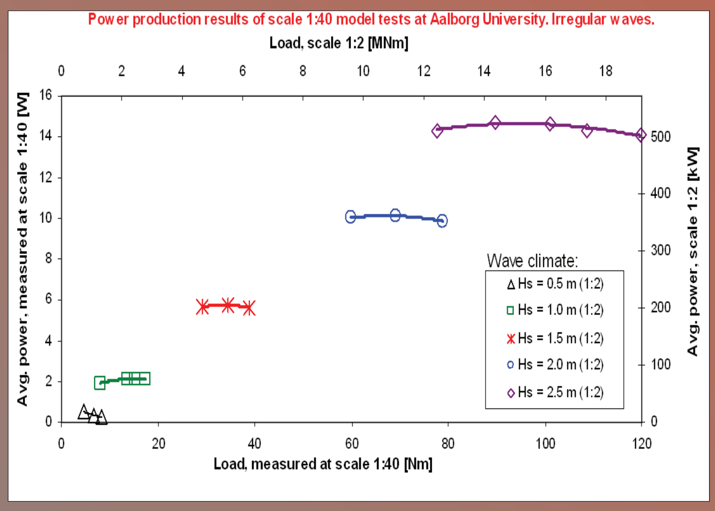


Figure 3:

Full scaled T & P_{out} curves (upscaled from Figure 2 model). Different geometries analyzed, hemisphere floater chosen.

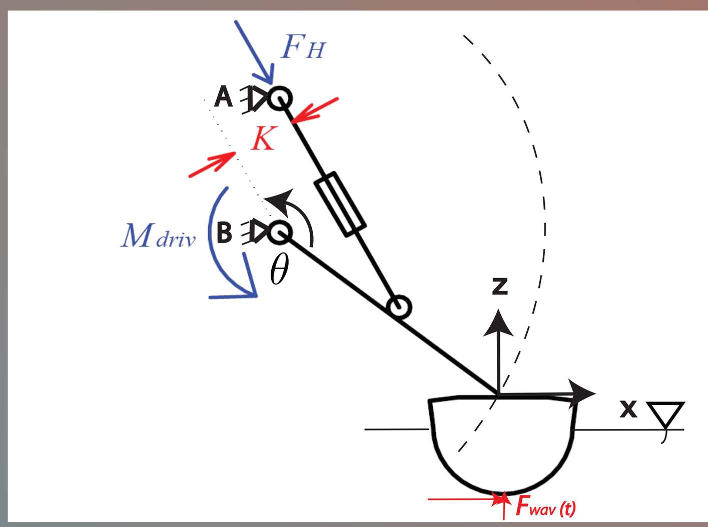
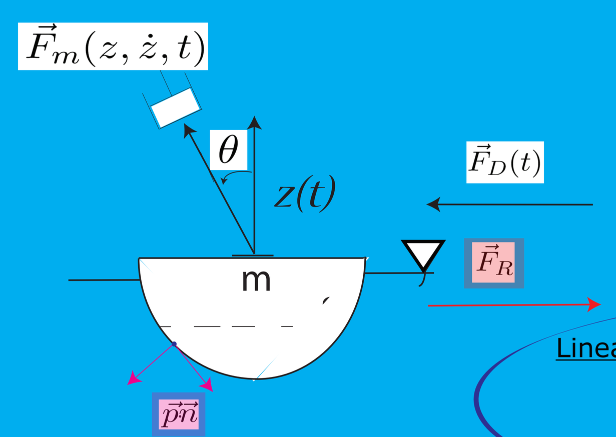


Figure 4:

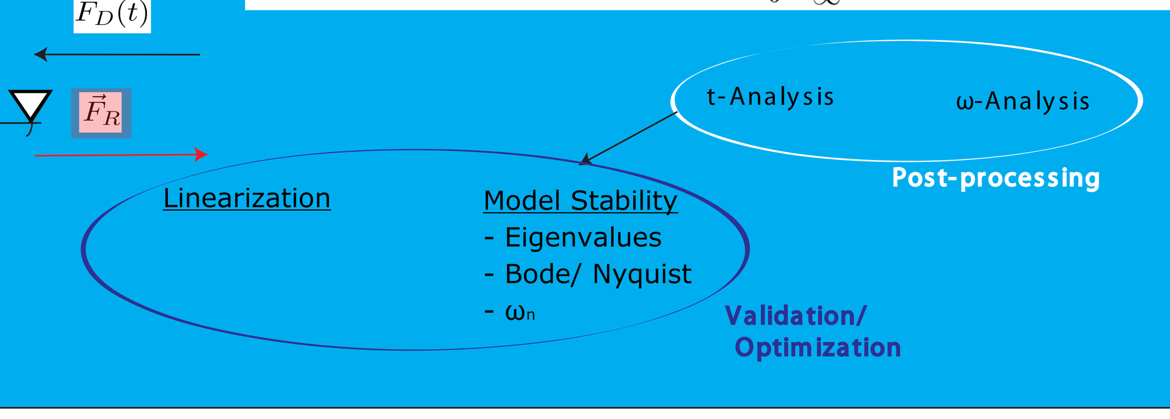
xz plane free cut showing applying forces & resulting torque around lower bearing B.

Control System Modelling

Time-domain analysis and frequency domain are used with BEM to describe the equations of motion for the floating body on the right. They relate the wave potential F_d and F_r to the floaters displacement θ(t) and the hydraulic forces $F_m(\theta,\dot\theta,t)$. This way, components parameters such as the pressure p and the flow rate Q in the hydraulic system are to be modified improving the power generation modes. Control strategies to implement could rely on applying fixed F_m, implement the floaters "latching" or "declutching". It might be also of interest to evaluate the use of genetic algorithms for maximum energy absorption.



$$(m_f + A(\omega))\ddot{z} + (\rho g S + K)z + \int_{-\infty}^{t} L(t-\delta)\dot{z}d\delta = \vec{F}_D(t) + \vec{F}_m(z,\dot{z},t)$$



For efficiency maximization & optimization purposes the highly non-linear systems PTO has to be adapted to the incoming wave variables (direction, significant wave height H_s, wave period T_s and spectra). Given a control system hardware, such as a PLC, specific algorithms must be implemented additionally, so that the components react on the incoming waves. There has been remarkable research in this early stage field. And it is the subject of this thesis to set the System Equations Modeling of Wave Stars hydraulic system in Matlab, a so called wave-to-wire model. It is a WERG project at Civil Engineering Dept., Aalborg University.

Partners & References

WaveEnergy Centre · DONG energy · AALBORG UNIVERSITET · TECNEIRA TECNOLOGIAS ENERGÉTICAS S.A. · Dr.techn.Olav Olsen a.s · VATTENFALL · INGENIEURBÜRO FÜR BAUWESEN FEHLING + JUNGMANN GMBH · European Ocean Energy Association · Fraunhofer Center Windenergie und Meerestechnik · UNIKASSEL VERSITÄT

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