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# Proposition and experiment of a sliding angle self-tuning wave energy converter

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A B S T R A C T

The hydraulic power-take-off mechanism (HPTO) is one of the most popular methods in wave energy converters (WECs). However, the conventional HPTO with a fixed direction motion has some drawbacks which limit its power capture capability. This paper proposes a *sliding angle self-tuning wave energy converter (SASTWEC)* to find the optimal sliding angle automatically, with the purpose of increasing the power capture capability and energy efficiency. Furthermore, a small scale WEC test rig was fabricated and a wave making source has been employed to verify the sliding angle performance and efficiency of the proposed system throughout experiments.

## 1. Introduction

The increased energy demand and environmental pollution push people and organizations to find sustainable energy sources and reduce exhaust emissions. An urgent need exists to harvest energy from renewable sources such as wave energy. Many studies have been conducted in the field of wave energy and various wave energy conversion systems or wave energy converters (WECs) are currently being developed, such as overtopping devices (e.g., the Wave Dragon), attenuators (Pelamis), and point absorbers (WaveBob, OPT PowerBuoy), as noted in (Nielsen et al., 2006). the main principle of WECs is to convert wave energy into high-pressure hydraulic on, which is used to drive a hydraulic motor coaxially connected to an electric generator. The mechanism by which energy is transferred from waves to the WEC, and subsequently or directly into a useful form is called a hydraulic power take-off mechanism, generally known as the power take-off (PTO). The Pelamis WEC, using an active control of PTO to maximize the absorbed power throughout a range of sea-states was presented in (Henderson, 2006). A seabed-mounted bottom-hinged flap-type wave energy converter was proposed and designed in (Folley and Whittaker, 20092009a) increases the capture factor width and wave frequency. While this design appears to be effective, when it is mounted on the sea bottom, several problems appear such as difficulty in maintenance, corrosion by sea water, and oil leakage pollution. In (Anbarsooz et al., 2014), a flap-type wave maker and the submerged cylinder WEC is proposed and modeled based on the complete solution of the Navier-Stokes equations to predict the behavior of the submerged cylinder WEC subjected to highly nonlinear incident waves. The numerical results and the analytics are observed in a good agreement, and the maximum efficiency point moves toward higher wave frequencies with increasing the wave height. One of the simplest and most popular wave energy converters is the point absorber type, mentioned in (Oskamp and Özkan-Haller, 2012) and (Zurkinden et al., 2014). However, wave energy is absorbed in only one direction, either vertical or horizontal. Therefore, this limits the total efficiency of the converter. Evans in (Evans.Evans, 1976) proposed a wave-power absorption device which can absorb both the horizontal and vertical force components. It is shown that theoretically 100% efficiency is possible in some cases. In (Heikkinen et al., 2013), Heikkinen et al. proposed a new structure of cylindrical wave energy converters oscillating in two modes. This approach can absorb energy in two directions to improve the total efficiency. However, similar to the seabed-mounted bottom-hinged wave energy converter in (Folley and Whittaker, 20092009a), it still has some drawbacks, such as difficulty in maintenance, corrosion, and oil leakage. To determine the cylindrical wave coefficients of any wave field from a known circular-cylindrical section, four types of WECs were used: a heaving point absorber, a surging point absorber, a terminator, and an attenuator in

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(McNatt et al., 2013). According to Folley in (Folley and Whittaker, 2009b), there exists a significant direction or sector in which wave energy is the most energetic. Therefore, a wave energy converter with a predefined direction is more effective than the conventional WEC, such as a vertical linear motion WEC.

Moreover, to overcome the disadvantages of the above wave energy converters and enhance the total efficiency, a sliding angle self-tuning wave energy converter (SAST-WEC) is proposed in this paper. The optimal sliding angle varies with the wave condition. In the proposed system, SAST-WEC can calculate the optimal sliding angle and self-tune the sliding angle to enhance the output power and efficiency. A small-scale SAST-WEC test rig is fabricated to verify the effect of the proposed method. An experiment was carried out in three wave conditions for monitoring the performance of SAST-WEC, although the wave condition changes in reality. This work is the next step of the research has been presented in (Do et al., 2015).

The remainder of this paper is organized as follows. Section 2 describes the wave making tank and the test rig of the SAST-WEC, Section 3 presents the mathematical model of SAST-WEC, and Section 4 shows the experiments and analysis of the experimental results. Finally, conclusions and future works are presented in Section 5.

## 2. Description of wave making tank and adjustable sliding angle wave energy converter

### 2.1. Wave making tank

To carry out the experiment, a wave making tank with an adjustable amplitude and frequency is employed, as shown in Fig. 1. The wave making tank includes a wave making wall moved by propulsion hydraulic cylinders, placed in a water tank. A slope damping net attached at the opposite side of the wave making wall eliminates the reflex wave to avoid unexpected noise. The motion of the wave making wall and cylinders are set up and controlled by a computer and sensors to achieve the exact wave amplitude and frequency. The working principle of the wave making tank in this research is similar to the *wave maker* described in (Anbarsooz et al., 2013).

### 2.2. Self-tuning sliding angle wave energy converter

The sea wave has the vertical oscillation and the horizontal propagation. These two motions bring the sea water and create the hydrodynamic forces. The vertical oscillation creates the heave force and the horizontal propagation creates the surge force. The heave force and the surge force will be shown in Eq. (4) and Eq. (14) of the subsection 3.2. The conventional PTO with vertical oscillation can absorb the heave force only, whereas the proposed PTO can absorb both the heave force and the surge force, as shown in Fig. 2. The force $F_w$ is the resultant of $F_{heav}$ and $F_{surg}$. Therefore, the force $F_w$ is obviously greater than the heave force $F_{heav}$ only.

In addition, the buoy's stroke of the proposed PTO is longer than the buoy's stroke of the conventional PTO. With the same wave amplitude and frequency, when moving in the slope angle from the wave trough to the wave crest, due to the buoy's stroke is longer than moving a vertical direction. As illustrated in Fig. 3, the buoy's stroke Δ in the slope angle in longer than the buoy's stroke $\Psi$ of the conventional PTO.

The stronger force gives the higher pressure, and the longer stroke gives the higher flow rate at the cylinder. Hydraulic power generated at the cylinder is calculated by the product of fluid pressure and fluid flow rate. Hence, the hydraulic power of the proposed PTO is higher. The effects of non-vertical linear motions the investigation of optimal sliding angle was presented in (Do et al., 2015).

The test rig of SAST-WEC includes two components, as shown in Fig. 4: the HPTO and the hydraulic transmission. In the HPTO, a

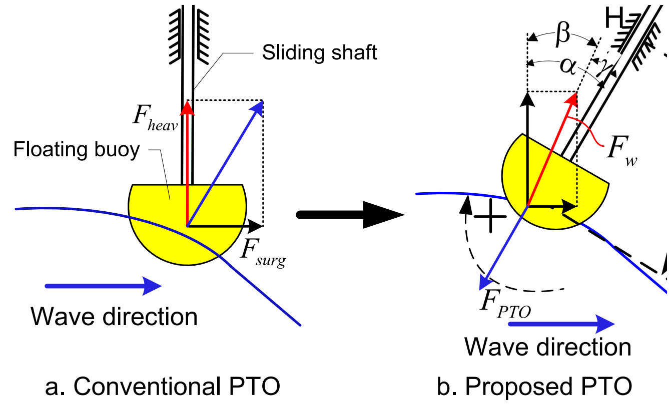


**Fig. 2.** Force comparison between the conventional PTO and the proposed PTO.

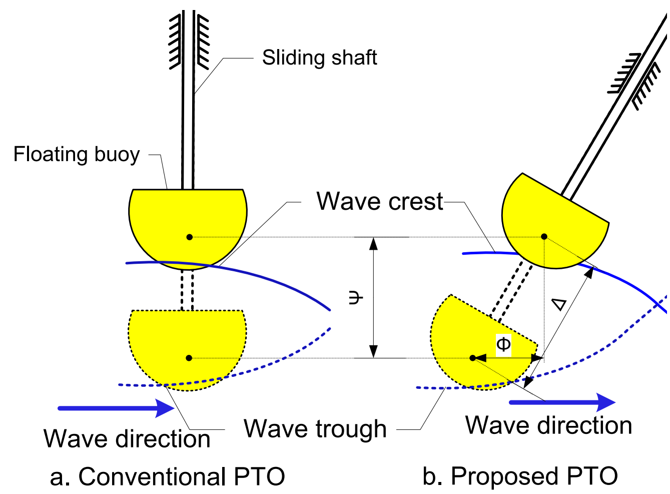


**Fig. 3.** Buoy's stroke comparison between the conventional PTO and the proposed PTO.

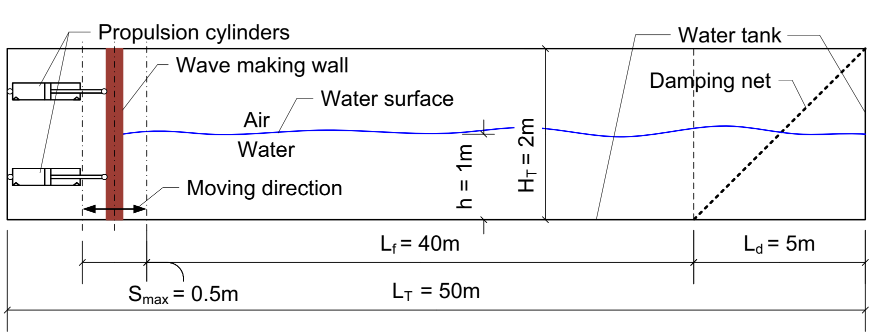


**Fig. 1.** Schematic diagram of wave making tank.