ICOE 2014 INTERNATIONAL CONFERENCE ON OCEAN ENERGY
NOVEMBER 4-6, 2014
Halifax, Nova Scotia Canada
ICOE2014CANADA.ORG

The Next 90: Using Vortex Power to Extract Energy from Ocean Currents Flowing below 3 Meters per Second

D. Kane

InCurrent Turbines Ltd.
105 Anfield Crescent, Ottawa, On. K2G 7B7 Canada
E-mail: dougkane@vortexpowerdrive.com
www.vortexpowerdrive.com

Abstract

A study of the potential to extract energy from ocean currents using vortex formation around a bluff body is reported, using experimental models in a RHRC 2436 water channel and dimensional analysis. The vortex shedding around a bluff body placed in a flowing fluid shows that energy can be extracted from flows as little as 0.3 m/s, up to 3 meters per second and beyond. Worldwide, most ocean currents flow below 3 meters per second and have the theoretical power capacity in excess of 50,000 TW-h/year: 163 TWh/year off the US coast between Florida and North Carolina[1] alone. It is shown that the Vortex Power Drive technology, combined with the appropriate energy generation system would have the ability to extract energy from 90% of the world's ocean currents. As presented at the 2010 ICOE conference by S. Robles et al titled : "The potential for Ocean Energy in the Region of Andalucia (South of Spain)" 7 GW of Tidal/marine current energy is extractable in the Straits of Gibraltar at 1.5 m/s but "most converters under development for tidal currents are designed for flows of more than 4 knots (approx. 2 m/s)."[2], energy extraction below 3 meters per second, as demonstrated by the Vortex Power Drive, is required to further the ocean energy development industry.

Keywords: Ocean energy, Tidal energy, energy extraction, ocean currents.

1. Introduction

The study of the interaction between flowing fluids and bluff bodies in fluid mechanics shows us that bluff bodies over a certain range of Reynolds number will produce vortexes that are shed from alternating sides of the body in a consistent fashion. This phenomenon is known as a Kármán vortex street after Theodore von Kármán, who explained it theoretically in 1921[3]. The effects of this vortex formation on the bluff body can be significant, especially for long slender structures like those found in the oil and gas industry. Suppression of this phenomenon is heavily studied but enhancing and harnessing this interaction for the purpose of energy extraction is just now being considered. The Vortex Power Drive (VPD), an expanded bluff body, was presented to Dick Engineering Inc. and Carleton University to determine the type of interaction between the VPD and the fluid through experimental modeling and to determine the theoretical energy extraction capability of the full scale device.

2. Background

The extraction of ocean energy in the form of motion has been ongoing for 400 million years. Untold variations of sea animals have been extracting energy from the oceans in the form of a bluff bodies creating vortexes. These vortexes change the sea pressure acting against the body. This pressure differential can then act against the body to produce motion. It was theorized that instead of extracting energy in the form of forward motion of the bluff body that energy from moving fluids could be extracted by a stationary bluff body through the same mechanism of vortex formation and shedding and sea pressure changes. In much the same way that the Wright brothers used the design of a bird's wing to create pressure differentials against their bluff body wing to produce life, the Vortex Power Drive uses the design of a fish to form alternating zones of low pressure to produce oscillating movement about a center drive shaft. This movement can then be converted into energy.

3. Methodology

The experiment consisted of three main phases: confirming the driving force behind the oscillation with the help of flow visualization, defining the shape of a well oscillating bluff body and using dimensional analysis techniques to scale the model results up to full prototype dimensions.

3.1 Water Channel

All tests were performed in Carleton University's RHRC 2436 water channel.

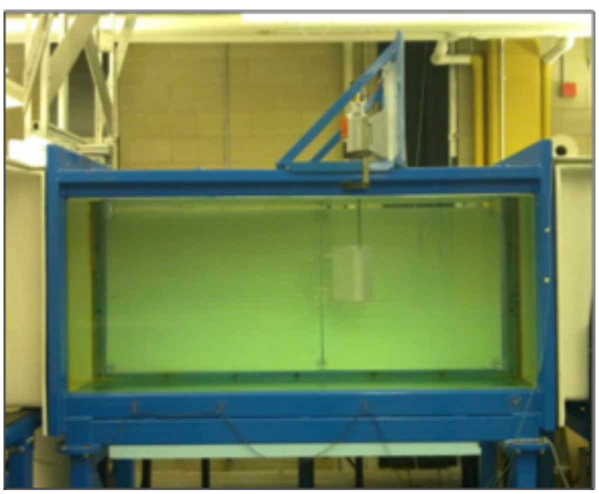

Figure 1: The RHRC 2436 water channel test section

3.2 Test Apparatus

The ultra low friction bearing set load absorber was mounted vertically so that it could receive the rod mounted specimens. The complete setup was calibrated using a constant current power supply so that the system's rotational resistance could be determined. A microcontroller was programmed to monitor the load absorber's current and angular displacement and sent to a labVIEW program. This program displayed and recorded the angular displacement, load absorber current, average angular velocity, and average power. The collected data files were then post processed using a MATLAB program to identify target specific parameters.

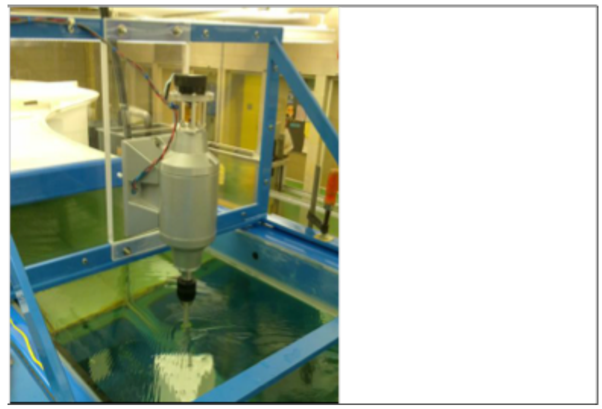

Figure 2: Laboratory apparatus

3.3 Flow Visualization

The specimen was mounted in the apparatus and dye was injected into the water at specific locations to visualize patterns.

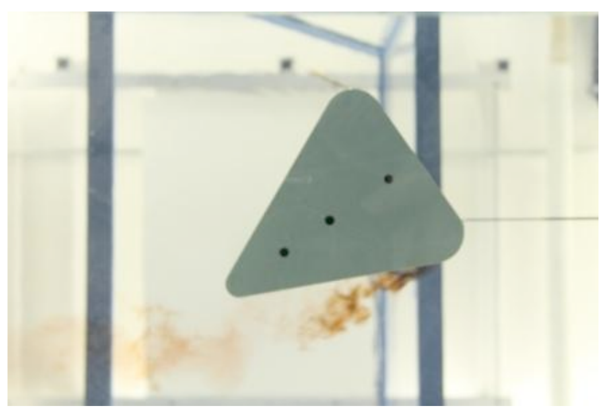

Figure 3: Flow Visualization

3.4 Driving Force

The flow mechanism responsible for the oscillations of the Vortex Power Drive bluff body was confirmed to be vortex shedding on alternating sides of the body.

3.5 Shape of a Well Oscillating Bluff Body

Many experiments were conducted to determine the optimum shape for the oscillating Bluff Body. The shape and specific vortex enhancing and compartmentalizing characteristics increased the energy extraction capability by more than four fold over the original model. Further optimization is warranted with the expectation of further increases in energy extraction capability.

3.6 Dimensional Analysis Techniques

A typical test involved mounting the test specimen in the apparatus and setting the flow speed to the maximum velocity of 0.30 m/s (12 in/s). After recording the temperature of the water, the specimen was manually positioned to the approximate 0° angular position and the system was reset to accept this position as 0°. Then the body was released to oscillate. Once regular oscillations were observed the current from the power supply was incrementally increased to increase the resistance provided by the eddy current brake. When the body ceased to oscillate due to excessive braking force, the current was reduced to zero to allow the body to restart its oscillations and a slightly lower current value was selected to find the maximum load that the system could sustain for a minimum of 2 minutes.

Dimensional analysis techniques were used to scale the results of the study. In general, this means that a number of non-dimensional parameters are required to have the same value for the model and the prototype, respectively. This required the identification of a further four flow defining parameters: Free stream velocity (U), Density (ρ), Viscosity (μ), and Oscillation frequency (f).

All variables were combined using the Buckingham Pi theorem to form the non-dimensional parameters. One can attain geometric similarity by matching the model and prototype aspect ratios, trailing edge angles, relative edge radii and relative roughness. Kinematic similarity would be attained if the axis of rotation is positioned at the same location on the model and the prototype respectively and if the inertia of the system is scaled appropriately.

Since all dimensionless parameters have been shown to remain constant for this test series, a trend between power coefficient and Reynolds number can be determined and expected to hold true for other bodies meeting the same similarity criteria. It is furthermore expected that a well defined trend between the power coefficient and the Reynolds number can be extrapolated over a greater Reynolds number range to predict the power output of a scaled device as a function of Reynolds number. This again precludes that all similarity criteria are met between the model and the full-sized prototype.

4. Results

This series of tests had an operational target velocity for the fluid of 0.30 m/s (12 in/s). The Vortex Power Drive has been shown to use vortex formation and shedding about a bluff body to extract energy from flowing fluids. The Drive was self-starting at a flow rate of 0.075 m/s (3 in/s) and tests were performed in the range of 0.15 to 0.3 m/s (6 to 12 in/s).

Flow Velocity (in/s)	Reynolds Number	Maximum Time-averaged Power (mW)	Power Coefficient
12	43000	39	0.070
11	40000	27	0.064
10	36000	22	0.070
9	33000	16	0.069
8	29000	12	0.071
7	25000	8.1	0.074
6	22000	5.1	0.075

Figure 4: Power coefficient and efficiency of test series

Dimensional analysis of the trend data extrapolated the estimated energy output for full scale drives as seen in figure 5.

Frontal Width[6] (m)	Height (m)	Flow Velocity (m/s)	Reynolds Number	Power Coefficient	Predicted Time-averaged Power Output (W)	Predicted Efficiency (%)
3	5	0.5	1,150,000	0.031	35	3.8
3	5	1.0	2,300,000	0.024	210	2.9
3	5	1.5	3,440,000	0.019	590	2.3
3	5	2.0	4,590,000	0.016	1200	2.0
3	5	2.5	5,740,000	0.014	1900	1.7
3	5	3.0	6,890,000	0.012	2900	1.4

Figure 5: Power output prediction for a prototype

Due to the limited data sample size and limits to the range of Reynolds number achievable in the laboratory the uncertainty of the predicted value increases significantly the further the prototype Reynolds number is displaced from the range analyzed in the experiment. For example, if the data point collected at the 11 in/s flow velocity proved to be an erroneous outlier then the predicted value for Figure 5 may be underrepresented by as large as 100%.

5. Conclusion

It is possible to extract energy from flowing fluids where the velocity of the fluid is less than 3 m/s using vortex formation and shedding about a bluff body. Utilizing this type of energy extraction in ocean currents carries with it many positive benefits:

- Base load energy generation
- Isolated energy generation for:
    - Scientific experiments
    - Coastal subsea monitoring
    - Isolated communities
- Separation of energy extraction from energy generation
- Greater site selection options
- Reduced cost per kW of generation
- Modular construction

5.1 Base Load Energy Generation

Ocean currents generally flow continuously. Extracting energy from this power source would enable electricity to be generated 24 hours per day, 365 days a year, providing a source of base load renewable energy to the grid. This type of energy could be used exclusively or in conjunction with sources of renewable peaking generation to provide a 100% renewable grid.

5.2 Isolated Energy Generation

Scientific Experiments

Subsea scientific experiments are limited in time due to the restriction of battery lifespan. The Vortex Power Drive provides continuous charging capability for these batteries even in areas where the flow of the ocean is only a few centimeters per second. Small, one off VPD's would keep batteries charged indefinitely.

Coastal Subsea Monitoring

Coastal security requiring subsea monitoring could be powered by devices using an array of VPD's. These arrays would be located on the sea floor, undetectable from surface vessels. Because the driving mechanism is vortex shedding the drives would not have a discernible audio signature and as such would be undetectable acoustically.

Isolated Communities

Communities isolated from the electricity grid would have a larger option for placement of ocean renewable energy since the VPD has the ability to extract energy from a wide range of flows. The base load nature of the VPD would provide continuous, pollution free energy.

5.3 Separation of Energy Extraction from Energy Generation

At its core the Vortex Power Drive is a simple piston oscillating about a center drive shaft. It is this drive shaft that opens up a wide range of energy generation options. Many Drives can be stacked on one another, combining their energy onto a single drive shaft. This grouping of Drives can reduce the overall generation costs. Using a hydraulic system to collect the energy from a number of these grouped Drives and delivering that energy to a single generation unit would further reduce construction and maintenance costs. This hydraulic system and generation unit could be sourced from conventional suppliers thereby reducing the overall project cost and removing the risk created by custom constructed generation units.

5.4 Greater Site Selection Options

With 90% of the ocean's currents flowing below 3 m/s the sites that the VPD can extract energy from are many. In S. Robles presentation "The potential for Ocean Energy in the Region of Andalucia (South of Spain)" ocean current energy was by far the largest available energy with a potential of 7 GW, with waves coming in a distant second at 2 GW gross potential.

5.5 Reduced Cost per kW of Generation

Targeting oceans where the current flows below 3 m/s reduces many of the extra engineering and mooring costs associated with higher flow regions. additionally, since the energy extraction would be continuous the cost per kW would be averaged out over a greater degree of generation. As an example a wave device rated at 125 kW but generating a time averaged 25 to 40 kW would have a longer payback period vs. a 125 kW VPD ocean current farm delivering a time averaged 125 kW.

5.6 Modular Construction

The advantage to installing an array of drives comes from reducing down time scenarios. With a single 10 MW machine down time, no matter the cause, means no revenue. The longer the down time the less revenue you make. Conversely, having an array of 100 VPD platforms generating 10 MW in total means that downtime for any one platform only affects 1% of your production. This becomes very critical if you have become reliant upon renewable energy for your community. One scenario leaves your community in a complete blackout while the other does not.

Acknowledgment

Brian Kane - "Try it one more time".

References

[1] *Assessment of Energy Production Potential from Ocean Currents along the United States Coastline*, Georgia Tech Research Corporation for the US government. http://energy.gov/sites/prod/files/2013/12/f5/energy_production_ocean_currents_us_0.pdf Sept 30 2014

[2] *The potential for Ocean Energy in the Region of Andalucia (South of Spain),* S. Robles et al. http://www.icoe-conference.com/publication/the_potential_for_ocean_energy_in_the_region_of_andalucia_south_of_spain_/ Sept 30, 2014

[3] F. M. White, Fluid Mechanics, 6th. ed., New York, NY: McGraw Hill, 2008