CALCULATION OF SHIP'S ACTIVE BRAKING CHARACTERISTICS

Yevgeniy Kalinichenko
Department of Ship Handling
National University «Odessa Maritime Academy»
8 Didrikhson, str., Odessa, Ukraine, 65029
kyevgeniy@ukr.net

Abstract: The article considers a new calculation method for determining the ship's maneuvering elements (inertial-braking characteristics) using an alternative approach. Based on the new methodology, the procedure for calculating the inertial-braking parameters of the ship is given. Within the framework of this task, an alternative approach is considered for determining the inertial-braking characteristics of a ship. The article shows that the entire braking process is divided by speed into several elementary sections and it is assumed that in each section the work of the resistance forces and the propeller stop is equal to the work of their average values Pav and Rav. And as an alternative method for determining the characteristics of the slowed and accelerated motion of the ship and its characteristics of active braking, theorems on the change in the amount of motion and kinetic energy are used. As a result, expressions of the braking time t and the coasting time S are obtained. Using the obtained expressions, an example of calculating the length and time of the coasting with active braking in the reverse direction from full forward to "full reverse" is given.

Keywords: navigation, ship maneuvering, inertial-braking characteristics, mathematical models of braking.

1. Introduction

The coasting length and the time of active braking of the ship in the training literature [1] is decided to be determined by dividing the slow motion process into three periods: the period of the command's passing until the fuel or steam closes to the main engine; the period from the closing of the fuel or steam prior to the start of the propeller rotation to the reverse and the period from the start of the propeller rotation to the reverse to the complete stop of the ship. In the first period (5–7 s) it is assumed that the ship continues to move at a steady forward speed. In the second period, it is assumed that the braking occurs only under the influence of the hull's resistance force, and the thrust of the propeller is zero. In the third period, the ship braking occurs under the influence of the hull's resistance force and the propeller stop on the reverse course in the mooring mode [1–5].

2. Methods

In fact, in the second period, the propeller, rotating in the mode of the hydro turbine, creates additional resistance, which increases the hull resistance by approximately 30 % [6]. Ignoring the resistance force of a freely rotating propeller can introduce significant errors into the calculated braking characteristics, and dividing the active braking process considerably complicates the calculation and formalization for the PC use.

The proposed alternative approach eliminates these shortcomings and greatly simplifies the procedure for calculating the braking characteristics of the ship.

3. Results

The trajectory described by the center of gravity of the ship during braking is called the braking distance. The shortest distance from the beginning of the braking of the ship to its stopping or to a specified speed is called a coasting. If the vessel does not deviate from the initial course during the braking process (the coasting length is equal to the length of the stopping distance), then the law of its motion is described by the differential equation

$$(1+k)m\frac{dv}{dt}=-\sum F, \tag{1}$$

in which the sum of the braking forces ΣF consists of the hull resistance R and the propeller stop in the back stroke P, N, k – the coefficient of the attached mass, v– the ship's speed, m/s, m – the ship's mass, kg.

The entire braking process is divided by speed into several sections. Let's assume that in each section the work of the resistance forces and the propeller stop is equal to the work of their average values P_{av}, R_{av}..Then let's rewrite the right-hand side of equation (1) thus:

$$(1+k)m\frac{dv}{dt}=-(R_{av}+P_{av}). \tag{2}$$

In ship theory, the hull resistance of a ship is approximated by a power-law dependence of the form $R=\mu v^a$, where μ – the proportionality coefficient; a – the exponent.

To determine the average resistance at each speed segment, let's apply the theorem on the mean integral calculus [7]. According to this theorem

$$R_{av}=\frac{1}{v_0-v}\int_v^{v_0}\mu v^a dv = \\ =\frac{\mu(v_0^{a+1}-v^{a+1})}{(a+1)(v_0-v)}, \tag{3}$$

where v_o – the initial speed before braking.

In the case of a complete stop of the ship, i. e. when v=0

$$R_{av}=\frac{\mu v_0^a}{a+1}.$$

For the most common case, when a=2:

$$R_{av}=\frac{\mu}{3}(v_o^2+v_o v+v^2). \tag{4}$$

Since the ship's weight during the braking time practically does not change, equation (2) can be represented in the following form:

$$\frac{d[(1+k)mv]}{dt}=-(R_{av}+P_{av}).$$

Let's multiply both sides of this equality by dt and take integrals from them. In this case, on the left, where integration is over the speed, the limits of the integral are v_o and v, and on the right, where the integration is over the time, the limits of the integrals are 0 and t. As a result, let's obtain that the change in the amount of movement of the ship in this segment of braking is equal to the sum of the impulses acting on it, i. e.,

$$(1+k)mv_o-(1+k)mv=R_{av}t+P_{av}t. \tag{5}$$

Solving equation (5) with respect to t, let's obtain:

$$t=\frac{(1+k)m}{R_{av}+P_{av}}[v_o-v], \tag{6}$$

where t – braking time in seconds.

For v=0, i. e. at full stop of the ship

$$t=\frac{(1+k)mv_o}{R_{av}+P_{av}}. \tag{7}$$

To find the coasting length, let's represent the acceleration in equation (2) in the form:

$$\frac{dv}{dt}=\frac{dv}{dS}\frac{dS}{dt}=v\frac{dv}{dS}=\frac{1}{2}\frac{dv^2}{dS}.$$

Then

$$\frac{(1+k)mv^2}{2dS}=-(R_{av}+P_{av}). \quad (8)$$

Let's multiply both sides of (8) by dS and insert (1+k)m under the sign of the differential.

Let's obtain the expression for the theorem on the change in the kinetic energy in a differential form:

$$d\left[\frac{(1+k)mv^2}{2}\right]=-(R_{av}+P_{av})dS, \quad (9)$$

so the coasting length at each speed section during braking is:

$$S=\frac{(1+k)m}{2(R_{av}+Pav)}[v_o^2-v^2], \quad (10)$$

where S – the coasting length in meters.

For v=0, formula (10) is simplified:

$$S=\frac{(1+k)mv_o^2}{2(R_{av}+P_{av})}. \quad (11)$$

The calculation by formulas (6), (7) and (10), (11) will be more accurate the smaller the difference in the speeds $(v_o^2-v^2)$ and (v_o-v).

Let's make one more assumption that the propeller stop force is a linear function of speed from the beginning of braking to the speed of the reverse beginning, v of the reverse, after which it becomes constant and equal to the value in the mooring mode [8]. At the steady speed of the forward stroke, the hull resistance will be equal to the propeller stop force, corrected by the coefficient of the associated flow, i. e.

$$R_o=(1-\Psi)P_o, \quad (12)$$

where Ψ – the co-flow coefficient.

Taking into account the above, let's obtain expressions for determining the mean propeller stop at given speed sections:

$$P_{av}=R_0-(R_o-P)\frac{v_{av}}{v_{rev\ 1}}, \quad (13)$$

where

$$v_{av}=\frac{v_n+v_{n+1}}{2}.$$

When $v_{av}=v_{rev}$, then $P_{av}=P_1$, i. e. the propeller stop to the reverse in the mooring mode.

The propeller stop force on the reverse course in the mooring mode is determined by the formula known from the ship theory:

$$P_1=\rho K_1 n_1^2 D_p^4, \quad (14)$$

where ρ=1025 kg/m^3 – the mass density of sea water; K_1 – the propeller stop coefficient to the reverse in the mooring mode; n_1 – the rotation frequency of the propeller to the reverse, rev/s; D_p – diameter of the propeller, m.

If there is no information about the propeller stop coefficient to the reverse, its value can be determined by the formula:

$$K_1=0,4\frac{H}{D_p}-0,07, \quad (15)$$

where H/Dp – the step ratio of the propeller.

There are several ways to determine the value of the proportionality coefficient, for calculating the hull resistance of the ship. Here let's give only the simplest empirical formula [9]:

$$R=58\frac{D_c}{L}v^2,$$

so

$$\mu=58\frac{D_c}{L}, \quad (16)$$

where D_c – displacement of the ship in cargo, t; L – ship's length between perpendiculars, m.

When the Froude number

$$Fr=\frac{v}{\sqrt{gL}}<0.25,$$

in which most transport ships usually fit, formula (16) gives satisfactory results for the ship in cargo. In the formula (16) the following notations are introduced:

To recalculate the coefficient μ for a smaller displacement, it is possible to use the formula:

$$\mu=\mu_c\left(\frac{D}{D_c}\right)^{1,167}. \quad (17)$$

The effect of the attached mass occurs when the solid moves in the fluid. When the ship is brake, the value of the attached mass is somewhat greater than when the motion is steady and the coefficient of the attached mass is:

$$k=\frac{\Delta m}{m},$$

where Δm – the value of the attached mass, which is determined by the formula:

$$\Delta m=\frac{1,5\pi\rho}{4}T^2B, \quad (18)$$

where T – the average draft of the ship, m; B – ship's width, m; π=3.14...

Then the ship's weight, taking into account the attached mass, will be:

$$m+\Delta m=(1+k)m. \quad (19)$$

4. Discussion

The calculation procedure [10]:

1. Determination of the value of the added mass by the formula (18).

2. Determination of the ship's weight, taking into account the attached mass by the formula (1+k)D×10^3, kg.

3. Determination of the coefficient μ for ship in the cargo by the formula (16), and of the ship in the ballast by the formula (17).

4. Determination of the ratio of the propeller stopper, K_1 according to the formula (15).

5. Determination of the propeller stop force on the reverse in the mooring mode, P by the formula (14).

6. Determination of the average propeller stop force, P_{av} for given speed sections by the formula (13), taking into account that when V_{av} becomes equal to V_{rev}, then P_{av} will become equal to P_1.

References

1. Snopkov, V. Y. (Ed.) (1991). Upravlenye sudnom. Moscow: Transport, 359.
2. Demyn, S. Y. (1975). Tormozhenye sudna. Moscow: Transport, 81.
3. Demyn, S. Y. (1980). Analytycheskyi metod opredelenyia elementov tormozhenyia sudov. Ekspress-informatsyia TsBNTY MMF. Seryia: Sudovozhdenye y sviaz, 3 (128), 21–33.
4. Maltsev, A. S. (1989). Uchet manevrennykh kharakteristik dlia obespecheniia bezopasnosty plavaniia. Sudostroenye i remont, 5, 29–31.
5. Turchak, L. Y. (1987). Osnovy chyslennykh metodov. Moscow: Nauka. Glavnaya redaktsiya fiziko-matematicheskoy literatury, 320.
6. Tani, H. (1970). On the Stopping Distances of Giant Vessels. Journal of Navigation, 23 (2), 196–211. doi: 10.1017/s0373463300038406
7. Yarkyn, P. Y. (1975). Opredelenye i uchet kharakterystyk uskorennoho i zamedlennoho dvizheniia sudna. Moscow: Reklamynformbiuro MMF, 71.
8. Yarkyn, P. Y., Maltsev, A. S., Kalynychenko, E. V. (2004). Opredelenye kharakterystyk razghona i podtormazhyvanyia sudna. Alternatyvnyi podkhod. Visnyk ONMU, 13, 63–71.
9. Norrbin, N. H. (1971). Theory and observations on the use of a mathematical model for ship manoeuvring in deep and confined waters. Trans. Swedish State Shipbuilding Experimental tank. Goteborg, 68 (19), 117.
10. Kalynychenko, E. V. (2005). Prakticheskyi raschet inertsyonno-tormoznykh kharakterystik sudna. Sudovozhdenie, 10, 58–63.