Sea Floor Energy Harvesting

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Energy harvesting, converting surrounding motion into electrical power, is growing into an increasing number of applications. We're aware of photovoltaics, hydroelectric stations, and wind turbines as large scale energy harvesting technologies. Smaller scale technologies are in development as well to produce smaller amounts of local power. Uses of energy harvesting include using vibrations to power distributed sensor nodes, using wave energy to power buoys, and using low speed ocean currents to recharge submerged sensors for tsunami detection.

All of the energy harvesting technologies are fundamentally multiphysics design problems. Motion from some source is coupled to a mechanical system that in turn is coupled to an energy conversion system to produce electrical power. Motion can be vibration, direct mechanical contact, or fluid flow. Energy conversion can be electromagnetic, piezoelectric, electrostatic, or electrorestrictive. Given this diversity, COMSOL provides an important simulation tool that can account for all the coupled physical processes for initial proof of concept evaluation, and later for product design and optimization.

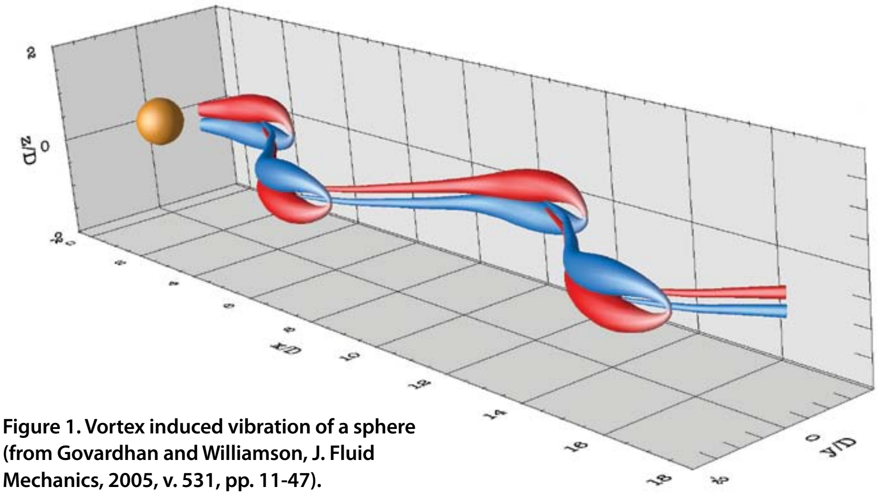

Figure 1. Vortex induced vibration of a sphere (from Govardhan and Williamson, J. Fluid Mechanics, 2005, v. 531, pp. 11-47).

Energy from Ocean Currents

Veryst Engineering has been working for several years in energy harvesting, providing design solutions for a variety of industries. One example is harvesting energy from constant, low speed ocean floor currents to power ocean floor sensors. Such sensors are used in naval applications, environmental monitoring, earthquake monitoring and oil exploration. Ocean floor sensors are currently battery-powered, requiring very expensive battery replacement or recharging using ship based services. Although the cost of the batteries may be low, the cost of sending a ship out to replacement can be prohibitively high. By some estimates, the in-field maintenance of underwater sensors arrays in naval applications can cost hundreds of thousands per service interval.

To address this problem, Veryst has been working to develop a technology to harvest energy from low speed sea floor ocean currents. The concept illustrated in Figure 1 converts a steady fluid flow into an alternating train of vortices than can be directed to an energy conversion device. A bluff body is placed on the ocean floor into the steady low speed current. The geometry of the bluff body is selected to cause the flow to develop a laminar Karman vortex street. A vane is inserted downstream from the bluff body and pivoted at its leading edge. The vortices introduce an alternating motion in the vane which can then be coupled to an electromagnetic generator to produce power. The design is simple, uses basic off-the-shelf components, and can be encapsulated to eliminate the need for moving shafts and reduce biofouling. An alternative Veryst design involved harvesting energy from the oscillating force on the bluff body, without the vane.


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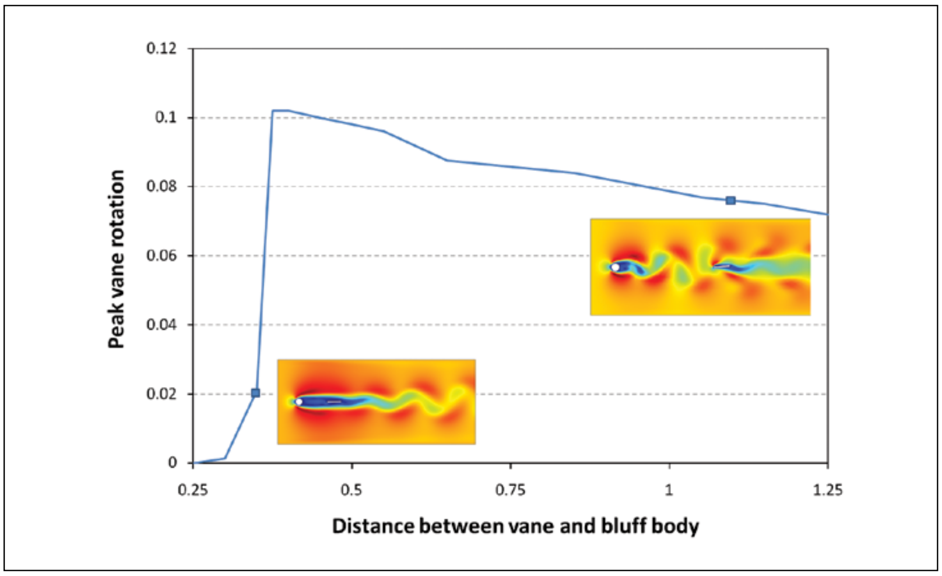

Figure 3. Effect of distance between vane and bluff body on vane rotation.

A Reliable Model

Veryst modeled the flow and mechanical motion of the vane in COMSOL to examine the interaction between fluid velocity, bluff body geometry, vane geometry, and vane position. This energy harvesting application is challenging due to the small amounts of energy involved. A few watts can make a big difference in the feasibility of the energy harvesting design. Empirical equations are not suitable for validating the design since they do not provide the desired accuracy, and prototyping and experimentation cannot realistically be done for all possible design parameters. A reliable multiphysics modeling tool is required. COMSOL's main appeal was the seamless integration of different physics modules. COMSOL provides additional physics models if we need to account for other processes such as electromagnetic fields, or more advanced solid mechanics effects.

It was more efficient to model the vane as a rigid body with a single rotational degree of freedom about its leading edge instead of a general fluid-structure interaction (FSI) analysis. The kinematic and dynamic relationships governing the rotation of the vane were input to COMSOL directly in equation form. This direct input of equations is a unique COMSOL feature that simplified the modeling. A moving mesh feature is used to update the CFD mesh due to the deformation of the vane. Simulations were performed without the vane to validate the CFD model. The resulting laminar vortex shedding flow was in agreement with Karman vortex street predictions in terms of both frequency and amplitude of oscillations.

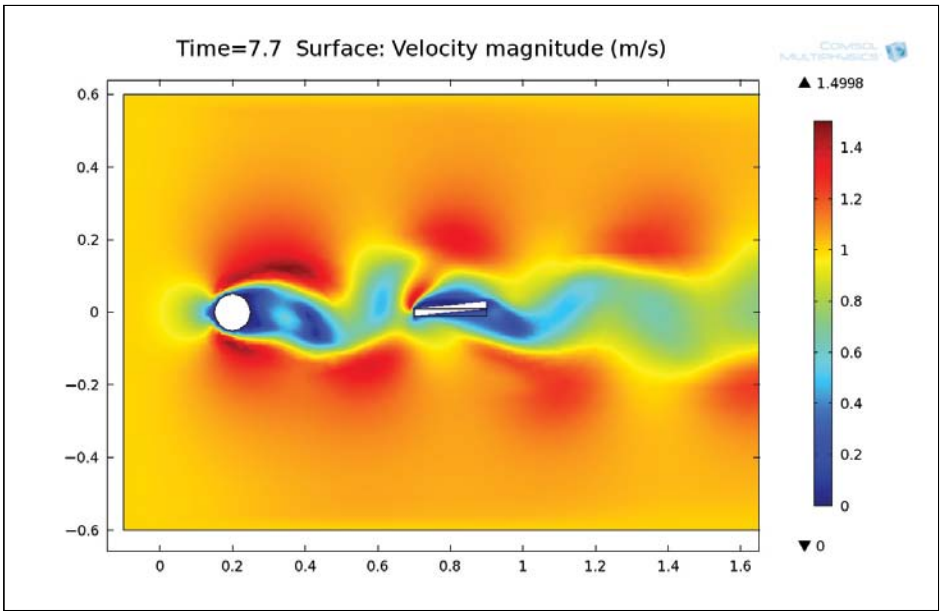

Figure 2. Velocity contours for a specific energy harvester configuration.

Design Optimization

The multiphysics COMSOL simulations provided immediate prediction of the amount of available energy for conversion and facilitated the design optimization of this energy harvesting device. Figure 2 shows one configuration where there is vortex shedding. Figure 3 shows the effect of one parameter, the distance between the bluff body and the vane, on the amount of vane rotation, which determines the amount of available energy. This type of parametric sweeps is easy to perform in COMSOL. There is an optimal range of locations for the vane. When placed in closer proximity to the bluff body the vane delays the formation of the vortices and when placed further away the effect of vortex shedding gradually diminishes. ■