[0015]

[4]

The method for predicting the frictional resistance of a rough surface described in [1], wherein the prominent peak projected area A is a value calculated using Equation (6) wherein RSm is the average length of roughness curve elements and Ra is the arithmetic average roughness both measured as roughness wavelength λ and roughness height R, respectively, in accordance with the regulations in ISO 4287: 1997 (JIS B 0601: 2001).

[0016]

[Math. 6]

$$A = \frac{(Ra - \delta s)}{RSm} \qquad (6)$$

(In Equation (6), δs used to calculate the prominent peak projected area A is the viscous sublayer thickness measured by a frictional resistance test with respect to a smooth surface and is a value determined in such a manner that the frictional velocity u* is calculated from the frictional resistance τ_0 of the smooth surface using Equation (5), δs is calculated from Equation (4) using the dimensionless distance y^+ ($2 < y^+ < 8$) and the kinematic viscosity coefficient ν of a fluid of interest, and, from among the values of δs thus calculated, the value which provides a high coefficient of correlation between FIR

[0022]

[Fig. 1] Fig. 1 is a diagram illustrating a relationship between the friction increase ratio FIR (%) and the prominent peak projected area $A = 0.5 \times (Rc - \delta s)^2/(Rc \times RSm)$.

[Fig. 2] Fig. 2 is a diagram illustrating a relationship between the friction increase ratio FIR (%) and the prominent peak projected area $A = (Ra - \delta s)/RSm$.

[Fig. 3] Fig. 3 is a schematic view illustrating a change of δs and prominent peak projected area by a change in flow velocity.

[Fig. 4] Fig. 4 is a schematic view illustrating how the projected area a of a peak standing out above the viscous sublayer thickness δs is calculated using Rc.

[Fig. 5] Fig. 5 is a set of diagrams illustrating relationships of Rc and roughness parameters Rz, Ra, Rq and Rzjis.

[Fig. 6] Fig. 6 is a set of diagrams illustrating relationships of Ra and roughness parameters Rz, Rc, Rq and Rzjis.

[Fig. 7] Fig. 7 is a diagram illustrating a relationship between $\Delta\tau$ (N/m^2) and $0.5 \times \rho \times A \times V^2$ wherein $A = 0.5 \times (Rc - \delta s)^2/(Rc \times RSm)$.

[Fig. 8] Fig. 8 is a diagram illustrating a relationship between $\Delta\tau$ (N/m^2) and $0.5 \times \rho \times A \times V^2$ wherein $A = (Ra - \delta s)/RSm$.

example, the viscous sublayer thickness δs was calculated using Equations (17) and (18) assuming that the dimensionless distance (y^+) was 4.0, the results being described in Table 5. Using the viscous sublayer thickness δs in Table 5 and the average element height Rc of each cylinder described in Table 1, the prominent peak projected area A was calculated from Equation (1), the results being described in Table 6. The graph in Fig. 1 plots the prominent peak projected area A in Table 6 on the abscissa and the FIR (%) in Table 4 on the ordinate. C = 1274.

[0071]

An example of resistance prediction using this example will be described below.

Provided that the viscous sublayer thickness δs of the fluid of interest is 10 μm (dimensionless distance $y^+ = 4.0$), Rc is 40 μm and the wavelength is 3000 μm, the prominent peak projected area A calculated from Equation (1) is 0.0075 (m^2). Because C = 1274, the FIR (%) is calculated to be 9.6% from Equation (19).

[0072]

[Example 2]

Frictional resistance test Prominent peak projected area A = (Ra - δs)/RSm

The frictional resistance measurement method and the

roughness measurement method are the same as described in [Example 1]. In this example, the viscous sublayer thickness δs was calculated using Equations (17) and (18) assuming that the dimensionless distance (y^+) was 2.5, the results being described in Table 7. Using the viscous sublayer thickness δs in Table 7 and the average element height Ra of each cylinder described in Table 1, the prominent peak projected area A was calculated from Equation (2), the results being described in Table 8.

The graph in Fig. 2 plots the prominent peak projected area A in Table 8 on the abscissa and the FIR (%) in Table 4 on the ordinate. C = 1800.

An example of resistance prediction using this example will be described below.

[0073]

Provided that the viscous sublayer thickness δs of the fluid of interest is 6.5 μm (dimensionless distance $y^+ = 2.5$), Ra is 20 μm and the wavelength is 3000 μm, the prominent peak projected area A calculated from Equation (2) is 0.0045 (m^2). Because C = 1800, the FIR (%) is calculated to be 8.1% from Equation (19).

[0074]

[Example 3]

Regarding the roughness parameters of the cylinders

velocity V described in Table 10 on the abscissa and $\Delta\tau$ in Table 9 on the ordinate. C_r = 0.0556.

[0076]

An example of resistance prediction using this example will be described below.

Provided that the fluid of interest has a density ρ = 1023.95 (kg/m^3) and flows at a velocity of 8.4 (m/sec), the viscous sublayer thickness δs is 10 μm (dimensionless distance y^+ = 4.0), Rc is 40 μm and the wavelength is 3000 μm, the prominent peak projected area A calculated from Equation (1) is 0.0075 (m^2). Because C_r = 0.0556, the frictional resistance increase $\Delta\tau$ is calculated to be 15 (N/m^2) from Equation (24).

[0077]

[Example 5]

Using the frictional resistance τ_0 of the smooth surface described in Table 2 and the frictional resistance τ_r of the rough surface described in Table 3, the frictional resistance increase $\Delta\tau$ (N/m^2) of the rough surface compared to the smooth surface was calculated from Equation (21), the results being described in Table 9. Using the flow velocity V, the fluid density ρ and the prominent peak projected area A in Table 8 calculated in [Example 2], 0.5 × fluid density ρ × prominent peak projected area A × squared flow velocity V was calculated, the results being described in Table 11. Here, the flow

[Table 1]

Table 1 Results of measurement of roughness parameters

Cylinders Nos.	Film thickness (μm)	Rz (μm)	Rzjis (μm)	Rc (μm)	Ra (μm)	Rq (μm)	Rsk	Rku	RSm (μm)
A	262	166.9	134.1	64.8	22.9	28.9	0.2	3.1	998
B	321	256.9	133.1	148.3	51.0	63.3	0.5	3.0	5604
C	242	149.9	105.7	76.3	26.7	32.8	0.1	2.7	3214
D	324	156.9	105.4	77.6	27.0	33.6	0.2	2.9	3404
E	219	140.1	97.8	68.2	24.0	29.8	0.2	2.9	3042
F	309	144.9	96.4	71.4	25.3	31.4	0.2	2.9	3449
G	257	134.6	92.9	65.4	23.2	28.8	0.2	2.9	3112
H	216	117.7	78.1	55.1	19.1	24.3	0.6	3.5	3057
I	391	104.1	57.0	55.2	19.7	24.4	0.3	2.9	5111
J	454	84.0	53.9	41.6	14.7	18.3	0.2	3.0	3777
K	311	75.2	47.1	35.0	12.4	15.9	0.6	3.7	3523
L	484	75.0	46.9	36.9	13.1	16.3	0.2	3.0	3910
M	46	62.0	40.8	28.2	10.3	13.0	0.3	3.2	3095
N	140	50.4	32.5	23.5	8.7	10.9	0.3	3.1	3385
O	283	38.7	18.6	20.9	7.8	9.6	0.1	2.8	6063

The roughness was measured at measurement pitches of 50 μm for Cylinder A and at measurement pitches of 250 μm for Cylinders B to O.

[0089]

[Table 10]

Table 10 Calculation of 0.5 × fluid density ρ × prominent peak projected area A × squared flow velocity V (Example 4)

	$0.5 \times \rho \times A \times V^2$ $A = 0.5 \times (Rc - \delta s)^2/(Rc \times RSm)$										
(rpm)	1000	950	900	850	800	750	700	650	600	550	500
(m/sec)	8.4	8.0	7.5	7.1	6.7	6.3	5.9	5.4	5.0	4.6	4.2
A	821.6	728.5	641.2	559.4	482.8	412.3	347.7	288.4	234.7	187.0	144.8
B	411.1	368.4	328.1	290.2	254.5	221.2	190.4	161.8	135.5	111.7	90.2
C	317.8	282.7	249.7	218.7	189.6	162.8	138.1	115.4	94.7	76.2	59.8
D	307.0	273.1	241.3	211.5	183.5	157.6	133.8	111.8	91.9	74.0	58.1
E	288.9	256.4	225.9	197.4	170.6	146.0	123.3	102.5	83.7	66.9	52.0
F	271.3	241.0	212.6	186.0	161.0	137.9	116.7	97.3	79.6	63.8	49.8
G	266.7	236.6	208.2	181.7	156.9	134.0	113.1	93.8	76.4	60.9	47.2
H	212.7	187.9	164.6	142.9	122.6	104.0	87.1	71.5	57.6	45.2	34.4
I	127.8	112.9	99.0	86.0	73.8	62.6	52.4	43.1	34.7	27.2	20.8
J	111.4	97.5	84.6	72.6	61.4	51.2	42.0	33.7	26.4	20.0	14.5
K	88.1	76.4	65.6	55.7	46.4	38.1	30.7	24.1	18.3	13.3	9.2
L	87.6	76.2	65.7	56.0	46.9	38.8	31.4	24.9	19.0	14.1	9.9
M	64.6	55.2	46.5	38.6	31.4	24.9	19.3	14.4	10.2	6.8	4.1
N	38.4	32.2	26.5	21.4	16.7	12.7	9.3	6.4	4.1	2.3	1.0
O	15.6	12.8	10.3	8.1	6.1	4.4	3.1	1.9	1.1	0.5	0.1

[0090]

[Table 11]

Table 11 Calculation of 0.5 × fluid density ρ × prominent peak projected area A × squared flow velocity V (Example 5)

	$0.5 \times \rho \times A \times V^2$ $A = (Ra - \delta s)/RSm$										
(rpm)	1000	950	900	850	800	750	700	650	600	550	500
(m/sec)	8.4	8.0	7.5	7.1	6.7	6.3	5.9	5.4	5.0	4.6	4.2
A	590.1	522.8	459.6	400.5	344.9	293.7	246.8	203.5	164.3	129.4	98.4
B	285.3	255.8	227.8	201.5	176.8	153.7	132.3	112.4	94.2	77.6	62.6
C	225.6	200.6	177.0	155.0	134.2	115.0	97.4	81.1	66.3	53.0	41.2
D	216.3	192.4	169.9	148.7	128.9	110.5	93.6	78.0	63.8	51.1	39.7
E	206.4	183.1	161.2	140.6	121.4	103.6	87.2	72.2	58.5	46.3	35.5
F	195.8	173.8	153.3	134.0	115.8	99.1	83.7	69.5	56.6	45.0	34.8
G	192.6	170.7	150.1	130.9	112.8	96.1	80.8	66.7	53.9	42.5	32.4
H	147.8	130.2	113.7	98.3	83.9	70.6	58.6	47.5	37.5	28.7	20.9
I	92.8	81.9	71.6	62.0	53.0	44.8	37.2	30.3	24.0	18.5	13.6
J	78.1	67.9	58.5	49.7	41.4	33.9	27.1	21.0	15.5	10.7	6.6
K	60.1	51.5	43.5	36.1	29.2	23.0	17.5	12.4	8.0	4.3	1.1
L	60.8	52.4	44.6	37.4	30.6	24.5	19.0	14.1	9.7	5.9	2.7
M	43.5	36.1	29.3	23.0	17.2	12.1	7.5	3.5	0.0	-2.8	-5.1
N	23.0	17.8	13.2	8.9	5.0	1.6	-1.3	-3.9	-6.0	-7.6	-8.8
O	7.6	5.3	3.2	1.3	-0.5	-2.0	-3.2	-4.3	-5.2	-5.8	-6.2

velocity u* is calculated from the frictional resistance τ_0 of the smooth surface using Equation (5), δs is calculated from Equation (4) using the dimensionless distance y^+ ($2 < y^+ < 8$) and the kinematic viscosity coefficient ν of a fluid of interest, and, from among the values of δs thus calculated, the value which provides a high coefficient of correlation between FIR (%) and the prominent peak projected area A in Equation (1) is selected).

[Claim 5]

The method for predicting the frictional resistance of a rough surface according to Claim 4, wherein the prominent peak projected area A is calculated in such a manner that Rz, Rzjis, Rq or Rc is measured as roughness height R", the slope a of the Ra to the measured parameter is determined and the parameter is converted assuming that $Ra = a \times R''$ (R" is Rz, Rzjis, Rq or Rc).

[Claim 6]

A surface performance estimating apparatus for estimating surface performance by the prediction method described in any of Claims 1 to 5, the apparatus comprising:

a measurement section configured to measure the roughness height R and the average length RSm of roughness curve elements, and

a calculation unit configured to calculate the prominent