Uni-Directional Impulse Turbine for the Powering of Offshore Monitoring Systems

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Description: Numerical modeling and experimental testing of turbine for wave energy conversion. The University of Central Florida and Harris Corporation have joined efforts to design, build and analyze a wave powered abandoned oil well monitoring system for use in the Gulf of Mexico. This system proposes a fully automated oil leak detection system which is self-powered by the local ocean energy which is converted to electricity, conditioned and sent from the surface buoy to the ocean floor to supply power for an abandoned oil well monitoring system.

Budget: $5,000
Universities: UCF
External Collaborators: Harris Corporation

Progress Summary

The University of Central Florida and Harris Corporation have joined efforts to design, build and analyze a wave powered abandoned oil well monitoring system for use in the Gulf of Mexico. This system proposes a fully automated oil leak detection system which is self-powered by the local ocean energy which is converted to electricity, conditioned and sent from the surface buoy to the ocean floor to supply power for an abandoned oil well monitoring system.

This project was split into four different components which were completed by four UCF senior design teams; three of the teams were chosen from last year's Mechanical Materials and Aerospace Department (MMAE) senior design class and the fourth team was chosen from the electrical engineering senior design class. The project was split into two major components, the first one being the design, construction and testing of a fully automated and battery powered oil well monitoring system. The second component focuses on the conversion of wave motion into electrical energy which is used to power the sensor battery system. Each of these two major components has been undertaken by two teams. In order to summarize the joint efforts contributed by each team a brief description of each team's goals and accomplishments is given below. A more indebt description of each team is provided after this summary.

In order to provide a monitoring system for abandoned oil wells a mechanical senior design team designed, tested, and built a fully powered and automated oil detection system for end users such as the EPA. The system acts like a cap to be installed on the top of all abandoned oil wells. The cap is shaped like a nozzle, which forces any leaking oil from the well to flow out through the nozzle and through a channel were a series of sensors detect for the presence of oil.

Since ocean waves provide an intermittent and inconsistent source of energy a smart energy converter was needed to convert, condition, and supply consistent power to the sensor system. For this purpose an electrical engineering team created a black box electrical unit which was made in four parts: Input Circuit, DC-DC Converter, Battery Charge Controller, and Microcontroller.

In order to provide electrical energy for the monitoring system a unique uni-directional impulse turbine was designed, built and tested. The team made the design schematics which were built by the HARRIS Corp. through the use of their rapid prototyping machine. The experimental testing resulted in 44% turbine efficiency for the optimal flow coefficient.

In order to house the turbine and generator system a mechanical engineering senior design team designed, built and tested a floating buoy which was acted as the link between the ocean wave motion and the impulse of air flow through the turbine section. A quarter scaled buoy was constructed and was hydro-dynamically stable in all of the field tests.

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Along with the work of the senior design teams, graduate student Carlos Velez has conducted research in the modeling of a uni-directional impulse turbine for wave energy conversion. He has created a analytical model and a 3-dimensinal viscous CFD (computational fluid dynamics) simulation to predict the performance of the turbine for a range of flow coefficients. An illustration of turbine is shown below in figure 1.

The CFD simulations and numerical model are in agreement with the findings in the literature and experimental results. The validated simulations are used to find the key losses in the turbine passage in an attempt to increase the efficiency over a larger range of flow coefficients. Since this turbine is used in an oscillating wave column there exists no set design point, this requires the turbine to function efficiently in a large range of flow coefficients. For most of the non-ideal flow coefficients large flow separation can be seen at the trailing edge of turbine. To counter this affect the use of injection jets on the rotor blade has been used to create regions of low pressure on the rotor surface. This process is energy friendly as it uses the pressure difference which already exists in the oscillating wave column chamber to drive air through the turbine blades through small holes at large velocities. The results of the injection simulations are very promising.

The injection system considerably reduces the amount of flow separation occurring across the rotor blade and an increase in efficiency is encountered across the entire flow regime. The results show an average of 6% increase across the entire range of flow coefficient with highest increases in efficiency (12%) occurring at flow coefficients above unity. A comparison plot of efficiency with and without injection is show below in figure 2.

To extend the research beyond simulations a new set of senior design projects have been initiated with the construction of a full scale uni-directional impulse turbine and bi-directional wind tunnel which will replicate the air flow encountered in an oscillating wave column.

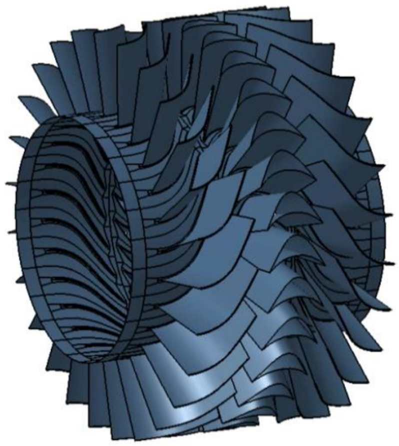

Figure 1. Turbine Schematic

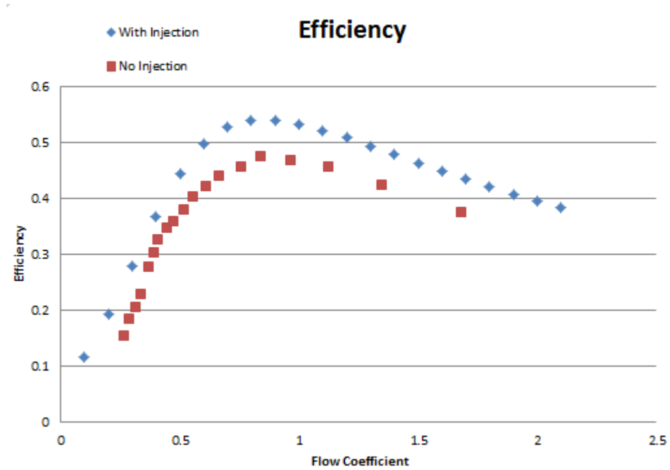

Figure 2. Turbine efficiency with and without injection

To detail the work contributed by each of last year's senior design teams the following section will describe the process and findings for each senior design project.

Sensor Team Summary

In order to provide a monitoring system for abandoned oil wells a mechanical senior design team designed, tested, and built a fully powered and automated oil detection system for end users such as the EPA. The system acts like a cap to be installed on the top of all abandoned oil wells. The cap is shaped like a nozzle as seen in figure 1, which forces any leaking oil from the well to flow out through the nozzle and through a channel were a series of sensors detect for the presence of oil.

Various sensors were considered for this task, the team concluded that the use of a fluorometer and pressure sensor would work best for detecting the presence of oil. The fluorometer is an electronic sensor which can detect the presence of oil in water through the use of the luminescent properties of oil. The second sensor is a pressure transducer which can detect the presence of oil in the configuration designed by this group by detecting a pressure drop. Minimal power is consumed by each of these sensors with total power consumption equal to about 360 mW. The final requirement to be able to wirelessly transmit the signal produced by the fluorometer and pressure transducer was accomplished through the use of a product called a Wi-Ranger. The actual oceanic design consists of the two sensors and a data acquisition system which would be attached to the funnel design which would encapsulate any leaking oil from an abandoned oil well. The data acquisition system, which is housed in a hermetic electronics enclosure, would convert the signal from the sensors into a useable and interpretable signal. A wire from the data acquisition system would be connected to the buoy, which also provides the power for the sensors, on the surface of the water where the signal could be transmitted wirelessly.

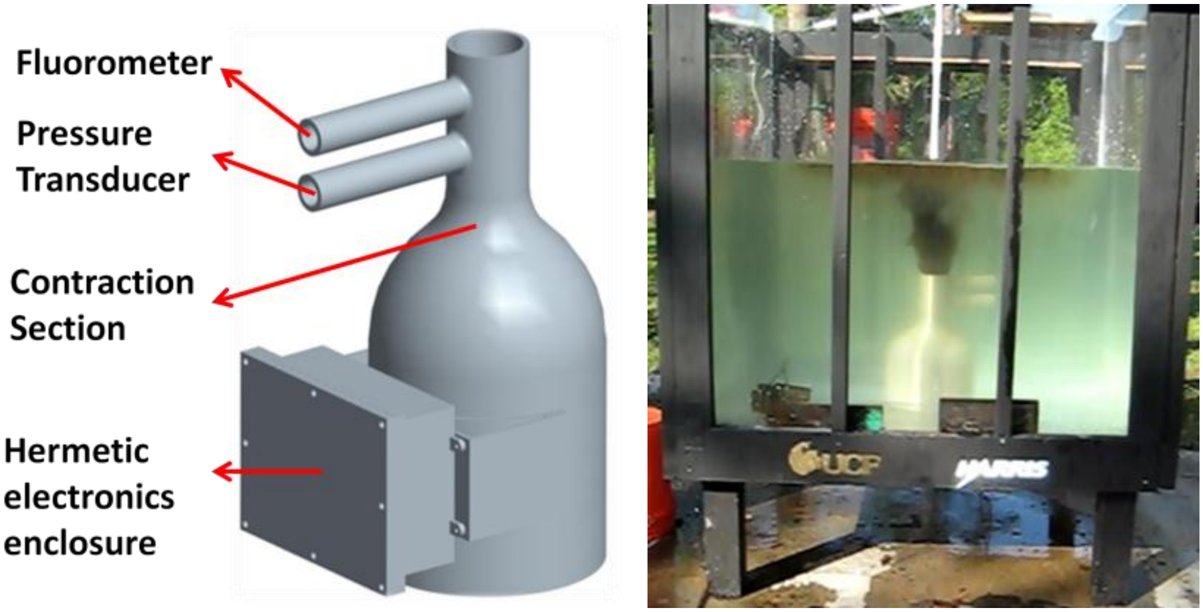

Fig 3. Illustration of funnel design and experimental testing of funnel prototype

Electrical Team Summary

Since ocean waves provide an intermittent and inconsistent source of energy a smart energy converter was needed to convert, condition, and supply consistent power to the sensor system. For this purpose an electrical engineering team created a black box electrical unit which was made in four parts: Input Circuit, DC-DC Converter, Battery Charge Controller, and Microcontroller.

According to the specs given by the turbine team, the generator would produce about 0VAC (assuming no wave conditions) to 60VAC. This input was rectified by the Input Circuit via a full wave bridge rectifier. A large smoothing capacitor was then used to convert this full wave rectified signal to a DC signal. The output of this circuit was 0VDC to 56VDC. The DC signal then needed to be stepped down using a buck converter. A circuit for this purpose was used to convert the input DC voltage to a steady 15.6VDC for the Battery Charge Controller. A few components such as resistance and capacitance in the circuit can easily be changed in order to change the output voltage. It was decided to use a battery in order to provide constant power to the sensors. Hence, to charge the battery, a Battery Charge Controller circuit was made. This circuit ensured a high charging efficiency for the battery under various load conditions. The 15.6VDC from the DC-DC Converter Circuit was used as an input to the battery charge controller. The output of this circuit was a 13.8VDC which was then used to charge a 12V lead-acid battery. In order to maximize the power for any kind of wave conditions (heavy or calm), a PIC microcontroller was used to control the load distribution in the circuit for large or small power extraction based on the past history of the input signal. This smart system was designed to optimize overall power production and conversion efficiency. The control hysteresis is defined and controlled using C code which manages the charging conditions. The charging of the battery only takes place between 15VDC and 55VDC for undercharging and overcharging protection. This protects the battery by allowing the input signal to operate within safe parameters for the battery. Future work would involve implementing a power factor correction system which would optimize the generator load to reach optimal ranges of rotor RPM.

Fig 4. AC-DC converter and battery charging system

Turbine Team Summary

A mainly aerospace team was constructed to design, build and test a bi-directional turbine for use in a water medium. The team chose this turbine design based on its unique capability of rotating in a single direction independent of the fluid direction. This has obvious advantages in the ocean environment as the oscillating motion of waves can be a difficult motion to harness with typical mechanical systems. The team then sought out to design the turbine blade based on the previously documented dimensions. The blade number and arrangement was designed by the team based on several CFD simulations and analytical numerical models which simulate the performance of the turbine under various flow conditions. The team designed the blades through the use of the software SolidWorks and the design schematics were built by the HARRIS corp. through the use of their rapid prototyping machine. The first prototype consisted on the essential single rotor and double stator blade design along with a converging diverging nozzle which would help to accelerate the flow at the turbine and there for increase the power. The prototype was tested through the use of a 6 DOF motion platform located on campus, the turbine channel was submerged in a water tank and was rigidly fixed to the table. This allowed for the turbine to be plunged up and down inside the water tank to simulate the oscillating motion of the waves. The experimental data showed that the turbine was successful in spinning in a single direction regardless of the table/wave motion. The first prototype had an efficiency of 22%, which was low but agreed with the prediction found in the numerical model which was very important. Now that the numerical model had been validated an optimization scheme was implemented by the team. The team found that using the same turbine blades a new channel could be designed with a larger area ratio which would double the speed of the fluid at the turbine. Thus, the second channel prototype was built with a RPM with an inlet to channel area ratio of approximately four. The nozzle worked as expected by the model and the efficiency of the system increased to 44%. This was a very important factor which showed the designs capability to withstand and harness a wide variety of loads. The conclusion of the experimental and numerical analysis resulted in a system with high adaptability and large power consumption with minimal stresses acting on the system.

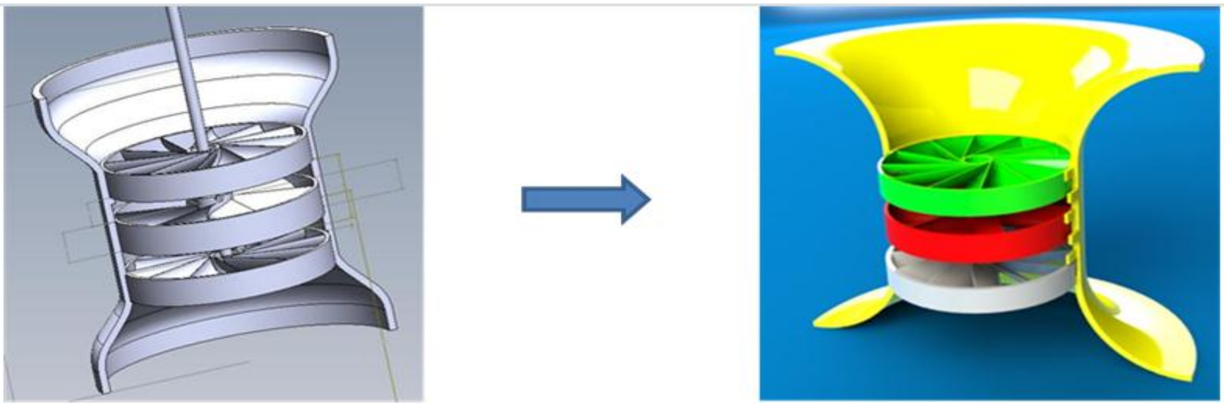

Fig 5. Illustration of two prototypes of the bi-directional turbine and nozzle design

Buoy Team Summary

As described in the turbine team summary, a turbine can transfer bi-directional translational motion very efficiently to rotational motion. This team set out to determine if more energy can be harnessed by creating a buoy which would produce a larger relative velocity between the turbine and the water then what is normally found between the wave and buoy. This concept is based on the non-synchronies relative motion between the buoy and wave. The team found that if the buoy were perfectly out of phase with the wave motion the relative velocity between the turbine and the wave can be theoretically doubled. This would allow for water which is rising to drive the turbine faster since the turbine itself is dropping relative to the water. With this motivation the team set out to build a consistent, stable, water proof, buoy which would house the generator, electrical system and turbine safely while producing the highest potential power. Three major experiments were conducted to test the performance of various components of the buoy along with fluid simulations which were created to optimize the buoy geometry.
The main components of the design are as follows:

1. **Buoy**- Geometric design promotes a lag between wave and buoy.
2. **Swivel-** Keeps turbine held vertically so that any pitching of the buoy will still produce vertical fluid motion through the turbine.
3. **Generator Housing-**Water tight enclosure provides a dry environment for the generator
4. **Turbine Housing-** Turbine is held in place by the "swinging" shaft
5. **Shaft Assembly-** A dual shaft system is used to separate the shaft from the wet environment to a dry environment where the generator is driven**.**

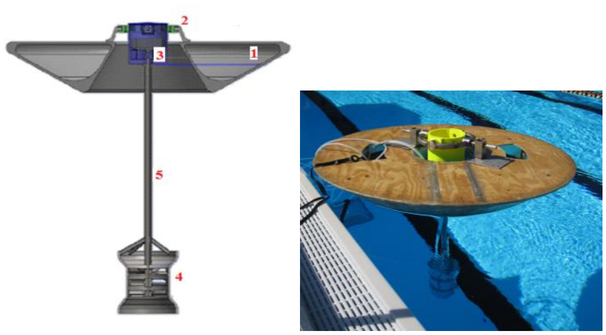

Fig 6. Illustration of buoy components and buoy experimental prototype