脱炭素船の MBD

MBD of Wind Assistive Ships

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Reducing CO2 emission is one of the targets for the many governments and companies. In marine industry, many steps were taken to reduce the CO2 emission levels and one of the ways is to use clean energy as much as possible and avoid using fossil fuels. Wind assistance system uses wind power to generate thrust and reduce the required propeller power generated by main engine. 1D CAE model of wind assisted ship was created to understand how each subsystem affects another and to estimate how much power reduction can be achieved by using wind sails.

Key Words : model-based design, system modelling, wind, sail, CO2 emission,

1. Introduction

Increasing CO2 emission is one the problems that many of industries are facing now. There are tremendous efforts to reduce the CO2 emission and to improve clean technologies. In marine industry, rotor sails, wing sails[1], kites, etc. were proposed to reduce required propulsive power from propeller. To understand the effect of different design parameters of the wind assist system on ship motion and ship maneuvering, model-based design approach can be used. The MMG model of ship was used to model motion of ship. The effect of hull, rudder, and propeller was considered separately. The effect of wind and wind sail system was included in this study [2]. The effect of wind sailing system on the performance was investigated.

2. Method

1D CAE model of the ship was created as shown in Figure 1. Hull resistance, propeller, rudder, main engine, hull-wind interaction, wind assist system, shaft generator, auxiliary diesel engine, battery and switchboard were included in the model. When main engine starts running at certain speed, rotational motion is transferred to propeller to generate propulsive forces. The remaining power of main engine is transferred to shaft generator. During the course of the ship, resistive forces were generated due to hull-sea and hull-wind interactions. The heading and position of the ship is controlled by rudder. In addition to conventional ships, wind sail generated forces acting on ship. The speed and heading of the ship were controlled by using PID controller.

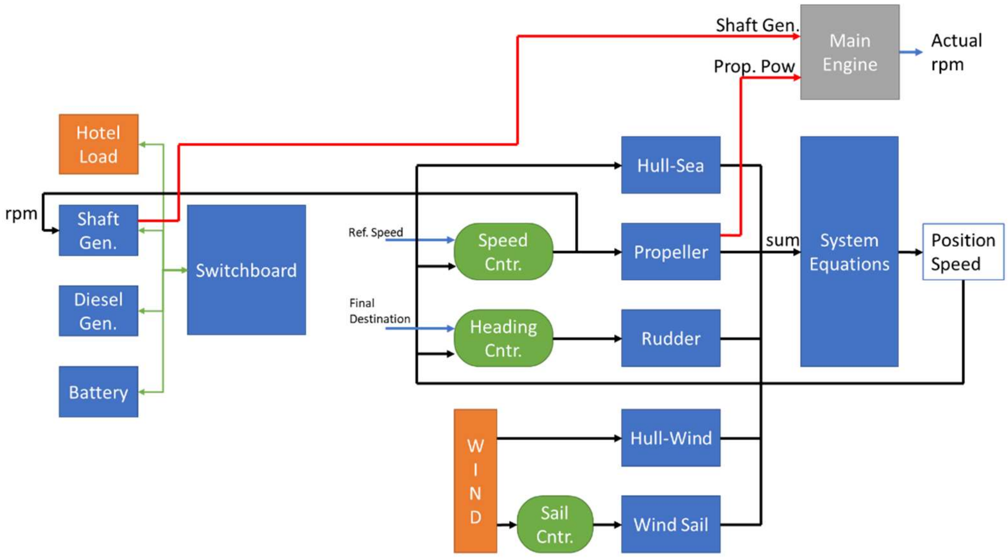

Figure 1. Overview of the system

The motion and manoeuvring of the ship were modelled based on the MMG model proposed by Yasukawa and Yoshimura[2]. MMG model considers each source of force separately and combine the effect of each system. Then, equation of motion is solved. Force generated by hull resistance, propeller, rudder, hull-wind interaction, and wind sailing system were shown in Eq. (1)-(5). $(X\text{-}Y\text{-}N)_H$, $(X\text{-}Y\text{-}N)_P$, $(X\text{-}Y\text{-}N)_R$, $(X\text{-}Y\text{-}N)_W$, are $(X\text{-}Y\text{-}N)_{WS}$ are forces created by hull resistance, propeller force, rudder force, wind effect on hull, and wind sailing systems. Hull resistance depends on density of water ρ, length of ship between perpendiculars L_{pp}, ship draft d, speed of ship U and hydrodynamic coefficients $(X-Y-N)'_H$. Hydrodynamic coefficients were found by normalized velocities v'_m and r' in y- and n-direction. Forces due to propeller was calculated by using thrust deduction factor t_p, density of water ρ, rotational speed o propeller n_p, diameter of propeller D_p and open water characteristics of propeller K_T, which depends on advance ratio J_P. Velocity around rudder section U_R and effective inflow angle to rudder α_R should be calculated to find rudder force. It also depends on density of water ρ, rudder area A_R, rudder lift gradient coefficient f_α, rudder angle δ, and rudder position x_R. Lift and drag forces due to interaction between hull and wind were calculated by considering dynamic pressure q_A, frontal and lateral area A_F and A_L, and aerodynamic coefficients of C_X, C_Y and C_N. Besides, wind sailing system also produces forces depending on the area of rotor sailing system A_{WS} and aerodynamic coefficients of C_{XS}, C_{YS} and C_{NS}.

$$
\begin{aligned}
X_H &= \left(\frac{1}{2}\right)\rho L_{pp} d U^2 X'_H(v'_m, r') \\
Y_H &= \left(\frac{1}{2}\right)\rho L_{pp} d U^2 Y'_H(v'_m, r') \\
N_H &= \left(\frac{1}{2}\right)\rho L_{pp}^2 d U^2 N'_H(v'_m, r')
\end{aligned} \tag{1}
$$

$$X_P = (1-t_p)\rho n_P^2 D_P^4 K_T(J_P) \tag{2}$$

$$
\begin{aligned}
X_R &= -(1-t_R)\left(\frac{1}{2}\right)\rho A_R U_R^2 f_\alpha \sin(\alpha_R)\sin(\delta) \\
Y_R &= -(1-a_H)\left(\frac{1}{2}\right)\rho A_R U_R^2 f_\alpha \sin(\alpha_R)\cos(\delta) \\
N_R &= -(x_R + a_H x_H)(1/2)\rho A_R U_R^2 f_\alpha \sin(\alpha_R)\cos(\delta)
\end{aligned} \tag{3}
$$

$$
\begin{aligned}
X_W &= q_A A_F C_X \\
Y_W &= q_A A_L C_Y \\
N_W &= q_A A_L L_{OA} C_N
\end{aligned} \tag{4}
$$

$$
\begin{aligned}
X_{WS} &= q_A A_{WS} C_{XS} \\
Y_{WS} &= q_A A_{WS} C_{YS} \\
N_{WS} &= q_A A_{WS} L_{OA} C_{NS}
\end{aligned} \tag{5}
$$

Power management system is also necessary to distribute and store energy during travelling. A simple priority-based power management system was implemented. Shaft generator generates power by connecting to main engine. The amount of energy to operate ship, which is called as hotel load, is obtained from shaft generator first. If additional energy is required, battery system supply energy to ship to overcome the energy requirement of the ship. If further energy is required, auxiliary diesel engines work. Also, there are cases in which shaft generator generates more power than required. In such cases, the excessive energy can be used to charge battery system.

In this study, mechanical systems and power systems were modelled to understand the effect of wind sailing systems on ship performance. How each subsystem works and how they affect each other was investigated by using 1D CAE and model-based design (MBD) approach.

3. Results

3・1 Ship Performance Under Constant Wind

First, the effect of sailing system and how each system interacts with each other was investigated under a given constant wind speed and direction. Wind was assumed to have speed of 20 m/s and coming from sides. The ship was initially at rest U=0 m/s. Then, propeller starts to rotate to achieve target speed controlled by speed controller. Target power of the main engine was reduced at 7500 seconds. Wind assisted systems activated at 10000 seconds. Variation of total power, shaft power, and propeller power was given in Figure 2.

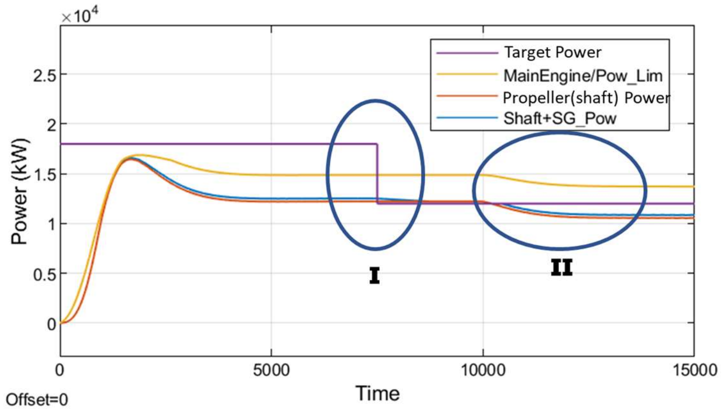

Figure 2. The variation of power systems of the ship

3・2 Ship Performance Under Real Wind Data

Secondly, a real wind data was applied to system and power variations were obtained as shown in Figure 3. In addition to variation of power, the performance of power management was also shown.

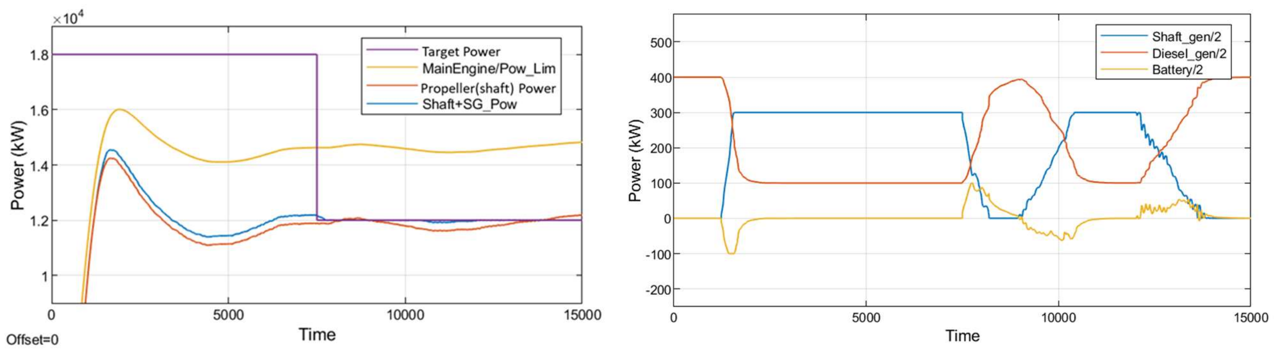

Figure 3. Power and electric system performance

4. Discussion

Model-based design approach allows us to understand the interaction between each subsystem. It was found that wind assistive systems reduced to propeller power and leads reduction in fuel consumption. The reduction in fuel consumption will cause a reduction of CO2 emission.

In the present study, target power is directly assumed to be a value, however, it should be updated through motion and determined based on engine characteristics. In future studies, it was planned to include main engine characteristics, and to improve subsystem modelling. Also, wind sailing system used in the present study have constant aerodynamic coefficients. Introducing varying aerodynamic coefficients depending on wind speed, rotational speed of rotor sail, etc. the optimal control of wind assist will reduce total power consumption further.

5. Conclusion

The present study focuses on how to model mechanical and power characteristics of wind assistive ship by using model-based design approach. 1D CAE model of wind assistive ships allows us to understand and predict the performance of wind assistive ship, develop the performance of wind assistance and to improve the controlling strategies.

References

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