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Strategies for active tuning of Wave Energy Converter hydraulic power take-off mechanisms

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ABSTRACT

This paper presents a study of practically implementable active tuning methods for a Wave Energy Converter (WEC) power take-off (PTO). It is distinguished from other simulation studies by the level of detail and realism in the inputs and the PTO model. Wave data recorded at the European Marine Energy Centre is used to derive input data for a detailed component level model of a hydraulic PTO. A methodology is presented for obtaining the optimum PTO damping co-efficient for a given sea state, and an open loop active tuning method is used to adjust the PTO parameters to achieve this optimum damping in service. The investigation shows that tuning of a hydraulic PTO to an estimated wave frequency is a difficult task due to sea state estimation errors and the complex dynamics of a realistic PTO. Preview knowledge of the future waves was shown to provide no meaningful improvement in energy capture for the device under investigation. Significantly, power gains observed in similar work using simplified linear PTO models or simplified sea states are not seen here, demonstrating that over-simplification of the PTO during the simulation phase of WEC development could lead to incorrect design decisions and subsequent additional delay and cost.

1. Introduction

The optimization of Wave Energy Converter (WEC) hydraulic power take-offs (PTO) in sea states of varying wave amplitude, direction, and frequency is a significant problem. Sub-optimal configuration can result in very inefficient energy conversion [1], so understanding the design trade-offs is key to the success of the technology. This work focuses on a generic point absorber type WEC. Previous work by the authors has considered the optimisation of this device for regular waves [2] and synthesised irregular waves [3] to gain an understanding of the fundamental issues. This paper considers real wave data from the European Marine Energy Centre (EMEC) based in Orkney, Scotland. It presents techniques to analyse the wave energy resource at a particular site by using statistics that are calculated from the raw data. A method to calculate the wave excitation force from the raw wave displacement is presented and this is then used as the input to a simulation model. This provides a prediction of how the WEC will behave and the power which can be generated in real wave conditions.

PTO tuning is investigated using the real data and compared to the results found previously [2,3]. Real time tuning methods are analysed to determine the best method to maximise power generation by updating the PTO damping. Active and passive methods are examined which tune the PTO to a wave frequency calculated from different horizons of wave data.

2. Background

Previous work has focused on developing control methods for point absorbers to maximize the energy absorbed. Falcao [4] used a simplified hydraulic PTO unit connected to a point absorber to develop an algorithm to optimize the converter. The algorithm was shown to be weakly dependent on wave period and independent of wave height when simulated in real sea conditions and to produce power levels similar to a fully linear PTO unit. This work was continued in Falcao [5] to include a strategy for phase control by latching to increase the absorbed power further. In Babarit et al. [6] three different latching control strategies are compared to show their effectiveness in different sea states with all three strategies giving a considerably increased efficiency in irregular waves. In Yavuz et al. [7] work focuses on assessing the performance of a tuneable point absorber by trying to fulfil the condition of

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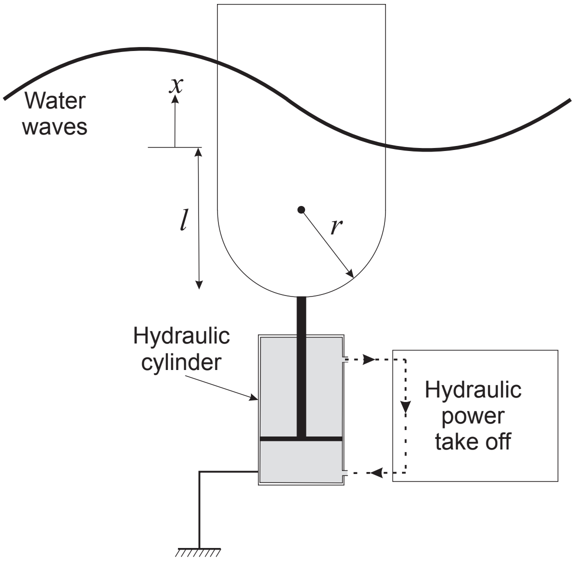

Fig. 1. Schematic diagram of the WEC.

resonance by varying the PTO characteristics. Results showed a maximum power capture of 50% of the rated power in regular waves. This work was continued in Yavuz et al. [8] with irregular waves to show that power capture can be maximized by continuously tuning the natural frequency of the device to the incoming wave frequency. More recently, in Folley and Whittaker [9], a new control method called active bipolar damping or declutching is proposed which tries to shift the buoy's velocity so it is in phase with the wave force. When compared theoretically to other methods, it shows a higher power capture than optimum linear damping without the requirement of reactive energy storage. This control method has been investigated in Babarit et al. [10] using a hydraulic PTO and compared to a control method which tries to mimic the continuous behaviour of a viscous damper. Results show greater power levels from the declutching control method with the added advantage of requiring a less complex system. Most of these investigations use linearized models and do not consider real hydraulic circuits and components in their investigations.

3. Hydrodynamics of the WEC

A point absorber type device is used for this study and is the same as that used in Refs. [2] and [3]. A diagram of the heaving buoy is shown in Fig. 1, and it has a mass of 39 tonnes, a radius of 2 m and a draft of 4 m. A point mass acting at the centre of the buoy is assumed. The governing equation of motion for the buoy in heave is

$$m\ddot{x} = f_h(t) + \Phi(t) \tag{1}$$

where m is the mass of the buoy, $\ddot{x}$ is the buoy's acceleration, $f_h(t)$ is the total wave force and $\Phi(t)$ is the mechanical force created by the PTO and moorings. Assuming linear wave theory, the wave force can be approximated as

$$f_h(t) = f_e(t) + f_r(t) + f_{hs}(t) \tag{2}$$

where $f_e(t)$ is the excitation force produced by an incident wave on an otherwise fixed body, $f_r(t)$ is the radiation force and $f_{hs}(t)$ is the hydrostatic buoyancy force. For a regular wave of frquency ω the excitation force is given by

$$f_e(t) = \mathrm{Re}\left(F_e e^{j\omega t}\right) \tag{3}$$

where F_e is the complex excitation force amplitude. Following the approach described in Ref. [3] and using the assumptions of [11] and Hulme [12], for a hemispherical body that is small in comparison to the incident wavelength, F_e may be approximated by

$$F_e \approx \frac{H\rho}{\omega}\sqrt{\frac{\pi}{3}g^3 r^3 \varepsilon e^{-2kl}} \tag{4}$$

where H is the free surface elevation, ρ is the water density, g is the acceleration due to gravity, r and l are the radius and half-height of the buoy, ε is Havelock's dimensionless damping coefficient computed by Hulme [12] and k is the wave number $\left(k = \frac{\omega^2}{g}\right)$given by the deep water dispersion equation.

The radiation force $f_r(t)$ can be decomposed into components in phase with the buoy's acceleration and velocity [11] [13] so that

$$f_r(t) = -A(\omega)\ddot{x} - B(\omega)\dot{x} \tag{5}$$

where $A(\omega)$ is the added mass coefficient and $B(\omega)$ is the radiation

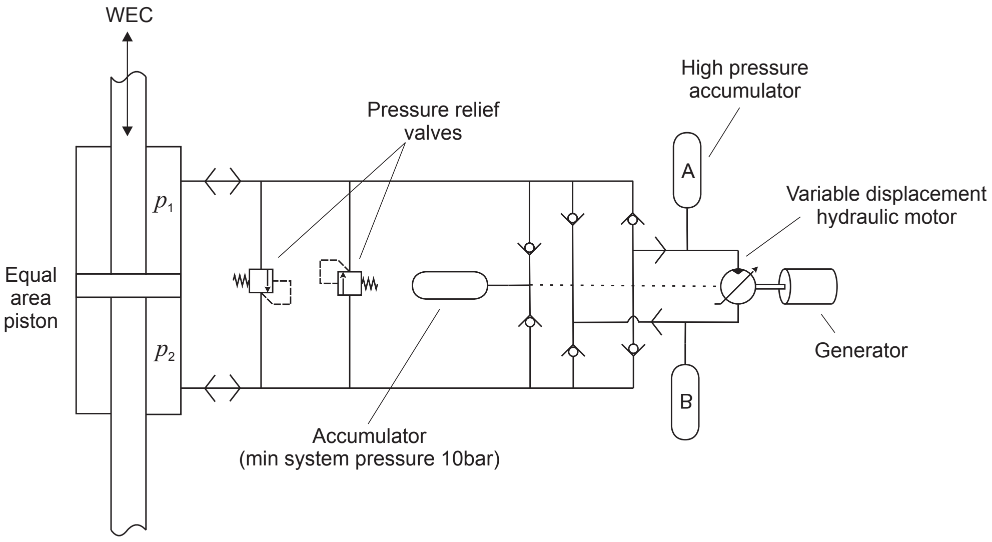

Fig. 2. Hydraulic PTO circuit diagram.