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Experimental evaluation of azimuth thruster for tanker scale model with dynamic positioning system

Lázaro Moratelli Jr.* Hélio Mitio Morishita* Carlos A.G.F. Souza*
Pedro Gomes da Costa Renan E. Fonseca* Eduardo A. Tannuri.****

**Department of Naval Architecture and Ocean Engineering, University of São Paulo, São Paulo, Brazil (e-mail:lazaro.moratelli@usp.br, hmmorish@usp.br, cafsouza@usp.br, renan.pmf@gmail.com).*
***Department of Mechatronics and Mechanical Systems Engineering, University of São Paulo, São Paulo, Brazil (e-mail: pedrogc2@hotmail.com and eduat@usp.br).*

Abstract: The thrust-propeller shaft speed relationship is required to calibrate control parameters in order to perform experimental tests with dynamic positioning system (DPS) installed in the scale model. In general, actuators of a DPS are main propeller, side and azimuth thrusters and their characteristic curves are quite difficult to be obtained theoretically. Therefore, tests in laboratory are necessary to evaluate the performance of those propellers, so tests carried out with azimuth thruster with nozzle are presented. The focuses are twofold: the first one is to evaluate the bollard pull varying the propeller shaft speed and the azimuth angle, as well; the second purpose is to evaluate the thrust while the azimuth is swiveling. In order to do it, the thruster is installed in a captive container and forces and moments in horizontal plane are measured by the load and torque cells connected in a vertical beam. The preliminary bollard pull test results indicate some influence in the thrust due to the relative angle between the azimuth propeller and hull. Swiveling tests results show some thrust reduction in comparison to the bollard pull tests for the some azimuth angle and a difference between clockwise and counterclockwise is observed, albeit not relevant.

Keywords: azimuth thruster, dynamic positioning, scale model, shuttle tanker.

1. INTRODUCTION

The number of ships with dynamic positioning system has increased due to their flexibility to keep position and attitude elsewhere. In special, DPS has been installed in shuttle tankers so as to maintain the ship within the restricted operational area during the offloading operation. In order to do it, a propulsion system is required to compensate the environment moment and forces and a controller system is needed to command the actuators properly. The controller parameters are calibrated using both ship and actuators characteristics and overall ship performance is investigated with computational simulations and experimental tests with scale model.

However, the theoretical prediction of the DPS ship performance is quite difficult, since mathematical models comprise nonlinear motion equations, and some intricate hydrodynamic phenomena are not adequately modeled. The problem arises with installations of actuators such as tunnel and azimuth thrusters.

Nowadays, most of the DPS ships have installed azimuth thrusters as it allows directing thrust in any direction. However, the precise characteristic of the azimuth thruster is difficult to predict because it depends on its angle with respect to the hull, ship speed and environmental conditions. Hence, tests with DPS scale model in ocean basin are the main concern to evaluate vessel dynamic in realistic environmental conditions and to predict its performance.

In Brazil, the number of DPS vessels has increased and it has encouraged the development of experimental facilities for tests with DPS scale models in the local ocean basin. Tests with scale model require preliminary investigation of the thruster performance. Systematic experiments with nozzle propellers are carried out by Oosterveld, M.W.C. (1973) resulting in a propeller series with both accelerating and decelerating nozzles. Interaction effects of azimuth thrusters and their mechanical characteristics are commented by Norrby, R. Å and Ridley, D.E. (1980). Tests varying azimuth angle for bollard pull condition are shown by Dijk, R. Th. V. and Aalbers, A.B. (2001). Interference between two azimuth thrusters in relation to their azimuth angles and shaft propeller are presented by Ekstrom, L. and Brown, D.T. (2002). An overview of thruster types and a study of a more efficient kind of nozzle are commented by Dang, J. and Laheij, H. (2004).

Results of preliminary tests carried out with scale model of azimuth thruster in the Department of Naval Architecture and Ocean Engineering of the University of São Paulo are presented. The purpose is to evaluate the thruster performance considering the effect of the azimuth angle and its swiveling speed. The thrust-propeller shaft speed relationship is the main characteristic required by control parameters calibration. In order to measure that relationship, an electronic driver is used to control the shaft speed and the thrust is measured by a special device which was assembled and is here described.

The tests are part of a research program that intends to perform tests with DPS scale model in Brazilian laboratories in the near future (Morishita et al, 2009).

2. EXPERIMENTAL SET UP

The purpose of the tests is to evaluate the thrust-propeller shaft speed relationship because it is necessary to the calibration of the control parameters. As the component has two degrees of freedom, i.e., azimuth angle and propeller speed, two kind of tests are carried out: a) measurement of the bollard pull varying the propeller speed and holding the azimuth angle with respect to the hull; b) measurement of the thrust while the azimuth is swiveling during both clockwise and counterclockwise rotation while the shaft speed is held.

The thrust measurement as a function of those variables is difficult once the azimuth thruster can propel the hull in different directions. Thus, a special apparatus based on vertical beam with strain gages and torque cell is assembled to measure forces and moments caused by the thrusters in the horizontal plane, as shown in Fig. 1.

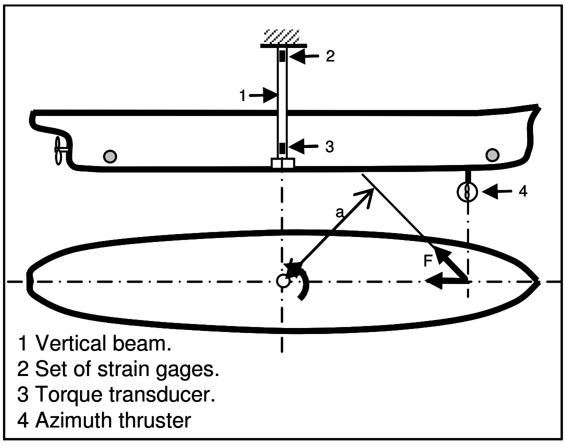

Fig. 1. Sketch of thrust measurement system.

The top side of the circular beam is fixed in an inertial frame and the bottom side is connected to the hull. A load cell is assembled by strain gages located on the top of the beam to measure the forces in the longitudinal (*X*) and lateral (*Y*) directions. A torque cell is attached to the bottom of the beam and it measures moment (*N*) in the horizontal plane. The torque for the azimuth propeller is supplied by an electric motor and a step motor swivels the azimuth thruster. An electronic driver controls the azimuth angle and holds the propeller shaft speed. The azimuth has a 19A nozzle and the propeller dimension is shown in Table 1.

Table 1. Dimensions of azimuth propeller.

D [mm]	32
Z	2
P/D	1.6
Ae_Ao estimated	0.48
Material	Beryllium Copper

It is worth remarking that the thrust can be measured through both the load cell and the torque cell except in the longitudinal direction, in which there is no moment in the beam. During the tests, the thrust (T) measured by the load cell, the propeller shaft speed (n) and moment are recorded. For more information about the apparatus, see Morishita et al (2009).

However, before performing tests with DPS scale model, preliminary tests are carried out in a small container. The purpose of those tests is to verify the feasibility of the apparatus for evaluating the thrust of azimuth propeller. The sketch of the container with the apparatus is shown in Fig. 2.

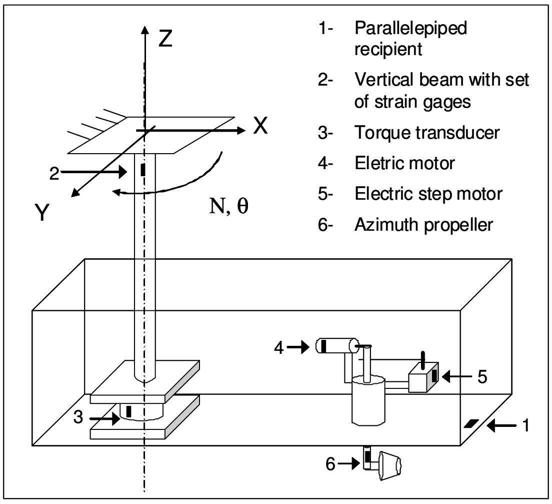

Fig. 2. Sketch of parallelepiped container with azimuth thruster.

3. INTERACTIONS EFFECTS

Some hydrodynamic interaction is expected to happen between the container and the azimuth thruster (Moratelli, L. Jr. and Morishita, H.M. (2008)). The major consequence of the interaction is the degradation of the available thrust (Nordtveit, R. et al, 2007). The procedure of the tests show here measures the thrust taking into account all hydrodynamic interactions. For more detailed information about thrust degradation, see Taniguchi et al (1966), Pivano, L (2008) and Smogeli, Ø.N. (2006).

Besides thruster-hull interactions, the relative speed between fluid and azimuth thruster influences the net thrust. This kind of phenomenon needs to be considered during the swivel of the azimuth propeller, for instance. The phenomenon happens when the azimuth thruster swivels and some transversal speed is added in the jet propeller. This transversal speed modifies the flow field of the jet and, consequently, the pressure field is altered decreasing the effective thrust in the axial direction.

Thus, a thrust reduction is expected in swiveling tests in comparison to the thrust of the bollard pull tests, when the azimuth thruster is stationary. Using the same approach presented by Beveridge, J.L. (1972), the speed ratio (*m*) is evaluated to study the thrust reduction in the model scale. Speed ratio is the relationship between the main stream speed around thruster v and the jet speed of propeller v_j. While the main stream speed is ship speed in Beveridge, J.L. (1972), here the main stream speed is equal to tangential speed in the edge of the nozzle, as shown in Fig. 3.

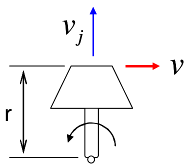

Fig. 3. Sketch of vectorial speeds in swiveling test.

The main stream speed is calculated using (1), where r is the distance between the swiveling center and the edge of the nozzle and t is period of the swivel. The jet speed is calculated using (2), where ρ is the water density and A is the frontal area of the nozzle exit.

$$v = \frac{2\pi r}{t} \quad (1)$$

$$v_j = \sqrt{\frac{T}{\rho A}} \quad (2)$$

4. RESULTS

The results of both bollard pull and swiveling tests are presented in terms of thrust coefficient (*Kt*), which is calculated by (3), in S.I. units.

$$K_t = \frac{T}{\rho . n^2 . D^4} \quad (3)$$

Bollard pull condition tests are made for azimuth angles between 0° and 180° with 45°-step and propeller speed is set between 500rpm and 3000rpm with 500rpm-step. The thrust coefficients obtained from load and torque cells are shown in Fig. 4 and Fig. 5, respectively.

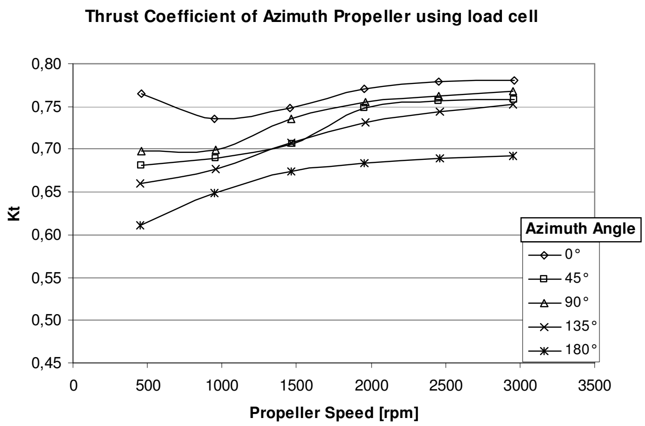

Fig. 4. Thrust coefficient as a function of propeller speed, values measured using load cell.

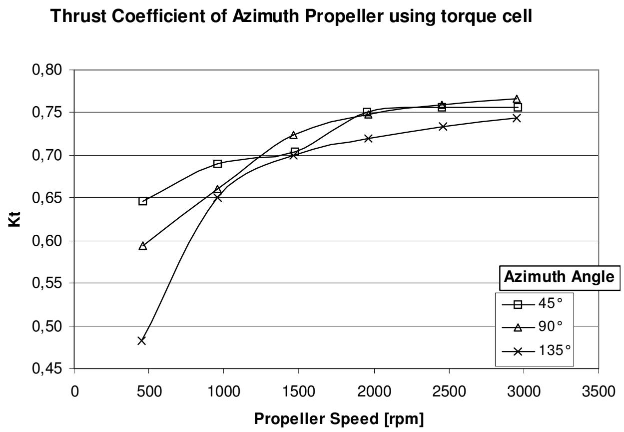

Fig. 5.Thrust coefficient as a function of propeller speed, values measured using torque cell.

It seems that for azimuth angles 45°, 90° and 135°, the thrust coefficient obtained from data of load and torque cells presents similar values for propeller speed above 1000rpm. The results show the thrust coefficients depend on the azimuth angle. Hydrodynamic interactions, such as Coanda effect and frictional losses, can explain those differences.

Observing the experimental set up, one can guess that the values of the thrust coefficients increase with the azimuth angle according to the following sequence: $T_{180^\circ} < T_{0^\circ} < T_{90^\circ}$. The reason is the length between the propeller and the edge of the container that changes with the azimuth angle. The values of thrust coefficients for 45° and 135° must be between 0° to 90° and 90° to 180°, respectively. The expected tendency is noticed in the test, except for 0°-azimuth angle, which produces a higher thrust than 90°-thrust. Further analysis has shown that there was calibration loss in the *X* direction. The thrust coefficient of the azimuth propeller installed in the container presented a variation around 10% between the maximum and minimum values. This difference can be higher when the azimuth thruster is operating in a scale model because the length between the propeller and the edge of the hull can increase depending on azimuth angles. In practice, a loss factor is considered to compensate the thrust reduction.

In swiveling tests, two swivels are done for both clockwise (CW) and counterclockwise (CCW) rotation and the test results are presented considering the average values among the swivels done in the same rotation. The measured thrust presents some noise which is filtered by using a low-pass filter. The thrust coefficient of swiveling tests in comparison with bollard pull tests (BP) are presented for 1000rpm, 2000 rpm and 3000 rpm propeller speed in Fig. 6, Fig. 7 and Fig. 8, respectively.

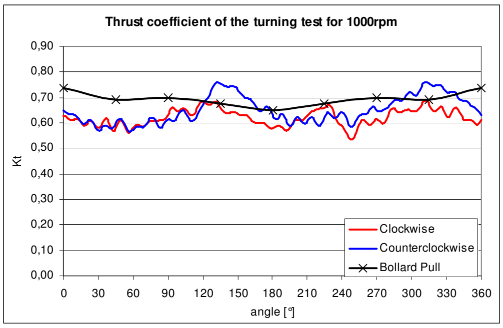

Fig. 6. Thrust coefficient of the swiveling test for 1000rpm.

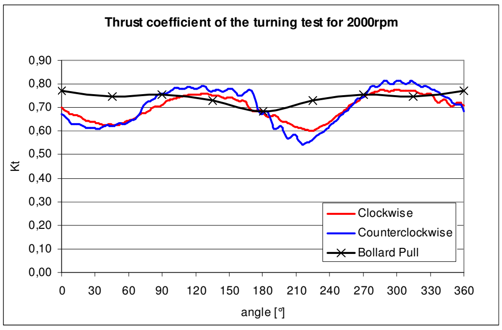

Fig. 7. Thrust coefficient of the swiveling test for 2000rpm.

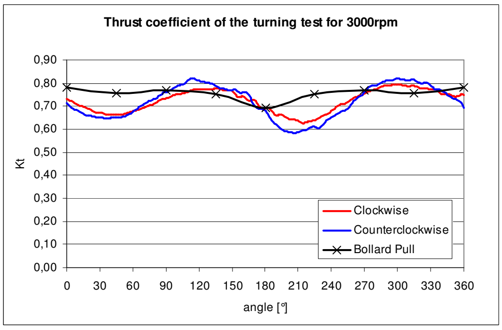

Fig. 8. Thrust coefficient of the swiveling test for 3000rpm.

Swiveling tests present some difference between clockwise and counterclockwise rotation, although they present a similar tendency in terms of values. Some reduction in thrust coefficient for swiveling tests is expected in relation to bollard pull tests, but those swiveling tests present higher values than BP tests for the angle around 120° and 300° azimuth angles. Those results have not been clarified. Apparently, the swivel of the azimuth generates a transient flow that modifies the thruster-hull interaction and the value of the force in the load cell.

Besides, the procedure considered here to measure the forces presents some drawbacks: a) cross talking of the strain gage arrangements; b) relative position of the nozzle and electric motor to the container that affects the measurement of the real propeller thrust, since for every position of the nozzle there is a particular residual strength; c) the resistive torque of the electric motor that also modifies the strength in the beam. Those influences are deduced from the original signal in the results presented in this paper.

However, in some particular azimuth angles, all those problems are minimized, namely 0°, 90° and 180°. In Table 2, the values of the thrust coefficients for swiveling and bollard pull tests are shown, for different values of the propeller speed and direction of the swivel of the azimuth. The comparison shows some reduction of thrust coefficient for the swiveling test in comparison to the bollard pull tests, as expected. It seems that the value of the reduction increases as the propeller speed decreases. Furthermore, the increase in thrust reduction is also expected when the swivel speed of the azimuth thruster increases. The thrust reduction is evaluated for ducted thrusters by Beveridge (1972). In that study, the speed ratio is calculated using the ship speed as the main stream speed and the results show that thrust efficiency is not affected between $0\% < m < 20\%$.

Table 2. Thrust coefficient during the swiveling test.

	Kt				
	0° - Load Cell				
n [rpm]	Kt BP	Kt CW	Δ	Kt CCW	Δ
1000	0.74	0.63	15.17%	0.63	14.56%
2000	0.77	0.70	9.10%	0.68	11.30%
3000	0.78	0.73	6.05%	0.69	11.02%
	90° - Load Cell				
n [rpm]	Kt BP	Kt CW	Δ	Kt CCW	Δ
1000	0.7	0.64	8.67%	0.65	6.49%
2000	0.75	0.71	4.85%	0.74	0.88%
3000	0.77	0.73	4.70%	0.76	1.76%
	180° - Load Cell				
n [rpm]	Kt BP	Kt CW	Δ	Kt CCW	Δ
1000	0.65	0.58	11.33%	0.63	2.79%
2000	0.68	0.68	0.18%	0.68	0.63%
3000	0.69	0.69	0.19%	0.68	1.53%

In swiveling tests, rotation speed of azimuth propeller (main stream) is held and equals 4.9 rpm and the values of the speed ratio do not reach values up to 20%, as shown in Table 3. However, even the swivel speed is held constant and although the speed ratio values are low, thrust reduction is realized. This can happen because the azimuth thruster is more affected by the hydrodynamic interactions than ducted propellers and the value of model scale can also influence the thruster performance.

Table 3. Speed ratio values of the swiveling tests.

	$m = v/v_j$	
n (rpm)	minimum	maximum
1000	3.3%	3.8%
2000	1.6%	2.0%
3000	1.1%	1.3%

5. CONCLUSIONS

Preliminary results of the measurement of the thrust of an azimuth propeller in bollard pull and swiveling condition are presented. In order to do it, a special device based on a beam and strain gages and torque cell is assembled.

Bollard pull tests show the influence of the distance between the propeller and the edge of the hull in the thrust coefficient. The magnitude of the difference noticed in this work is around 10%. It can be explained by hydrodynamic interaction between hull and propeller.

The swiveling test results reveal that the thrust coefficient depends on the azimuth angle and the speed ratio. The thrust coefficient reduction reaches up to 15% in comparison to the bollard pull test and seems to increase as the propeller speed decreases, i.e., influence of the speed ratio. Additionally, the swiveling tests show that the direction of the swivel is not relevant for the thrust coefficient.

Future tests will evaluate the thrust coefficient of azimuth propeller installed in the DPS scale model in order to carry out experimental tests and to analyze the dynamic performance of the model.

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