International Journal of Offshore and Coastal Engineering
Vol.9 | No. 1 | pp. 28 – 31 | May 2025
e-ISSN: 2580-0914

Submitted: January 6, 2025 | Revised : February 28, 2025 | Accepted: April 21, 2025

Replace Experimental and Numerical Study on Ocean Current Turbine Performance with Innovative Idea Using Toroidal Propeller

Dendy Satrio [a) *], Mohammad Fahrur Riza Al Azizy [a)], Deva Ery Aditya Putra [a)], Sandi Jagat Pasma [a)], Dio Alif Wahyudo [a)], and Zaidan Arsa Sulthana [a)]

[a)] Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
*Corresponding author: dendy.satrio@its.ac.id

ABSTRACT

According to the HEESI, the share of renewable energy production is only 13.29% of the total energy production, with a target of 23% by 2025. One promising renewable energy source with a potential of 41 GW is ocean currents. To harness this potential, propeller turbines can be used. Propellers are a critical component of these turbines, typically designed based on the Wageningen B series. However, this series still exhibits issues such as cavitation and noise during operation. Toroidal propellers offer advantages by eliminating tip vortices, resulting in quieter operation, and reduced fatigue. This study aims to enhance the efficiency of propeller turbines through modifications using toroidal propellers. The study employs ANSYS Fluent for simulation and experiments. The process includes designing toroidal propellers with a maximum diameter of 3 meters, blade pitch angles of 60°, and blade counts ranging from 3 to 9. These designs are then simulated to analyze power and efficiency. Performance testing will measure RPM, and observe cavitation. The results are for blades ranging from 3 to 9 generates 42.6 to 63.2 kW. Therefore the best design is 9 blades that generate 63.7 kW of power with a maximum RPM of 89.9.

Keywords: *Renewable Energy, Current Turbine, Toroidal Propeller, Experimental Study, Numerical Study*

1. PRELIMINARY

Replace On September 28, 2015, the United Nations introduced the Sustainable Development Goals (SDGs) to enhance human well-being while preserving the planet, divided into 17 goals to be achieved by 2030. This research focuses on SDG No. 7, which states, "Ensure access to affordable, reliable, sustainable, and modern energy for all." This underscores the need for energy sources that are accessible, reliable, and sustainable [1], commonly known as renewable energy (RE). The share of renewable energy production in Indonesia is only 13.29% of the total energy production, with a target of 23% by 2025 [2]. One of the renewable energy sources is derived from water and marine energy [3]. Marine energy remains one of the least developed energy sources in Indonesia, particularly ocean currents, despite its theoretical and technical potential to generate 288 GW and 18-72 GW of energy, respectively [4].

One of the most promising renewable marine energy sources with a potential of 41 GW is ocean currents [5]. In the Karimata Strait, ocean current speeds range between 0.9 to 2.4 m/s [6]. These currents can be harnessed using propeller turbines, which convert the kinetic energy of ocean currents into electricity [7]. Propeller turbines are commonly used due to their stable efficiency across a wide specific speed (Ns) range, between 300-1000 m-Kw [8], and their ability to generate up to 49.7 kW of power [9].

This study will utilize a propeller turbine, with the propeller being one of the most significant components of the turbine. Typically, propeller designs follow the Wageningen B-series [10], which are still prone to cavitation, vibration, and noise during operation [11]. However, toroidal propellers offer an advantage by eliminating tip vortices or cavitation [12] resulting in quieter operation, reduced fatigue on ships, and higher service speeds compared to conventional propellers at the same RPM [13].

2. METHODOLOGY

2.1 Tools and Material

The tools used in this research include AutoCAD, Ansys Fluent, Dorchester 3D, Electric Pump, Tachometer, Propeller Support Tools, Camera, Tripod, Stopwatch (via smartphone), Current Meter, Test Pool, 3D Propeller, Balance Tube, Soldering Iron, Dimmer, Paint Brush, and Hammer. The materials used include Sandpaper, PLA Filament, Epoxy Resin, Photopolymer Resin, Hardener, Bearings, 20mmx1400mm Steel, Strip Plate Steel, Reinforced Steel, Aluminum Powder, Rexco, Styrofoam, Marker, and Glue.

2.2 Toroidal Propeller Design Stages

In designing the toroidal propeller, we used a general toroidal propeller design and modified the number of blades. The number of blades ranged from 3 to 9 blades.

2.3 Ansys Fluent Simulation Stages

Simulations of several propeller designs were carried out using Ansys software. In Ansys Fluent (Flow) Workbench, each propeller design was imported into the geometry module to compare the results. The imported designs were modified in the Design Modeler geometry to create a domain for propeller testing. The geometry was further modified in the Mesh module of Ansys Workbench. These modifications to the Mesh aimed to set the necessary details on the propeller and domain to produce valid data without errors. Once the propeller and virtual medium were adjusted, the setup could be performed in Workbench. Variables such as current speed (m/s) and propeller rotational speed (rad/s) were input. The current speed was set at 2 m/s, while the propeller's rotational speed was set at 8.9 rad/s.

When evaluating the turbine's performance, the Ansys simulation data, including torque, must be processed to determine the turbine's efficiency. The turbine power can be calculated using the following equation.

$$PT = T.\omega \tag{1}$$

Where Pt = turbine output power (watt); T = torque (N.m); ω = angular velocity (rad/s). Before calculating the turbine's efficiency, the input power must be determined using the following formula. The turbine efficiency can then be calculated by comparing the turbine output power and input power.

$$Ph = \frac{1}{2} \times \rho \times A \times V^2 \tag{2}$$

$$\eta = \left(\frac{PT}{PH}\right) \times 100\% \tag{3}$$

Where: Ph = turbine input power (watt); ρ = seawater density (1025 kg/m^3); V = flow velocity (m/s); η = turbine efficiency (%).

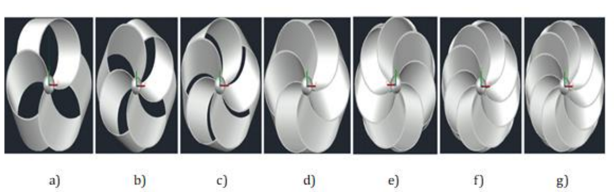

Figure 1. Propeller Design Results Using AutoCAD. a) 3 Blades b) 4 Blades c) 5 Blades d) 6 Blades e) 7 Blades f) 8 Blades g) 9 Blades

2.4 Performance Testing Stages

The performance testing was conducted in an aquarium tank measuring 200x40x40 cm, with a pump capable of generating a maximum current of 2 m/s. The test was conducted over 5 minutes with five repetitions. Every change in the tachometer reading was recorded to obtain the average RPM value in 1-minute intervals over the 5-minute period. Additionally, during the test, the toroidal propeller's movement was observed to detect any cavitation.

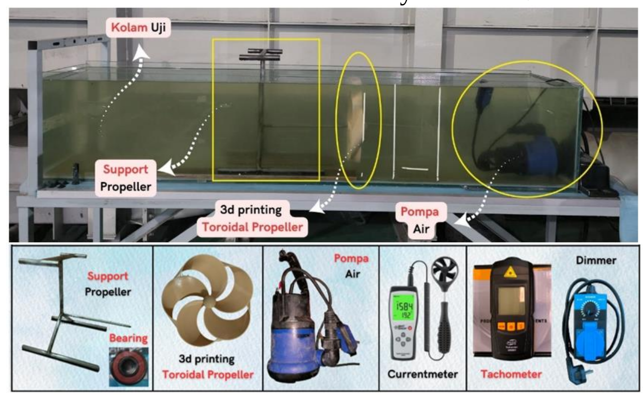

Figure 2. Physical Testing Installation

3. RESULT AND DISCUSSION

3.1 Design Result of Toroidal Propeller

The toroidal propeller design was created using AutoCAD 3D software. This design process was conducted to produce a 3D model of the toroidal propeller with various variables, resulting in a total of 7 propeller designs. The design results shown in Figure 3.

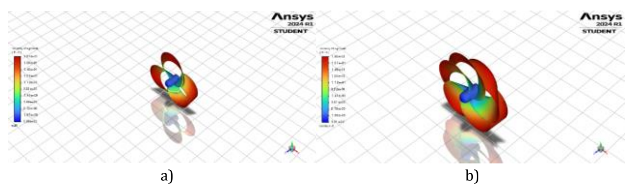

Figure 3. Contours (a) Contour Result of 60D3B (b) Contour Result of 60D5B

After obtaining data on torque and forces, these data were processed into power values, as shown in the table below.

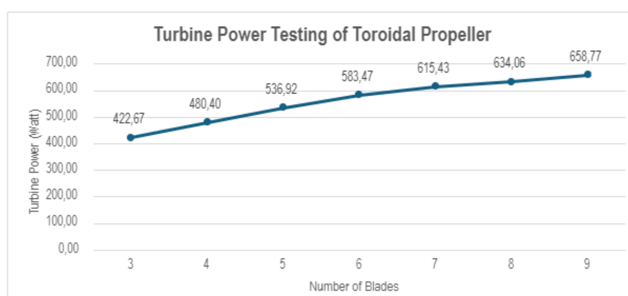

Figure 4. Power Values of the Propeller Turbine

As shown in figure 4. The modified toroidal propeller with 3 blades was able to generate a power of 422.67 watts, meanwhile the modified toroidal propeller with 9 blades was able to generate a power of 658.77 watts showing an increase of 56% power generated. Then in figure 5. Shown that toroidal propeller with 9 blades can achieve 8.08% of efficiency.

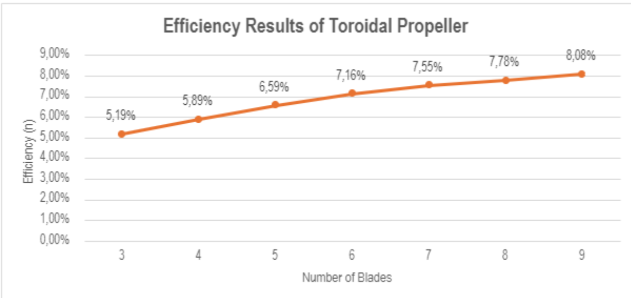

Figure 5. Efficiency Results of Toroidal Propeller

3.3 Performance Testing of Toroidal Propeller

The performance testing of the toroidal propeller was conducted in a test pool to obtain data such as the revolutions per minute, detection of cavitation, and the required current speed to move the propeller.

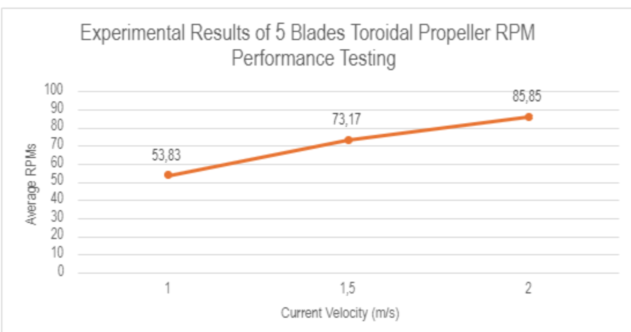

Figure 6. Experimental Results of Toroidal Propeller RPM Performance Testing

The data obtained in Table 1. showed that no cavitation was detected during testing. The propeller began to rotate at an ocean current speed of 0.6 m/s, and according to Figure 5, the toroidal propeller with the design code 5 Blades achieved an average RPM of 87.

Table 1. Experimental Results of 5 Blades Toroidal Propeller RPM Performance Testing

Current Velocity (m/s)	Cavitation	Average RPM	Min RPM	Max RPM
1	Undetected	53,83	44,6	58,7
1,5	Undetected	73,17	63,3	79
2	Undetected	86,62	74,5	92,2

4. CONCLUSION

This study demonstrates that the use of toroidal propellers in ocean current turbines significantly improves performance compared to conventional propeller designs. Through numerical simulation using ANSYS Fluent and physical testing in the laboratory, it was found that the optimal configuration is a propeller with five blades and a 60° pitch angle, capable of generating up to 63.7 kW of power and reaching a maximum rotation speed of 89.9 RPM. This design also effectively reduces cavitation and turbulence, supporting more efficient and durable turbine operation. Therefore, toroidal propellers have strong potential to be further developed as an innovative solution for harnessing renewable energy from ocean currents in Indonesia.

ACKNOWLEDGEMENTS

Acknowledgments are given to the Ministry of Education, Culture, Research, and Technology for funding all activities of the 2024 Student Creativity Program (PKM). The authors also express their gratitude to the Institut Teknologi Sepuluh Nopember in general and the Department of Marine Engineering in particular for facilitating this PKM activity.

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