An energy harvester for Kuroshio power

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Abstract

In the response of the increasing energy demand and the global trend in renewable energy development, Kuroshio energy harvesting becomes an important issue of Taiwan. In this study, the feasibility of nozzle-diffuser duct as a Kuroshio energy harvester is investigated. The computation fluid dynamics (CFD) software ANSYS-Fluent was used to calculate the drag and added mass of the duct. The simulation of single duct anchored on the seabed under normal and storm waves was established by Orcaflex. Under normal wave condition, the high Power Take Off (PTO) was assured when the duct siting near free surface location. However, the duct must be sink to deeper location (100 m below sea surface) to avoid the assaulting of Typhoon wave action. The PTO of the proposed nozzle-diffuser duct is 15 kW if the Kuroshio speed is 1.0 m / s. To implement a Mega PTO system, 66 ducts are needed and a suitable platform is needed to carry as many ducts as possible.

Keywords: ANSYS Fluent, ANSYS Aqwa, OrcaFlex, Duct type current power generator

1. Introduction

Most of the energy is primarily coming from the nonrenewable resources such as coal, natural gas, oil and nuclear power. Burning fossil fuels, however, is harmful to the environment, and fossil fuel supplies are limited and subject to price volatility. The safe storage and disposal of radioactive waste, the potential for radioactive contamination from accidents or sabotage, and the threat of nuclear proliferation are serious challenges to use nuclear power. Renewable resources such as wind, solar and ocean power possess great potential because they are indigenous, nonpolluting, and inexhaustible. The techniques for capturing wind and solar powers are very mature, whereas the development in capturing ocean power like wave, tidal and current is still under research and may become another important technique in the future.

Most of the fuels is imported in Taiwan, developing renewable energy becomes an important policy in Taiwan. Bedard (2006) reported "Overview: EPRI Ocean Energy Program, The Possibilities in California" and indicated the wind power can generate 70% capacitance for Taiwan in winter time, whereas only 6% capacitance in summer season. In other words, the wind power is not the stable and can not play a substitutable energy resources in Taiwan. Solar power might be the alternative energy, but Taiwan does not have sufficient land to install solar panels. Develop ocean energy harvesting techniques might become a good alternative since Taiwan is surrounded by the ocean. Ocean energy includes tidal, current, wave and thermos, but the tidal and ocean current are more attractable because the second largest ocean current, Kuroshio Current, is flowing through east coast of Taiwan. Capturing Kuroshio power might fulfill the total electric capacity in Taiwan.

Figure 1 shows the Kuroshio Current which is one of the Western Boundary Currents, also the second strongest north Pacific current to Gulf Stream. The Current speed is about 0.5 m/s to 2.0 m/s and the mass flow is measured about 20 to 40 Sv (10^6 m^3/s) which is about 100 times compare to Amazon River. The best advantage for current power is that the current flow is stable and working 24 h and the generator may functioning more than 300 days in a year (Chen, 2010). Although, there is a drawback that Taiwan is located at the area where typhoon always passing through in the summer season. Under the storm wave condition, instead of shutting down the generator, the harvester might work well when it is sinking deep to avoid the strong wave condition and this is part of the purpose of this study. In conclusion, ocean current energy can be a good alternative renewable energy for Taiwan in the future.

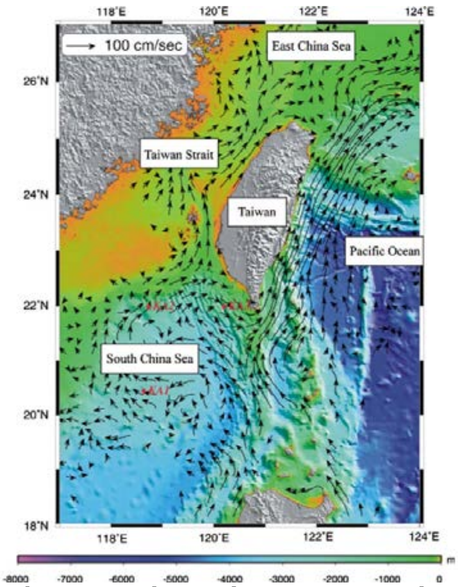

Figure 1 Bathymetry and coastal geometry around Taiwan, vectors show mean ocean current velocities. The Kuroshio Current dominates the velocity field east of Taiwan (adapted from National Center for Ocean Research, Taiwan, http://www.ncor.ntu.edu.tw with permission).

The objective of this study is to investigate the feasibility of the application of an ocean current energy harvester designed by Chen and Huang (2016) to harvest the Kuroshio power. Section 1 introduces the advantages of current power generation compared to other natural resources, and gives a brief review of previous studies and recent development of the ocean current capturing techniques. Section 2 describes the methods used in flying ducts design and they include three software packages, the CFD software ANSYS Fluent for calculating hydrodynamic coefficients, ANSYS Aqwa for added mass calculation and OrcaFlex for mooring line design. The calculation of the hydrodynamic coefficients is crucial to prepare input parameters for OrcaFlex and the detail procedures are listed in section 3. The investigated results include the design of a single duct generator anchored to the seabed in a shallow water environment (200 m). The simulated results are reported and detailed discussed in section 4. Final section gives the concluding remarks found in this study.

II Methodology

There are three different softwares were used in this study and they are ANSYS Fluent, ANSYS Aqwa and Orcaflex. ANSYS Fluent is a CFD (Computational Fluid Dynamics) software developed by ANASYS Inc. Fluent have two types of solver which are Pressure base type and Density type.The pressure base type solver is much more appropriate for Kuroshio simulation and we chose SIMPLEC method for steady state cases, and use PISO and Coupled method for transient cases. Besides, the central difference method, and the second order upwind are used in all the simulation cases of this study. The pressure-based solver along with realizable k-ε model and standard wall function were used to solve the governing equations. Different values of k and ε were assigned in the model according to the characteristic length of the flow projected area. The residuals of these two cases were also different; for steady case, it was set as 1E−6, but for transient case it was set as 1E−12. In addition, the second order upwind method was employed for the hexahedron meshes.

ANSYS Aqwa is an engineering software package used to investigate of the effects of wave, wind and current on floating and fixed offshore and marine structure, including Spars, semi-submersibles…etc. Only two softwares (Aqwa and WAMIT) are certified to import the hydrodynamic data of vessels and floating structures into OrcaFlex.

OrcaFlex software is developed by British company “Orcina”. It is a simulation software wildly used in developing offshore oil drilling project and dynamic analysis for offshore platform including risers and mooring line system. The dynamic motions in OrcaFlex is using Finite Element Method (FEM) in 3D nonlinear time domain. Also, it set lumped-mass element approach to simplify the mathematic calculation, make the program can run more efficiently.

Ⅱ.1 Added mass and drag coefficients

Before building a 6D lumped buoy model in OrcaFlex, the added mass coefficient (C_a) and drag coefficient (C_d) are needed to be determined. The accuracy of these two coefficients rely much on the mesh quality, mesh number, and the domain size. Huang (2016) investigated the mesh number and domain size needed for surge motion of the duct-type generator. Thus, same domain and mesh settings in ANSYS Fluent were used in this study to calculate C_a and C_d for the sway and heave motions. Since this set of domain and mesh for numerical simulations had not been verified for the rotational motions, i.e., roll, pitch, and yaw, and domain test for rotational motions is made in this study. Figs. 3 and 4 show the final domain sizes for translational and rotational motions after domain size tests were made.

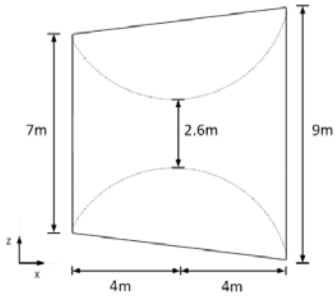

Figure 2 Geometry of the duct for the added mass and drag coefficients.

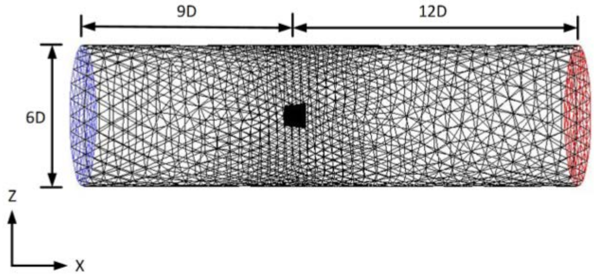

Figure 3 Computational domain for translational motion,

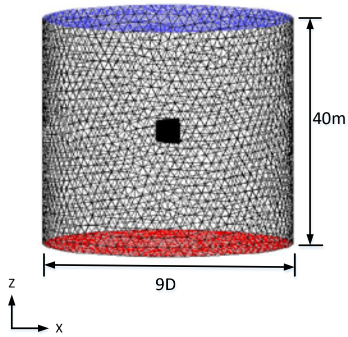

Figure 4 The domain size for rotational motion calculations.

III. Results and discussion

After all the needed parameters are calculated, a mooring line model is constructed in OrcaFlex. In this section, the model construction of a single duct including two wings attached on the two sides was introduced. The submerged model was anchored on the seabed under water depth of 200 m and current speed of 1 m/s. Storm and normal wave conditions of JONSWAP spectrum in Taitung area (Lai, 2017) were employed to investigate the motion of the duct.

III.1 The nozzle-diffusor duct anchored on the seabed

The duct was built by the functions of “6D Buoy” and “Shape” in the OrcaFlex. Since the “6D Buoy” function does not provide any option to construct the duct model in a nozzle shape, the model was then constructed by the “Shape” function. By dividing the duct into 80 pieces of thick plates of different inner and outer diameters, the model of the duct was established as shown in Figure 5. Another function called “Wings” was also used to include two wings to the duct, which can build the NACA 6409 wing type in the model. Lift and drag coefficients of the 2D NACA 6409 provided by Xfoil (20) were used, which corresponds to the lift and drag forces on the angles between −20° and 20° with span width of 2.5 m.

The mooring system consists of three lines connected in a Y shape to anchor the duct to the seabed. Each mooring line and the Y connection were designed as 200 m and 5 m long, respectively. The nominal diameter of the line was assumed 0.133 m as the studless chain used in Kyu (2013). Other properties automatically determined by OrcaFlex were listed in Table 9. It is to be noted that those properties provided by Marlow Ropes Ltd do not include the coefficient of friction; however, the seabed condition was assumed frictionless in this study, the coefficient of friction of the line was also set as zero. Figure 6 illustrates the whole system of single duct anchored on the seabed.

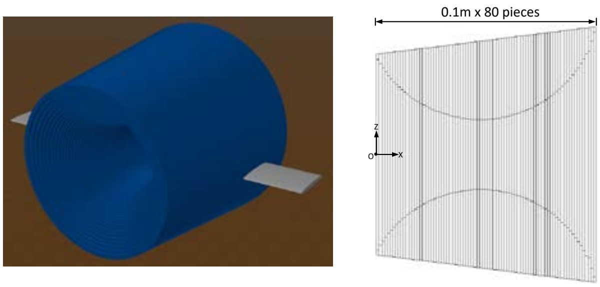

Figure 5. Duct model in OrcaFlex.

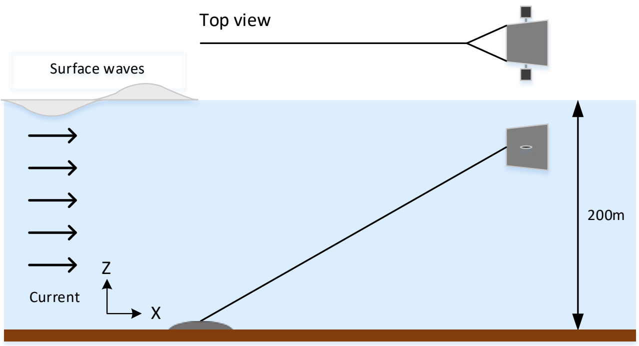

Figure 6. Illustration of single duct anchored on the seabed.

III.2 Response to Waves and Current

Since stronger Kuroshio current is passing through east coast of Taiwan. The JONSWAP spectrum data of Lai (2015) was adopted in this study, Lai's study analyzed the wave spectrum in Taitung Buoy which is located at the east coast of Taiwan. Two kinds of JONSWAP parameters are listed in Table 1 including normal wave and storm wave condition. The design criteria is to maintain a high PTO for the duct that is pitch and yaw motions must be smaller than 10°.

Table 1 JONSWAP parameters for normal and storm wave conditions for Taitung area

	γ	σ	f_p
Normal wave condition	1.59	0.0151	0.094
Storm wave condition	1.22	0.0047	0.105

Typhoon always attacks Taiwan during summer season and the stability of the duct facing storm wave condition also needed to be tested. The storm wave elevation used in this study is shown in Figure 7 and the largest wave is larger than 9 m. The wave assaulting direction is 90° which might be the most likely wave direction that the duct will face at east coast of Taiwan during Typhoon season. The time histories of the responses of the duct locating at a shallow position are shown in Figure 8. A large shock movement occurred in all 6 DOF responses, and the yam motion is over 10° and it is beyond the design criterion. Besides, the strong surge and heave motions indicate the high risk of the stability of the duct submerged near sea surface during storm wave condition. The duct seems needed to be sink deeper to avoid storm wave action. Question remains how deep is enough?

Figure 9 depicts the time histories of the responses of the duct facing 90° wave when the duct is sink down to 100 m below sea surface. The largest rotational angle was less than 5° in three rotational motions. Meanwhile, the maximum translational displacements were all less than 1.5 m.

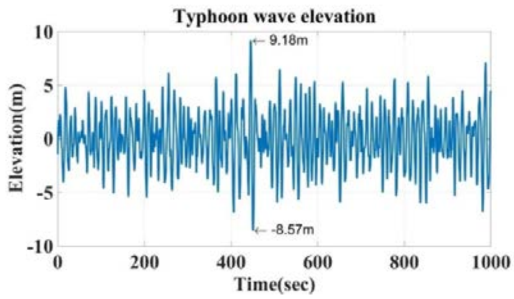

Figure 7 Time histories of storm wave condition.

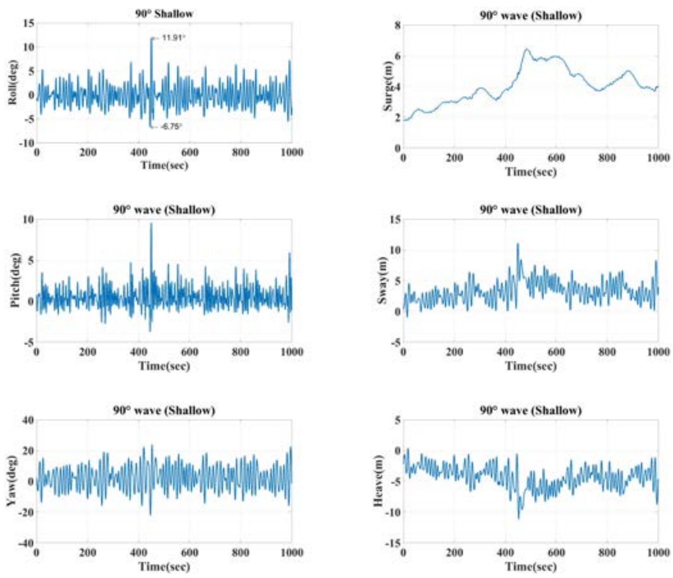

Figure 8 Time histories of the response of duct locating at shallow position facing 90° storm wave condition.

IV. Conclusion

The ocean current power capture system was designed including a spar platform carrying multiple nozzle duct type ocean current power generators. By collaborating the data from ANSYS Fluent and ANSYS Aqwa to OrcaFlex, whole system including mooring lines and the duct lines was simulated. The results of single ducts anchored on the seabed and the spar carrying ducts under storm wave condition and normal wave condition with constant 1 m/s current speed was presented. The following concluded remarks can be given:

1. The hydrodynamic coefficients including C_d and C_a of the duct in translational and rotational motions were calculated. The rotational domain was verified in this study with the domain length and diameter as 40 m and 9D m. Two methods were compared to verify the accuracy of C_d, and the results agrees well which means the data for C_a from the acceleration method was also confirmed.
2. The numerical model of the duct was established in OrcaFlex. Also, the determination of the duct weight and

the relationship between CG and pitch angle of the duct under different weight conditions was tested in this study. With the configurations of mooring line and duct, the simulation shows a high stability of the duct under normal wave conditions. Meanwhile, the duct was very safe at the deep position when the storm waves approaching.

3. This study proved that lowering the duct to deeper location would be a safe operation to avoid large wave load. In addition, the displacement of the duct is small when the wave direction is against the direction of current. With the configurations in this chapter, it is possible to install multiple ducts on the seabed as an ocean current farm to maximize the total capacity of the current power generation.

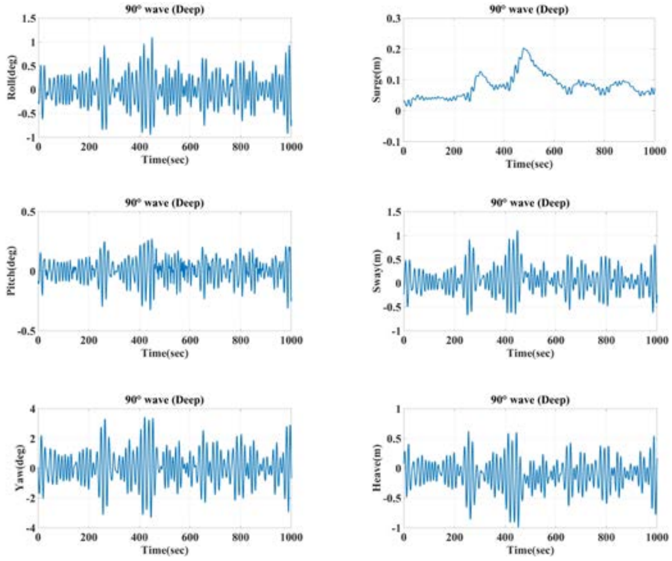

Figure 9 Time histories of the response of duct locating at deep position facing 90° storm wave condition.

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