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Boarding control system for improved accessibility to offshore wind turbines: Full-scale testing

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ABSTRACT

This paper considers the dynamic modelling and motion control of a Surface Effect Ship (SES) for safer transfer of personnel and equipment from vessel to-and-from an offshore wind-turbine. The control system designed is referred to as Boarding Control System (BCS). The performance of this system is investigated for a specific wind-farm service vessel—The Wave Craft. On a SES, the pressurized air cushion supports the majority of the weight of the vessel. The control problem considered relates to the actuation of the pressure such that wave-induced vessel motions are minimized. Results are given through simulation, model- and full-scale experimental testing.

1. Introduction

1.1. A growing market for offshore wind-farms

As reported by the European Environment Agency's EEA (2008), it is expected that in 2020 there will be 30–40 times the installed offshore-wind infrastructure developed in 2008. Fig. 2 illustrates that the installation of offshore wind-turbines in Europe is currently increasing.

The next generation of turbines are located significantly further offshore. Therefore, they experience higher sea states, which require specialized service vessels for operation and maintenance (O&M) (OWA, 2014). Fig. 1 shows the model- and full-scale version of the vessel studied in this paper. A key issue for good economics on an offshore wind farm is the maximization of access feasibility for O&M. The majority of the Crew Transfer Vessels (CTV's) are accessing the turbine using propulsion-thrust which sticks the bow fender to a turbine ladder. Surface Effect Ship (SES) equipped with the Boarding Control System (BCS), which is introduced in this paper, increases the annual dates where turbine access is possible while significantly decreasing sea-sickness incidents. The BCS leads to safer personnel transfer in higher seas than what is possible today and it is an enabling technology for O&M of offshore wind-energy infrastructure.

Today, the offshore wind marked for CTV's is dominated by catamarans (Bard & Thalemann, 2012; OWA, 2010). They offer transfer speed up to 25–27 kn, turbine accessibility is usually possible in up to 1.5–1.75 m significant wave height (Hs) and the typical vessel lengths are 18–27 m. The SWATH (Small-waterplane-area twin hull) is becoming more and more popular as the structure of the hull minimizes the hydrodynamic contact area, making them capable of withstanding rougher sea conditions than the catamaran design. However they suffer from lower transit speeds.

A two-modality vessel model is presented to account for the vessel's free motion and motion whilst in contact with a wind-turbine. A mathematical model is developed and stability properties for the BCS are investigated. Based on modelling and experimental validation (for data corresponding to the British North Sea), we estimate that a like-sized SES equipped with the BCS can enable safe turbine access in sea states up to 2.5 m Hs and at least 3.2 m for long-crested seas which is higher than the competing CTV's. After being in operation for 5 months and counting, the captains onboard the Wave Craft series prototype, *Umoe Ventus* reports that there has not been a single event where the bow fender have slipped the turbine. As a side note, the maximum speed of the vessel is in excess of 40 kn and it got a minimum draft of 1.1 m.

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Nomenclature

$\Delta A_L(t)$	commanded dynamic cushion leakage area
$\dot{V}_0(t)$	air cushion wave volume pumping
γ	heat capacity ratio for air
κ	sea wave number
μ_s, μ_k	static- and kinetic-friction coefficient, respectively, between turbine and spring suspension (bow fender)
$\mu_u(t)$	uniform dynamic cushion excess pressure
ρ_{c0}, ρ_a	air cushion- and ambient-density, respectively
$\theta(t)$	pitch angle
ζ_a, ω_0	sea wave amplitude and period, respectively
A_0	equilibrium cushion leakage area
A_c	air cushion area
$A_L(t)$	total cushion leakage area
A_{ii}, B_{ii}	hydrodynamic terms, $i \in \{1, 3, 5\}$
c_n	orifice coefficient for vent valve duct shape
c_v, c_h	damper coefficients for the vertical- and horizontal-spring system, respectively
C_{ii}	hydrostatic terms, $i \in \{1, 3, 5\}$
h_0, L	height- and length-of air cushion, respectively
k_v, k_h	spring coefficients for the vertical- and horizontal-spring system, respectively
K_{BP}	Bollard pull
m, I_{55}	vessel mass and moment of inertia, respectively
$M^i_{prop}(t)$	propulsion moment in pitch
$M^i_{waves}(t)$	sea wave excitation moment in pitch
m_*	fictitious mass of the spring suspension
P_0	equilibrium air cushion excess pressure
P_a	atmospheric pressure
$P_u(t)$	uniform air cushion excess pressure
q	the number of (identical) lift fans
Q_0	equilibrium air cushion air flow
Q_{in}	air flow into the cushion from one lift fan
Q_{out}	total air flow out from the air cushion
$x^b_{C/B}$	offsets in x-direction between the bow and below CG (point B)
$X^i_s(t)$	spring force in surge
$x^i_{B/O}(t)$	surge displacement
$x^i_{C/O}(t)$	surge displacement of the bow tip
$x^i_{M/O}(t)$	surge displacement of the spring
$X^i_{prop}(t)$	propulsion force in surge
$X^i_{waves}(t)$	sea wave excitation force in surge
x_{cp}	longitudinal length between CG and center of pressure
$z^b_{C/B}$	offsets in z-direction between the bow and below CG (point B)
$Z^i_f(t)$	friction force between turbine column and spring suspension (bow fender)
$Z^i_s(t)$	spring force in heave
$z^i_{B/O}(t)$	heave displacement
$z^i_{C/O}(t)$	heave displacement of the bow tip
$z^i_{M/O}(t)$	heave displacement of the spring
$Z^i_{prop}(t)$	propulsion force in heave
$Z^i_{waves}(t)$	sea wave excitation force in heave

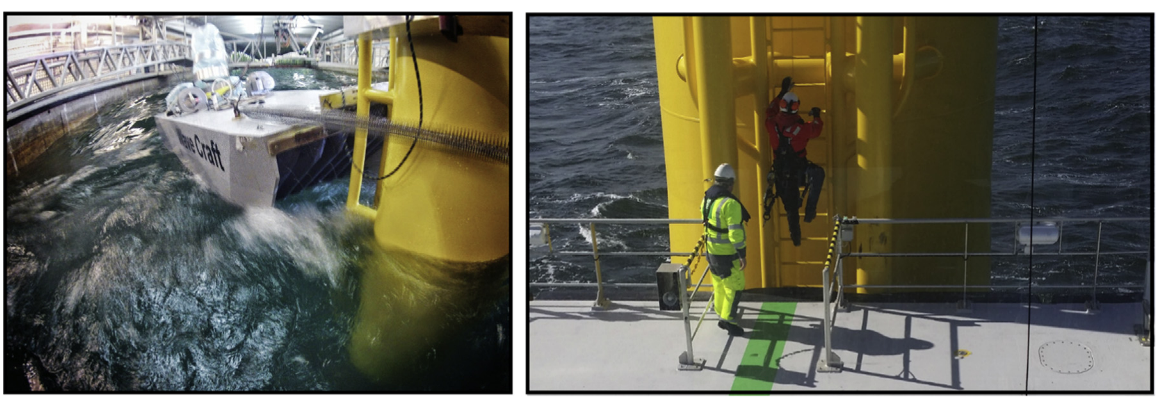

Fig. 1. The Wave Craft model-test and prototype in BCS mode. Courtesy of Umoe Mandal (UM).

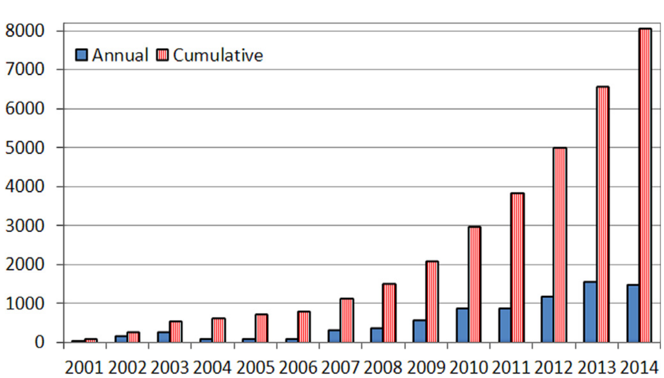

Fig. 2. Annual and cumulative installations of offshore wind capacity – adapted from EWEA (2015).

1.2. Surface effect ships

SES are known to offer very high speed and excellent sea keeping performance in high seas compared to conventional, equally sized, catamarans. The SES rides on an air cushion which is enclosed by two rigid catamaran side-hulls and flexible rubber seals at the bow and the stern.

Fig. 3 shows a cut view along the longitudinal center-plane of a typical SES. The air cushion is pressurized by centrifugal lift fans that blow air into the cushion. The air cushion lifts the vessel vertically and the pressurized cushion can support up to 80% of the total vessel weight. When this is the case, only a minor part of the hull is submerged and exposed to hydrodynamic drag. Two comprehensive works on the SES are given by Butler (1985) and Lavis (1998).

The pressure is controlled by controlling the position of a set of vent valves that varies the cushion air leakage. This can alter the crafts submerged level considerably (2 m on a 26 m long Wave Craft). To obtain high performance during turbine boarding, a Wave Craft has installed twice the air-flow actuation capacity necessary for traditional SES high-speed mode. This is the consequence of the BCS needing to transfer large amount of air for