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Design, simulation, and testing of a novel hydraulic power take-off system for the Pelamis wave energy converter

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Abstract

The economic viability of a wave energy converter depends largely on its power take-off system. Active control of the power take-off is necessary to maximise power capture across a range of sea-states and can also improve survivability. The high force, low speed regime of wave energy conversion makes it a suitable application for high-pressure hydraulics.

This paper describes the hydraulic power take-off system employed in the Pelamis wave energy converter. The process of the system's development is presented, including simulation and laboratory tests at 1/7th and fullscale. Results of efficiency measurements are also presented.

Keywords: Hydraulic power take-off; Wave energy converter; Pelamis

1. Introduction

The extraction, by any wave energy converter (WEC), of useful energy from ocean waves requires that the waves apply force to some form of responsive mechanism able to resist the working force that the waves apply, and some form of reference against which that mechanism can react. The mechanism by which energy is transferred between the waves and the WEC, and subsequently or directly into useful form, is generally known as the power take-off (PTO). Control of the response of a WEC can be achieved through active control of the PTO.

Control of the PTO is central to the economic viability of wave energy; a major sustainable resource that has, as yet, remained untapped. It is important to show the potential of wave energy at an early stage by firstly, ensuring that machines can survive under arduous conditions, and

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secondly, by absorbing and converting a respectable amount of energy. These goals can, in large part, be achieved through control of the PTO.

To extract a maximum amount of power from the incident waves, the PTO should be capable of applying a restraining force varying appropriately with time as the WEC responds. This requires real-time measurement of response, and control of the PTO over the wave cycle. Moreover, to operate effectively across different sea-states, the control and PTO must be able to adapt such that power absorption is maximised in small seas and the risk of damage is minimised in large seas.

For maximum power absorption, a WEC should respond in resonance with the waves such that the exciting force and the response velocity are in phase [1]. While, with appropriate design, a WEC can possess inherent dynamics such that its natural response frequency is in the correct range to match the central excitation frequency of most sea-states, active control is necessary to maximise power capture across a range of sea-states and in irregular (realistic) seas where a range of component frequencies are present. Control can also play a vital role in improving survival characteristics although, whilst crucially important, this aspect is not generally expanded on in the existing literature.

2. Hydraulic PTO

Wave energy conversion can be considered a very suitable application for hydraulics. Waves apply large forces at slow speeds and hydraulic systems are suited to absorbing energy under this regime. Moreover, it is a simple matter to achieve short-term energy storage, necessary to achieve the smooth electricity production required for a marketable machine, with the use of cheap and available high-pressure gas accumulators.

Hydraulic systems have many favourable characteristics and many WEC proposals have incorporated hydraulic PTO in their design [2–4]. However, the majority of literature on PTO has focused on air turbines operating within oscillating water columns, such as employed in existing shoreline plants [5,6]. This is perhaps the result of researchers gravitation to the technology most deployed and recognised, rather than the ultimate suitability of air turbines as a means of wave power conversion.

Salter et al. [7] and Artemis Intelligent Power Ltd [8] have developed a novel digital hydraulic pump/motor, originally intended for a wave energy application, capable of offering a continuously variable transmission of hydraulic power at much higher efficiencies than conventional hydrostatic transmissions. While the technology is nearing commercial application, it is still at the prototype stage and unsuitable for immediate deployment in a WEC.

Eidsmoen [9] described a hydraulic control system using a latching strategy, originally suggested by Budal [10] and independently by French [11] to avoid the need for variable transmission or reactive power.

3. Pelamis PTO

The Pelamis [12,13] is an offshore, floating, slack-moored wave energy converter consisting of a set of semi-submerged cylinders linked by hinged joints. Ocean waves perform work on the Pelamis by moving adjacent cylindrical sections relative to each other across two degree of freedom joints. The two axes that comprise each joint are inclined to the horizontal to allow a net inclined response to be induced by the PTO, which resists and reacts against the relative angular motion of the joints. The inclined response offers an effective hydrostatic stiffness reduced from