Modeling and Control of Surface Effect Ship

Time-varying Potential Coefficients and Adaptive Heave Control

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Figure 1: Sprinter WAVECRAFT

Introduction

First developed in the 1960s, the Surface Effect Ship is a unique type of vessel combining a catamaran hull and an encapsulated air cushion, to form a vessel capable of reaching high speeds, while the surface - piercing nature of the SES hull, enables the usage of submerged water propulsion systems, as compared to an air cushion vehicle (ACV).

Historically, the development of the Surface Effect Ship took place with the intention of reaching increasingly higher speeds, which was anticipated to be of huge impact in military applications. The idea behind the SES, was that the air cushion, despite requiring a vast power input to sustain pressure, would support such a large portion of the weight of the vessel, reducing the draft and the ship resistance to motion. Compared to a traditional monohull structure, the decrease in resistance is great enough to justify the energy input to the air cushion.

Today, UMOE Mandal, located in Mandal, Norway, are at the forefront of research and development with regards to SES technology. Advancements in materials, engineering methods and technology feeds the process of further utilizing the unique characteristics of the SES, to establish a viable option for a high speed vessel with a low environmental impact.

Since the 1990s, UMOE Mandal have delivered several classes of vessels to the Norwegian Navy. In recent years, focus has been on the development of the WAVECRAFT Crew Transfer Vessel for use in offshore oil and gas, renewables, passenger and defence purposes.

A major market for the WAVECRAFT, is the offshore wind industry. Below is a depiction of the development of wind turbine capacity in recent years in Europe alone. This trend, along with the fact that newly established wind farms average a distance from shore of 41 km, rises the demand for means of transporting crew and equipment between turbines. As the distance from shore increases and the fact that wind farms in nature are required to be situated in location prone to wind, and thus rough seas, crew accessibility for operation and maintenance purposes is limited.

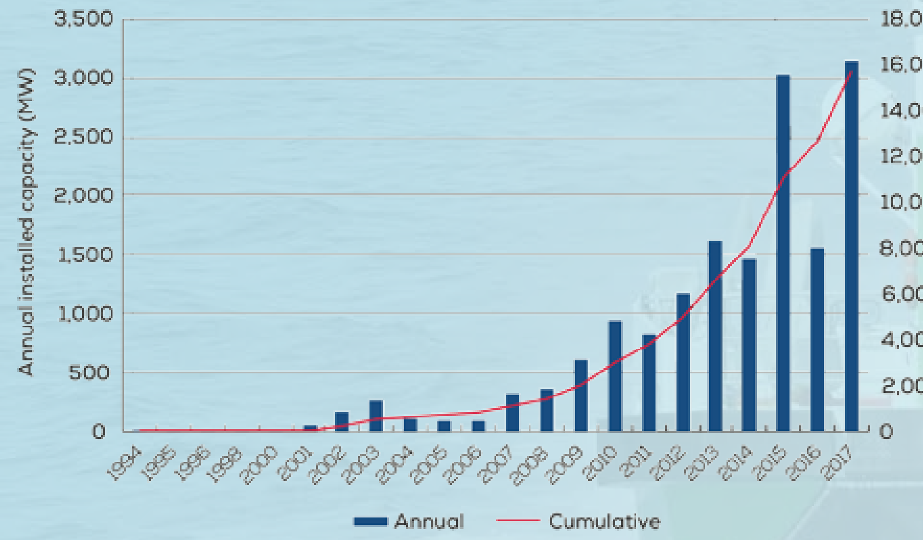

Figure 2: Cumulative and annual offshore wind energy installations

To increase the window of wind turbine accessibility, UMOE Mandal have developed a heave control system which utilizes the SES air cushion as an actuator in a heave compensation system. With the use of ventilation louvers, the WAVECRAFT is able to change the draft of the vessel by altering the cushion pressure. By doing this process in phase with the incident vessel motion, the WAVECRAFT is able to dampen a large amount of the exiting vertical forces.

Main Objectives

1. Develop an extensive simulation model for seakeeping of the SES by means of accounting for the change in potential coefficients when the ship alters its draft. Then verify the coefficients against the ones identified with ShipX(VERES) at the respective draft conditions.
2. Develop an adaptive controller scheme where controller parameters of the current BCS-system are obtained automatically for varying sea states.

Materials and Methods

In order to develop an universal seakeeping model, the drastic changes in hydrodynamics, due to time varying draft T (t), must be accounted for. Since the hydrodynamic calculations are carried out by ShipX, which analyzes based on satisfied linearity assumption, only draft-independent hydrostatic coefficients can be obtained. In addition, the retardation functions are also approximated by LTI state-space model. To overcome such difficulties, linear interpolation of hydrostatic coefficients and retardation forces of the vessel hydrodynamics linearized around multiple draft conditions, were proposed to capture the correct vessel dynamics in varying draft conditions.

The strategy used for development of the adaptive controller, was finding a balance between the dampening capabilities of the controller and the level of actuation for the ventilation valves. The controller parameter is adjusted by continuously seeking to minimize a cost function by evaluating the changes in effort versus the magnitude of vessel motion. A major challenge lied in applying wave filtering while maintaining acceptable ability to adapt to slowly varying changes in an irregular sea state.

Process Plant Model

The ships equations of motion with time varying potential coefficients

$$\begin{aligned} \dot{\eta} &= J_{\Theta}(\eta)\nu \\ (M_{RB} + A_{\infty}(t))\dot{\nu} + \mu(t) + G(t)\eta &= \tau_{exc} + \tau_{aircushion} \\ \dot{\chi} &= \hat{A}\chi + \hat{B}\nu \;, \quad \chi(0) = 0 \\ \hat{\mu} &= \hat{C}\chi + \hat{D}\nu \end{aligned} \tag{1}$$

Control Plant Model

For development of the adaptive controller, a simplified control plant model capturing necessary SES - dynamics in heave and pitch was used. The simplified model use the following equations of motion:

$$\begin{aligned} \dot{V}_0(t) &= A_c \zeta_a \omega_0 \frac{\sin \frac{kL}{2}}{\frac{kL}{2}} \cos(\omega_0 t) \\ K_1 \dot{\mu}_u(t) + \mu_u t + \rho_{c0} A_c \dot{\eta}_3(t) &= K_2 \Delta A_L(t) \quad \rho_{c0} \dot{V}_0(t) \\ (m + A_{33})\ddot{\eta}_3(t) + B_{33}\dot{\eta}_3(t) + C_{33}\eta_3(t) - A_c P_0 \mu_u(t) &= F_3^e(t) \\ (I_{55} + A_{55})\ddot{\eta}_5(t) + B_{55}\dot{\eta}_5(t) + C_{55}\eta_5(t) - A_c P_0 X_{cp} \mu_u(t) &= F_5^e(t) \end{aligned} \tag{2}$$

Results

	Interpolated	Identified	Rel. Error
$A_{\infty,33}$[kg]	2.1247×10^4	2.1214×10^4	0.16%
$A_{\infty,35}$[kgm]	3.7474×10^4	3.7839×10^4	0.96%
$A_{\infty,55}$[kgm^2]	6.8399×10^5	6.8927×10^5	0.77%
C_{33}[kg/s^2]	3.7228×10^5	3.7216×10^5	0.032%
C_{35}[kgm/s^2]	9.9411×10^4	1.0016×10^5	0.75%
C_{55}[kgm^2/s^2]	1.0173×10^7	1.0165×10^7	0.079%

Table 1: Interpolated Versus Calculated Coefficients at 63% of max cushion pressure

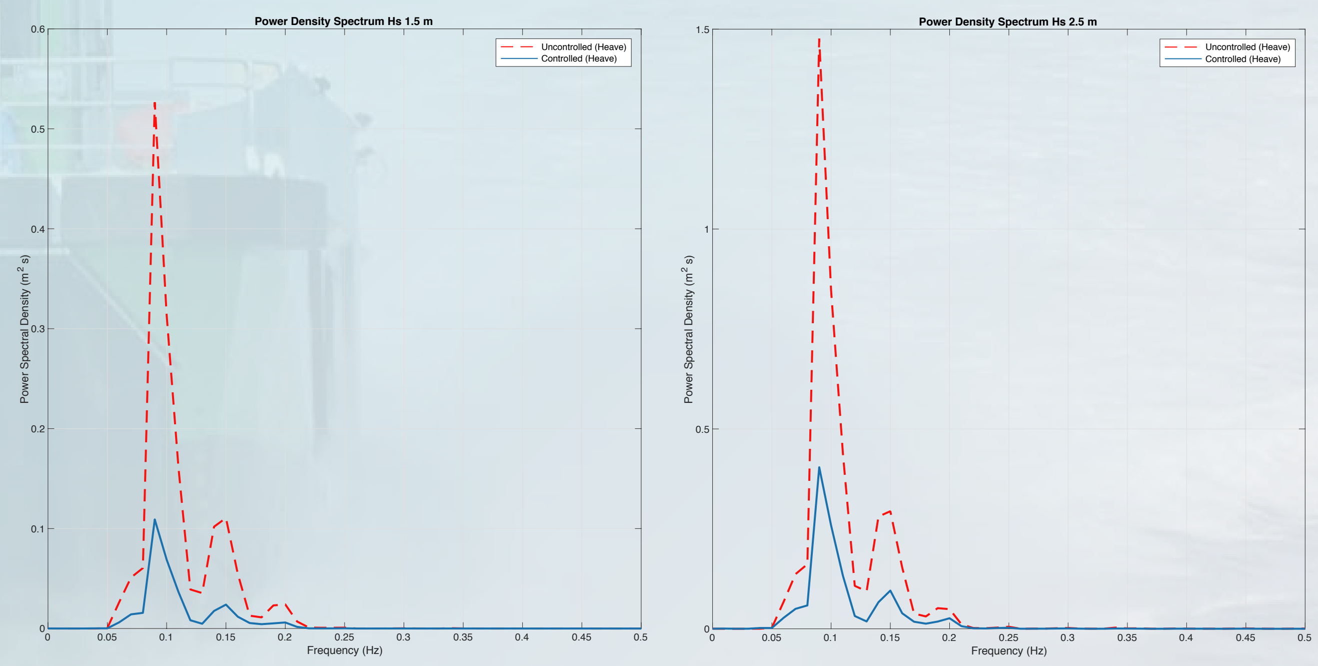

Figure 3: Power Spectral Density plots for different significant wave heights at different obtained controller parameters

Conclusions

- Linear interpolation proves to suffice as a method for development of simulation model for the SES with time-varying potential coefficients, with satisfactory small errors.
- Adaptive Control is applicable to the BCS, as means of obtaining satisfactory performance without operator intervention.