Analysis of the Influence of Propeller Fouling on the Shaft Power Due to the Long Immobility Periods

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1. Introduction

Biofouling is a significant factor that declines the propulsion performance of all vessels. Aquatic species on the hull and the propeller cause an increase in frictional resistance on the hull and the propeller. Finally, it leads to the degradation of the propulsion performance. Some studies analyzed the fouling influence on entire vessels based on monitoring data of actual vessels. However, few studies evaluated the fouling influence only on the propeller. It was not able to figure only the fouling influence on the propeller out from the observed data on the actual ship because the ship performance is affected by both the hull roughness and the propeller roughness. To analyze only the influence of the propeller fouling, this paper focuses on the required power at the specific condition of a controllable pitch propeller (CPP) that does not provide any net thrust by tuning its blade angle in neutral. This study named this required power Rotational horsepower (RHP)[(1)]. The previous study[(2)] analyzed the change of RHP values from the observed data on ship A. Fig. 1 shows the trend of RHP for a year after leaving a dock each year for a decade from September 2011 to September 2020. From this result, it was found that RHP increases for a time after dry-docking, and it means the increase in RHP indicates the progression of the propeller fouling.

In general, the amount of fouling on the hull is related to the amount of time a vessel has spent in a port because aquatic organisms can easily attach to a hull while a ship stays in a port. Some ship companies conduct short navigation to prevent fouling on the hull and to peel off fouling from the hull[(3)]. Similarly to the hull, it can be assumed that a propeller gets fouled significantly during a port stay. This paper analyzes the influence of the propeller fouling due to long immobility periods. By comparing values of RHP before and after immobility periods, this paper attempts to evaluate the influence of a long immobility period on the progression of the propeller fouling.

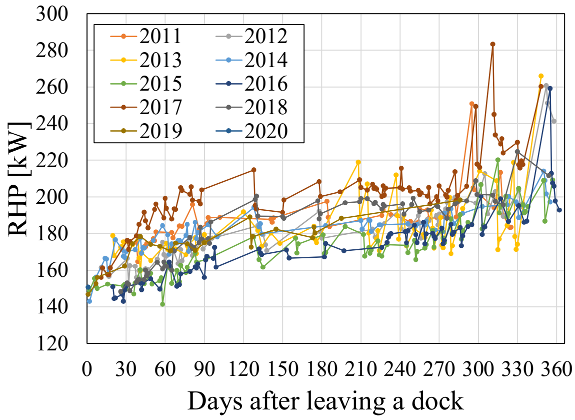

Fig. 1 Trend of RHP

2. Observed Data

This paper uses the observed data from 2011 to 2020 on ship A which is the training ship that mainly navigated in Tokyo Bay. Table 1 shows the specifications of ship A. The data are recorded every second and obtained by using an onboard monitoring system. Shaft power (SHP), shaft speed, propeller blade angle, rudder angle, ship speed, and ship’s heading course were used to analyze the fouling and to extract the data in the static condition.

Table 1 Specifications of ship A

Items	Ship A
Length over all	49.9 m
Shaft speed	300 min^{-1}
Rated power of the main engine	1,000 kW
Maximum ship speed at sea trial	14.5 kt
Propeller	4 blade CPP

3. Rotational Horsepower (RHP)

3.1 Definition of RHP

To analyze the influence of the propeller fouling, the specific condition of a CPP was focused on. Generally, a CPP is driven at a constant speed, and its blade angle is changed to control the thrust force. When the propeller blade angle is neutral, the propeller does not push the hull. However, a CPP requires power to some extent for keeping its constant speed even if its blade angle θ is neutral. The energy is mainly dissipated to rotate seawater around the propeller. Hence, it is named rotational horsepower (RHP) in this study. It is assumed that the increase in RHP means that the frictional resistance of the propeller is increasing because the fouling on the propeller is proceeding.

$$RHP = SHP_{(\theta=\text{Neutral})} \qquad (1)$$

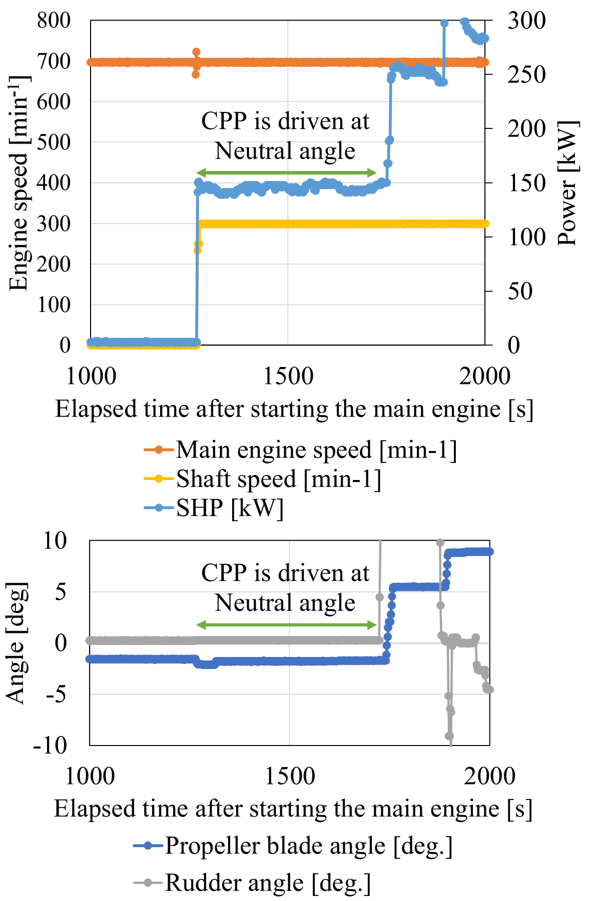

Fig. 2 Measuring period of RHP before starting navigation

3.2 Measuring of RHP

RHP values were extracted from observed data just before starting the navigation and finishing the navigation. Fig. 2 shows a sample of the observed main engine speed, shaft speed, SHP, blade angle of a CPP, and rudder angle during the period when the voyage started. Before starting the voyage, the main engine runs at idling condition for a while so that engineers check all operating status in the propulsion system and the power plant. To obtain the RHP value from the observed data, thresholds were set for shaft speed, propeller blade angle, and rudder angle. RHP was obtained from the data which satisfies all the thresholds. The average of RHP was calculated on each voyage and recorded as a representative value, respectively.

In the previous study, the RHP value was only observed from the monitoring data just before the start of a voyage. However, it is natural to think that the amount of fouling can be changed during a voyage. To obtain the change of RHP accurately, the RHP value just before finishing the navigation was also obtained using the same scheme mentioned above. The RHP value just before starting the navigation is named RHP_s, and the RHP value just before finishing the navigation is named RHP_f as illustrated in Fig. 3.

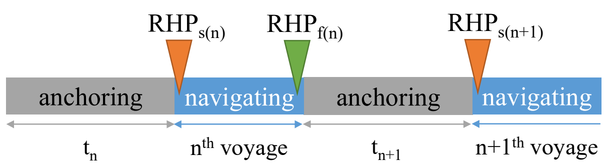

Fig. 3 measurement points of RHP

4. Immobility Periods

4.1 Calculation

4.1.1 Immobility periods

In this study, immobility periods are defined as the number of nights the ship is anchored or moored before the next voyage. The minimum immobility period is one night because ship A did not navigate during the nighttime. The immobility period is determined by the number of nights between $(n-1)^{th}$ voyage and n^{th} voyage as follows:

$$t_{(n)} = date_{(n)} - date_{(n-1)} \qquad (2)$$

where,

$t_{(n)}$ is the immobility period of n[th] voyage;

$date_{(n)}$ is the date of n[th] voyage.

4.1.2 Change of RHP

To investigate the influence of immobility periods, the change of RHP between two consecutive voyages was calculated as the following formula.

$$\Delta RHP_{(n)} = RHP_{s(n)} - RHP_{f(n-1)} \qquad (3)$$

where,

$\Delta RHP_{(n)}$ is the change of RHP during an immobility period in kW;

$RHP_{s(n)}$ is the RHP value measured at the start of n[th] voyage in kW;

$RHP_{f(n-1)}$ is the RHP value measured at the end of (n-1)[th] voyage in kW.

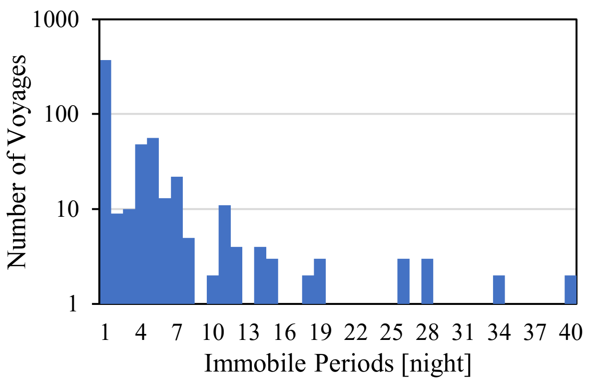

Fig. 4 Histogram of immobility periods

4.2 Distribution of immobility periods

Fig. 4 shows the histogram of immobility periods for 10 years. Ship A experienced one night immobility period many times. On the other hand, long immobility periods over 8 days account for 10% and there are the data for much longer immobility periods: over two weeks. It is thought that these long immobility periods correspond to a new year holiday or a spring vacation.

4.3 Increase in power

An increase in RHP means the progression of fouling on the propeller because the propeller fouling affects the frictional resistance on the propeller, which increases the power required to keep its constant speed. If the propeller fouling progresses according to the immobility period, it can be assumed that ΔRHP during the long immobility period becomes higher than ΔRHP during the short immobility period. To compare ΔRHP values by immobility periods, immobility periods were classified into the following three groups: (1) 1-3 nights, (2) 4-7 nights, and (3) over 8 nights. It is thought that the propeller easily gets fouled when the seawater temperature is high because aquatic species reproduce actively, which may lead RHP to be larger. Thus, the observed data were also classified into the following three seasons by days after docking: (I) under 90 days after docking, (II) 91-270 days after docking, and (III) over 271 days after docking. Fig. 5 shows the boxplots of ΔRHP in each season. Ship A used to be dry-docked every summer season, thus each season is approximately equivalent to (I) September to November,

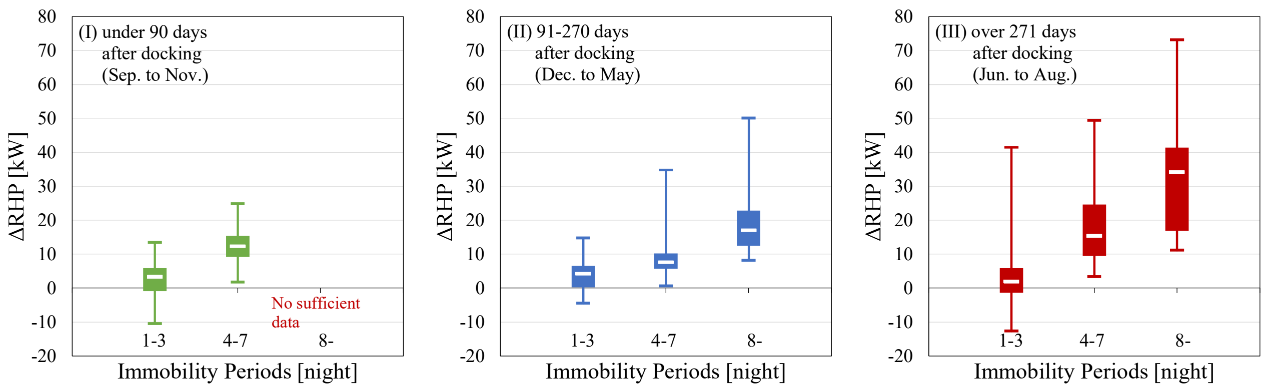

Fig. 5 Increase in RHP

(II) December to May, and (III) June to August.

Fig. 5 indicates that ΔRHP with a long immobility period is greater than ΔRHP with a short immobility period in all groups. The median values of ΔRHP after the short immobility under 3 nights were close to zero. However, both maximum, median, and minimum values of ΔRHP increased with the immobility periods. Comparing the results in each season, ΔRHP in (III) is higher than the others in the same immobility group, and this tendency is particularly apparent in the data during long immobility periods over 4 nights. Therefore, it is considered that the propeller gets fouled more severely during a long immobility period than during a short immobility period. Especially, the immobility period has a great impact on the fouling during the summer season from June to August.

4.4 Fouling decrease during navigation

Focusing on Fig. 1, RHP does not always increase monotonically over time, but rather repeatedly increases and decreases. It is thought that a part of fouling on a propeller is removed while a propeller is driven. To figure it out, the change of RHP between RHP_s and RHP_f at the same voyage was calculated using the following equation:

$$\Delta RHP'_{(n)} = RHP_{f(n)} - RHP_{s(n)} \qquad (4)$$

where,

$\Delta RHP'_{(n)}$ is the change of RHP during n^th voyage in kW.

$\Delta RHP_{(n)}$ shows the increase in the fouling during the immobility period before n^th voyage, and $\Delta RHP'_{(n)}$ shows the increase in the fouling during navigation on n^th voyage. ΔRHP and ΔRHP′ were compared to pursue the change of fouling. Fig. 6 shows the correlation between ΔRHP and ΔRHP′, and the linear line with slope -1. Judging from the figure, ΔRHP′ has a negative value in most cases, though the value of ΔRHP becomes positive. It is thought that RHP was changed in the following sequences. (1) RHP increased during an immobility period, which makes ΔRHP positive, and (2) RHP decreased during several hours of navigation, which makes ΔRHP′ negative. Going through these procedures, it is thought that a major part of the fouling was removed while the ship went on the subsequent voyage. Therefore, the increase in RHP due to the long immobility period does not persist, and some of the fouling peels off when the propeller rotates. Comparing the data in Fig. 6 to the linear line with slope -1, most of the data in which ΔRHP is over 20 kW are on the right side of the linear line with slope -1. It means that the significant fouling due to a long immobility period is not removed completely during navigation even if the propeller rotates for several hours.

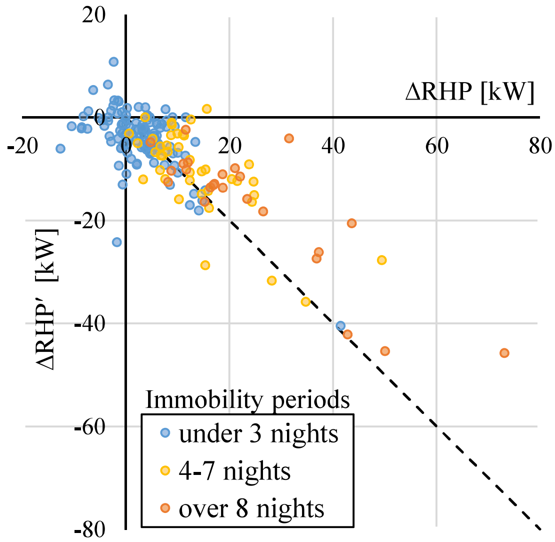

Fig. 6 Correlation between ΔRHP and ΔRHP′

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