Monitoring of Service Performance of a ROPAX Ferry

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The original evaluation of the propulsive performance of a ship should target the real sea area performance. Evaluations of the age deterioration and of the influences of the external forces of wind and waves are also needed. However, the grasp of the actual propulsive performance is hindered by many challenges, including difficulties with the methods for measuring a real ship and evaluating the measurement data etc. that should be examined. We installed a service-monitoring system on a large passenger ferry built by Mitsubishi Heavy Industries, Ltd. (MHI), and collected data to quantify components of propulsive performance such as the engine output, speed, fuel oil consumption, etc. under actual service conditions. This paper reports the results of the service monitoring of a ROPAX ferry in operation in the Seto Inland Sea route, as an example of a case analysis. The results show the suitability of our analysis method and confirm the excellent propulsive performance of this MHI-built ferry even in actual seas.

1. Introduction

The propulsive performance of a ship is evaluated and guaranteed by a speed trial, with the expectation that the seas will be calm during the official sea trial prior to delivery. However, wind and waves influence the ship during actually operation. Therefore, in recent years, an approach to evaluate the performance based on the performance in a real sea area has been activated(1-3).

MHI has been developing a system for monitoring the service performance using the ROPAX Ferry as a model case, and trying the grasp of the ability of the ship in actual service(4). If the propulsive performance of a ship can be analyzed by sampling data suitable for grasping the propulsive performance under actual conditions (e.g., in a sea area with sufficiently deep water, etc.) while considering the effects of disturbances such as wind and waves, then we will be able to clearly understand the difference in actual performance from the performance determined in an official sea trial, and to evaluate the suitability of the planned sea margin for the ship at the same time. Information useful to the economical operation of a ship can also be offered, if both the propulsive performance and fuel oil consumption performance can be evaluated together.

This paper outlines the monitoring system developed by MHI, describes a trial use of this system to monitor the service performance of a ROPAX ferry in service in the Seto Inland Sea, and reports the results of a trial analysis of factors that increase resistance and horsepower by applying a trial analysis procedure.

2. The system for monitoring the service performance

2.1 Outline of the system

The system for monitoring service performance analyzes the actual service of a ship by recording the various signals (engine, ship motion, meteorological phenomenon, operations, etc.) from the ship with an automatic recording device installed inside the ship and then using and analyzing the recorded data on land.

2.2 Configuration of the system

This system is composed of two components: and automatic recording device for data measurement processing and a data analysis system for analysis processing. **Figure 1** shows the system configuration of the monitoring system.

2.3 Automatic recording device

Figure 2 shows an example of an automatic recording device installed. This device is composed with general-purpose equipment such as a personal computer, A/D converter, communication board, instrumentation amplifier, UPS, etc.

Analog signals, digital signals, communication data, etc. output from the ship are registered every arbitrary sampling cycle (one second or longer) via instrumentation boards installed inside the automatic recording device and recorded as a file in the storage device once each hour. Twenty four files are produced every day, each of them named based on the date and time. The system also computes and creates a file of the average values every 20 seconds by primary analysis, in order to facilitate and simplify the data analysis. **Table 1** shows the data items (typical example) measured by this device.

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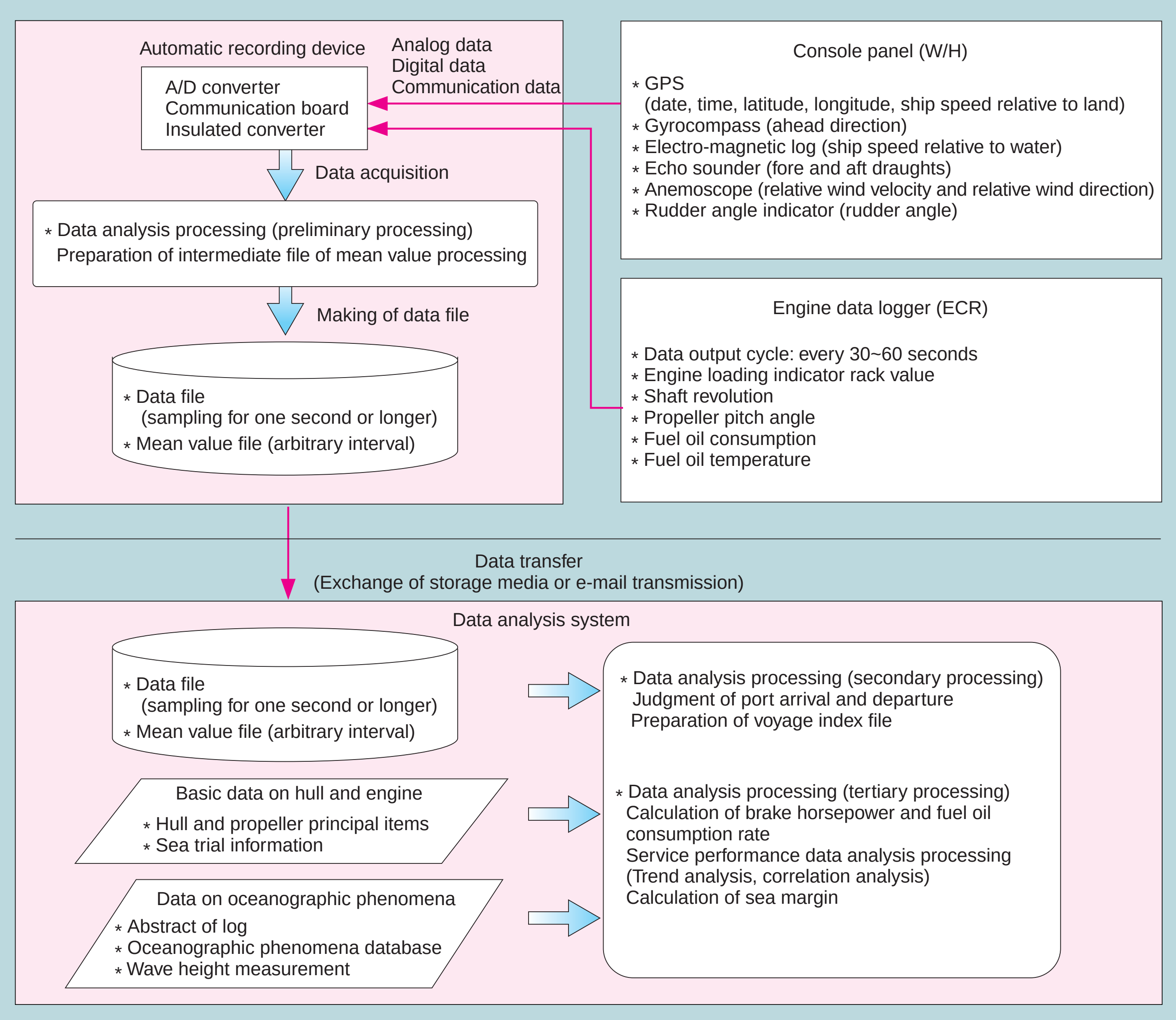

Fig. 1 System configuration scheme
The system is composed of an automatic recording device and data analysis system.

Fig. 2 Example of system installation
Personal computer and instrumentation equipment are gathered into an exclusive-use unit and installed on the bridge of the ship.

Table 1 Example of measured items recorded by the monitoring system

Name of data-sampling device	Data item
GPS	UTC time→ JST time(note)
	Latitude and longitude
	Ship speed relative to land
Gyrocompass	Ahead direction
Electro-magnetic log	Ship speed relative to water
Echo sounder	Fore and aft draughts, and water depth
Anemoscope	Relative wind velocity and relative wind direction
Rudder angle indicator	Rudder angle
Engine data logger	Engine loading indicator rack value
	Shaft revolution
	Propeller pitch angle
	Fuel oil consumption
	Fuel oil temperature
	Fuel oil pressure
(Calculation result value)	Shaft horsepower (rack horsepower)
	Fuel oil consumption rate

(Note) UTC, Universal Time Coordinated; JST, Japan Standard Time

Figure 3 shows the time series plots as an example of the recorded data. These data files are stored in a storage device and the data are collected every several months by exchanging the storage media. Though their use is limited in domestic coastal zones, packet communication services using cell phones are now widespread. These services can also be used to transfer the data to land by sending multiple e-mails with files attachments

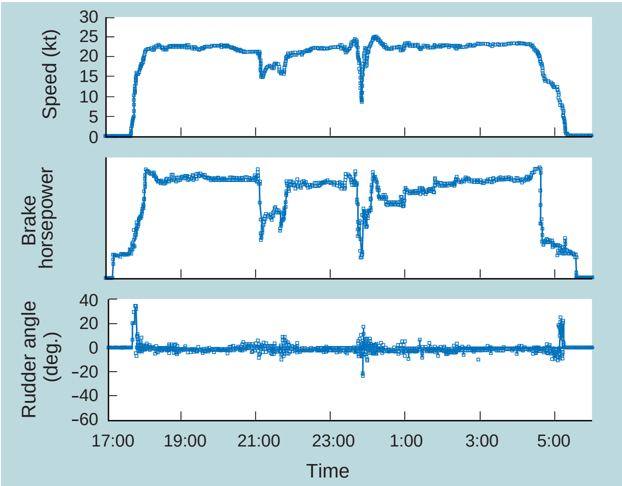

Fig. 3 Measurement data time series plots
These curves show the time series (ship speed, brake horsepower, rudder angle) of the measurement data for one voyage from port departure to port arrival of the ship.

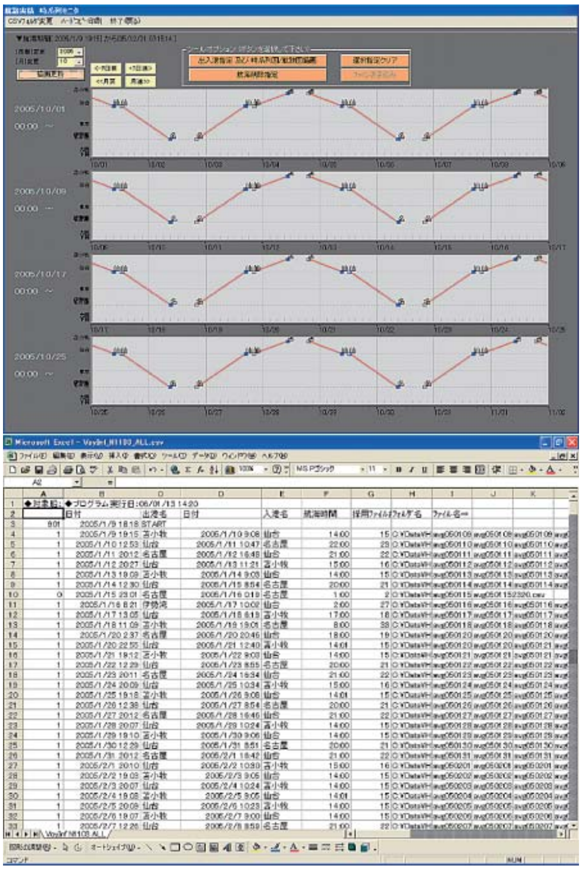

Fig. 4 Preparation of voyage information
The port departure and arrival of the ship are automatically distinguished, and the voyage of the ship and the recording service performance data file are associated.

to data analysis stations on land in regions where stabilized communication is enabled during calls at port.

2.4 Data analysis system

The data analysis system verifies whether the measurement data continuously measured are adequate, and performs service analysis by extracting and voyage-indexing the steady-service performance data.

The measurement data input into the system are compared with the positional information on the port of call of the ship in service (this information is set beforehand) and the positional information obtained from the GPS of the ship, in order to extract the steady-service performance data. When the data indicate latitudes and longitudes within certain ranges and the ship speed is sufficiently low, the ship is judged to be engaged in port entrance or departure. The time of port entrance, the time of port departure, the name of the port, and the name of the object data file are then extracted, and the file association is assigned.

The voyage index file shown in **Fig. 4** contains the steady-service performance data extracted by this secondary analysis. Time series display and chart of track display functions are used to manually judge whether the measurement data are sufficient (see in **Fig. 5**), in order to remove the nonconforming data in the index.

Basic data on the hull, engine, propeller and engine characteristic information obtained from the official sea

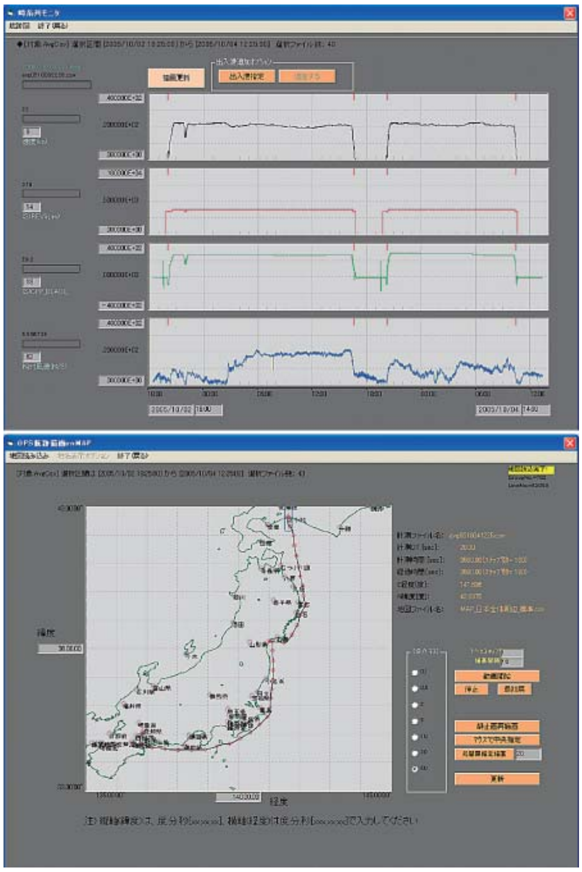

Fig. 5 Screen display of time series and wake verification
Data are checked on screen to verify the time series and wake of the measurement data by specifying the time and date.

trial results are input based on the prepared index, and the service performance results of the horsepower and the specific fuel consumption, etc. are calculated by carrying out the trend analysis of the service data for each voyage as shown in the next chapter. The final results are prepared by extracting and summarizing the respective average values of all data items for all of the voyages from the result files analyzed for each voyage.

3. Monitoring of service performance of ROPAX ferry

Here we present an example of monitoring with the ROPAX Ferry built by MHI as a sample case. The ship is propelled by two medium-speed diesel engines and two controllable pitch propellers. She operates along a route through Seto Inland Sea between Kita-Kyushu and Osaka. To monitor the performance, personal computers for measurement and the various instrumentation equipments were installed on the bridge. The monitored items are summarized and shown in **Table 2**.

This ship is not equipped with torsion meters or a sensor of the ship speed relative to water. Accordingly, the engine output (BHP) was presumed from the rack value of the engine loading indicator and the engine revolution, based on a characteristic curve prepared in advance. The characteristic curve was determined from data obtained by a torsion meter installed during an official sea trial.

The ship speed relative to water was determined in accordance with MHI's sea trial analysis procedure, by using the brake horsepower and propeller revolution.

4. Analysis result

4.1 Sampling of service performance data

The data for each voyage were inspected after service performance data had been collected for about two years, as shown in Fig. 3. The analysis covered periods of service when the water was sufficiently deep (about 50 m) and the ship operated under a constant condition during which the course changes and the fluctuation of the engine revolutions were small. The average values and standard deviations were calculated for the measured items by extracting the service performance data when the ship passed through the selected point. The mean values of the ship speed relative to land, the relative wind direction and wind velocity, the engine rack value and revolution, and the CPP pitch angle were calculated. For the rudder angle, the standard deviation was calculated to grasp the magnitude of fluctuation of the angle in addition to the mean values.

In measuring the fore and aft draughts, the measured values of static pressure were converted to the values of the draught. Because of this, the effects of dynamic pressure while the ship was running at considerable speed made it impossible to obtain exact values. Thus, the average values measured when the ship was running at sufficiently low speed were used as the mean draughts for the voyage.

Table 2 Measured items of monitored ship (selected)

1	Date and time
2	Current ship position (latitude, longitude)
3	Ship speed relative to land
4	Relative wind direction/wind velocity
5	Fore and aft draughts
6	Rudder angle
7	Engine loading indication rack value/speed of rotation (port, starboard)
8	CPP pitch angle (port, starboard)
9	Water depth

4.2 Procedure for analyzing the service performance data

Based on the average values of the engine output (BHP) and the engine revolution obtained from the service performance data, we analyzed the ship speed relative to the water, total resistance, etc. using the MHI procedure for sea trial analyses shown in Reference (4).

The total resistance coefficient (C_T) was calculated based on the expression of the total resistance (R) with specified parameters non-dimensionally. ΔCr, the value obtained by subtracting the friction resistance coefficient (Cf) and residual resistance coefficient (Cr) from the total resistance coefficient (C_T), corresponded to the resistance increment from calm water resistance.

The friction resistance coefficient (Cf) was obtained by the specified friction resistance calculation formula from the average ship speed, etc. during service. The residual resistance coefficient (Cr) was used for the value of the tank test result. The tank test result was used to calculate the residual resistance coefficient (Cr).

4.3 Analysis results

Figure 6 shows a trend graph for the ship speed rela-

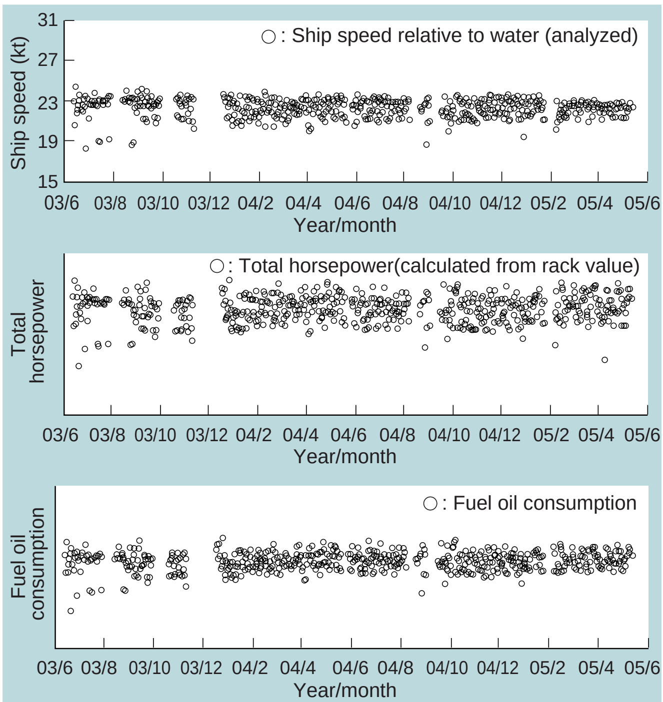

Fig. 6 Trend graph of measurement results
The average value of each voyage is determined and the trend of the long-term fluctuation of the measured values is shown.

tive to water, (analyzed by the method described in the preceding paragraph), the engine output calculated from the rack value, and the measured fuel oil consumption (June 2003 to May 2005).

As shown in **Fig. 7** and **Fig. 8**, the fuel oil consumption increased approximately in proportion to the increases in the ship speed and engine output, respectively. The rate of fuel oil consumption was calculated based on the fuel oil consumption and engine output. Here we used the actual values during the official sea trial, as we had no way to determine the physical properties such as the calorific values of the fuel, etc. during the service. The fuel oil consumption rate during the service was +5.6% higher, on average, than the result of the engine shop test. The factors behind this increase were presumably the load fluctuation due to disturbance, the difference of the measurement method, etc.

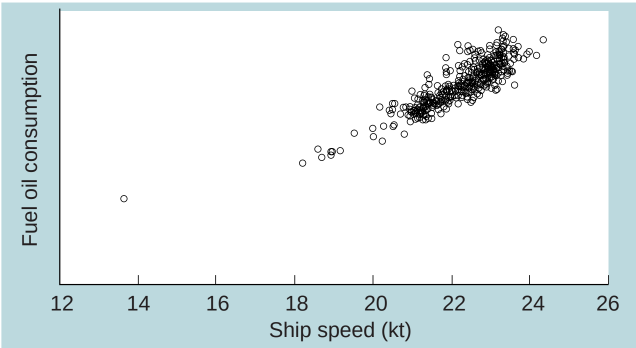

Fig. 7 Relation between ship speed and fuel oil consumption
Fuel oil consumption increases as the ship speed increases.

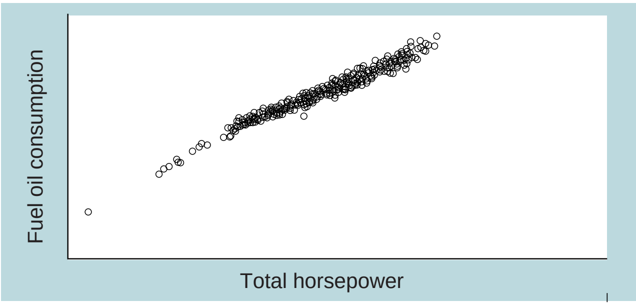

Fig. 8 Relation between brake horsepower and fuel oil consumption
Fuel oil consumption increases in proportion to brake horsepower.

Figure 9 shows the relation between the ship speed relative to water and the engine output (BHP). ⊿*Cr* obtained from the measurement result is shown in **Fig. 10** using the ratio to *Cr* (⊿*Cr*/*Cr*). The BHP to the ship speed relative to water had a non-negligible scatter which corresponded to the scatter of ⊿*Cr*/*Cr*. The scatter of ⊿*Cr*/*Cr* was approximately 75%. ⊿*Cr*/*Cr* = 15% (⊿*Cr* = 0.001) corresponded to 5% of the average value when converted to BHP. This scatter of ⊿Cr therefore corresponded to that of BHP of 25%, and it demonstrated that the increase in hull resistance as a result of disturbance was substantial.

The components of ⊿*Cr* were presumed to be the effects of wind, tidal current, wave, draught (displacement), trim, etc. As the Seto Inland Sea is generally a calm sea area, waves presumably had only a small effect. The ship itself is a large passenger ferry with big super-structures. In order to investigate the effect of wind on air resistance increase, ⊿*Cr* was corrected to a no-wind condition as a trial. The wind resistance (*Rwind*) was calculated from the relative wind direction and velocity, the air resistance coefficient for headwind, etc., taking into consideration the air resistance due to the advanced speed of the ship. After subtracting *Rwind* from the total resistance (*R*) and calculating ⊿*Cr* again, we could obtain a ⊿Cr value corrected to the no-wind condition.

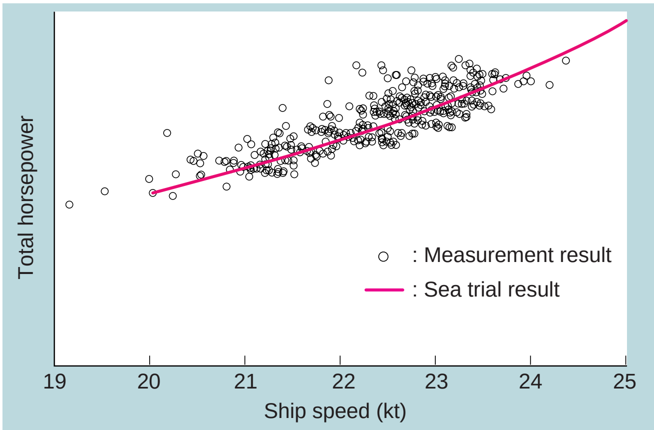

Fig. 9 Ship speed-brake horsepower curve (measurement result)
When the measured service performance data on ship speed and brake horsepower are plotted, disturbances such as wind, waves, etc. cause data scatter.

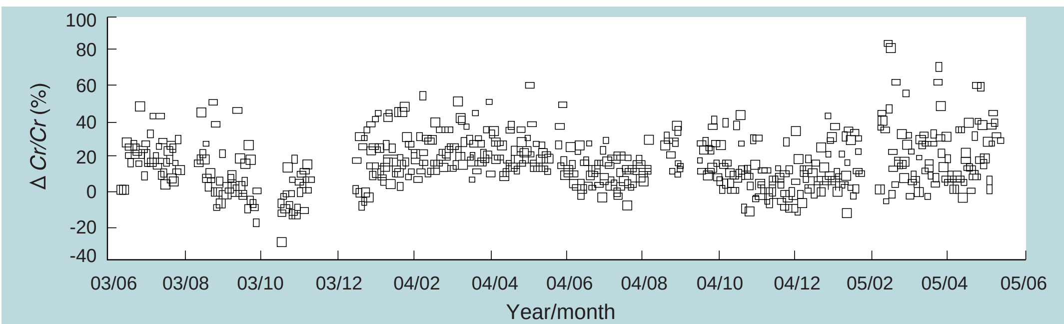

Fig. 10 Fluctuation of resistance increment (Δ *Cr*/*Cr*)
The resistance increment (non-dimensional value) determined by analysis is shown. Scatter rises to 25% of BHP, confirming the large resistance increment due to disturbance.

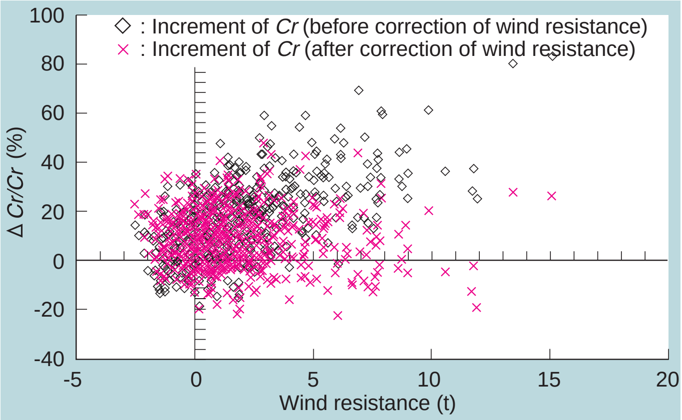

Fig. 11 Relation between wind resistance and Δ ***Cr/Cr***
While Δ *Cr/Cr* before correction increases according to increase of wind resistance, that after correction to a no-wind condition is constant regardless of the wind resistance.

Figure 11 compares the $\Delta Cr/Cr$ ratio between before and after the correction. $\Delta Cr/Cr$ before the correction increases according to increase of wind resistance.

The scatter of $\Delta Cr/Cr$ after the correction for wind resistance was much reduced in comparison with the scatter of $\Delta Cr/Cr$ before correction, and was distributed close to zero. We can thus see that the fluctuation of the air resistance contributed robustly to the scatter of $\Delta Cr/Cr$.

Figure 12 shows the relation between the BHP corrected to the no-wind condition and the ship speed. We see that the scatter of the BHP to the ship speed was significantly reduced in comparison with Fig. 9.

Here we calculated the calm-water horsepower by determining the residual resistance and the friction resistance corresponding to the displacement and wetted surface area during the service from the tank test results. The sea margin (S.M.), thereafter, was obtained from the difference between the actual value of the brake horsepower during service and the value of calm-water. **Figure 13** shows the sea margin in comparison with the wind resistance. The sea margin grew large as the wind resistance increased.

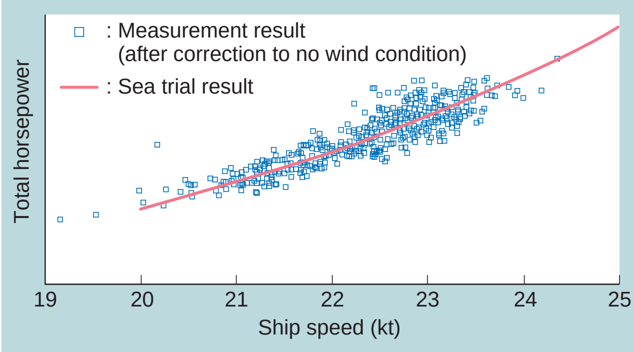

Fig. 12 Ship speed-brake horsepower curve (correction to a no-wind condition)
Brake horsepower is corrected to a no-wind condition. The scatter of brake horsepower becomes smaller, and good agreement with the official sea trial result is achieved.

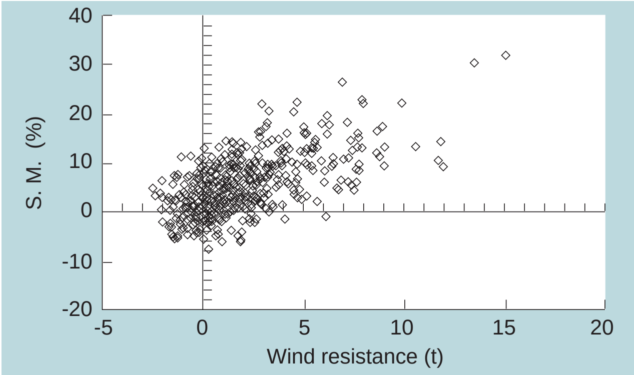

Fig. 13 Relation between wind resistance and sea margin
The sea margin grew large as the wind resistance increased. The wind resistance is supposed to be a major factor to increase resistance of this ship.

5. Conclusion

Service performance data were sampled for about two years by installing a system for monitoring service performance on a ROPAX Ferry built by MHI. As observed from the results described here, the data obtained remained precise with good precision and stability for a long period.

The service performance data recorded when the ship passed through the same sea area were extracted and analyzed, in order to examine the causes behind increases in resistance and horsepower. The results confirm that the performance of the ROPAX Ferry after two years of service remains equivalent to that determined at the commencement of service soon after the ship was built. The results also clarify that increases in resistance were almost exclusively due to wind, and scarcely due to waves. Two reasons can be offered as explanation: the large superstructures of the ROPAX ferry make the vessel especially susceptible to the wind, and the external force of the waves seems to be small in the Seto Inland Sea route.

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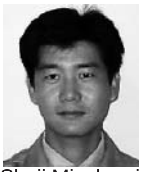
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