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ISWEC: A gyroscopic mechanism for wave power exploitation

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ABSTRACT

In the past four decades, hundreds of Wave Energy Converters (WECs) have been proposed and studied, but so far a final architecture to harvest wave power has not been identified. Many engineering problems are still to be solved, like survivability, durability and effective power capture in a variable wave climate. ISWEC (Inertial Sea Wave Energy Converter) is a system using the gyroscopic reactions provided from a spinning flywheel to extract power. The flywheel works inside a sealed floating body in order to be protected from the outer environment and grant a reliable and durable operation. The article summarizes the design procedure of a 1:45 scaled ISWEC device with rated power 2.2 W and the tank tests performed with a simplified plain float to verify the actual prototype power capabilities. The article then focuses on the implementation of a non-linear coupled model (mechanics + hydrodynamics) to improve the float shape in order to maximize the power absorption. The final result is a float shape capable to absorb a power almost three times bigger (5.96 W) than the initial float shape.

1. Introduction

Oceans are a huge reservoir of different types of renewable energy. Tidal energy is perhaps the most known source of energy from the ocean because of its effective use since the sixties. However the oceans provide different kinds of renewable energy, such as OTEC power (Ocean Thermal Energy Conversion), marine current power, salinity gradient power and finally wave power [1–3]. Wave power is the science studying the extraction of energy from sea waves. The field is explored since the seventies when the Duck, one of the first Wave Energy Converter (WEC), was proposed from Salter at the University of Edinburgh in 1974 [4,5]. The Duck is a slack-moored cam-shaped floating body, constrained to rock around a spine moored to the seabed and extracting energy thanks to the relative motion between Duck and spine. Since then hundreds of devices have been proposed and studied and some of them have reached a pre-commercial stage [6–10]. However, unlikely from what happened for other types of renewables, so far a final architecture to extract wave power has not been identified.

One of the problems to be solved in a WEC is the so called "reaction problem": in order to extract power from the sea surface with a force, a reaction to that force must be provided. In his analysis [11], French highlighted that the reaction force can be given in four different ways: reacting on a large structure bigger than the wavelength and therefore hydrodynamically stable, reacting to the seabed, reacting to a mass that is part of the WEC and reacting against a part of the sea. Except from the third choice, the others possibilities have to use mechanical parts in relative motion working immersed into sea water or spray. Those parts can be protected against corrosion, but they could remain a problem in a WEC durability. In this article the system ISWEC (Inertial Sea Wave Energy Converter) is proposed [12,14]. ISWEC uses a gyroscope to create an internal inertial reaction able to harvest wave power without exposing mechanical parts to the harsh oceanic environment. In fact ISWEC externally presents as a monolithic float. The float rocks in reaction to the incoming wave and the gyroscopic system is sealed inside. The gyroscope drives a PTO system (Power Take Off) converting mechanical power into electrical power. Furthermore, by switching off the gyroscopic system, ISWEC behaves as a bulky dead body and thus increasing its chances of survival in case of storm. In this article ISWEC is analyzed

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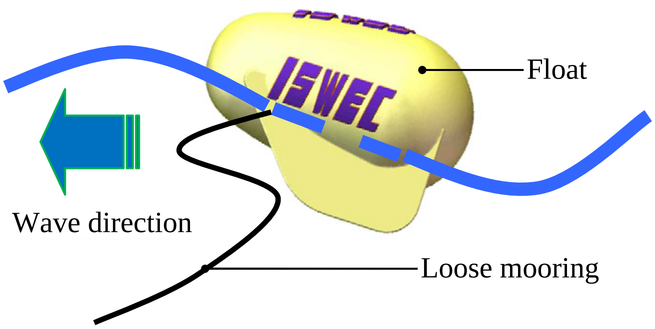

Fig. 1. System external appearance.

from the mechanic and hydrodynamic points of view in order to determine its power conversion capabilities and to maximize the power output for a given design wave.

2. Power conversion principle

As shown in Fig. 1, the ISWEC device is composed mainly of a floating body with a slack mooring to the seabed. The waves tilt the buoy with a rocking motion that is transmitted to the gyroscopic system inside the buoy shown in Fig. 2. The gyroscopic system is composed of a spinning flywheel carried on a platform allowing the flywheel to rotate along the y_1 axis. As the device works, the gyroscopic effects born from the combination of the flywheel spinning velocity $\dot{\varphi}$ and the wave induced pitching velocity $\dot{\delta}$ create a torque along the ε coordinate. Using this torque to drive an electrical generator, the extraction of energy from the system – and therefore from the waves – is possible. In Fig. 3 the functional layout of ISWEC is shown: a supervisor must be connected to the system to behave as a MPPT (Maximum Power Point Tracker) maximizing the power production.

The reference frames used in the analysis of the system are shown in Fig. 4. A mobile reference frame $x_1y_1z_1$ is obtained respect to the inertial reference frame xyz with the two sub-sequential rotations δ and ε.

With reference to Figs. 2 and 4, the mechanical behavior of the system can be easily explained by starting from the initial position in which $\delta = 0$ and $\varepsilon = 0$, no waves are present and the flywheel rotates around the axis z_1 with constant angular velocity $\dot{\varphi}$. As an effect of the first incoming wave, the system is tilted along the pitch direction δ gaining a certain velocity $\dot{\delta}$ around the x axis. The flywheel is therefore subjected to the two angular velocities $\dot{\varphi}$ and $\dot{\delta}$ and the gyroscopic effects produce a torque on the direction y_1 perpendicular to both the velocities. If the gyroscope is free to rotate along the y_1 direction with rotation ε, its behavior is governed from the inertia and, being the system conservative, there is no mechanical power available for generation.

The extraction of energy from the system can be performed by damping the motion along the ε coordinate. In this situation the gyroscope acts as a *motor* on the rotary damper and the energy extracted from the system by the damper is considered here available for power generation. The damper can be for instance an electric generator directly coupled on the ε shaft. During the

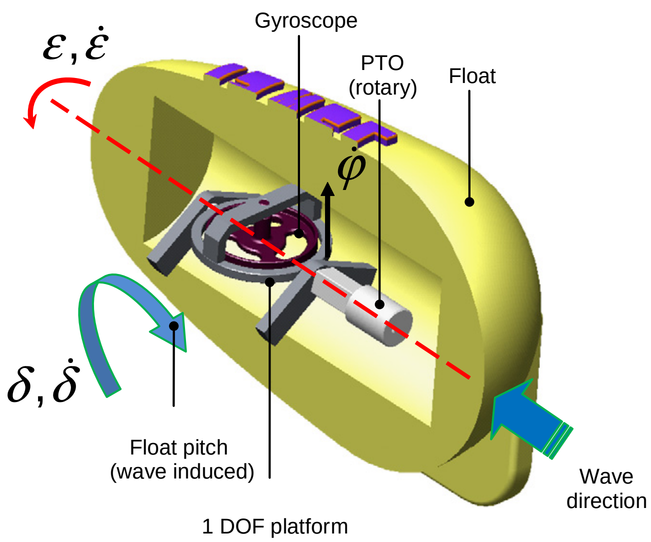

Fig. 2. Gyroscopic mechanism.