Parameterized Dynamic Modeling Approach for Conceptual Dimensioning of a Floating Wind Turbine System

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Introduction

For a new generation of low-cost and low-maintenance foundations for large offshore wind turbines a concrete torus design is one of the concepts considered in INNWIND.EU. Pre-stressed concrete allows a reduced material cost and an extended lifetime of up to 100 years. The submerged torus features a low sensitivity to wave excitation forces and has a lower draft than common spar-type platforms. The general parameters of the platform and the INNWIND.EU 10MW reference wind turbine are given on the right.

Variations of the inner and outer diameter and the draft result in different dynamics of the floating body but also of the whole floating wind turbine system. In the following the hydrodynamic and the fully coupled behavior is analyzed for the whole design space leading also to the design of the controller.

Motivation

The aim of this work is to calculate the coupled and uncoupled dynamic properties of the novel concrete torus platform design for a whole design space with potential flow and simplified coupled models.
Thereby also the open-loop wind turbine aerodynamics are taken into account.

Table 1: Floating wind turbine properties.

Platform:	Outer diameter [m]	$17,\dots,21$
	Inner diameter [m]	$5,\dots,16$
	Draft [m]	$32,\dots,121$
	Platform mass [t]	$3.2,\dots,5.2\times10^4$
Wind turb.:	Rating [MW]	10.0
	Rotor diameter [m]	178.3
	Hub height [m]	119.0
	Rotor-nacelle mass [kg]	8.84×10^5

The Concrete Torus Concept

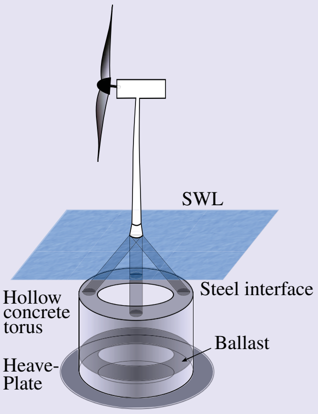

Figure 1: Concrete torus platform concept.

Hydrodynamics

The equation of motion of the rigid floating body with the structural mass matrix M, added mass matrix $\mathbf{A}$, damping matrix $\mathbf{B}$ and the wave excitation vector $\mathbf{F}_{wave}$ remains for the six spatial degrees of freedom $\mathbf{X}$ as

$$(\mathbf{M}+\mathbf{A})\mathbf{X}\omega^2+\mathbf{B}\mathbf{X}i\omega+\underbrace{\mathbf{C}\mathbf{X}}_{\text{Hydrostatics}}=\underbrace{\mathbf{F}_{wave}}_{\text{Wave excitation}}+\mathbf{F}_{lines}+\mathbf{F}_{wind}. \tag{1}$$

Hydrostatics

The hydrostatic restoring stiffness in pitch (nodding) direction will be constant for all geometries to achieve a constant static heeling angle. Therefore, the hydrostatic stiffness C_{55}, which is a function of the inner and outer radius R, r and draft h,

$$C_{55}=f(R,r,h), \tag{2}$$

allows the calculation of the draft for any given combination of inner and outer torus radius. The material cost (CAPEX) has been estimated for the reinforced concrete.

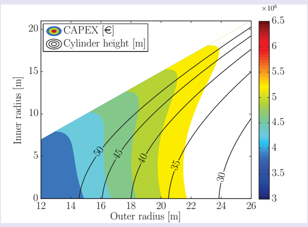

Figure 2: Platform geometric design space for $C_{55}=2.922\times10^9$ Nm/rad.

Wave Excitation

The wave excitation force should be as small as possible. Figure 3 shows the Froude-Krylov & diffraction forces at several frequencies for the whole design space. For the pitch-direction (5,5), the inner radius is most influential.

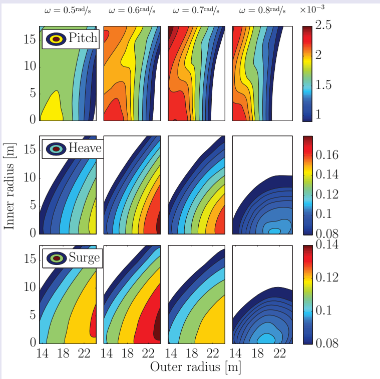

Figure 3: Wave excitation force amplitude.

Coupled Dynamics

Equation 1 changes its characteristics when flexible elements such as the wind turbine tower and blades are added. Additionally, the blade pitch controller can change the dynamic behavior significantly, especially for above-rated wind speeds. For controller design, the transfer function from blade pitch angle to rotor speed $G(j\omega)$ is important, since it reveals the constraints of the system in terms of the applicable bandwidth due to two right half-plane zeros (RHPZ). Figure 4 shows the two RHPZ for the coupled system including the hydrodynamics, the tower dynamics and simplified aerodynamics, see also [1].

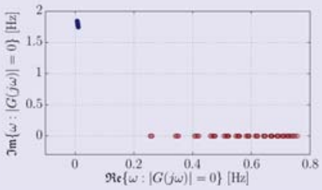

Figure 4: Open-loop right half plane zeros on complex plane.

As RHPZ are a constraint for controller design, it is of importance to identify the parameters responsible for their location. Figure 5 shows the frequency of the real RHPZ on the design space with a dependency on both, inner and outer radius.

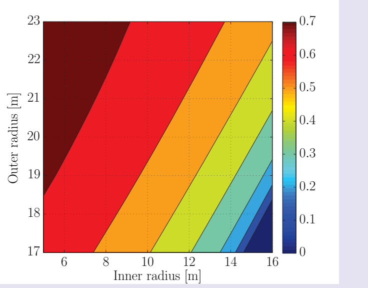

Figure 5: Frequency of real zero $f=\frac{1}{\tau}$ [Hz].

Conclusions

A range of parametric variatons of the concrete torus design has been analysed with respect to hydrostatic, potential flow and coupled multi-body calculations. The process of a stepwise increase of the model complexity allows a thorough understanding of the design properties. Finally, the coupled dynamics of the platform have been analysed to lay out the basis for controller design. The requirements for controller design can therefore already be incorporated in the design of the floating platform to understand the origin of right half-plane zeros of the coupled system from the beginning of the conceptual design.

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[1] Sandner F, Schlipf D, Matha D, Cheng P (2014) Integrated Optimization of Floating Wind Turbine Systems. In *Proceedings of the 33rd International Conference on Ocean, Offshore and Arctic Engineering OMAE*. San Francisco/USA.