Lecture 14 - Introduction to experimental work
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Introduction to Experiments

Morten Kramer

PhD course
"Numerical and experimental modelling and control of Wave Energy Converters"

Tuesday 1 September 2015
Location: Ecole Centrale Nantes, Nantes, France
Laboratory test set-up of pivoting absorber

Laser to measure position

Electrical actuator to apply any specified motion or force

Force sensor

Float

Bearing around which the motion takes place

Fixed support

Moving rigid body

Pivoting motions are described by rotations $\theta_A$.

Newton’s second law:

$$J\ddot{\theta}_A = M_d - M_g - M_c$$

- $J$: Mass inertia moment of the moving body
- $M_d$: Hydrodynamic moment (from water pressure on hull)
- $M_g$: Gravitational moment
- $M_c$: Control moment from Power Take Off
Control sketch

Laptop
- Simulink model. Model is compiled to C/C++ code and transferred to xPc before tests are executed.

PC with xPc
- Online execution of control model and data acquisition. The control model specifies the target force or position based on measured inputs from the NI DAQ.

NI DAQ
- Data logger with inputs and outputs. One output for the Linmot controller is the target force or position.

Linmot controller
- Hardware controller. Takes care of achieving the specified target position or force using position feedback from actuator or force feedback from external force sensor.

Actuator
- Linear motor (electrical cylinder). The linear motor consists of two parts: The fixed stator (tube) and the moveable slider (piston). An internal position encoder is included and used for position control.
Waves in basin

Waves are measured without the device in the basin.

Measured waves are considered as incoming waves (reflections from the beach and side walls are not taken into account).

Small wave

Large wave
Moment due to gravity

\[ J \ddot{\theta}_A = M_d - M_g - M_c \]
\[ \leftrightarrow 0 = 0 - M_g - M_c, \quad \dot{\theta}_A \approx M_d \approx 0 \]
\[ \leftrightarrow M_g = -M_c \]

Slow motion in air with sinus
Mass inertia moment

Accelerating motion in air

$$J\ddot{\theta}_A = M_d - M_g - M_c$$

$$\leftrightarrow J\dot{\theta}_A = 0 - M_g - M_c, \quad M_d = 0$$

$$\leftrightarrow -M_c - M_g = J\dot{\theta}_A$$
Hydrostatic stiffness
Slow sinusoidal motion in calm water

\[ J\ddot{\theta}_A = M_{hs} + M_r + M_e - M_c \]
\[ \leftrightarrow 0 = M_{hs} + 0 + 0 - M_c \]
\[ \ddot{\theta}_A \approx \dot{\theta}_A \approx 0 \]

Hydrostatic moment: \( M_{hs} \)
Radiation moment: \( M_r \)
Wave excitation moment: \( M_e \)
Control moment: \( M_c \)

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Slow motion in water, hydrostatics. Setup no. 1

[Graph showing data]

- Measurements
- Linear fit, \( k_h = 92.1 \text{ Nm/\text{rad}} \) (range -0.1 to +0.1 rad)
- Numerical from non-linear element model
- Numerical from 3D drawing
Radiation force

Example figures with sinusoidal motion ($T = 1.0$ s, motion amplitude = 0.1 rad)

\[ J\ddot{\theta}_A = M_{hs} + M_r + M_e - M_c \]
\[ \leftrightarrow J\ddot{\theta}_A = M_{hs} + M_r + 0 - M_c , \quad M_e = 0 \]
\[ \leftrightarrow M_r = M_c + J\ddot{\theta}_A - M_{hs} \]
Wave excitation force

\[ J\ddot{\theta}_A = M_{hs} + M_r + M_e - M_c \]
\[ \leftrightarrow 0 = 0 + 0 + M_e - M_c, \ddot{\theta}_A \approx \dot{\theta}_A \approx \theta_A \approx 0 \]
\[ \leftrightarrow M_c = M_e \]

IRA4
\[ H_{m0, WG4} = 0.081 \text{ m}, \; T_p = 2.0 \text{ s} \]

IRB5
\[ H_{m0, WG4} = 0.242 \text{ m}, \; T_p = 3.0 \text{ s} \]
Float in operation  Example with sea-state IRB1 ($H_{m0,WG4} = 0.051$ m, $T_p = 1.0$ s)

Linear damping control $c_x = 4.0$ Nm/rad/s, wave dir 0°, IRB1 ($H_{m0} = 0.051$ m, $T_p = 1.0$ s)

Graphs showing various parameters over time.