GECCO Ocean Energy System

Luis Maristany, Nicole Waters, Billy W. Wells Jr., Mario Suarez, Richard Gestewitz, Alexej Wiest, Stephen L. Wood, Ph.D., P.E.
Ocean Engineering
Florida Institute of Technology
Melbourne, Florida, USA
swood@fit.edu

Abstract—In today’s world the oil and gas industries play major roles in energy consumption. Nations depend heavily on these resources despite their major disadvantage: They are not renewable. As the demand for renewable energy increases, it is necessary to identify new energy sources and to invent ways of harvesting these energies by designing new systems. The ocean is a major resource for all types of materials, supplies, as well as energy; however the exploration of wave energy as a resource is still in its infancy. The Florida Institute of Technology has constructed an alternative energy system independent of non-renewable resources, such as oil and gas. The GECCO (Green Energy Coastal Collection Operation) is a wave energy converter that extracts kinetic energy from ocean waves using a rugged, innovative mechanical multi-system.

Index Terms—Ocean energy, wave energy, hydrokinetic energy, alternative energy, wave energy converters, green energy.

I. INTRODUCTION

As the demand for renewable energy increases, it is necessary to innovate our ways of producing energy by identifying new energy sources and designing new prototypes to harvest energy. The ocean is a major resource for all types of materials and supplies; however wave energy has yet to be fully explored. The GECCO (see Fig. 1), which stands for Green Energy Coastal Collection Operation, is a wave energy converter that extracts kinetic energy from ocean waves in a new, innovative way. The GECCO is an alternative energy system independent of non-renewable resources, such as oil and gas. The system harnesses the energy contained in the waves and converts it to usable electric energy.

People have used renewable sources of energy for thousands of years; everything from the use of a water wheel to grind wheat into flour to the invention of the sail, which revolutionized trade and exploration. Nowadays engineers are trying to find new ways to harness renewable sources of energy in order to meet the planet’s increase in demand.

The goal is to reduce the dependency on these nonrenewable resources. The ocean itself holds an enormous amount of energy that can be captured; it is anticipated that using 1/1000th of the existing energy in the Gulf Stream could supply the state of Florida with 35% of its electrical needs [1]. The GECCO prototype is designed to harness the power stored in ocean waves and effectively produce useful amounts of electricity.

II. BACKGROUND

There are many variations in the types and effectiveness of wave energy converters (WEC). Usually, WECs are grouped by the location of the wave in which energy is extracted. The most common types of WECs include terminators, attenuators, point absorbers, and overtopping devices.

- **Terminator WECs** gather a wave’s energy and stop the forward propagation of the wave. These types of WECs usually exist on the shoreline, since the wave terminates there anyway.
- **Attenuator WECs** either float on the ocean surface or are partially submerged. They usually contain some sort of hinge mechanism and body section, which move independently from one another about the hinge. As the wave passes the attenuator, energy is harvested, and the wave continues propagation further along the surface of the ocean.
- **Point Absorbers** are usually stationary and work on differences in pressure and/or elevation in the surface of the ocean and after the energy is absorbed from a wave, the wave itself continues on its journey across the ocean.
- **Overtopping Devices** collect water as it passes over some sort of boundary, essentially filling with water and using the pressure created by the collected water to create energy.

The Green Energy Coastal Collection Operation (GECCO) is a floating heave/surge type of attenuator WEC. The GECCO floats atop the ocean surface and articulates about a fixed hinge and is freely moored to the ocean floor using mooring lines.

Fig. 1. GECCO system
III. GREEN ENERGY COASTAL COLLECTION OPERATION

Under the supervision of ocean engineering Professor Stephen L. Wood, Ph.D., P.E., a team Florida Tech’s Ocean Engineering students in 2009 began investigating methods to harvest energy via ocean surface waves. During this investigation the Pelamis system (Fig. 2) and the Salter’s Ducks (Fig. 3) were identified as excellent methods to harvest surface wave energy. The Pelamis Wave Energy Converter device is 180-m long and divided into 4 sections that are allowed to freely move with the ocean surface. The up and down movement created by the waves is then transferred to the Pelamis and converted into electrical energy by generators within the sections [4]. The GECCO prototype similarly harnesses the vertical motion of ocean waves and converts it to electrical energy.

What contributes to the GECCO prototype being different than that of the Pelamis is that it integrates the Salter Duck technology to capture the rotational motion of the waves. The Salter Duck is a teardrop shaped wave terminator system oriented perpendicular to the direction of the wave with the nose of the teardrop facing the oncoming wave. The device was designed to rotate and “bob” up and down as a wave passes [5]. The bobbing and rotating motion is used to pump hydraulics, which drives an electrical generator. So the GECCO is a floating heave/surge attenuator that works with a combination of a mechanical and a hydraulic system in unison. The GECCO harvests not only the energy of the big swells of the ocean, but the small capillary waves by the addition of Stephen Salters’ “Salter Ducks.”

The two systems are combined using two or three cylindrical sections along with four Salter’s ducks, where each component works in unison with a pulley and hydraulic system to pump the hydraulic fluid into an expansion tank (i.e., accumulator) to create pressure. The pressure is then released into an electric generator to generate electricity.

The first prototype system developed in 2009/2010 was found to be overly complicated and that the joints were subjected to high stresses due to the design, e.g., the cables that drove the hydraulic rams were subject to failure if they were subjected to a rapid load.

A new system was designed that is basically the same as the first but with several significant changes. First, the Salter’s Ducks were moved away from the joint reducing the stress on the joint. Next, inside the cylindrical section, aluminum scaffolding was designed to strengthen the system once all of the hydraulic equipment was installed. This hydraulic system operates on a set of pulleys to move hydraulic fluid via a ram mounted inside the body section. For this prototype version, the Salter’s Ducks acted only as stabilizers and were not used for harvesting energy.

The main goal was to prove the concept of the system by an actual deployment of the system off of the Florida coast in July 2011, rather than generating energy. Significant lessons learned from this initial deployment of the GECCO, e.g., deployment difficulties and techniques along with water intrusion and the effect it can have on a surface mounted system. The main points of ingress were the large aluminum end caps as well as the maneuver points for the rods which hold the Salter’s Ducks. The joint did not suffer any noticeable damages.

In spring and summer of 2012, work was done to improve upon the existing GECCO and to generate electricity. This mainly deals with the mounting of the hydraulic system and pulley system within the body of the GECCO.

The hydraulic accumulator and generator were not installed inside any section of the GECCO; instead a floating vessel containing the power take off components was moored nearby and the hydraulic fluid pumped to it.

IV. THEORY

As our ability to forecast weather patterns becomes more advanced, so does forecasting the incoming energy from waves. Wave characteristics can be estimated as a function of the weather patterns that generate the waves. In order to fully assess the energy potential, an investigation of the amount of energy flux must be introduced. The summation of energies per
unit volume can be given by the basic Bernoulli’s equation (assuming irrotational flow of propagating waves)

\[ \frac{\partial \Phi}{\partial t} + \frac{1}{2}V^2 + gz + \int \frac{dp}{\rho} = f(t) \]  

(1)

Where \( \Phi \) = Velocity potential, \( V \) = water particle velocity, \( g \) = acceleration of gravity = 9.81-m/s², \( p \) = pressure, and \( \rho \) = density of fluid.

The local energy per meter length of wave crest transmitted can be calculated and estimated using the wave energy equation:

\[ p = \frac{\rho g^2 T^2 H^2}{32 \pi} \text{ W/m} \]  

(2)

where \( \rho \) = density of seawater = 1025-kg/m³, \( g \) = acceleration of gravity = 9.81-m/s², \( T \) = wave period in seconds, \( H \) = wave height in meters.

When considering a wave propagating toward shore with respect to harvesting its energy, the main focus is on the horizontal presentation of the wave energy as it arrives normal to the affected shoreline. This is the energy flux, which in general terms is the time rate of change of energy per unit area normal to the flow direction. In mathematical terms, the energy flux can be determined by multiplying the energy per unit volume by the individual particle velocities (see Eq. 3 the Wave Energy Flux).

\[ \Delta \dot{E} = \rho \frac{\partial \Phi}{\partial t} V = \rho \frac{\partial \Phi}{\partial t} \nabla \Phi \]  

(3)

By describing the velocity potential in terms of wave height, water depth, horizontal distance over a given period, and wave length, and by integrating this over the wave period and the water depth, the average wave energy flux is described in Eq. 4.

\[ \dot{E} = \frac{\rho a^2 g^3}{T c \cosh^2(kh)} \int_0^\infty [\cosh(kx + kh) \cos(kx - \omega t) - \cosh(kx + kh) \cos(kx + \omega t) \sinh(kx + kh) \cdot \sin(kx - \omega t) \cdot \sinh(kx + kh)] \omega^2 \rho g \omega^2 \dot{E} \]  

(4)

Theses energy calculations provide a reasonable estimate as to what sort of energy is available along our coastal zones, where these specific WECs are placed for deployment testing.

The basis for design parameters is the wave characteristics which the WECs will encounter during testing. The National Wave Buoy Data Center collects wave spectral analysis from various buoys moored throughout the world. Historical wave data for specific locations is available online at the National Wave Buoy Data homepage. Types of data available are wave heights, periods, and direction of swell (see Figs. 4 and 5).

Swell and sea height data are extremely important for determining the amount of movement expected from each WEC. In conjunction with the National Data Buoy Center, Scripps Institute hosts the Wave Rider Buoy [Station ID: 41114, Location: 27.551° N, 80.225° W]. Through the use of Fast Fourier Transforms, spectral analysis of the raw data collected from the buoy is made into a useable form for predicting significant wave heights. By analyzing historical data, a legitimate estimation of wave heights during the proposed deployment window can be determined. Through the use of buoyancy calculations the angle of movement about GECCO’s hinge can be calculated. The efficiency of the design relies on the spatial orientation with respect to incoming ground swells. By knowing the direction of average swell, the system can be oriented for maximum energy conversion. This wave data is the beginning of the power output calculations, due mostly in part to the fact that these criteria cannot be changed.

V. DESIGN CONCEPT

The GECCO is made up of three 3.05-m (10-ft) sections of fiberglass pipe connected by two joints that bend vertically. As a wave passes, a pulley system attached to the joint translates the motion of the wave into pumping of the hydraulic...
cylinders. Similarly, ducks are attached to the main body section of the GECCO; which bend horizontally in a back and forth motion.

The motion that the joints and ducks have allows hydraulic fluid to be pumped into an accumulator; once the accumulator reaches a maximum pressure the fluid will drive a turbine creating electricity. The estimated weight of the system is about 1,368-kg (3,016-lbs) with a 30.5-cm (1-ft) draft. The GECCO was manufactured to be strong enough to withstand the marine environment for its design life.

The GECCO is a combination of multiple systems working in unison to extract the most amount of energy from ocean waves. The joint and the ducks are integrated into one hydraulic system that converts the energy extracted into electricity.

A. The Joint

The function of the joint is to connect the sections of the GECCO while allowing them to undulate independently of each other in order to efficiently extract the vertical wave energy. The overlapping plates used for the joint provide a design that does not pinch, functions smoothly, and most importantly it is very strong. The joint’s two sides are held together by a stainless steel shaft that is very strong and can be removed to disconnect the sections from each other if necessary.

B. The Ducks

The system was designed using four ducks 0.914-m (3-ft) in length to extract energy from small waves, 0.3-m to 0.6-m (1 to 2-ft) in wave height. In order to keep the ducks in optimal position a counterweight is precisely placed within the ducks to ensure high efficiency. A stainless steel shaft runs through the entirety of each of the ducks and connects through the main body section of the GECCO. The ducks are connected to the body in such a way that will hold the ducks in place while allowing for uninhibited rotation. Utilizing this low friction system, the highest amount of energy can be extracted from each of the ducks. The energy from each individual duck is then compounded into one hydraulic system.

C. Hydraulics

Early design considerations for the internal pump system of GECCO consisted of a spring mechanical spring system, a hydraulic gear system, and a hydraulic pulley system. With the time and funding limitations a hydraulic pulley system was most feasible. This internal pulley system is comprised of six smaller pulleys with a seventh larger pulley. These pulleys are mounted on the inside of the aluminum ribbing located inside one of GECCO’s 3.05-m (10-ft) sections. The pulleys are placed strategically to allow a 0.48-cm (3/16-in) steel cable to attach to a hydraulic cylinder with a 30.5-cm (12-in) stroke length while avoiding slack in the cable. The steel cable connected to top and bottom of the opposing 3.05-m (10-ft) section of GECCO thus providing the rocking motion for the cable to pump the hydraulic cylinder forcing pressurized fresh water to the accumulator on the Power-Take-Off raft. Stainless steel hardware in addition to rubber washers are used in the mounting of the pulleys. Each pulleys ball bearing is serviced with marine grade grease to ensure smooth rotation during testing. The rubber washers separate aluminum and stainless steel material within the assembly.

Fig. 6. Design concept

Fig. 7. GECCO hydraulic system design concept
Located in the body section of the GECCO, the hydraulics is the heart of the system (see Fig. 7); they are used to extract the kinetic energy of the waves and convert it into usable electrical energy. The hydraulic system is divided into two systems that extract the energy at the ducks and the joint. A hydraulic ram is connected to the joint and to the body, as the wave hits the system the joint causes the hydraulic ram to contract and then retract; this motion pumps hydraulic fluid into an accumulator tank. Once the accumulator tank reaches the designated pressure it releases the hydraulic fluid into a turbine creating electricity.

The other component of the hydraulic system uses the rotation of the duck to pump more hydraulic fluid through the system. The ducks connected via chains to a gear that is attached to a hydraulic pump. A one-way bearing is attached to the gears in order to allow for positive net movement of the hydraulic pump; as the duck is rotated by a wave it rotates the pump, which in turn moves hydraulic fluid through the system. Both the joint and the ducks contribute hydraulic pressure to the system and run the turbine in unison.

Within the body of the GECCO there is a square ribbing system mounted on tracks that support the structure (Fig. 8) provide housing for the hydraulic system, as well as a stable platform to attach the ducks to. The track system allows the ribbing to slide out of the body with little effort making repairs to internal components possible without completely disassembling the entire body. This ribbing functions as structural reinforcement to the pipe as well as providing a rigid platform to mount all of the mechanical systems within the GECCO. The duck shafts are inserted through bearings attached to the ribbing, which distributes the forces on the ducks throughout the ribbing and not the fiberglass pipe.

VI. TESTING AND DEPLOYMENT OF THE GECCO

Every prototype must be tested to allow the engineer to verify, improve and/or modify the design. The GECCO received structural testing by manual methods on land, and found to function as intended with the addition of the hydraulic systems and mechanical modifications. The installed components and hydraulics within the main section of the GECCO were displaced manually after analysis of a typical wave found off east the coast of Florida (see Fig. 9). The ram was not filled up with any type of working fluid, since the hydraulic lines were still being designed. The main purpose of displacing the ram manually was to determine if all of the cable clamps were holding correctly and if the hydraulic ram was moving without any problem.

Once the hydraulic lines were completed and ready for installation, a secondary hydraulic ram was used to check if the flow of the working fluid was correct once the lines were connected to it. The secondary hydraulic ram had the same characteristics as the one inside the GECCO.

The deployment procedure to deploy the GECCO was by hooks that were fixed at the external side of each section of the prototype with a lift strap onto the A-frame of the ship. To prevent the prototype from bending a special stopper was manufactured from wood, steel, and fiberglass to fit around the joint between the sections. Once the prototype was on the water a small boat would hold the system in position while the divers prepare the mooring lines.
On June 26, 2011 (Fig. 10) and again on June 6th, 2012 (Fig. 11) the GECCO prototype was taken to Fort Pierce and loaded on the M/V Thunderforce and deployed just south of the Fort Pierce Inlet. During the 2011 deployment, many observations were made to determine the functionality of the system in the marine environment. The three day test during the cruise focused primarily on seeing how well the GECCO handled being berated by the sea as well as observing the motions of the joint and the ducks with different wave and current scenarios encountered during the testing period. For the duration of these cruises only two body sections and one joint were used. This however did not hinder any of the testing data and the motion of the GECCO was still able to be analyzed.

During the 2012 deployment, the first few hours went exceptionally well with the GECCO being towed into position and anchored using 1.52-m (5-ft) sand screws, for hookup to the generator the next morning. Unfortunately, four hours into the dynamic testing the ducks shafts failed. This was a surprise at first until analysis of the ducks showed that they had been damaged during transportation and consequently experienced severe water intrusion. This flooding of the ducks exerted excessive stresses on the stainless steel shaft connecting the ducks. Upon further analysis, the highest stresses experienced were precisely where a hole had been drilled in the shaft just outside of the GECCO shell where a pin prevented lateral shifting of the ducks. This exact point was where the shearing moment occurred during deployment.

The force analysis performed on the sheared stainless steel shafts, with a cross sectional areas of 5-cm² (0.785-in²) had a yield strength of roughly 15,467,530-kg/m² (22,000-psi). The total amount of stress applied due to water intrusion on the entire GECCO system was calculated to be 7667.5-kg (16,904-lb) causing failure at the weak point where the pin hole resided.

VII. RESULTS

Due to failure of GECCO no energy data was recorded. Work on the GECCO continues to take place at Florida Institute of Technology. A new and improved prototype of the GECCO is currently underway, containing a new joint, a third body section, and a fully functional energy conversion system. The ducks require refurbishing and the stainless steel shafts will be replaced. In the next version, the Ducks will be integrated into the pump system with sealed bearing mechanisms resulting in four total sealed bearings allowing for independent rotation of the ducks while preventing water intrusion into the GECCO shell.

Once these new additions have been made the GECCO will be ready for a third trial out at sea to obtain energy data. This data will help determine the future of the GECCO and the positive impact of ocean energy devices on the current energy crisis.

REFERENCES


