

DESCRIPTION

A METHOD OF ESTIMATING FRICTIONAL RESISTANCE OF SHIP BOTTOM
COATING FILM, AND A METHOD OF EVALUATING COATING FILM PERFORMANCE
USING SAID METHOD AND A DEVICE FOR EVALUATING COATING FILM
5 PERFORMANCE

TECHNICAL FIELD

[0001]

The present invention relates to a method of estimating a
10 frictional resistance increase rate of a ship bottom coating film
wherein the method can simply and quickly provide evaluation
results without individual differences. Furthermore, it relates
to a method of evaluating a coating film performance simply on
a ship bottom coating film of an actual ship and it also relates
15 to an evaluating device.

TECHNICAL BACKGROUND

[0002]

In order to improve a propulsion performance which is the
most important item of energy saving measures for ships, the
20 frictional resistance in ship bottom has a major role together
with wave-making resistance and viscous pressure resistance.

[0003]

It is reported that this frictional resistance accounts for
60 to 80 percent of all resistances which a ship receives. The

decrease of the frictional resistance is very important for saving the fuel economy of ships.

[0004]

For ship bottoms, antifouling coating paints are used in order to prevent from attachment of aquatic organism and prevent from deterioration of fuel consumption caused by the aquatic organism attachment. The antifouling coating paints are always applied on the bottom parts where a ship contacts with seawater. Therefore, it is important to prevent increase of the roughness of a coating film surface and thereby decrease the frictional resistance by carrying out a proper coating control or employing an antifouling coating paint having a high smoothing performance in the step of newly building a ship. As such a coating film having antifouling performance and capable of decreasing frictional resistance, there are a self-polishing type coating film, a foul-release type coating film and the like.

[0005]

It is generally considered that the surface roughness is a major factor in the increase of the frictional resistance. Methods of estimating a ship performance from the surface roughness of a coating film has been studied for a long time.

[0006]

Non patent document 1 discloses a method of evaluating ship performance by the roughness of a ship bottom, and the roughness

measurement is carried out by a method of using a contact type displacement meter with a BSRA roughness meter developed by BSRA (British Ship Building Association). It also discloses that the roughness is measured by this method and the increase of frictional resistance is determined from the following numerical formula (1) or (2). These formulas are empirical formulas obtained by measuring the surface roughness of an actual ship by the BSRA roughness instrument.

[0007] [Numerical formula 1]

$$\Delta C_F \times 10^3 = 105 \left(\frac{k}{L_{pp}} \right)^{\frac{1}{3}} - 0.64 \quad (1)$$

[0008] [Numerical formula 2]

$$\frac{\Delta P_b}{P_b} \times 100\% = 3.8 \times \{ (K_2)^{\frac{1}{3}} - (K_1)^{\frac{1}{3}} \} \quad (2)$$

In the numerical formula (1), ΔC_F is an increase of a frictional resistance coefficient, k is a mean roughness height measured by the BSRA roughness instrument and L_{pp} is a ship length. In the numerical formula (2), $\Delta P_b/P_b$ is an increase rate of supply horsepower, k_1 is a roughness height of a ship bottom in an early stage and k_2 is a roughness height of the ship bottom in a final stage.

[0009]

Furthermore, non-patent document 1 discloses that the estimateion of using only the roughness height is insufficient

and discloses an evaluation method of using a surface shape parameter t .

[0010] [Numerical formula 3]

$$t = f(\alpha) \quad (\alpha = m_0 m_4 / m_2^2) \quad (3)$$

5

In the numerical formula, α is a spectrum parameter, m_0 is a 0-dimensional spectrum moment, m_2 is a 2-dimensional spectrum moment and m_4 is a 4-dimensional spectrum moment. As a convenience method, it discloses a method of determining α from $(D_E/D_Z)^2$ (D_E is a shape density of the maximum- the minimum and D_Z is a crossing at 0 point. It furthermore indicates that in the evaluation with the surface shape parameter t , a difference of about $\pm 4\%$ in supply horsepower appears by the difference of the surface shape parameter t even in the same BSRA roughness height (450 μ).

15 [0011]

Non patent document 2 discloses a relationship of H^2/λ wherein H is an apparent wave height (roughness height) and λ is an apparent wavelength and frictional resistances in an actual ship and a flat panel test. The roughness height H and the wavelength λ used herein are determined by the following procedures (I) to (viii). This method has been used before computer development, the roughness height and wavelength are determined from a sectional curve with working by hand.

(i) Vertical break-lines are drawn for dividing in a horizontally long recorded diagram with a certain constant distance (at first, about 20-50 m in an actual length on an outer plate).

(ii) The maximum point and the minimum point are selected each in each divided section of the recorded diagram.

(iii) Adjacent maximum points in the sections or adjacent minimums in the sections are connected respectively to make two sequential line graphs.

(iv) In the vertical break-lines drawn at the beginning procedure, the length of a part that is sandwiched and intercepted between the two sequential lines is taken as an apparent wave height (H_i) of this section. Furthermore, the distance of the first vertical section lines is taken as an apparent wave length (λ).

(v) In one ship or one specimen steel plate, the apparent wave height H to λ is a mean of H_i 's in the above procedures.

(vi) Next, on the center of each vertical break-lines, one additional break-line is drawn each and the procedures (ii) to (v) are repeated.

(vii) In this manner, the recorded diagram is divided by 2m, and a sequential line is drawn by plotting $1/\lambda$ (corresponds to a roughness frequency) in the transversal axis and H and H/λ in the vertical axis.

(viii) If a sequential line is determined by (vii) in accordance with the measured number for one ship or steel plate, the average

curve is drawn as a whole and taken as H and H/λ to the apparent wavelength λ .

[0012]

As described above, the apparent wave height H and the
5 apparent wave length λ are different from the roughness height
 R determined in JIS and the average length R_{Sm} of the roughness
curve elements. Moreover, the non-patent document 2 discloses
that a specimen steel plate having a length of 3 m, a width of
0.7 m width and a thickness of 6 mm was subjected to a towing tank
10 test for confirmation of the same tendency, but the maximum speed
was limited to 6 (m/s) and the influence due to the roughness
parameter was not confirmed.

[0013]

Thus, it discloses the relationship between the frictional
15 resistance and the surface roughness, but does not disclose a
method of estimating the frictional resistance by the surface
roughness with a high reliability.

PRIOR ART DOCUMENT

NON-PATENT DOCUMENT

20 [0014]

Non-patent document 1: D.Byrne; "Hull roughness and the impact
of outer hull maintenance decisions on ship efficiency", The First
International Ship Repair, Spares and Maintenance Conference
(1983) p33-51

Non-patent document 2: SASAJIMA Hideo, TERA0 Teiichi, YOKOO Koichi, NAKATO Michio and OGAWA Akihiro "Experimental study for Hull outer plate roughness and frictional resistance increase" Journal of the Society of Naval Architects of Japan Vol.117, pp58-71, 1965-06

5 SUMMARY OF THE INVENTION

OBJECT FOR SOLVING BY THE INVENTION

[0015]

Generally, the increase of a frictional resistance due to a surface roughness in an actual ship is practically estimated
10 by the measurement of a horsepower. In practical running conditions, the increase thereof also depends on other influences such as wave-making resistance, air, wave, tidal current, contamination hull fouling and the like, and thereby it is difficult to evaluate by choosing the influence due to frictional
15 resistance. With regard to coating films coated on the outer hull of a ship, the surface roughness analysis is evaluating by the maximum height in an evaluation length of 50 mm developed by BSRA. However, it has a problem such that the maximum height in a length of 50 mm is only measured and thereby the influences due to other
20 parameters cannot be estimated. There are examples that the increase rate of a frictional resistance in an actual ship is shown by parameters of a height and a wave length, or a height and a gradient, but the optimum evaluation method, the evaluation length and cut-off wave-length are not determined in the case of an actual

ship.

[0016]

The evaluation of the frictional resistance in an actual ship is difficult as described above, so that it is necessary to estimate the frictional resistance simply and easily by another method for evaluating the frictional resistance in place of an actual ship, but a method of measuring the increase of a frictional resistance from the roughness corresponding to an actual ship is limited. It is important to estimate the increase of an resistance corresponding to an actual ship by the proper combined use of the roughness measuring method and the frictional resistance measuring method.

MEANS FOR SOLVING THE SUBJECT

[0017]

Under the circumstances, the present inventors have studied on a simple and optimum method of evaluating the coating film of an actual ship.

[0018]

As a result, the inventors have found that the frictional resistance of a coating film of a ship can be estimated by the following compositions. Thus the present invention has been accomplished.

[0019]

[1] A method of estimating a frictional resistace of a ship

bottom coating film which method comprises measuring any one of Rz (Maximum height roughness), Rc (mean height of roughness curve elements), Ra (arithmetical average roughness), Rq (root mean square roughness) and RZJIS (ten-point mean roughness) as a roughness height R at a mean length RSm of roughness curve elements in the range of 2,000 to 10,000 μm according to JIS B 0601:2001 (ISO4287:1997) on a coating film obtainable by applying a ship bottom coating paint on a substrate, and computing a frictional resistance increase rate FIR (%) from a mirror plane by the following formula (4);

[0020] [Numerical formula 4]

$$\text{FIR}(\%) = C \frac{R^2}{R_{\text{Sm}}} \quad (4)$$

wherein the coefficient C is a coefficient depending on the kind of a roughness height R and a method of testing a frictional resistance, and it is determined by subjecting a plurality of ship bottom coating films each having a different roughness in a specified evaluation length to roughness measurement and frictional resistance test and determining by the formula (4) using the measured roughness height R, the mean length RSm of the roughness curve elements and the frictional resistance increase rate FIR (%).

[2] The method of estimating a frictional resistance of a ship bottom coating film according to the item [1] is characterized in that the roughness is measured in an evaluation length of not less than 10,000 μm , in a measurement pitch of not more than 500 μm , in the standard as defined in JIS B 0601:2001 (ISO 4287:1997).

[0021]

[3] The method of estimating a frictional resistance of a ship bottom coating film according to the item [2] is characterized in that the roughness is measured by applying a high-pass filter such that the cut-off value λ_c is not less than 10,000 μm .

[0022]

[4] The method of estimating a frictional resistance of a ship bottom coating film according to any one of the items [1] to [3] is characterized in that the coefficient C is previously determined in a frictional resistance test in such a manner that a double circular cylinder device is used, a torque T_0 which works a mirror surface internal cylinder at the time of rotating an external cylinder is firstly determined, and then a torque T is determined at the time of rotating the internal cylinder coated with a ship bottom coating paint in the same rotating condition, the frictional resistance increase rate $\text{FIR}(\%)$ is determined by the following formula (5):

[0023] [Numerical formula 5]

$$\text{FIR}(\%) = \frac{T - T_0}{T_0} \times 100 \quad (5)$$

and then the coefficient C is determined from the formula (4) which relates to the roughness height R and the mean length RSm of the roughness curve elements of the coated film in the internal
5 cylinder.

[0024]

[5] The method of estimating a frictional resistance of a ship bottom coating film according to any one of the items [1] to [4] is characterized by measuring the roughness height R and the
10 mean length RSm of the roughness curve elements by means of a stylus type roughness measuring device or a laser displacement type roughness measuring device.

[0025]

[6] A method of evaluating a coating film performance of a ship
15 bottom coating film which method comprises, using the coefficient C which has been previously determined, measuring the roughness height R and the mean length RSm of the roughness curve elements with regard to a coating film which is formed by applying a ship bottom coating paint on a substrate, and estimating the frictional
20 resistance increase rate FIR(%) by the above described formula (1).

[0026]

[7] The method of evaluating a coating film performance of a ship

bottom coating film according to the item [6] which method is characterized by evaluating the roughness height R and the mean length R_{Sm} of the roughness curve elements on a thermoplastic resin replica prepared by taking from a coating film of an actual ship
5 which has been coated.

[0027]

[8] A device for evaluating a coating film performance of a ship bottom coating film which is a device of evaluating the coating film performance of an actual ship coating film and comprises a
10 measuring part of measuring the roughness height R and the mean length R_{Sm} of the roughness curve elements and a frictional resistance calculating part of calculating a frictional resistance increase rate $FIR(\%)$ by using the above described formula (4).

15 EFFECT OF THE INVENTION

[0028]

According to the present invention, the frictional resistance increase rate of a coated film of a ship bottom can be estimated by a very simple method of just estimating the
20 roughness. This method can apply to a quick selection of an antifouling coating paint having a lower frictional resistance, a determination on good or bad coating, understanding on a performance of a coating equipment and so on. Moreover, this method can be used to a control of coating application of an

antifouling coating paint for an actual ship in a dockyard. The present invention also provides an evaluating device used for the method. The evaluation device can be made economically because the measuring conditions can be fixed by limiting the wavelength
5 range of the roughness.

BRIEF DESCRIPTION OF DRAWING

[0029]

Fig.1 shows a relationship between a frictional resistance increase rate FIR(%) and Rz^2/RSm .

10 Fig. 2 shows a relationship between a frictional resistance increase rate FIR(%) and a maximum height roughness Rz .

Fig. 3 shows a relationship between a frictional resistance increase rate and a mean length RSm of roughness curve elements.

Fig. 4 shows a roughness distribution of a bottom coating
15 film of an actual ship (a replica method/ evaluation length 30 mm).

Fig. 5 shows an example of roughness acquisition of a bottom coating film of an actual ship.

Fig. 6 shows an estimation example ($FIR(\%) = 2.62 \times Rz^2/RSm$)
20 of a frictional resistance increase rate FIR(%).

EMBODIMENT FOR CARRYING OUT THE INVENTION

[0030]

The present invention will be described in detail below.

[0031]

The coating paint for a ship bottom which paint is evaluated in the present invention is a coating paint used for corrosion prevention in a ship bottom, prevention of organism adhesion and the like. Particularly, the coating paint evaluated in the present invention is mainly a coating paint for a ship bottom of a steel ship.

[0032]

The present invention may apply for the Examples of the antifouling coating paint such as a self-polishing type antifouling coating paint and a fouling release type antifouling coating paint.

[0033]

Regarding to the self-polishing type antifouling coating paint, the coating film is dissolved little by little gradually and simultaneously an antifouling agent which is a component having a distaste for aquatic life is also eluted to prevent adhesion of aquatic organism from the film. Regarding to the fouling release type antifouling coating paint, aquatic organism is hardly adhered on the ship bottom by a coating film prepared of the fouling release type antifouling coating paint having smoothness, water repellency and elasticity.

[0034]

Examples of the antifouling coating paints are coating paints disclosed in JP-B-4884107, JP-B-4846093, JP-B-4837668,

JP-B-4813608, JP-B-4812947, JP-B-4812902, JP-B-4812895,
JP-B-4806769, JP-B-4786053, JP-B-4777591, JP-B-4776839,
JP-B-4769331, JP-B-4745351, JP-B-4709370, JP-B-4694583,
JP-B-4684465, JP-B-4675624, JP-B-4651792, JP-B-4647060,
5 JP-B-4644238, JP-B-4642204, JP-B-4641563, JP-B-4633224,
JP-B-4621901 and JP-B-4610763. These known coating paints can
be used without limitation.

[0035]

In the present invention, the evaluation is carried out on
10 a coating film formed by applying the coating paint for a ship
bottom on a substrate.

The substrate is not particularly limited. Usual examples
of the substrate are steels such as untreated steels,
blast-treated steels, acid-treated steels, zinc-plated steels,
15 and stainless steels; nonferrous metal materials such as aluminum
(alloy) materials and copper (alloy) materials; concretes; and
plastic materials such as vinyl chloride and the like. The shape
of the substrate is not also particularly limited. Usually, a
circular cylinder shape, a boat-like shape, a flat plate-like shape
20 and a tube-like shape are used for evaluation.

[0036]

The coating film for a ship bottom is formed by applying
an antifouling coating paint on the surface of a substrate in
accordance with a usual method and then, if necessary, vaporizing

and removing a solvent at an ordinary temperature or under heating. The coating method is not particularly limited. Examples of the method are conventionally known methods such as an immersing method, a spray method, a brush application, a roller application,
 5 an electrostatic application and an electrodeposition application. The spray method is more preferably used to coat a wide ship bottom uniformly.

[0037]

The film thickness is not particularly limited. The film
 10 may have a prescribed thickness. The film has a usual thickness of from 50 micron meter to 1,000 micron meter, such that the substrate is not shown and the roughness of the substrate surface is not affected.

Frictional resistance estimating method

15 Regarding a coating film formed by applying a coating paint for ship bottom on the substrate, any of R_z (the maximum height roughness), R_c (mean height of the roughness curve elements), R_a (arithmetical mean roughness), R_q (root mean square deviation roughness) and R_{zjis} (ten-point mean roughness) is measured in
 20 a mean length R_{Sm} of the roughness curved line elements of from 2,000 to 10,000 micron meter in accordance with the rule defined in JIS B 0601:2001 (ISO4287: 1997) and the frictional resistance increase rate FIR (%) from the mirror surface is calculated by the following formula (4).

[0038] [Numerical formula 6]

$$\text{FIR}(\%) = C \frac{R^2}{RSm} \quad (4)$$

In the formula, the fixed number C depends on the kind of the roughness height R and the frictional resistance test method and is determined as follows. The roughness measurement and the frictional resistance test on a fixed evaluation length are carried out, and then the roughness height R which is measured, the mean length RSm of the roughness curve elements and the frictional resistance increase rate FIR (%) are determined from the formula (4).

[0039]

RSm is a mean length of the roughness curve elements and is represented by the following formula (6) as the mean of the lengths XS of the roughness curve elements.

[0040] [Numerical formula 7]

$$RSm = \frac{1}{m} \sum_{i=1}^m XSi \quad (6)$$

Rz shows the maximum height roughness and is determined by the sum of the maximum profile peak height and the maximum profile valley depth in the standard length of the roughness curve. Rc shows the mean height of the roughness curve elements, Ra shows the arithmetical mean roughness and Rq shows the root mean square deviation roughness. RZJIS shows ten-point mean roughness and

is determined by the sum of the mean of the peak heights of five points in order of height from the maximum profile peak and the mean of valley depths of five points in order of depth from the maximum profile valley depth. These values are measured in accordance with the rule of JIS B 0601:2001 (ISO 4287:1997) [0041]

In the present invention, it is only necessary to measure any one of the Rz (maximum height roughness), Rc (mean height of roughness curve elements), Ra (arithmetical mean roughness), Rq (root mean square deviation roughness) and RZJIS (ten-point mean roughness). [0042]

These roughness measurements are conducted by using a contact type, a non-contact type, a manual type or an automatic type surface roughness measuring device. Furthermore, a stylus type or a laser displacement type surface roughness measuring device is preferably used in the standpoint of versatility and easy-to-use. [0043]

The resulting data may be saved or analog/digital-treated in the inside of a displacement instrument. For the measurement of the objective roughness, the evaluation length is not less than 10,000 μm , and the measurement pitch is not more than 500 μm in the present invention.

[0044]

In the parameter analysis, it is desired to use the profile curve as it is. When a swell of a wavelength of not less than 10,000 μm has an affect on the measuremernt, the roughness curve
 5 can be determined by including a high pass filter having a cut-off value (wavelength) λ_c of not less than 10,000 μm in accordance with JIS B 0601: 2001(ISO 4287: 1997).

[0045]

In the present invention, the necessary evaluation length
 10 and cut-off value λ_c for the acurate roughness evaluation are not less than 10,000 μm and the measurement pitch is not more than 500 μm . Furthermore, when the measurement pitch is 500 μm , the measurable minimum wavelength is 2,000 μm but the measurement error of the low wavelength roughness is large. Therefore, the
 15 practical measurement pitch is about 250 μm . When the measurement pitch is smaller, the measurement takes a longer period of time and influences on the wavelength of the low roughness height which is not related to the frictional resistance increase. Therefore, the measurement distance is preferably not less than 100 μm in
 20 the practical use. Moreover, when the measurement distance is small, or further the apparent wavelenth is small by the small roughness and the noize which do not contribute to the frictional resistance, cut by a low pass filter may be conducted.

Determination of coefficient C

The coefficient C of the formula (4) varies depending to the kind of the roughness height R and the frictional resistance test method. Previously, plural ship bottom coating films each having different roughness are formed on prescribed substrates and then evaluated on frictional resistance thereof by the frictional resistance test to determine the coefficient C in the formula (4). For example, when R_z and R_{Sm} are measured in an evaluation length of 50 mm and the frictional resistance test is carried out using a double circular cylinder device, the coefficient C is about 2 to 3. The frictional resistance test is necessary to be conducted by the method of showing a frictional resistance increase rate of not less than 5 % on the coating films having a roughness height R of 100 μm , R_{Sm} of 2,000 to 4,000 μm , which are determined by the above roughness measuring method.

This is a frictional resistance increase rate under the condition of a high Reynolds number and a thin viscous bottom layer thickness, which correspond to an actual ship. The tank towing test and the flowing round tank test which are generally used to ship evaluation are not appropriate because the velocity is low and the length of a test plate is short and thereby the roughness is in hiding under a viscous bottom layer, and as a result, the influence of the roughness is not exerted sufficiently.

[0046]

In order to realize the viscous bottom layer thickness which

corresponds to an actual ship, it is preferred to employ a method such that the distance between a main flow and the surface of a wall is short and the flow rate is as rapid as possible. The test capable of yielding these results are conducted by a double
 5 circular cylinder device, an in-pipe flow path or a cavitation water tank.

[0047]

In the case that the double circular cylinder device is used, when an external cylinder is rotated at a prescribed rotation number,
 10 a torque T_0 which works on an internal cylinder having a mirror surface is determined, and then when the rotation is carried out in the same conditions, a torque T which works on the internal cylinder coated with a ship bottom coating paint is determined. The frictional resistance increase rate FIR(%) is measured by the
 15 following formula (5).

[0048] [Numerical formula 8]

$$\text{FIR}(\%) = \frac{T - T_0}{T_0} \times 100 \quad (5)$$

Next, from the formula (4) showing the relationship of the FIR(%) measured, R and R_{Sm} of the coating film applied on the
 20 internal cylinder, the coefficient C is determined.

[0049]

When the coefficient C is used to the formula (4) and R and R_{Sm} are measured, the frictional resistance increase rate of the

coating film can be estimated regardless of the kind of the ship bottom coating paint.

[0050]

As is clear from the above, the coefficient C previously
5 determined is used, and the roughness hight R and the mean length RSm of the roughness curve elements are measured with respect to a coating film formed by applying the ship bottom coating paint on a substrate, and then the frictional resistance increase rate FIR(%) is estimated by the formula (4). Thus, the coating film
10 performance of the ship bottm coating film can be evaluated.

[0051]

In the ship coating job site of a dockyard, the surface roughness of a ship bottom coating film measured in the following manner that a thermoplastic resin is pressed against a frame
15 pattern to prepare a replica and the surface roughness thereof is measured. Consequently, the frictional resistance increase rate of the coating film of an actual ship can be estimated.

[0052]

Specifically, in order to obtain the sufficient accuracy,
20 the surface roughness of the coating film coated on the internal cylinder is measured by a laser displacement instrument on 10 lines which are selected from a starting line which is located in 50 mm from the bottom part of the internal cylinder to the upper part at intervals of 25 mm. The laser displacement instrument is

installed on the test device and the circular cylinder is rotated and then the surface roughness is measured. The displacement data are obtained at intervals of 250 μm , and thereby 4,000 data are obtained in the distance of 1,000 mm. The measured data in one
5 line are divided by 20 with an evaluation length of 50 mm and then an approximate curve with root mean square is subtracted from the above value to determine the profile curve.

[0053]

The device of evaluating the coating film performance of
10 the ship bottom coating film according to the present invention, which is conducted by the above estimating method, comprises a measurement part of measuring the roughness height R and the mean length R_{Sm} of the roughness curve elements, and a frictional resistance calculating part of calculating the frictional
15 resistance increase rate FIR (%) using the formula (4).

[0054]

The above described roughness measuring device is provided in the measuring part and in the estimating part, the resultant data are monitored and the frictional resistance increase rate
20 can be estimated from the formula (4).

[0055]

In the ship coating job site of a dockyard, the frictional resistance increase rate of a ship bottom coating film can be easily estimated by the use of this coating film performance

evaluation device, and the coating film performance can be evaluated.

[0056]

Moreover, as the wavelength range of the roughness is
5 limited, and the evaluation length, the measurement pitch and the
cutoff value λ_c , which are the roughness measurement conditions,
can be fixed, the coating film capacity evaluation device can be
provided at a low cost.

[0057]

10 EXAMPLE

The present invention will be described in more detail with
reference to the following examples below, and it should not be
limited by the examples.

Example 1 Frictional resistance test

15 (i) The case of a double circular cylinder device

The double circular cylinder device was used and the
relationship of the roughness height R , the mean length R_{Sm} of
the roughness curve elements and the frictional resistance
increase rate is evaluated.

20 [0058]

In the double circular cylinder device, a
poly-vinyl-chloride made test circular cylinder (internal
cylinder 310 mm diameter) on which a coating paint was applied
by spray coating was set in a stainless steel tank (external

cylinder 320 mm diameter) filled with an ion exchanged water (23°C).

[0059]

Regarding to the coating paints, BANNOH 500N (manufactured by Chugoku Marine Paints Ltd.) was used as a binder coat, and SEA GRANDPRIX 500, SEA GRANDPRIX 1000, SEAFLO NEO or BIOCLEAN HB (all is manufactured by Chugoku Marine Paints Ltd.) was used as an antifoling coating paint. The total thicknesses of the coating films was 125 μm or 250 μm .

10 [0060]

The external cylinder was rotated at 1000 rpm and a torque which worked on the internal cylinder on which the coating film was formed was measured. Subsequently, when the external cylinder was rotated at 1000 rpm, a torque which worked on the complete mirror surface having a film thickness of 125 μm was 6.55 N·m, and the torque which worked on the complete mirror surface having a film thickness of 250 μm was 6.63 N·m, and the frictional resistance increase rate FIR(%) was determined.

[0061]

20 The frictional resistance increase rate FIR (%) of the internal cylinder on which each coating film was formed was determined by the formula (5). In the formula (5), T_0 is the torque which worked on the internal cylinder of the mirror surface when the external cylinder was rotated at 1000 rpm, T_0 in a coating

film thickness of 125 μm was 6.55 N·m, and the torque T_0 in a film thickness of 250 μm was 6.63 N·m. T was a torque which worked on the internal cylinder coated with the ship bottom coating paint when the external cylinder was rotated in the same conditions.

5 [0062]

The roughness measurement was carried out on the internal cylinder on which each coating film was formed.

[0063]

In order to obtain sufficiently high accuracy, the surface
10 roughness of the internal cylinder on which the coating film was formed was measured on 10 lines which are selected from a starting line which is located in 50 mm from the bottom part to the upper part at intervals of 25 mm by a laser displacement instrument. The laser displacement instrument was installed on the double
15 circular cylinder device and the internal cylinder on which the coating film was formed was rotated and the surface roughness was measured. The displacement data were obtained at intervals of 250 μm and 4000 data were obtained in the distance of 1,000 mm. The measured data on one line was divided by 20 in an evaluation
20 length of 50 mm and then an approximate curve with the root mean square was subtracted to determine the profile curve.

[0064]

With regard to the coating film formed by a spray coating, R_z (maximum height roughness) and R_{Sm} (mean length of roughness

curve elements) were determined and as a result, in the evaluation length of 50 mm, R_z was 30 μm to 200 μm and R_{Sm} was 2,000 μm to 10,000 μm . In order to evaluate the R_{Sm} range accurately, the necessary evaluation length and cut-off value λ_c are 10,000 μm or more and the measurement pitch is 500 μm or lower. When the measurement distance is 500 μm , the measurable minimum wavelength is 2,000 μm , but the practical wavelength is about 250 μm because an error of the measurement of R_z and R_{Sm} in a low wavelength will be large. Furthermore, when the measurement distance is small, the measurement time is longer and thereby the practical wavelength is preferably 100 μm or more. Moreover, when the measurement pitch is smaller, it is occasionally preferred to conduct cutting by a low pass filter because an apparent wavelength will become small by the influences of a small roughness which does not contribute the frictional resistance and a noise. In the practical evaluation, it is preferred to determine a roughness curve by introducing a low pass filter in a cut-off wavelength λ_s in order to remove the influence of swell caused by a long wavelength. However, in the precisely processed circular cylinder, the profile curve was evaluated as it was because the affect of swell caused by a long wavelength was not investigated.

[0065]

From the profile curve, R_z (maximum height roughness), R_c (mean height of roughness curve elements), R_a (arithmetic mean

roughness), R_q (root mean square roughness), $RZJIS$ (ten-point mean roughness) and R_{Sm} were determined.

[0066]

In the case of the measurement using the double circle
 5 cylinder device, R_z , R_c , R_a , R_q , $RZJIS$ and R_{Sm} , and the frictional resistance increase rate $FIR(\%)$ were shown in Table 1. The mutual correlation analysis on R_z , R_c , R_a , R_q , $RZJIS$ and R_{Sm} was carried out and the results are shown in Table 2. As R_z , R_c , R_a , R_q and $RZJIS$ show a high correlation mutually, the evaluation may be
 10 carried out using any one of the roughness heights R . In the case that the relationship of R_{am} , R_{azz} and $FIR(\%)$ is evaluated, when the value R_z^2/R_{Sm} obtained by dividing R_z^2 by R_{Sm} is taken as a transverse axis and $FIR(\%)$ is taken as a vertical axis, a high correlation is confirmed along an approximation straight line as
 15 shown in Fig. 1. However, when R_{azz} or R_{am} is taken as a transverse axis and $FIR(\%)$ is taken as a vertical axis, large variation is observed as shown in Fig. 2 and Fig. 3. Therefore, it is preferred to estimate $FIR(\%)$ by R_z^2/R_{Sm} . In this example, the approximation line is a graph passing through the point 0 and having a gradient
 20 of 2.62. Accordingly, $FIR(\%)$ can be determined from R_z and R_{am} by calculating backwards from this numeral formula. As is shown in Fig. 2, R_c , R_a , R_q and $RZJIS$ have a high correlation with R_{azz} and thereby using any of them, the evaluation can be conducted

in the same manner. But, the coefficient C has a different value in accordance with the kind of the roughness height R.

[0067]

Table 1

5 Roughness height R, RSm, R_z^2/R_{Sm} and frictional resistance increase rate FIR(%) (length for evaluation 50 mm)

Maximum height of roughness (μm)	Rz	Mean height of roughness curve elements Rc(μm)	Arithmetic mean roughness Ra(μm)	Root mean square roughness Rq(μm)	Ten-point mean roughness Rzjis (μm)	Mean length of roughness curve elements RSm (μm)	Rz ² /RSm (μm)	Frictional resistance increase rate FIR(%)
51.8		22.5	8.5	10.7	33.5	5914	0.45	0.80
18.4		7.1	3.2	3.9	11.1	5917	0.06	1.16
54.3		27.4	9.7	12.1	32.3	8506	0.35	1.21
55.0		27.6	9.9	12.3	33.6	8321	0.36	1.44
58.1		26.4	9.6	12.1	36.3	6694	0.50	1.46
66.2		25.7	9.8	12.7	43.6	4400	1.00	1.57
21.0		8.0	3.4	4.2	13.9	4225	0.10	3.79
99.5		42.9	15.5	19.5	71.3	3927	2.52	5.99
61.3		24.2	9.0	11.4	45.2	3173	1.18	6.30
86.2		35.5	13.0	16.6	59.9	4133	1.80	7.00
84.4		35.9	13.2	16.5	61.1	3838	1.86	7.09
98.7		42.4	15.4	19.4	71.0	4007	2.43	7.87
85.1		36.5	13.4	16.7	62.3	3927	1.84	7.93
103.0		43.0	15.8	19.8	76.9	3244	3.27	8.54
130.9		53.7	19.5	24.8	97	3167	5.41	11.18
161.3		63.4	22.8	29.6	116.1	3096	8.40	21.64

[0068]

Table 2

Mutual correlation of roughness height R and RSm (length for evaluation 50 mm)

	Rz (μm)	Rc (μm)	Ra (μm)	Rq (μm)	Rzjis (μm)	RSm (μm)
Rz (μm)	1.00					
Rc (μm)	0.99	1.00				
Ra (μm)	0.99	1.00	1.00			
Rq (μm)	1.00	1.00	1.00	1.00		
Rzjis(μm)	1.00	0.98	0.99	0.99	1.00	
RSm (μm)	-0.57	-0.47	-0.50	-0.50	-0.63	1.00

Example 2

Roughness measurement of a coating film of an actual ship

With regard to real ship bottoms (4 ships), Rz, Rc, Ra, Rq, RZJIS and RSm were measured and the results are shown in Table 3. On the ship bottoms of the 4 ships, the antifouling paints (a) SEAFLONEO, (b) SEA GRANDPRIX 500HS, (c) SEA GRANDPRIX 500 and (d) SEA GRANDPRIX 1000 (any of the antifouling paints was manufactured by Chugoku Marine Paints, Ltd.) were applied respectively. A replica of the resultant coating film was taken by a thermoplastic resin and carried back to the laboratory and the roughness of the coating film was measured by the laser displacement instrument. The evaluation range was 30 mm x 30 mm, the measurement distance was 250 μm and the evaluation length was 30, 000 μm . Through this measurement, the roughness profiles as shown in Fig. 4 were measured. Rz, Rc, Ra, Rq, RZJIS and RSm were the same as those in Example 1. From this fact, the measurement in the same range of RSm as that in Example 1 can be carried out on the coating film of the bottom of an actual ship.

[0069]

Table 3

Surface roughness analysis example in an actual ship outer shell
(Replica method/evaluation length 30 mm)

	Rz	Rc	Ra	Rq	Rzjis	RSm
1)-1	43.6	21.0	7.8	9.6	24.3	4798
1)-2	60.1	23.7	10.2	12.7	30.9	4811
1)-3	53.7	28.1	9.6	11.9	26.6	4809
1)-4	52.3	14.1	8.5	10.7	26.1	4198
1)-5	71.1	25.3	12.8	15.8	39.9	4289
1)-6	55.4	11.3	9.0	11.3	25.4	5118
1)-7	57.0	15.7	10.0	12.3	28.0	4870
1)-8	78.2	23.7	11.0	14.6	35.5	5279
1)-9	53.8	22.2	10.1	12.2	27.8	6014
1)-10	52.1	18.7	9.6	11.6	29.1	4211
1)-11	72.9	17.5	12.7	16.0	31.6	6040
1)-12	67.3	13.2	11.9	14.9	29.5	4479
1)-13	73.2	25.2	12.3	15.3	38.6	4466
1)-14	65.6	18.9	11.4	14.2	30.0	4947
1)-15	54.5	31.2	9.8	12.0	28.9	5309
Mean	60.7	20.7	10.4	13.0	30.2	4909

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	Rz	Rc	Ra	Rq	Rzjis	RSm
2)-1	120.0	50.0	21.8	27.0	47.7	4727
2)-2	109.3	35.8	17.4	21.9	68.1	3228
2)-3	76.8	22.8	13.0	16.1	45.0	3414
2)-4	65.2	12.6	11.9	14.6	39.8	3762
2)-5	72.5	21.3	13.0	16.0	46.9	4094
2)-6	64.6	33.2	11.5	14.2	38.5	4098
2)-7	79.3	37.1	14.0	17.3	47.7	3832
2)-8	55.3	19.3	9.1	11.2	34.4	3407
2)-9	54.6	33.2	11.5	14.2	38.5	4098
2)-10	101.3	35.7	16.0	20.2	68.9	2823
2)-11	68.6	17.4	11.0	13.9	38.0	3087
2)-12	64.1	34.1	10.2	12.8	41.4	2784
2)-13	94.9	29.5	16.0	19.9	58.2	3263
2)-14	101.3	35.7	16.0	20.2	68.9	2823
2)-15	63.6	30.3	10.1	12.7	42.5	2775
Mean	80.1	29.9	13.5	16.8	48.3	3481

	Rz	Rc	Ra	Rq	Rzjis	RSm
3)-1	74.9	20.4	13.0	16.2	32.7	4318
3)-2	73.4	29.4	12.2	15.2	38.0	3854
3)-3	95.2	44.8	16.2	20.3	57.9	3579
3)-4	107.4	29.2	19.3	23.8	65.2	3438
3)-5	109.4	60.6	20.5	25.2	46.6	4082
3)-6	75.8	57.7	12.5	15.7	46.0	3476
3)-7	80.9	23.5	11.8	15.1	44.0	3636
3)-8	109.1	44.7	18.8	23.2	52.2	4764
3)-9	103.7	37.0	16.7	21.1	61.7	3330
3)-10	68.8	32.8	11.5	14.4	42.3	3537
3)-11	59.3	15.3	10.0	12.3	32.2	3336
3)-12	89.1	84.8	15.6	19.1	50.1	3144
Mean	89.9	38.0	15.2	19.0	48.7	3806

	Rz	Rc	Ra	Rq	Rzjis	RSm
4)-1	82.7	44.6	14.1	17.5	54.6	3733
4)-2	99.8	45.1	18.0	22.3	57.3	5134
4)-3	55.5	26.3	9.7	12.0	34.1	3613
4)-4	60.6	35.1	10.7	13.3	34.6	4643
4)-5	76.9	65.7	14.9	18.2	33.8	7592
4)-6	107.4	32.4	16.4	21.2	48.4	4231
4)-7	82.8	47.5	14.1	17.4	55.9	2597
4)-8	75.8	15.6	14.1	17.2	42.0	3337
4)-9	75.4	47.0	13.9	16.9	45.9	4876
Mean	79.7	39.9	14.0	17.3	45.2	4417

- 1) ... (a) SEAFLO NEO
- 2) ... (b) SEA GRANDPRIX 500HS
- 3) ... (c) SEA GRANDPRIX 500
- 4) ... (d) SEA GRANDPRIX 1000

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In Fig.5, the values Rz and RSm are shown by a three-dimensional column graph. From the result, it was found that the roughness of the ship outer shell can be evaluated by the method of the present invention. Furthermore, from the mean values Rz and RSm of each ship, the estimation value of FIR (%) was determined using the coefficient C of 2.62.

Example 3

A method of estimating the frictional resistance increase rate

The estimation example of the frictional resistance increase rate obtained in Example 1 are shown in Table 6. When FIR (%) was determined using the coefficient C of 2.62, it is confirmed there is a tendency such that as Rz is larger and RSm is smaller, FIR (%) is larger. From these figures, it can be easily estimated to the roughness range that FIR(%) increeases remarkably.

Furthermore, Rz and RSm are introduced into the estimation formula directly and thereby the difference of FIR (%) can be compared.

CLAIMS

1. A method of estimating a frictional resistance of a ship bottom coating film,

Wherein the method comprises measuring any one of Rz (Maximum height roughness), Rc (mean height of roughness curve elements), Ra (arithmetic mean roughness), Rq (root mean square roughness) and RZJIS (ten-point mean roughness) as a roughness height R at a mean length of roughness curve elements RSm in the range of 2,000 to 10,000 μm according to JIS B 0601:2001(ISO4287:1997) on a coating film of a ship bottom coating paint on a substrate and computing a frictional resistance increase rate of FIR (%) from a mirror plane by the following formula (1);

[Formula 1]

$$\text{FIR}(\%) = C \frac{R^2}{R_{\text{Sm}}} \quad (1)$$

(in the formula, the coefficient C is a constant depending on the kind of the roughness height R and the method of frictional resistance test, and with regard to plural ship bottom coating films each having a different roughness, the roughness measurement and the frictional resistance test in a definite evaluation length are previously carried out, and then the coefficient C is determined from the formula (1) of the relationship of the measured roughness height R, the mean length RSm of roughness curve elements and the frictional resistance increase rate FIR (%).)

2. The method of estimating a frictional resistace of a ship bottom coating film according to claim 1 wherein the roughness is measured in an evaluation length of 10,000 mm or more, and a measurement distance of 500 μm or lower in the rule defined in JIS B 0601:2001 (ISO 4287:1997).

3. The method of estimating a frictional resistace of a ship bottom coating film according to claim 2 wherein the roughness is measured in a high pass filter such that the cut-off value λc is 10,000 μm or more.

4. The method of estimating a frictional resistace of a ship bottom coating film according to any one of claims 1 to 3 wherein in the frictional resistance test, using a double circular cylinder device, when an external cylinder is rotated, a torque T₀ which works on an internal cylinder having a mirror surface is determined and then when the external cylinder is rotated in the same condition, a torque T which works on the internal cylinder on which the ship bottom coating paint is coated is determined and thereby the frictional resistance increase rate FIR (%) is determined from the following formula (2)

[Formula 2]

$$FIR(\%) = \frac{T - T_0}{T_0} \times 100 \quad (2)$$

and then from the formula 1 of the relationship of the roughness height R of the coating film applied on the internal

cylinder and the mean length R_m of the roughness curve elements, the coefficient C is determined.

5 5. The method of estimating a frictional resistance of a ship bottom coating film according to any one of claims 1 to 4 wherein the roughness height R and the mean length R_m of the roughness curve elements are measured by a stylus type roughness measurement device or a laser displacement type roughness measurement device.

10 6. A method of evaluating a coating film performance of a ship bottom coating film which method comprises measuring a roughness height R and a mean length R_m of roughness curve elements using a previously determined coefficient C with regard to a coating film which is formed by applying a ship bottom coating paint on a substrate and estimating a frictional resistance increase rate FIR (%) by the formula (1).

15 7. The method of evaluating a coating film performance of a ship bottom coating film according to claim 6 wherein the roughness height R and the mean length R_m of the roughness curve elements are evaluated on a thermoplastic resin replica prepared by taking from an actual ship coating film.

20 8. A device for evaluating a coating film performance which is a device of evaluating a coating film performance of an actual ship coating film and comprises a measuring part of measuring a roughness height R and a mean length R_m of roughness curve elements and a frictional resistance calculating part of

calculating a frictional resistance increase rate FIR (%) using the formula (1).