CONTENTS AUTHORS

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IMPACT OF THE ENVIRONMENTAL SEA CONDITIONS TO SHIP'S PROPULSION ENGINE DYNAMICS

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ABSTRACT
Safely ship open sea sailing within hard environmental conditions like sea waves, wind, sea currents, etc. is very dependent on the propulsion system and its resistance to such external disturbances. Propulsion system of the majority of modern merchant ships (e.g. containerships, VLCCs and others) utilises the marine diesel engine as propeller drive. Typical marine propulsion system includes a single, long-stroke, slow-speed, turbocharged, two-stroke diesel engine directly coupled to the fixed-pitch propeller. Slow-speed diesel engines are usually built with a smaller number of cylinders and, consequently, a smaller number of other moving parts, increasing thus the reliability and availability of the ship's propulsion system. It is very important to investigate and analyse external sea conditions and their effects on ship's propulsion system dynamics and operating possibilities. For that reason, simulation was done with conditions very close to real conditions at open sea using Kongsberg Full mission Engine Room Simulator with 2-stroke marine diesel engine for propulsion on the VLCC ship[1]. Relevant propulsion engine variables and parameters were monitored and at the same time control system response observed during simulation with different sea conditions. Analysis of simulation results has been done and some conclusions regarding impact of severe sea conditions on propulsion engine dynamics.

Keywords: ship, propulsion system, environmental conditions, simulation

1. INTRODUCTION
The wind, waves and sea current as a part of environmental disturbances to the ship, are highly nonlinear. Wind is defined as horizontal movement of air to the surface on the sea and generates waves. The nonlinear dynamic equations of marine vessel motion can be expressed as follow [1]:

$$M\dot{u} + C(u)u + D(u)u + g(\eta) = \tau_c + g_0 + w \tag{1}$$

where:
M - system inertia matrix (including added mass), u - ship speed, $C(u)$ - Coriolis-centripetal matrix (including added mass), $D(u)$ – damping matrix, $g(\eta)$ - vector of gravitational/buoyancy forces and moments, τ_c - vector of control inputs, g_o - vector for pretrimming (ballast control), w - vector of

[1] *The results presented in the paper have been derived from the scientific research project „New Technologies in Diagnosis and Control of Marine Propulsion Systems" supported by the Ministry of Science, Education and Sports of the Republic of Croatia.*

environmental disturbances (wind, waves and sea currents). For control system design it is common to apply the principle of superposition when considering effects of wind and wave disturbances:

$$w = w_{wind} + w_{wave} \tag{2}$$

where $w_{wind}, w_{wave} \in \Re^6$ and represent the generalized forces due to wind and waves.
In general, the environmental disturbances will be additive and multiplicative to the dynamic equations of motion.

2. MODEL OF THE SHIP'S PROPULSION SYSTEM

The overall function of the propulsion system is to maintain the ship's ability to propel itself and to manoeuvre. The dynamics of the ship's propulsion system is non-linear and very complex [2,3]. The environmental conditions are very hard and changeable. Figure 1. show block diagram of the ship propulsion system with external disturbance contributing to the ship's dynamics.

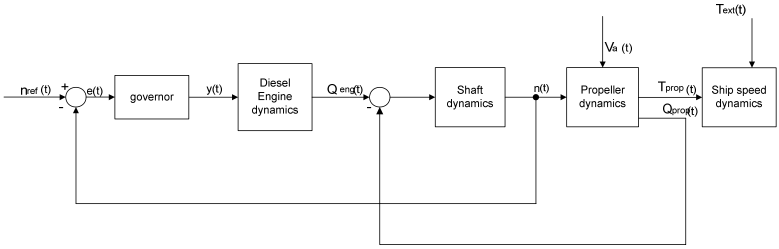

Figure 1. Block diagram of the ship propulsion system

2.1. Ship speed dynamics

The following non-linear differential equation approximates the ship speed dynamics [4]:

$$(m - X_{\dot{u}})\dot{u} = R(u) + (1 - t_T)T_{prop} + T_{ext} \tag{3}$$

The term *R(u)* describes the resistance of the ship in the water. It is a function of the ship speed and load conditions, $X_{\dot{u}}$ presents the added mass in surge, which is negative. The thrust deduction 1 - t_T represents the net thrust lost due to the propeller generated flow at the ship's stern. T_{ext} is the external torque i.e. disturbance to the ship caused by the wind and the waves.

3. SIMULATION CASES OF SEA ENVIRONMENTAL CONDITIONS

The simulation was done using Full Mission Engine Room Simulator with 2-stroke marine diesel engine of type MAN B&W 5L90MC [5] on the VLCC ship sailing at open sea. The simulations of environmental conditions include beaufort wind force of 0 (0 meter waves height and under 0,2 m/s wind speed), 5 (2,5 meter waves height and 30 m/s wind speed) and 10 (12,5 meter waves height and 90 m/s wind speed – storm). The simulation cases also include full loaded or in ballast ship's dynamics and different ship's speed. Table 1. shows relationship between scenario cases with different conditions and their impact on relevant ship's variables.

Table 1. Description of different scenario cases

Scenarios	Wind force		Ship load		Engine speed		Variables deviation	Actions
	5 Beauf.	10 Beauf.	ballast	Full (98%)	Half ahead	Full ahead		
Case 1.		x	x			x	very large	shut down
Case 2.		x		x		x	very large	shut down
Case 3.		x	x		x		large	alarms
Case 4.		x		x	x		large	alarms
Case 5.	x			x	x		small	no
Case 6.	x			x		x	small	no

During simulation, the most relevant ship's variables are continuously tracked: ship speed (red line), main engine shaft torque (orange line), main engine fuel oil consumption (green line), main engine exhaust gas smoke content (pink line), propeller efficiency (blue line) and total ship hull drag force (black line), see diagrams in figure 2. and figure 3. Minimum and maximum values of each variable are chosen to be the same in all scenario cases.

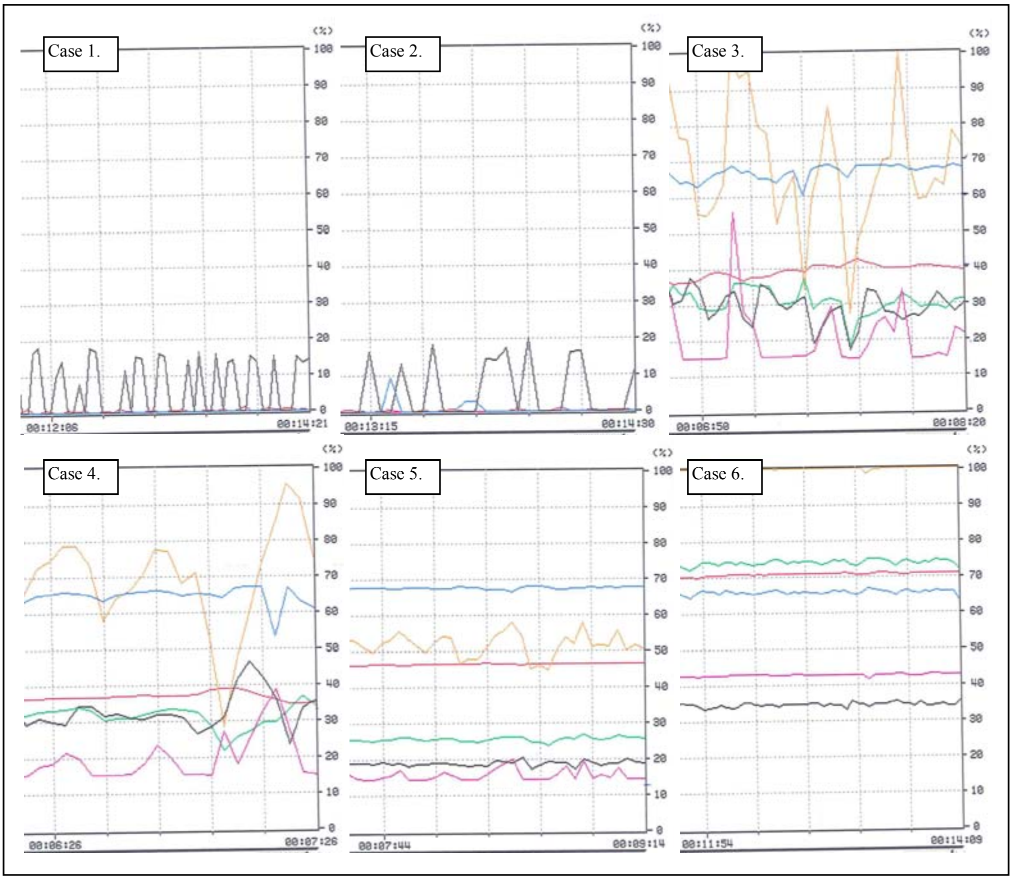

Figure 2. Graphs of scenario cases: see table 1.

From scenario cases 1. and 2. it can be seen, from engine variables time tracking, that all variables except ship hull drag force shortly after disturbance are reduced. In such hard environmental conditions ship's control system does not succeed to stabilize engine speed and power, so safety system takes, after short time, the shutdown action. In such environment condition engine running with full speed and full or ballast load can't ensure VLCC's sailing. Wind force of 10 beaufort has great impact on sea waves acting up to 2.5 MN force on ship's hull (sea wave force in state of 0 beaufort is 1 MN). If engine speed request is decreased to half ahead (case 3. with ballast and case 4. full loaded ship) within the same environmental disturbances on the VLCC ship, sailing is possible within tolerant fluctuations in engine and ship speed. In such hard sea conditions engine control system has to be very robust and self adaptive, even fault tolerant. Scenario cases 5. and 6. include the same ship's environmental and load conditions regarding different engine power. With full ahead engine running, variables: ship speed, main engine shaft torque, main engine fuel oil consumption and main engine exhaust gas smoke content are going to increase. However, comparing scenarios case 5. with scenarios case 6. it can be noticed that impact of wind and waves on ship's speed increase is much more expressed (ship hull drag force increases 44%). Comparing scenario case 6. with a case of calm sea condition (wind of 0 beaufort), effects of the environmental conditions can be clearly seen. Ship speed is reduced, 6.7%, main engine shaft torque is increased, 7%, main engine fuel oil consumption is increased, 5.5%, main engine exhaust gas smoke content is increased, 31% and total ship hull drag force is increased, 14%.

Influence of wind direction is also analysed and presented, see figure 3. Following conditions are the same in next scenario cases: wind force of 7 beaufort, half ahead engine power and full loaded ship. Case 7. includes wind direction of 0° (bow direction), case 8. of 90° (side direction) and case 9. of 180° (stern direction).

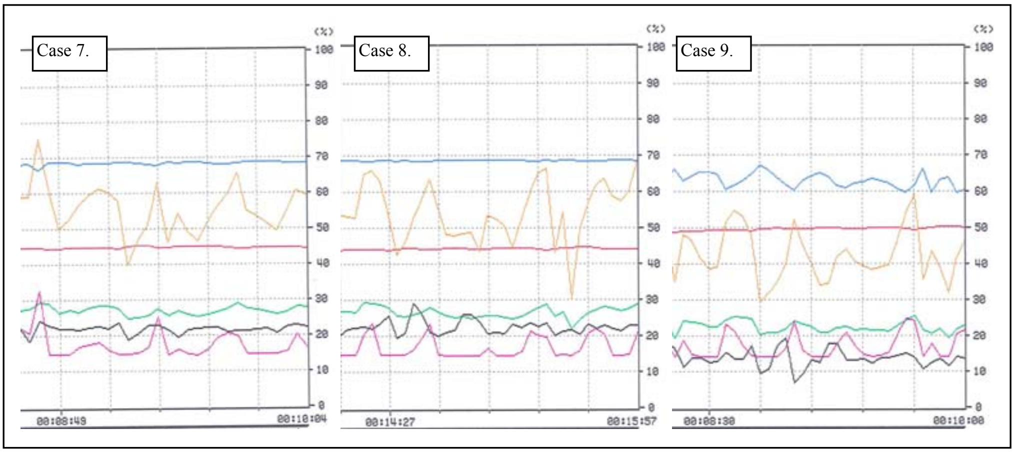

Figure 3. Graphs of scenario cases: impact of wind directions

Ship speed has the largest value with wind direction of 180° (10 knots), and the smallest value with wind direction of 90° (8.70 knots). Ship speed value with wind direction in bow is 8.85 knots. The other variables have the smallest values in case with wind direction of 180°. Total ship hull drag force variable is good example of the environmental influence to ship sailing dynamics. The smallest drag force is in the case of wind direction 180° (0.66 MN), and the great impact is in the case of wind direction of 0° (1.25 MN).

4. CONCLUSION

During sailing on the open sea, large ship has to dynamically respond to the various random disturbances, producing complex movement changes. It is very important to consider the impact of random wave disturbance forces and torques on the ship sailing and manoeuvring, starting from the phases of ship construction and building to the stage of ship's control system design and implementation. Te simulation method is very suitable for such tasks. The random wave disturbance forces and torques effecting on the large ship propulsion dynamics were simulated using Full mission engine room simulator with 2-stroke marine diesel engine for propulsion on the VLCC ship under different sea conditions. The simulation results show that the random wave disturbances have a great influence on the large ship dynamics. Simulation was done using different propulsion engine and ship conditions changing environmental sea conditions i.e. wave strength and wind power and directions.
The simulation results could be useful, especially in the control system design stage.

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