24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2528
POD DEVICE DEVELOPMENT FOR SMALL SCALE PROPELLER MODEL TESTS

José Marcos Paz de Souza
João Lucas Dozzi Dantas
Felipe Santos de Castro
André Mitsuo Kogishi
Institute for Technological Research, Av. Professor Almeida Prado, 532, Butantã, São Paulo, SP, 05508-901
jmarcos@ipt.br
jdantas@ipt.br
fscastro@ipt.br
amkogishi@ipt.br

Abstract. *In a ship project, the propeller is a vital component and tests should be done using small scale models to evaluate its performance according to the project requirements. Nowadays, azimuthal propulsion systems are frequently used in different types of ships, and laboratory tests using a small-scale POD device allow research development in this theme. This work aims to present the development of a POD device for small scale propeller model tests, considering propellers with 100 mm diameter. Tests with the first prototype of this project in the Cavitation Tunnel are presented, using a propeller model from Gawn-Burril series. Comparing the test results with empirical relationship, an offset between measured and estimated data shows that some improvements in the project are required.*

Keywords: *POD device, Propeller test, Cavitation Tunnel*

1. INTRODUCTION

The propeller is a vital ship component and its configuration depends on the ship type. Traditionally, the propulsion system consists in one drive shaft that connects the propeller to the engine through a gear box. An alternative that improves the ship maneuverability is an azimuthal propeller. This system allows the propeller turn 360 degrees around a vertical axis, eliminating the rudder. The azimuthal propeller has different configurations, as presented in Fig. 1, either using an internal transmission system or an electrical motor installed in a capsule, like a POD, as presented in Fig. 2.

Figure 1. Azimuthal propeller using internal transmission (Pacific, 2017)

Figure 2. Azimuthal podded propeller (ABB, 2010)

The elimination of the rudder is not the only positive aspect of the azimuth thruster. The proportionate increase in maneuverability allows the management of large vessels in confined spaces without the aid of tugs and, with an adequate number of units, the possibility of appropriate dynamic positioning of the vessel.

The propeller is a component of importance in a ship and during a new design, testing using small scale models produces valuable results. The Institute for Technological Research (IPT) has two facilities to test small-scale propeller models: a cavitation tunnel, which is used for cavitation and performance examinations, and a towing tank for open water and self-propulsion tests.

The IPT has a Cavitation Tunnel, Fig. 3, where tests of small-scale propeller models are performed to measures the propeller thrust and torque under different advance velocities, rotational rate and different cavitation conditions. Details of the IPT's Cavitation Tunnel can be found in Dantas *et al.* (2014).

Due to blockage effects (Katsuno and Dantas, 2017), the typical propeller diameter adopted in the IPT's Cavitation Tunnel during standard propeller tests have a maximum diameter of 200 mm (ITTC, 2008). For the case of podded propellers, which present a larger blocking area due to the POD structure, the propeller should present a smaller diameter. Therefore, in order to test podded propellers in the tunnel, a new device should be developed.

This article presents the methodology of development of a POD device for performance tests in the IPT's Cavitation Tunnel and the initial tests results.

Figure 3. IPT Cavitation Tunnel (left) and detail of test section (right)

2. CONCEPT

The propeller diameter adopted for tests using the POD device was 100 mm, which is smaller than the propellers used in the standard tests (200 mm), due to blockage concerns (ITTC, 2008).

The developed POD propeller presents two parts, the main body, i.e., the POD, and the upper body. These components are connected by a vertical faired structured, with the drive shaft passing through it.

The main body is used to measure the propeller thrust, accommodating the propeller shaft, the 90 degrees transmission gears to the upper body, bearings, the HBM U9C thrust load cell, and a high density polymer retainer, which allows the propeller shaft to rotate without water infiltration in the POD. The main body and its components are presented in Fig. 4.

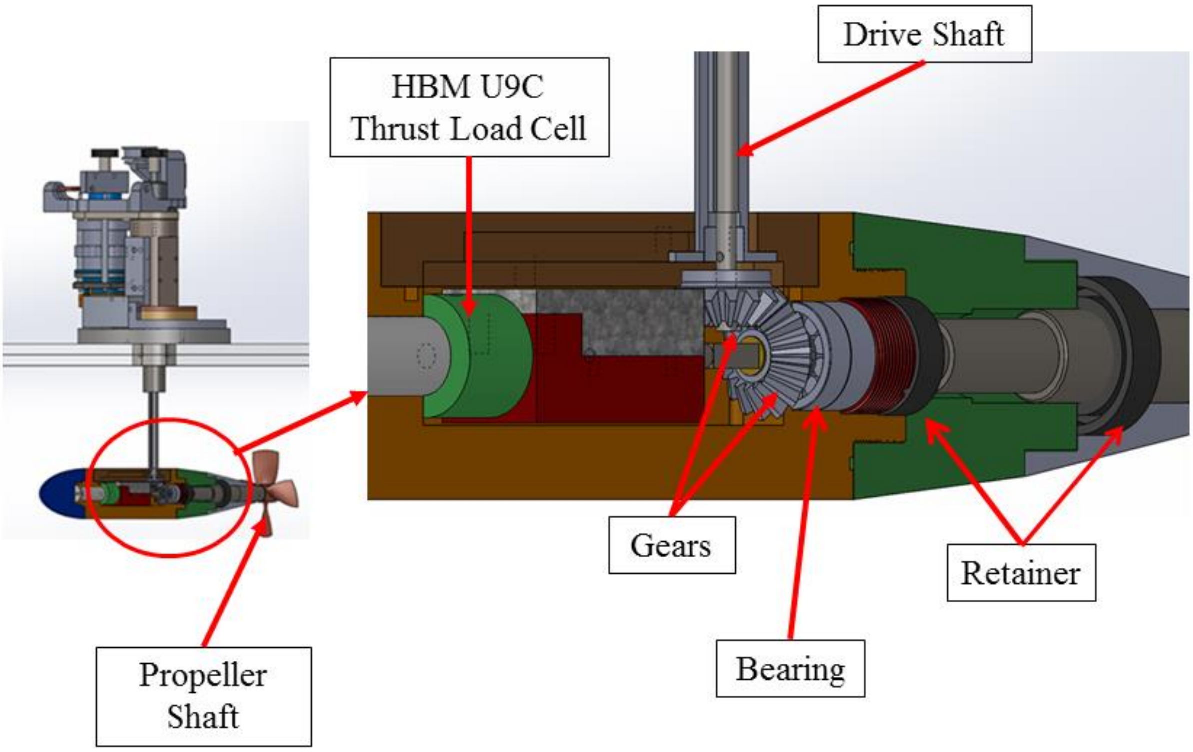

Figure 4. Pod device overview (left) and detail of main body (POD) with the components (right)

The upper part was designed to support the propeller motor and to measure its resistive torque. It contains a Futak QLA150 torque load cell, a Faulhaber brushless DC servo motor, drive shaft and a toothed belt transmission system, composed of two pulleys and a belt tensioner. The details of the POD upper part and its components are presented in the Fig. 5.

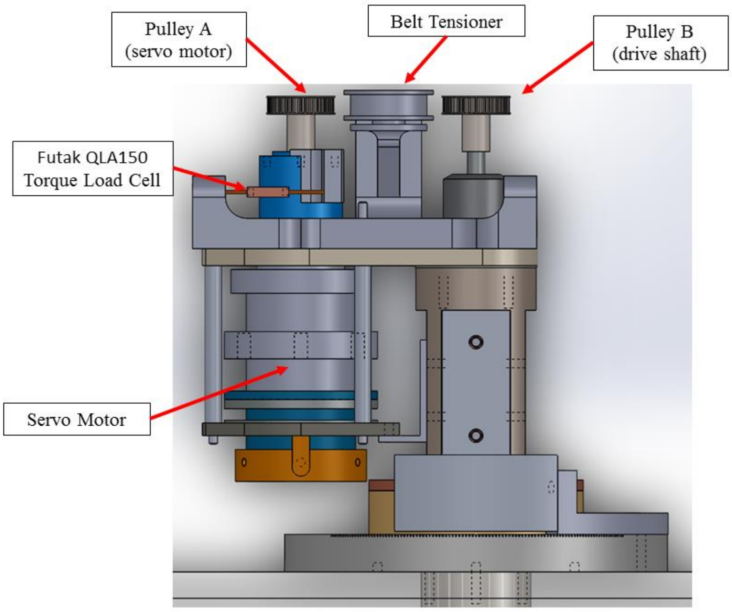

Figure 5. Assembly details of the POD upper part and its components

The POD parts were designed to be manufactured by aluminum, steel and plastic parts, depending of the required precision and stress load in the part. The shafts and gears were manufactured in steel due to the high stress in the thrust and torque transmission and to the need of a high precision connection between these parts and the propeller. The POD body was made of aluminum to ensure the POD seal using O-rings and retainers. Some elements of the upper part were also made in aluminum to support the high load when the belt transmission system is tensioned to eliminate the transmission hysteresis.

All the fairings, POD and vertical shaft are manufacture in ABS (Acrylonitrile Butadiene Styrene) using a FDM (Fused Deposition Modeling) additive manufacturing machine (3D printer), being subsequently treated to present a smooth surface roughness. Some other components such as the torque load cell support and the belt tensioner were constructed using the same process, as presented in Fig. 6. The FDM additive manufacturing process was performed to ensure a fast development and construction of the POD parts that do not present high stress loads or high precision requirements. The assembly and final overview of the model is presented in Fig. 7.

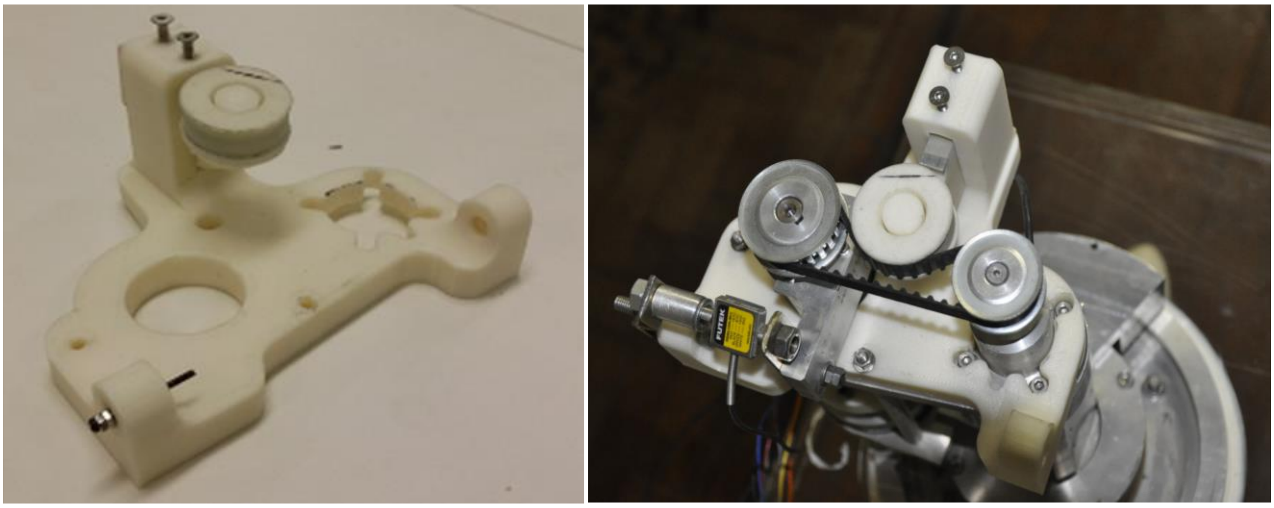

Figure 6. Details of the upper load cell support and belt tensioner made in ABS by FDM process

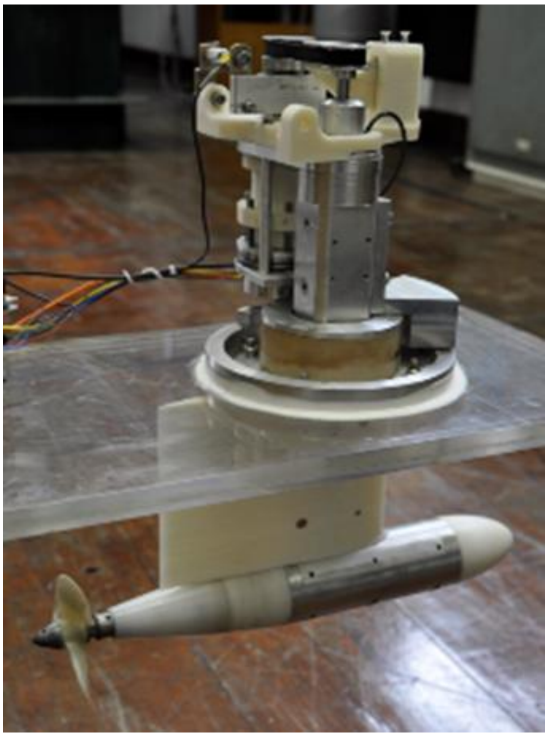

Figure 7. Picture of the POD device installed in Cavitation Tunnel window

The electric and control diagram developed for the POD system is presented in Fig. 8. In this system the Faulhaber 4490 H024B brushless DC Servomotor has its rotational velocity controlled by the Faulhaber BLD 7010 4-Quadrant PWM Servo Amplifier using, as the feedback, the Servomotor hall sensors and the electrical current and, as a reference, a voltage input from a potentiometer. The Servo Amplifier was adjusted to use a speed control mode, i.e., the rotational velocity is controlled by the feedback of the hall sensors, but the current signal was used to limit the motor operation. The motor velocity was controlled with an aid of a PID (proportional, integral, derivative) control, in which their gains were tuned from empirical methods with the POD assembled system.

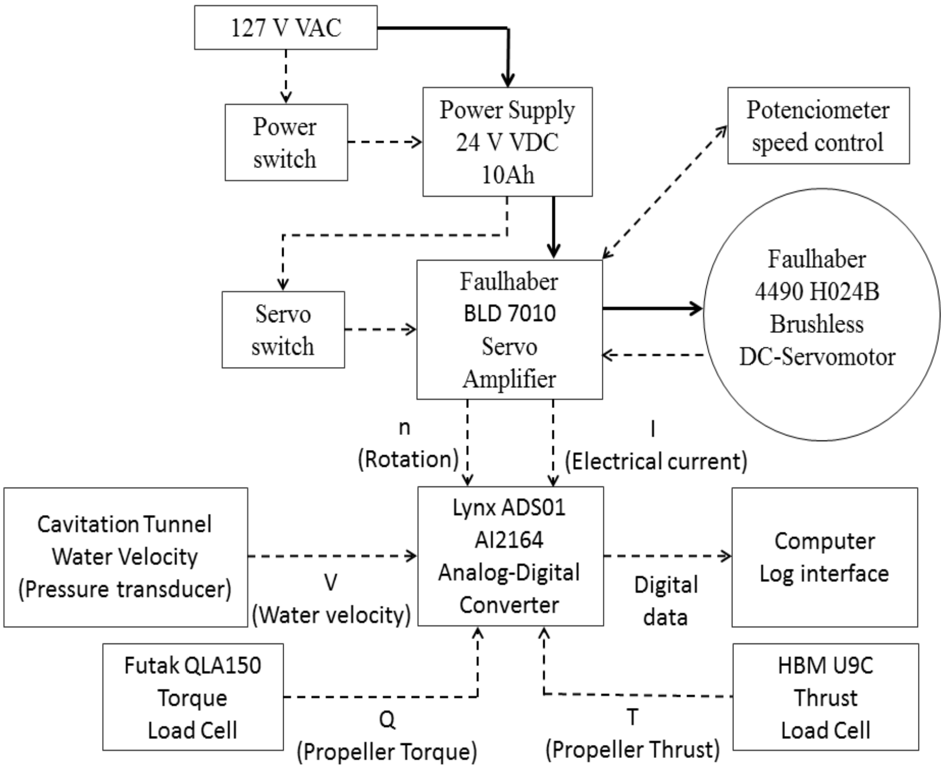

Figure 8. Electric and control diagram used in the POD system

The Lynx ADS01, with the modulus AI2164, was used to convert the analog signals to digital data, which is logged in a computer, at an acquisition rate of 100 Hz. In a standard operation the propeller thrust and torque from the load cells, propeller rotation and the motor electrical current from the servo amplifier, and the water velocity by pressure transducers, were measured. (Dantas *et al*., 2014).

3. EXPERIMENTAL PROCEDURE

In this section is presented the first test of the scale model, The POD was installed on the upper window of the test section, as presented in Fig. 9, and the tunnel is filled with water. The Cavitation Tunnel impeller makes the water circulating at an advanced velocity that together with the POD propeller rotation speed have a correspondence to the real-scale ship operation condition. The torque and thrust are measured to calculate the dimensionless hydrodynamic coefficients, which are used to extrapolate the propeller loads to the real scale. For the initial tests a Gawn-Burril series propeller were used, as this propeller series were well explored in the literature and tested in the IPT's Cavitation Tunnel (Katsuno e Dantas, 2017).

The test procedure follows the guidelines from the International Towing Tank Conference (ITTC, 2008), being detailed explained in Dantas et al. (2014).

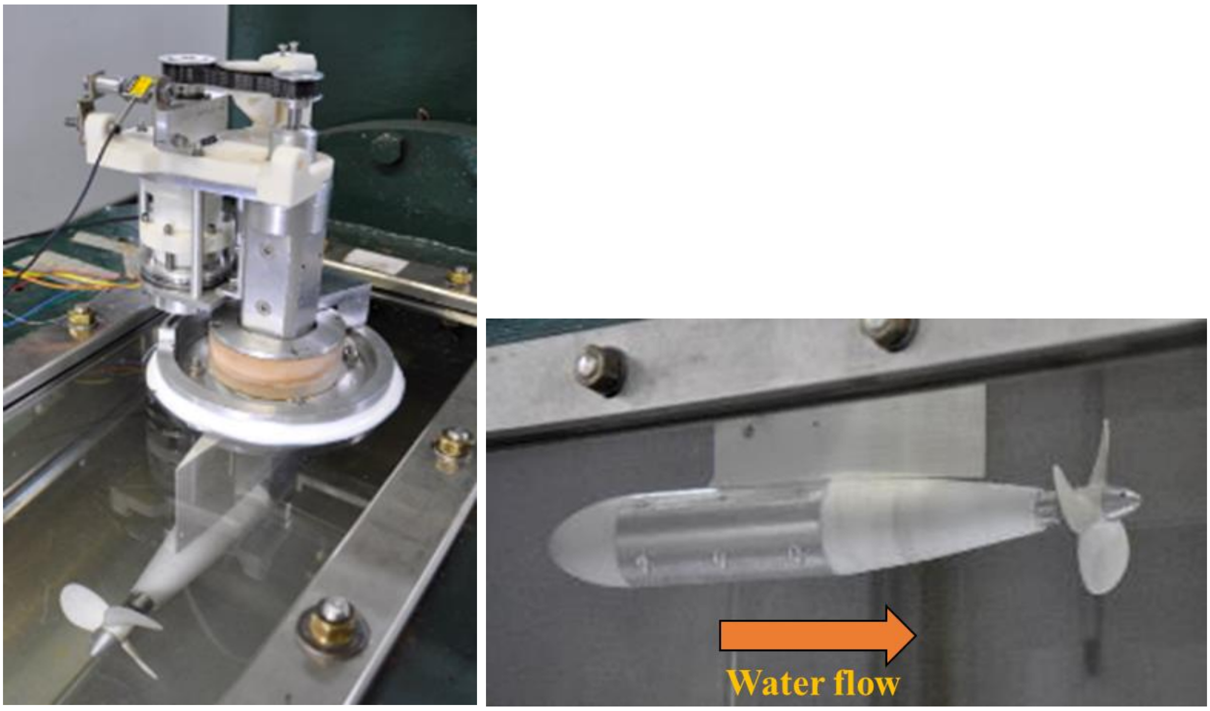

Figure 9. Pod device installed in the Cavitation Tunnel for tests

The tests were performed varying the water velocity and the propeller rotation, analyzing several operation conditions. For each combination of rotation and velocity, the system was kept running in steady condition for a sufficient period in order to measure properly the propeller thrust.

4. RESULTS AND DISCUSSION

The test matrix and the measured data are presented in Tab. 1, for the procedure presented in Section 3.

Table 1. Test matrix and the thrust measured

Water veloc (m/s)	Rotation (rpm)	T (N)
0	493	3,1086
0	564	3,2785
0	637	2,8344
0	690	3,9251
0	694	2,8945
0	732	4,3556
0	792	4,5358
0	800	4,6042
0,2	503	2,5668
0,2	569	1,9865
0,2	610	1,4274
0,2	660	1,6971
0,2	715	1,9981
0,2	806	3,2634
0,4	659	0,7631
0,4	682	0,9521
0,4	810	2,3592
0,53	510	0,6687
0,53	605	0,1326
0,53	614	-0,3045
0,53	685	0,2263
0,53	760	0,8241
0,53	827	1,2985
1	569	-2,1252
1	588	-2,2546
1	677	-1,9464
1	771	-1,5666
1	838	-0,9367

The objective of propeller tests using this device is obtain a curve of thrust coefficient (K_T) by advance ratio (J), according to Eq. (1) and Eq. (2), (Padovezi, 1997) respectively.

$$K_T = \frac{T}{\rho n^2 D^4} \quad (1)$$

$$J = \frac{V}{nD} \quad (2)$$

Where:

T: thrust (N);
V: water velocity (m/s);
ρ: water specific mass (kg/m³);
n: propeller rotation (rps);
D: propeller diameter (m).

The data obtained from the POD tests was compared to the standard correlation from the literature (Gawn and Burrill, 1957) that was obtained by several tests in a cavitation tunnel. This comparison is presented in Fig. 10.

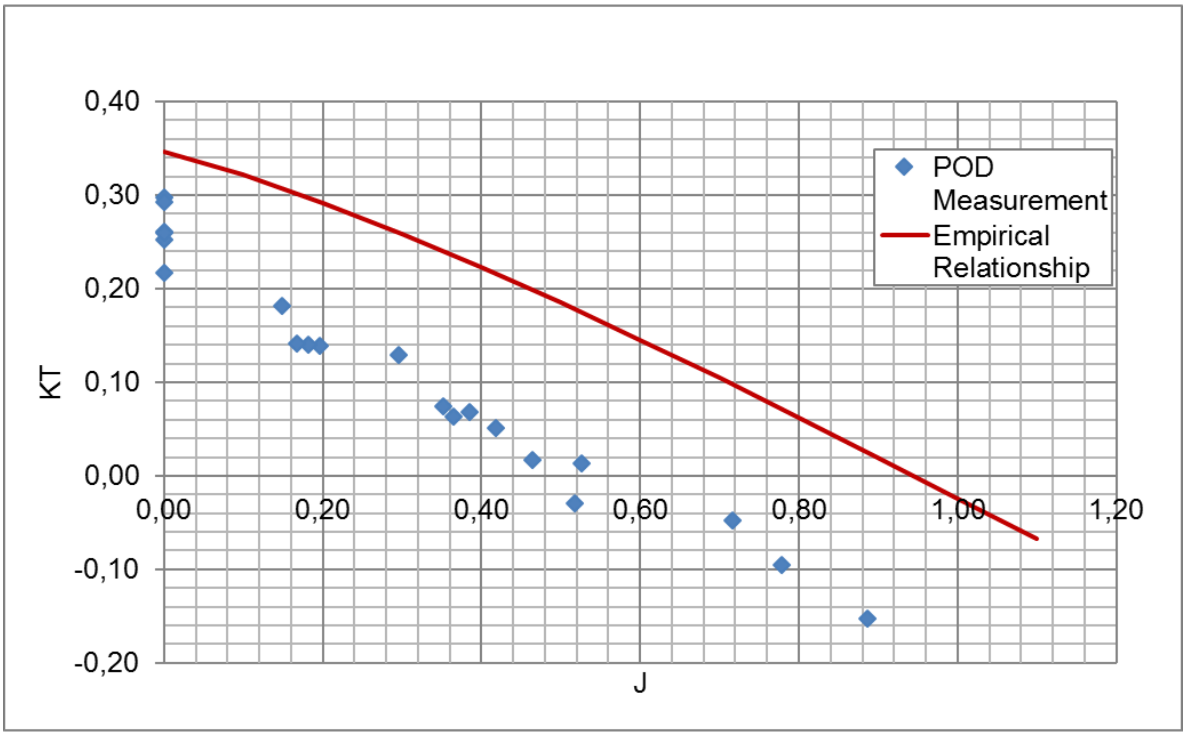

Figure 10. Comparison between the thrust coefficient (K_T) measured in the POD and the empirical relationship (Gawn and Burrill, 1957)

Fig. 10 shows a distinction in the measured data in comparison to the estimated ones, indicating that the measured thrust is significant lower than the reference curve. It is believed that this difference comes from the high friction between some of the transmission components, disturbing the measuring from the load cells.

5. CONCLUSIONS

This arcticle presented the POD device development for small scale propeller model tests. In order to evaluate the device performance, a test using a Gawn-Burril series propeller model were done. The test showed a difference between the reference data, indicating that the thrust measurement is lower than it should be. This difference is due to energy dissipated in the transmission components, as seals,gears and shafts.

Although, this results indicate that improvements in the device project must be done before used it for research purposes. The tests also indicate that the other parts of the POD design were successful, presenting a reasonable operability of the equipament once the system had no failures, leakege or broken parts. The research in this types of devices will continue, adapting the design to overcome the measurement problems making tests with diferent azimutal angles possible in the Towing Tank.

6. ACKNOWLEDGEMENTS

We would like to acknowledge Fabio Villas Boas and Hélio Corrêa da Silva Junior for started this project.

This work was supported by: CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico, process number 456359/2013-3; IPT – Institute for Technological Research.

7. REFERENCES

ABB, 2010. “Azipod® XO Brochure”. 16 Oct. 2017 <http://new.abb.com/marine/systems-and-solutions/electric-propulsion/azipod/for-ships>.

Dantas, J.L.D.; Guedes, D.L.; Kleine, F.A.S. ; Saggin, A.L.R. ; Katsuno, T. ; Souza, J.M.P. ; Monteiro, T.G. ; Zanutto, J.C. ; Padovezi, C.D. „Modernização do Túnel de Cavitação do Instituto de Pesquisas Tecnológicas de São Paulo”. In: SOBENA 2014, 2014, Rio de Janeiro. Congresso Nacional de Transporte Aquaviário, Construção Naval e Offshore. Rio de Janeiro: Sociedade Brasileira de Engenharia Naval, 2014. v. 25.

Gawl, R.W.L.; Burrill, L.C. “Effect of cavitation On the Performance of a Series of 16-Inch Model Propellers”. In: Trans. INA, Vol. 99, 1957.

Katsuno, E.T. ; Dantas, J.L.D. „Investigação da metodologia para simulações de propulsores utilizando fluidodinâmica computacional“. In: SOBENA 2016, 2016, Rio de Janeiro. Congresso Nacional de Transporte Aquaviário, Construção Naval e Offshore. Rio de Janeiro: Sociedade Brasileira de Engenharia Naval, 2016. v. 26.

ITTC, 2008. International Towing Tank Conference, “7.5-02-03-01.3 Recomended Procedures and Guidelines” 28 Apr. 2017 <http://ittc.info>.

Pacific Marine & Industrial ®, 2017. 16 Oct. 2017 <http://www.pacificmarine.net/engineering/propeller-and-propeller-shaft/azimuth-propeller.htm>.

Padovezi, C. D.,1997. “Aplicação de resultados de escala real no projeto de hélices de embarcações fluviais”, Dissertação de Mestrado, Universidade de São Paulo.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.