-The Wave Star-

Power Take-Off System Modelling

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

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Figure 1:

View of the Nissum Bredning plant in Storm protection mode. Platform support through pier. 20/20 sym. floater config. Rated 5.5 kW. Onboard DSP, Hydraulic and Control Rooms. 19000 hours operative, 15 storms without damage.

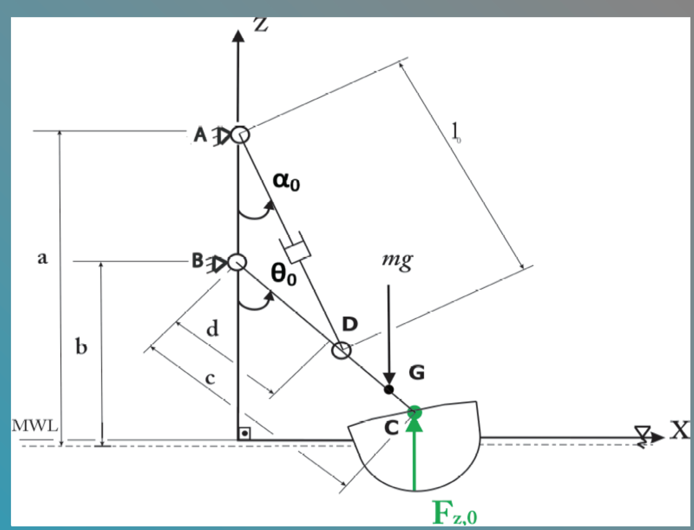

Figure 2:

Single Floater plane cut view through Mean Water Level. System control force $f_c = 0$. Upward applying Hydrodynamic wave force $F_{z,0}$ induces a Moment around bearing B. Result: Floater & piston excursion ($f_c\dot{u} > 0$ for Energy extraction).

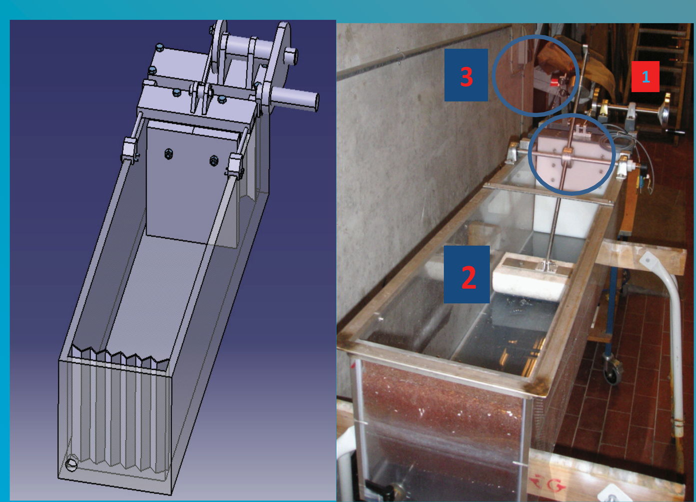

Figure 3:

1 Left: CAD model of a paddled Wave generator. Right: AAU's Basic lab prototype (250x300x1045mm) – Below, a semicil. 2 float (140x300). Above, Magnetic 3 Reelight "PTO" on strut. Experiments carried on a DC-motored unit (Scale 1:50).

Wave Energy is an arising renewable energy form. The Wave Star Energy A/S device has shown remarkable efforts through various testing in the department laboratories of AAU at 1:40 scale during 2000-2008. Furthermore, it has been tested and grid connected via hydraulic Power Take-Off on a 1:10 scale at the Helligsø pier in the Nissum Bredning fjord since 2006 until now. Further ongoing projects for the 1:2 scale in Denmark are being developed.

This thesis initially focuses on the Hydrodynamic modeling and the Control System study of the WSE Power Take-Off (PTO). It is completed through the experimental testing of a single floaters motion with an electromechanical drive.

Formulation - Nissum Bredning floater Semisphe: R = 0.5 m	1) STATICS: Force balance xz plane 2) DYNAMICS: Single Floater response, SDOF, Linear PTO Damping 2^{nd} order delay system		
Hydrodynamics	Domain	Subject	Stat.
- Regular Waves - Excitation frequency $\omega_e = 0.9$ rad/s - Wave Height: $H_s = 2$ m	**Time (Linear Time Variance)**	• Linear Potential theory • Coefficients • Equation of motion - Prony method	√ √ √
- Wave period: 0.5s < T ≤ 21 s (78 unequally spaced ω) - Draft: 0.5 m - Depth : 2 m **Model in background 256 quad elements mesh**	**Frequency (LTV)**	• Magnitude G , Phase Φ {Impedance} - |G(jω)| < 0 ∀ ω - -90° < Φ < 90° - Phase min. sys • Variable Damping • Power absorption ratio	√ √ √ √ √ √ ½
Exp. Testing - (~ Scale 1:40)	**Design**	single motored floater	√

Figure 4:

Conclusions	Status
• Sattisfactory overlapping of Floater response: z(t), v(t). (delay of 0.35 s neglectable)	√
• Computational efficiency in time: Prony approximation	√
• Matched Characteristic behaviour of a MSD in frequency	√
• Control systems: Basic predictive Scheme	√
FDM, System Markow parameters	½ √
• Partial Analysis of Power absorption ratio (Power spectra)	
Issues	**Status**
• Irregular Waves	Ø
○ Optimum Damping	Ø
• Control Strategies	Ø
○ Stability	Ø
○ State Feedback (Latching)	Ø
e.g. Kalman filter	Ø

$$P_a(\omega) = \frac{R_m\left|\hat{F}_e(\omega)\right|^2}{2(R_m+R_r)^2}\frac{1}{1+(\frac{\omega_0}{2\delta})^2(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega})^2}$$

Wave Star Energy (WSE) is a group of currently 13 employed engineers & technician, supported by Danfoss A/S. Covering the projects demand for installation, machine design, electronics & general simulation purposes, it is a steadily growing unit.

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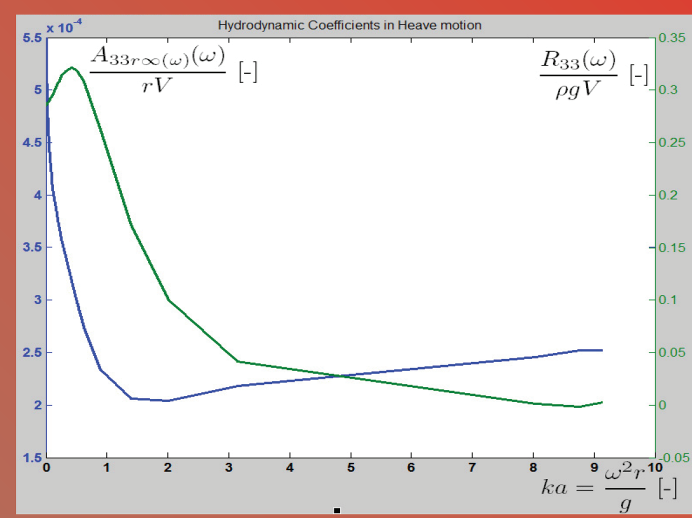

Figure 5:

Nondimensionalized Added Mass A(ω)/(rV) (blue) and Radiation Damping R(ω)/ρgω (green) in heave motion (33) over the normalized wave number $\omega^2 r/g$. Memory function $k_r(t)$ fitted over Prony method with 8 exponentials.

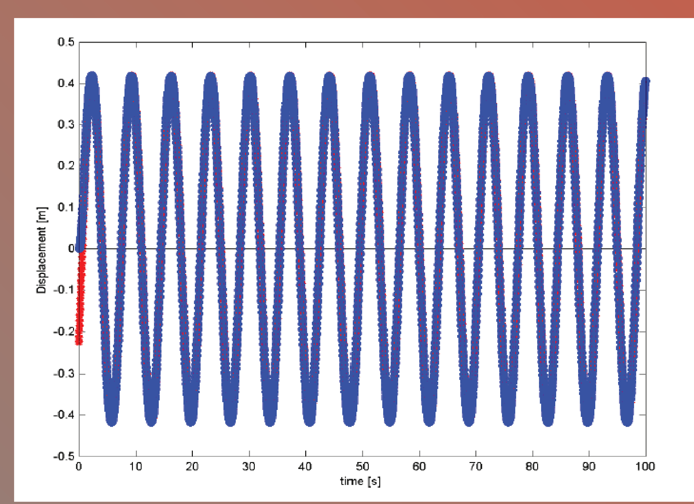

Figure 6:

Forced oscillation over 100 s: Displacement in m over time [s] for ω_e. Comparison of frequency domain derived values (blue z(t) := |G(jwₑ)| fₑ) and time calculated ones (red- z(t):=ode45). Hydrodynamic force amplitude 8 kN.

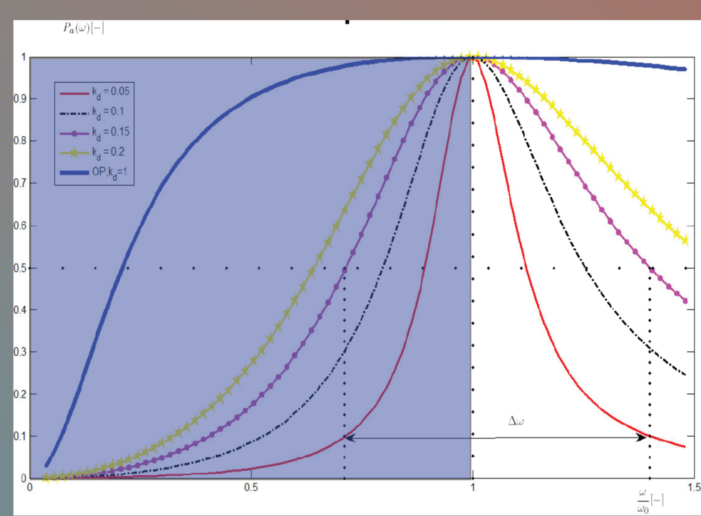

Figure 7:

Normalized Power absorption curve P_a [-] over variable linearized (Factor k_d)*damping ratios δ/w_0. Blue background (left Eqn.): Simulated ω-range (ω_0 = 8.5rad/s).Limited operative range due to ω_{max} = 12 rad/s. Right: Linear interpol. frequencies over ω_{max} for the LTV system.

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[1] Morten Kramer et al. Aalborg University (AAU), Denmark: The wave energy converter Wave Star, A multi point absorber system. 2006

[2] P. Frigaard, T. L. Andersen et Morten Kramer. Effektmålinger på Wave Star i Nissum Bredning. Final Report *PSO- 2008-1-10023*

[3] A. Babarit et al. Simulation of the SEAREV Wave Energy Converter with a by-pass control of its hydraulic PTO. WRECX. 2008

[4] G. de Backer: Bredning Basics in numerical time domain simulation of a heaving point absorber. Trainee Report. Nantes-Ghent University

[5] Falnes, J. Ocean Waves and Oscillating Systems. Cambridge. 2002