IEA Phase IV of OC3
Offshore Floating Wind Turbine
Status March 2009

Tor Anders Nygaard

Karl Jacob Maus

NORWEGIAN UNIVERSITY OF LIFE SCIENCES MDCCCLIX

Outline

- 3Dfloat model
- Modeling of the OC3-Hywind floating wind turbine
- Eigen frequency analysis
- Analysis of linearized wire characteristics
- Conclusions/further work

3Dfloat

- Finite Element (FEM) structural model
- Euler-Bernoulli beams with 12 degrees of freedom (DOF)
- Newmark and Wilson time integration schemes
- Geometric nonlinearities accounted for by corotated approach. Reference configuration is recent deformed state.
- Consistent (distributed) loads from gravity, waves, current, buoyancy and wind.
- Point forces can be applied to nodes
- Wind turbine rotors can be associated to nodes
- Blades and drive-train are currently rigid
- Mooring can be part of the FEM modeling using beam elements with cable options

Aerodynamics

- Unsteady blade element/momentum theory
- Airfoil data as lookup tables
- Extensions for variable inflow (time and space).
- Dynamic inflow model
- Extensions for yaw errors
- Evolving induction, no iterations
- Ref: Björck, A.: AERFORCE: Subroutine Package for unsteady Blade-Element/Momentum Calculations. FFA report TN 2000-07

Control System

- Generic
  - Variable speed, fixed pitch below rated wind speed
  - PI control of pitch angle to control rotational speed (and power) above rated wind speed.
  - Ref: Hansen, M. H. et al : Control design for a pitch-regulated, variable speed wind turbine. RISØ-R-1500(EN)
- Similar controllers from the IEA OC3 project

Loading

- Left Hand Side (LHS) : acceleration, damping and stiffness terms
- Right Hand Side (RHS): external forces
- Force evaluated at Gauss points in elements (wind , wave loads, buoyancy and gravity)
- Galerkin approach to evaluate consistent loads
- Wind : Nonlinear drag term on RHS.
- Wave loads: Morison term involving structure acceleration (added mass) added to mass matrix. The rest including nonlinear drag term kept on RHS.
- Buoyancy applied to RHS.
- Gravity applied to RHS.
- Gravity and buoyancy are applied to LHS for eigen frequency analysis

Finite Element Modeling of OC3-Hywind Physical model

- Two sections below floater taper, lower section has Cm at platform Cm
- 3 equations: total mass, pitch inertia, center of mass
- 3 unknowns: point mass at bottom, two section masses
- Floater from taper and up is massless
- Stiffness is 10000 x steel stiffness
- Yaw inertia is ignored for now, turns out to be 80% of OC3 spec with a material density of 8500 kg/m**3. Can adjust this by changing density and wall thickness.
- Tower is divided into elements with equal length, linear distribution of diameter and wall thickness.
- Massless element from tower top to nacelle/rotor Cm
- Nacelle/rotor represented with clump mass for now

Eigen frequency analysis

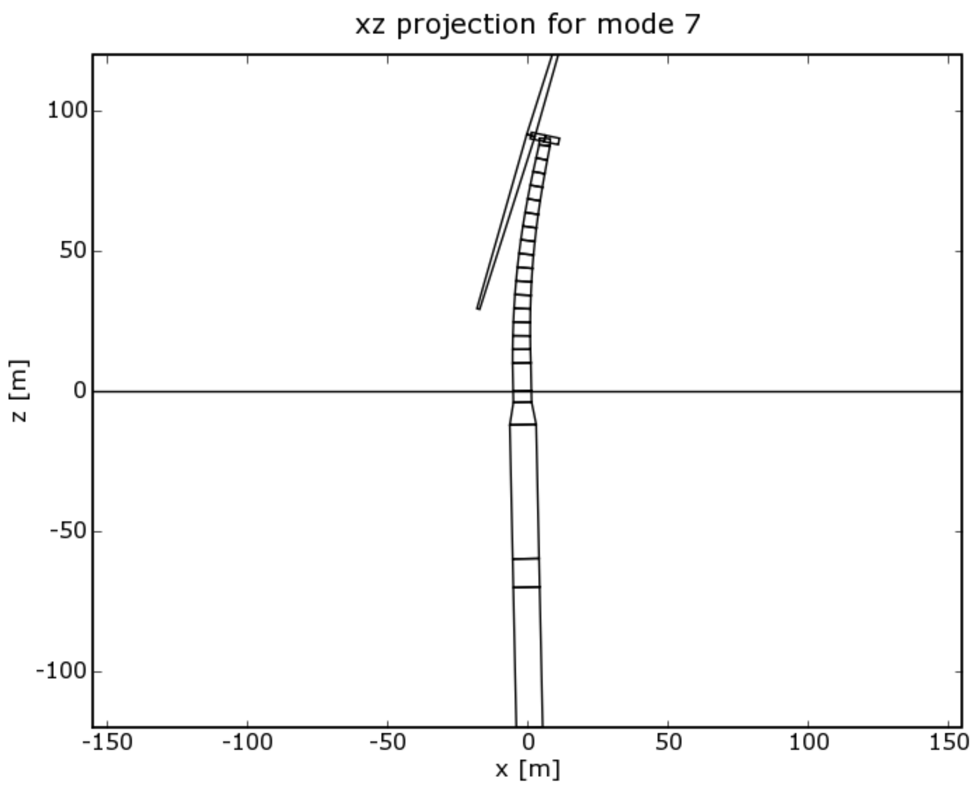
- The effect of buoyancy is taken into account by adding the linear hydrostatic restoring matrix to the stiffness matrix for the DOF’s associated with the node at Still Water Level (SWL)
- The effect of mooring is taken into account by adding the linearised mooring restoring matrix to the stiffness matrix for the DOF’s associated with the node SWL
- Righting moment due to center-of-gravity (CG) is taken into account by adding the total weight times CG offset from SWL, to stiffness matrix pitch and roll DOFs at SWL.
- Yaw stiffness due to the delta connection is added to stiffness matrix for the SWL node.

Department of Mathematical Sciences and Technology

Eigen analysis results

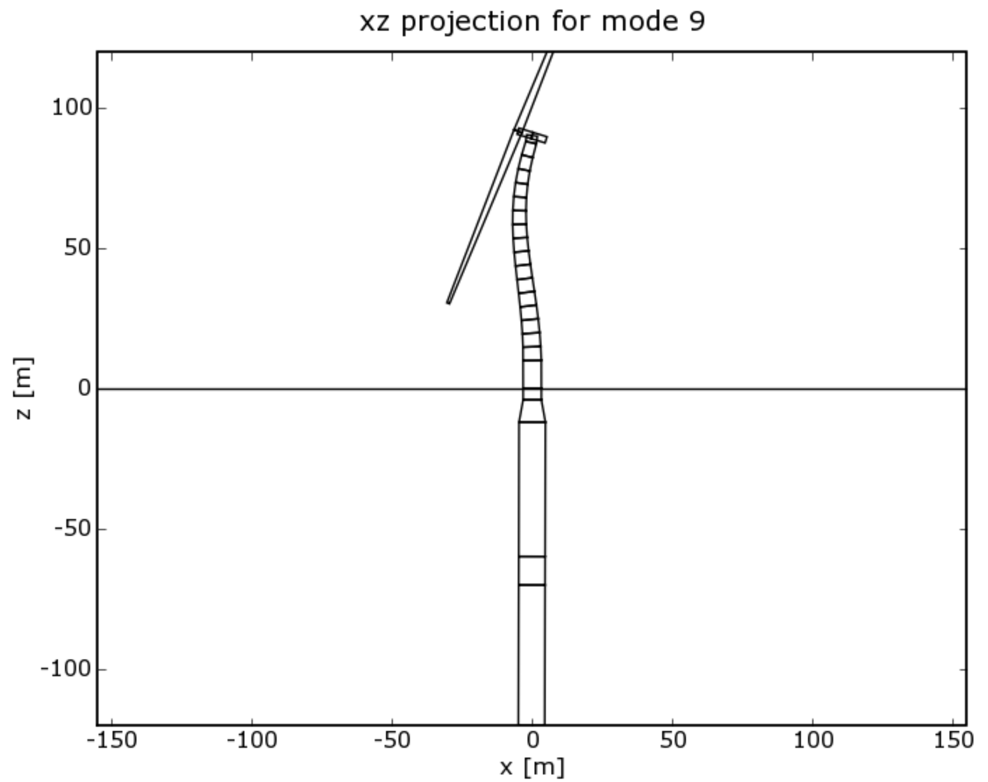
Mode	Natural frequency f [Hz]
Surge	0.00803
Sway	0.00803
Heave	0.033
Roll	0.0321
Pitch	0.0321
Yaw	0.14, Yaw inertia 133,298,000

Eigen analysis results, 1st tower fore-aft



Eigen frequency: 0.473 Hz

Eigen analysis results, 2nd tower fore-aft



Eigen frequency: 3.61 Hz

Linearized mooring restoring matrix
64 elements per wire, one-sided differences

	3Dfloat	FAST, Dr Jason Jonkman
C(1,1) [N/m]	4.139E5	4.118E5
C(5,1) [N/rad]	-2.829E6	-2.821E6
C(3,3) [N/m]	1.17E4	1.194E4
C(4,4) [Nm/rad]	3.15E8	3.11E8
C(2,4) [N/rad]	4.48E6	2.82E6
C(6,6) [Nm/rad]	1.185E7	1.156E7

Conclusions / further work

- Finite element representation of OC3-Hywind is updated.
- Eigen frequency analysis implemented i 3Dfloat. First results look reasonable
- Linearized wire characteristics agree well with FAST results, except side force due to roll.
- Next up:
  - Implement evaluation of damping ratios
  - Interface for wave- and wind fields
  - Flexible blades


NORWEGIAN UNIVERSITY OF LIFE SCIENCES
MDCCCLIX