TRANSNAV
http://www.transnav.eu
the International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 13
Number 4
December 2019
DOI: 10.12716/1001.13.04.19

Simulation study on the Influence of EEDI Requirements to Shiphandling in Heavy Weather

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ABSTRACT: In order to reduce the CO2 emission from ships, International Maritime Organization executes the restriction of Energy Efficiency Design Index (EEDI) which limits amount of CO2 when freight of one ton is carried at one mile. Although the realization of higher efficiency of main engine without reduction of engine output is the best solution, it might be impossible. To comply with the EEDI requirements, it is assumed that the ship's engine power becomes smaller than the existing ship by means of improving the ship propulsive efficiency. However, shiphandling in rough seas is expected to become difficult when the engine power is reduced. In this paper it is shown that the influence of the degraded main engine exerts on the safety of shiphandling in heavy weather based on the simulation study. In these experiments, both the simulation model that decreased engine power corresponding to EEDI requirement and that with the conventional engine power were tested, and masters in active service maneuvered the test ships in the rough seas.

1 INTRODUCTION

International Maritime Organization (IMO) executes the restriction of Energy Efficiency Design Index (EEDI) which limits amount of CO2 when freight of one ton is carried at one mile (MEPC,2009). Moreover, an efficient ship operation based on Energy Efficiency Operational Index (EEOI) was requested from IMO to the ship operators (MPEC,2009). In phase 3 that is final stage of EEDI, the reduction in 30% is requested from the current state. To comply with the EEDI phase 3 requirements, it is assumed that the ship's engine power becomes smaller than the existing ship. However, shiphandling in rough seas is expected to become difficult when the engine power is reduced. As temporary steps, IMO adopted the tentative minimum engine power in adverse condition (MPEC,2013). However, the restriction is gradually strengthened then it is predicted that the engine power is restricted smaller in a future.

Therefore, this study examines the influence that the degraded ship's engine exerts on the safety of shiphandling in heavy weather based on the simulation study. The main problem on the shiphandling at stormy weather is caused by the reduction of ship speed. When the ship proceeds toward the wave and wind, the resistance of the hull is increased, and then the ship decreases the speed. To keep the ship's speed, the main engine output must be increased. However, the main engine enters the stage of torque rich that is the torque over zone caused by the reduction of ship speed. In this condition, the main engine output is automatically reduced preventing the damage of the main engine, and as a result, the ship's speed becomes lower and lower. If the ship's speed decreases greatly in adverse condition, the performance of rudder may deteriorate and the ship is jeopardized. Then, the master maneuver the ship corresponding to various situations like the strength and direction of

disturbances, condition of ship's speed reduction, target course, type of ship, ship's size etc. Therefore, in this study, masters in active service are invited, and the ship maneuvering simulator experiments in heavy weather are performed. The simulator experiments were set for the comparative study with the maneuvering performance in rough seas by using the simulation model that decreased engine power corresponding to EEDI requirement and that of the conventional engine power (Yasukawa,2008). As the result of the simulator experiments, the safe shiphandling limit of the EEDI compliant ship has decreased by one stage comparing with conventional ship in the Beaufort scale.

In this paper, section 2 introduces the method of shiphandling in heavy weather of hearing from the masters. The experimental method and the experimental results are shown in section 3 and section 4 respectively. Finally, a discussion of our findings and the conclusion drawn from this study are presented in section 5 and 6, respectively.

2 METHOD OF SHIPHANDLING IN HEAVEY WEATHER

This section indicates the method of shiphandling in heavy weather. The method is different in each of ship's type. Therefore, the standard method and the typical method for bulk carrier and pure car carrier (PCC) are shown. The followings are the summaries of the interview results to masters.

2.1 *Standard Shiphandling Method in Heavy Weather*

During the heavy weather, as a danger phenomenon to be noticed on shiphandling when the ship proceeds against the wave, propeller racing, torque rich of the main engine, taking green water over the bow (green water taking), slamming and accompanying whipping can be pointed out. In order to avoid these danger phenomenon, it is known that speed deceleration and change of course are effective. In addition, as a shiphandling method when the ship encounters heavy weather and it becomes difficult to continue navigation, the master selects "Heave to" that reduces the speed of the ship to the extent that the steering effect is not lost and receives the wind and waves from 22 to 33 degrees from the bow.

2.2 *Shiphandling Method for Bulker in Heavy Weather*

In bulker, the output of the main engine is a relatively small compared with the hull size. Therefore, in calm weather the bulker sails at about 14 knots at full loading, and sails at about 15 knots at ballast condition. When bulker avoids stormy weather in advance, a speed of 12 knots or more is required. The bulker at the encounter of rough weather needs to pay attention to slamming and green water taking. Then, bulker sails by receiving the wave from the direction of 30° from the bow at a speed of 3 to 5 knots with lowering the main engine output with C fuel oil as it is. In addition, the master told that bulker rarely took "Heave to".

2.3 *Ship-handling Method for PCC in Heavy Weather*

Although PCC has a high-power main engine, it has a large wind receiving area. Therefore, in calm weather the PCC sails at 18.5 to 20 knots. Then, when it comes to the Beaufort scale 6 to 7, the PCC decelerates. When the PCC encounters stormy weather the master pays attention to green water taking than slamming. Then the PCC decelerates to 6 to 10 knots avoiding torque rich zone of main engine, and sails by receiving the wave from the direction of 40° from the bow when the ship condition is full loaded. At the ballast condition, the PCC sails by receiving the wave from the direction of 34° from the bow. In addition, when the PCC decelerates to 4 knots, the bow is hit by a wave and the hull lies between waves. This is a dangerous state where the ship is difficult to control her attitude by steering. In this case, the ship sails while receiving the transverse wave to the hull until the ship's speed increases to 8 knots. After that, the master changes the ship's course to windward and recover the ship's attitude.

3 EXPERIMENTS

3.1 *Target ships*

PCC carrying 3,500 units (Full load) and 54,000 DWT Panamax Bulker carrying wood chip (Half load condition) were used in this study. Principal particulars of these ships are shown in Table 1. "EEDI" included at main engine means the power corresponding to the EEDI Phase 3 in this table.

These are named (EEDI Power) and estimated from the existing power (Existing Power) improving the propulsive performances of ship. Method for estimating power curve and speed table of the EEDI power ship based on existing power ship are described in chapter 3.2.1. Additionally, procedure to realize the torque rich in simulator experiments is described in chapter 3.2.2.

Table 1. Principal particulars of target ships

	PCC	Panamax bulker
	3,000 units Full load	35,000 DWT Half load
Hull		
G.T.	51,819	43,000
LOA (m)	180.00	209.00
LPP (m)	170.00	204.00
B (m)	32.26	32.2
Fore Draft (m)	8.80	9.50
Aft Draft (m)	8.80	9.50
Trim (m)	Nil	Nil
Displacement (ton)	28,000	49,923
Main engine		
MCO (kW)	13,920	9,700
MCO (EEDI kW)	10,970	7,275

3.2 *Estimation of power curve and speed table*

3.2.1 *Power curve of EEDI power ship*

The calculation method of power curve and speed table of EEDI power ship are described in this chapter. The authors supposed that the ship resistance

in navigation speed of existing ship was reduced 20% by some technological innovation. In general, it is necessary to redesign principal dimension of propeller in this case. However, the self-propulsion factors remained unchanged for the estimation of EEDI power ship in this study. In such way, required engine output (BHP) of EEDI power was reduced 20% from the existing ship. The propeller efficiency was also improved by the reduction of propeller loading that was introduced by the reduction of ship resistance, which made BHP further reduce. Furthermore, the improvement in the fuel economy of entire plant was expected by some technological innovation in the future. As the results, power curve and speed table of EEDI power ship was calculated so as to be the total CO2 emissions cut by 30% in the 75%MCR speed from existing ships. Although the maximum power and revolutions of main engine are discontinuously provided in general, they could be selected as designed in this study.

PCC's power curve of existing ship and EEDI power ship are shown in Figure 1, and Panamax bulker's power curve of existing ship and that of EEDI power ship are shown in Figure 2. In each figure, the left ordinate indicates BHP and the right ordinate indicates revolutions of main engine. The abscissa indicates ship speed in these figures. The solid line of brown color shows power curve of existing ship, and the brake line of brown color shows power curve of EEDI power ship. Additionally, the solid line of blue color shows revolutions of existing ship in the 75%MCR speed, and the brake line of blue color shows revolutions of EEDI power ship in the 75%MCR speed.

3.2.2 *Setting of torque rich conditions*

Ship speed is significantly reduced by the head wave and wind in heavy weather. In this case, the propeller torque is increased. As a result, torque rich condition appears. In this condition, the governor of main engine is controlled to reduce revolution of main engine. In order to maintain the safety and serviceability of main engine, the controlling value of governor are set in advance by engine manufacturers. However, since the type of main engine could not be set in the simulator, the revolution of main engine was limited so as not to exceed the torque in the MCR speed simply.

Specifically, the each torque was calculated for various ship speed and revolution in advance, and the revolution of main engine was coercively set by the operator corresponding to the ship speed. When the revolution was limited by operator, it was soon informed to the bridge. This torque rich procedure was available when engine telegraph was set to over "Stand by Full". Red colored lines in Figure 1 and Figure 2 indicate maximum revolution of main engine used in simulator experiments.

3.2.3 *Setting of weather conditions*

The wind and wave in simulator experiments were set in the Beaufort scale 7 through 11, and the wind and wave conditions are shown in Table 2. The wind speed was set as the fluctuating wind and the wave was set as the irregular wave. In this Table, wind speed is average one and wave height is significant wave height corresponding to the Beaufort scale. The wave was defined as combination wave incorporate wind waves and swell. The wind direction and the wave direction were set as same value in the experiments.

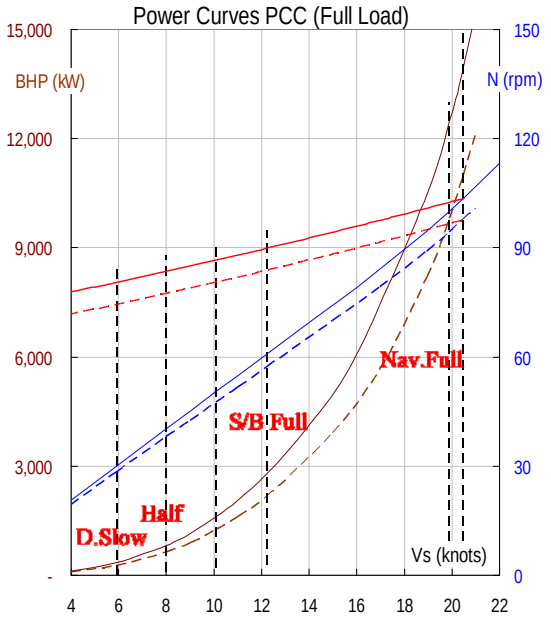

Figure 1. PCC's power curve of existing ship and EEDI power ship.

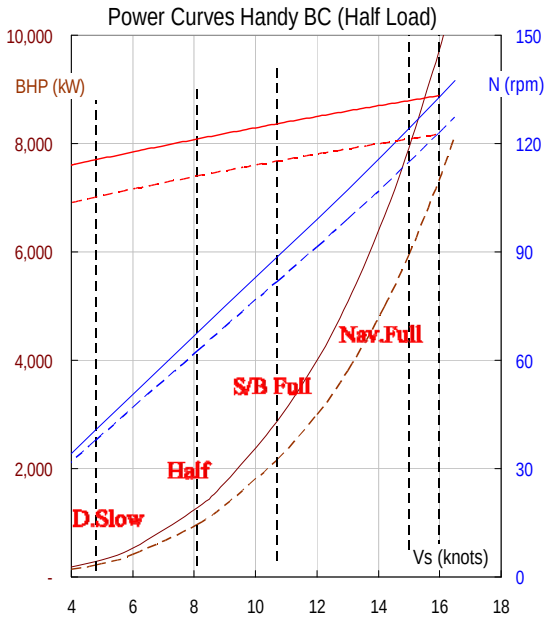

Figure 2. Panamax bulk carrier's power curve of existing ship and EEDI power ship.

Table 2. The wind and wave conditions in experiments.

Beaufort Scale	Wind (m/s)	Wave (m)
7	15	4
8	19	5.5
9	22	7
10	26	9
11	30	11.5

3.3 *Scenario of simulator experiments*

The scenario of simulator experiments is developed on the basis of the shiphandling methods in the head seas in heavy weather that are described in chapter 2.

The ship is proceeding with slow speed under receiving the bow seas. In this condition, the ship course changes by the wave force and ship begins to receive the transverse wave to the hull. As a result, rolling of ship is increased. In order to avoid the heavy rolling, it is necessary to change ship course to windward and recover the ship's attitude immediately.

Under the above condition, ship motions of EEDI power ship and existing ship were compared. Scenario and procedure of shiphandling are shown in

1 The initial speed of ship is 5 knots, and the ship receives the transverse wave and wind from
2 Ship course changes to the direction that the ship receives wind and wave of starboard bow

whether this course can be kept on the constant speed of 3 to 10 knots.

The effect of green water taking and slamming were not considered in experiments, because it is difficult to reproduce these phenomena in the simulator.

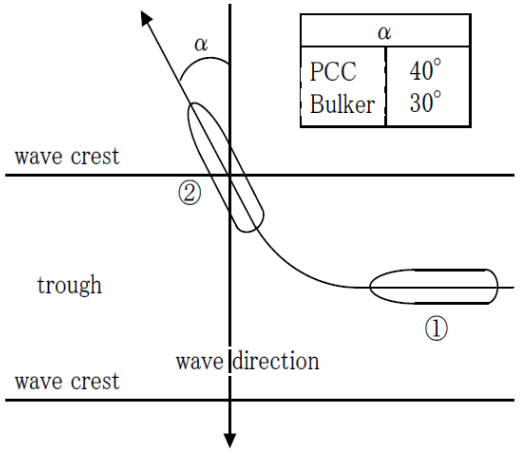

Figure 3. Scenario and procedure of shiphandling.

4 RESULTS OF EXPERIMENTS

4.1 *Results of PCC*

Ship tracks of the simulator experiment result are shown in Figure 4 and 5, and the time series of ship's heading and speed are shown in Figure 6 and 7. Figure 4 and 6 indicate the results of the conventional engine power ship, and Figure 5 and 7 indicate the results of the decreased engine power corresponding to EEDI requirements. In the figure 6 and 7, the black colored line shows result with Beaufort scale 7(BF7), the rad colored line shows result with Beaufort scale 8(BF8), the green colored line shows result with Beaufort scale 9(BF9), the blue colored line shows result with Beaufort scale 10(BF10), and the purple colored line shows result with Beaufort scale 11(BF11).

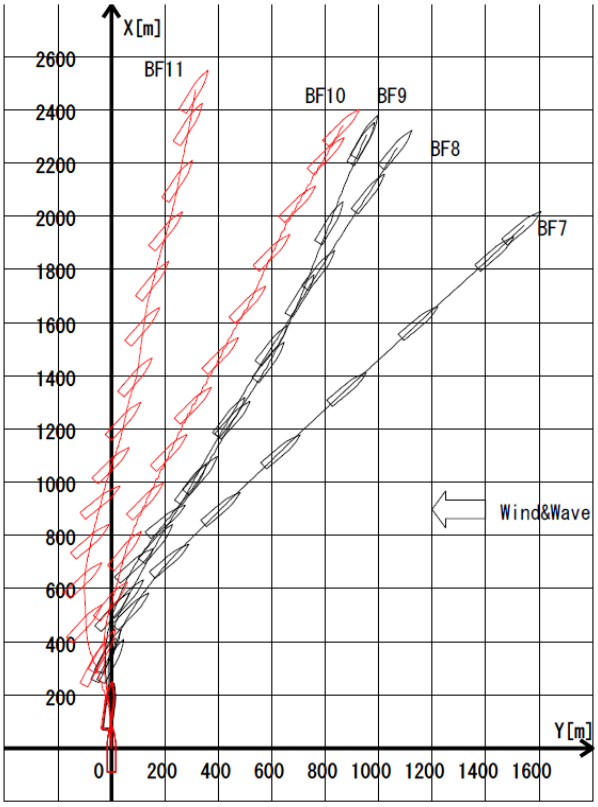

Figure 4. Ship tracks of PCC (Conventional)

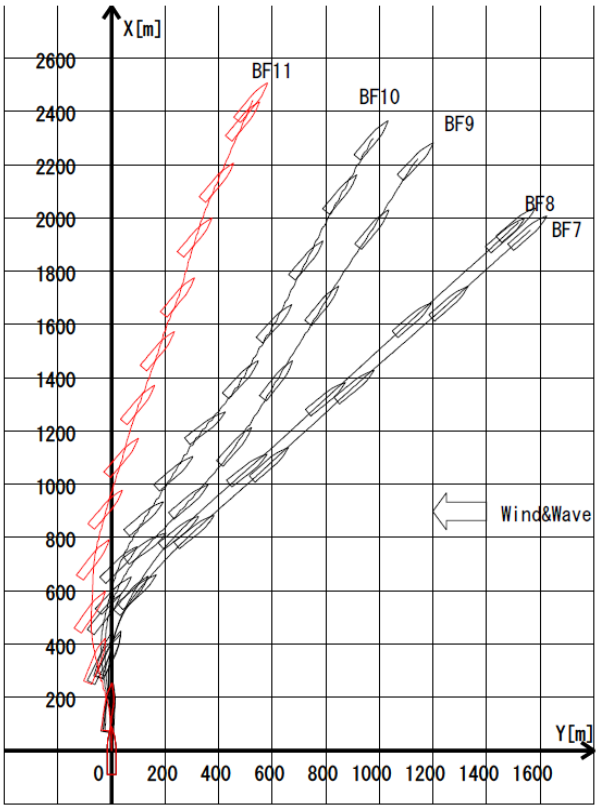

Figure 5. Ship tracks of PCC (EEDI)

The conventional engine power ship had enough speed at the heading of 50° in the case of BF7 and BF8, but in the case of BF9, the heading was changed to 40° to have enough speed. Also, the ship could have enough speed such as 10 knots with the heading of 40° in the case of BF10. However, in the case of BF11, it was only 7 knots even the heading was 40°. In that

state, the ship receives the diagonal wave and the ship rolls greatly. Therefore, it is difficult to do the shiphandling assumed by the scenario and to continue sailing by the same course.

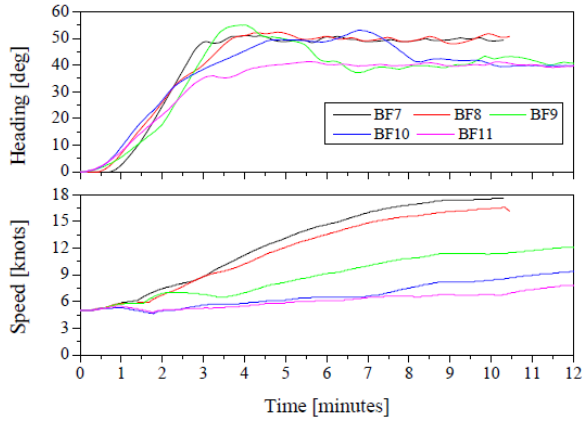

Figure 6. Time series of heading and speed of PCC (convent.)

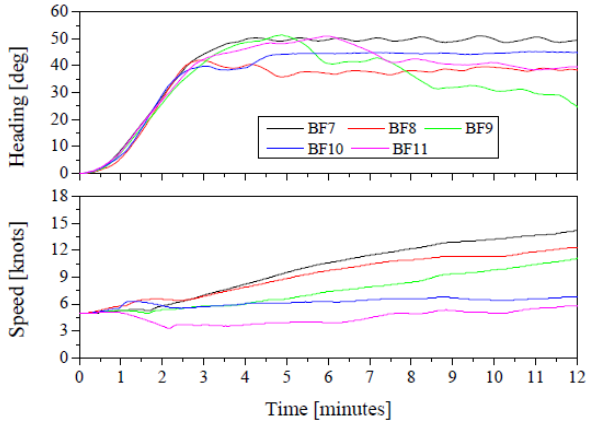

Figure 7. Time series of heading and speed of PCC (EEDI)

The EEDI power ship could keep enough speed at the heading of 50° only in the case of BF7. In the case of BF9, the ship could obtain the speed of 11 knots by changing the heading to 30°. However, in the case of BF10, the ship's speed was only 6 knots even the ship's heading was changed.

From the results of simulator experiments, the limitation where the shiphandling that is assumed by the scenario could be continued is BF10 for the conventional engine power ship, and BF9 for the case of corresponding to EEDI requirements.

4.2 *Results of Bulker*

For bulker, simulator experiments were conducted in Beaufort scale 7 through 9. The ship tracks are shown in figure 8 and 9, and the time series of ship's heading and speed are shown in figure 10 and 11. Figure 8 and 10 indicate the results of the conventional engine power ship, and figure 9 and 11 indicate the results of EEDI power ship. In the Figure 8 and 9, descriptions were same as Figure 4 and 5.

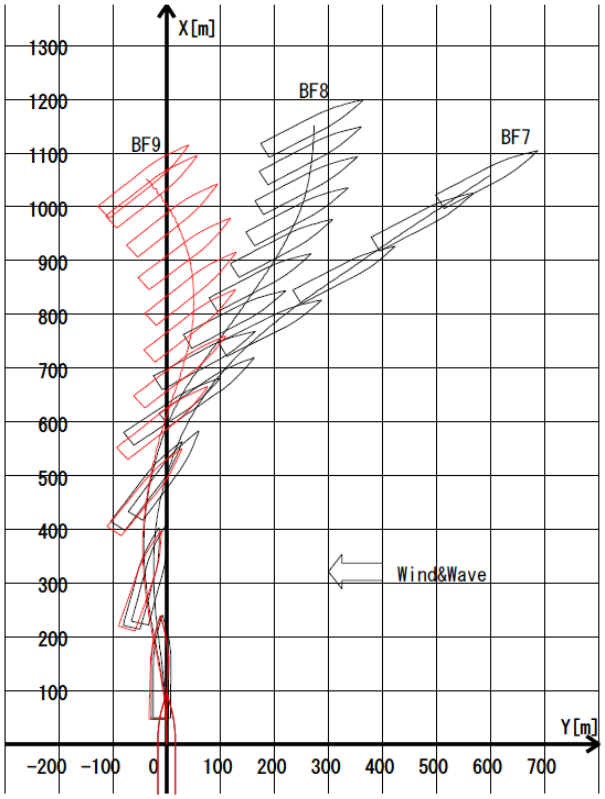

Figure 8. Ship tracks of bulk carrier (conventional)

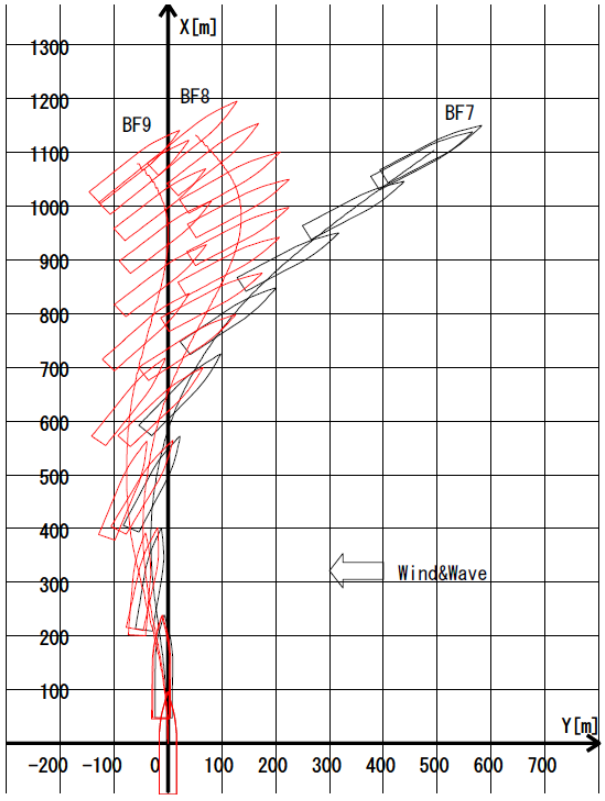

Figure 9. Ship tracks of bulk carrier (EEDI)

In the case of BF7, the conventional engine power ship could keep the ship's heading to 60° which was target course in the scenario with speed of 7 knots. In the case of BF8, the ship could keep the course to 60° however the ship's speed had been reduced to 1.5 knots. Then the ship's speed became almost zero, even if the ship's heading was changed to 50° in the case of BF9. This is the state of "Heave to" described

in section 2.1. The EEDI powership could keep the ship's heading to 60° with enough ship's speed to sail in the case of BF7. However, the ship's speed became almost zero in the case of BF8. That state is "Heave to" same as conventional ship in the case BF9.

From the results of simulator experiment, the limitation where the shiphandling assumed by the scenario could be continued is BF8 for the conventional engine power ship, and the case of corresponding to EEDI requirement is BF7.

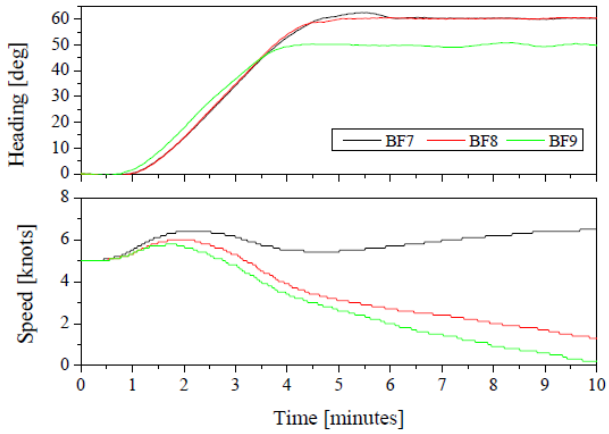

Figure 10. Time series of heading and speed of bulk carrier (conventional)

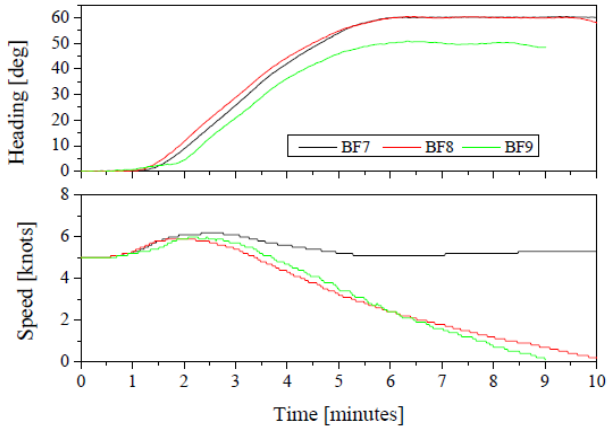

Figure 11. Time series of heading and speed of bulk carrier (EEDI)

5 DISCUSSION

Based on the experimental results, it can be said that in the case of a moderate high-speed ship with high power engine output such as PCC, the influence of reduction of the engine power due to the EEDI requirements on the shiphandling in the heavy wave is relatively small. However, the following comment was obtained from masters who participated in the experiments. "For recent 6,000 units PCC, the engine power is not larger than those of ten years ago, so when the ship encounters heavy weather we can-not steer with auto-pilot in early stage of heavy weather. The work load of the crew increases if the ship's course cannot be kept by the auto-pilot." Then, it is predicted that the ship corresponding to EEDI requirements cannot use auto-pilot at early stage of stormy weather than present PCC, and the crew's work load increases greatly.

On the other hand, since bulker has smaller main engine output against the hull size, reducing the main engine output by EEDI requirements has a big influence on shiphandling. Therefore, it is important to operate the EEDI power ship by means of avoiding heavy weather areas in advance properly accumulating the forecast information.

6 CONCLUSION

In this study, the authors conducted comparative simulator experiments of shiphandling in heavy weather with the conventional engine power ship and the EEDI power ship, and evaluated the influence of reduction of main engine output on the shiphandling. In the simulator experiments using PCC, the safe shiphandling limit of the EEDI power ship was the state of Beaufort scale 9 and that of conventional output ship was the state of Beaufort scale 10. For the simulator experiments using bulkier, the limit of shiphandling assumed to be the state of Beaufort scale 8 for conventional engine power ship and to be the state of Beaufort scale 7 for the EEDI power ship.

In this simulator experiments, it was carried out under limited conditions such as estimation of power curve, handling of torque rich, handling of waves, etc. as mentioned in Section 3. Also, the simulation did not consider the effects of slamming and green water taking. In the future, it may be desired to per-form the simulator experiment which more accurate-ly reflects the actual situation of shiphandling for heavy weather in the actual sea area.

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