ADVANCES IN THE DEVELOPMENT OF A MARINE CURRENT TURBINE FOR THE COZUMEL CHANNEL

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Introduction

Tidal energy currently concentrates the main effort in harnessing marine hydrokinetic energy. For example, *Sustainable Marine Energy* recently installed its *PLAT-I 6.4* platform in the Bay of Fundy, Canada ("Sustainable Marine Unveils …", 2021), while *Simec Atlantis Energy* installed one of their *AR500* turbines in the Goto Islands, Japan ("SAE achieves another …", 2021). Despite some similarities between tidal and marine currents, the latter tend to have a much lower energy density requiring special efforts in optimization of turbines for lower speeds. Based on the design of Bahaj et al., 2007, Encarnacion et al., 2019 is currently developing a rotor design for slow marine currents of approximately 1 m s^{-1}.

The present work pretends to expose the state of development of a working prototype for the Cozumel Channel. Currently, a laboratory-scale turbine has been fabricated for its characterization in the laboratory of the Institute of Engineering, UNAM. The prototype was produced keeping in mind its early stage of development and consequently the requirement for rapid prototyping.

Methods for torque measurements

For measuring the torque of lab-scale turbines commercial solutions are available which are either directly connected to the shaft (Bahaj et al., 2007) or connected to the drive train outside the turbine (Carlton, 2012). Other methods are the control of the rotational speed with an electrical motor while measuring the motor's reaction with strain gauges (Silva et al., 2019) or measure the electrical power output of a (recycled) motor/generator connected to a load resistor bank. In case the generator's characteristics are unknown it can be characterized with the methodology proposed by Ng et al., 2009. As last option the use of a Prony brake in combination with a load cell is considered.

Lab-Scale Turbine

The lab-scale turbine has a diameter of 0.3 m and a length of approximately 0.3 m. Based on the 3-bladed rotor design, the hub diameter was set to 0.06 m to accommodate all necessary equipment inside the turbine.

The blade design follows the design suggestion of Encarnacion et al., 2019 using the NACA 63-8xx profiles. The blades work at relatively high TSRs (tip speed ratios) with an expected power coefficient of $C_P = 0.4$ at a TSR of approximately $\lambda = 6$.

Fabrication of the turbine

Most parts of the turbine were produced by means of the FDM (fused deposit material) 3D-printing technology on an *Ultimaker 2+ extended*. As material polylactic acid (PLA) was chosen. All 3D-printed parts in contact with the water were coated with primer. On parts with high required geometric precision, the coat was sanded down afterwards to only fill in the gaps between individual layers of the 3D-printed part. A photo of the first produced prototype of the model is shown in Figure 1 with two of the three FDM-3D-printed blades installed.

Figure 1. First produced prototype of turbine.

Design of a Ducted Turbine

Alternatively to the design proposed by Encarnacion et al., 2019, a ducted turbine design is being evaluated (see Figure 2). The duct uses a NACA 0015 airfoil in the cross section to induce a flow circulation, and thus a lifting force toward the central axis, increasing the mass flow at the rotor plane. Additionally, a brim is included on the trailing edge to promote a turbulent mixing. This structure restores the momentum deficit behind the rotor by mixing the near wake flow with the undisturbed free stream flow (ten Hoopen, 2009).

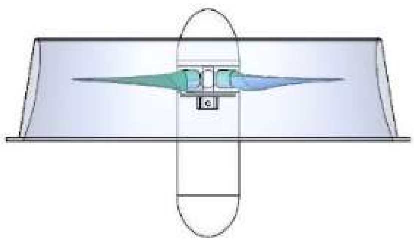

Figure 2. Render of ducted turbine, top view.

The blade design is adapted to achieve the maximum C_P at a low TSR ($\lambda = 4$). The actuator disc model is applied to represent the turbine inside a numerical framework. The model is based on a BEM (Blade Element Momentum) approach. Subsequently, the duct is mounted in the actuator disc to perform a CFD (computational fluid dynamics) simulation. The simulation estimates the power output and validates the design process.

Internal structure of the blades

Based on the ducted design of the turbine, the internal structure of the blades for a full-scale prototype with a diameter of 2 m is created. The loads on the blade are estimated by means of a CFD simulation, which serves as basis for a first design proposal. This proposal is then analyzed with the FEM (finite element method) and FSI (Fluid-Structure Interaction) where it is subsequently optimized according to the results.

Outlook

Keeping in mind the next stage of the project, that is a 2 m prototype, further work is being carried out by members of the full team working on this project: the design of the power train, life cycle assessment and the electrical part of the energy conversion system, amongst others.

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References

Bahaj, A. S., Molland, A. F., Chaplin, J. R., & Batten, W. M. J. (2007). Power and thrust measurements of marine current turbines under various hydrodynamic flow conditions in a cavitation tunnel and a towing tank. *Renewable Energy*, *32*(3): 407–426.

Carlton, J. S. (2012). *Marine Propellers and Propulsion*. Butterworth-Heinemann.

Encarnacion, J. I., Johnstone, C., & Ordonez-Sanchez, S. (2019). Design of a Horizontal Axis Tidal Turbine for Less Energetic Current Velocity Profiles. *Journal of Marine Science and Engineering*, *7*(7): 197.

Ng, P. H., Wong, S. L., & Mak, S. Y. (2009). Efficiency measurement using a motor-dynamo module. *Physics Education*, *44*(6): 639–643.

SAE achieves another tidal milestone with installation and successful generation of tidal turbine in Japan. (2021).https://simecatlantis.com/2021/02/15/sae-achieves-another-tidal-milestone-with-installation-and-successful-generation-of-tidal-turbine-in-japan/

Silva, A. L., Varanis, M., Mereles, A. G., Oliveira, C., & Balthazar, J. M. (2019). A study of strain and deformation measurement using the Arduino microcontroller and strain gauges devices. *Revista Brasileira de Ensino de Fisica*, 41(3).

Sustainable Marine Unveils 'Next-gen Platform' ahead of World-leading Tidal Energy Project. (2021).https://www.sustainablemarine.com/press-releases/-sustainable-marine-unveils-'next-gen-platform'-ahead-of-world-leading-tidal-energy-

ten Hoopen, P. D. C. (2009). An experimental and computational investigation of a diffuser augmented wind turbine with an application of vortex generators on the diffuser trailing edge. In *Faculty of Aerospace Engineering: Vol. MSc*. Delft University of Technology.

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