Particle Damping of Floating Oscillating Surge Wave Energy Converters

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Summary. Expanding the deployment of oscillating surge wave energy converters to deep waters requires mounting them on submerged platforms close to the water surface. One issue is that large amplitude waves, required for better energy generation, induce large platform motions, particularly in the surge direction. These motions could adversely impact the flap's hydrodynamic performance. We investigate, through an explanatory experimental study, the use of particle damping to control the surge motion of the platform under different wave excitations. The results point to complex nonlinear effects of particle damping and couplings among the different degrees of freedom, which yield differing responses under different excitation parameters.

Introduction

Oscillating surge wave energy converters (OSWEC) are one of the most efficient means for capturing and converting wave energy into a more useful form of energy, e.g., electricity. Because the surge component of ocean wave energy is most prevalent near the water surface, OSWEC wave capture components must be positioned near that surface to realize maximum efficiency. This placement, however, constrains their deployment to shallow water sites. In contrast, mounting the OSWEC onto a submerged platform close to the water surface, as schematically shown in Figure 1, expands the deployment range to deep water locations where there is need to power observation stations, autonomous underwater robots, offshore islands, ships and submarines, among many other blue economy systems and devices.

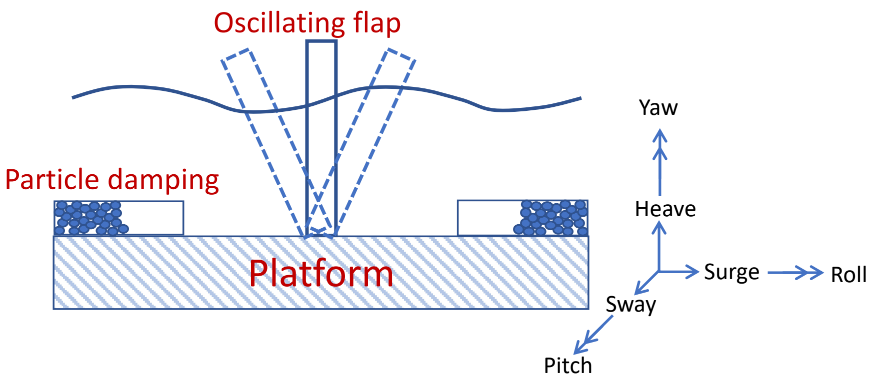

Figure 1: Schematic of oscillating surge wave energy converter mounted on a platform

Although resonance is always desired to achieve large amplitude motions for efficient energy generation, optimal wave energy conversion from a pitching flap-type device may not take place at resonance. Designing the flap to be resonant requires a relatively small added mass, which results in a small wave force. In contrast, designing the flap to attract a large wave force requires a large added mass, which results in a non-resonant device [1]. Clearly, larger wave forces induced by larger wave amplitudes, could be more effective in increasing the power capture than operating at resonance conditions for OSWEC. In the case of a floating oscillating surge wave energy converters (FOSWEC), large wave forces, intended to increase the flap's rotational displacement, could also induce significant platform motions, which may adversely impact the response of the flap oscillator and reduce the level of generated power. Consequently, it is important to control the platform's motion.

One control approach is to introduce passive damping by attaching a set of cylinders or boxes containing particle dampers to the platform, as schematically shown in Figure 1. This robust approach is particularly effective and practical under random excitation [2] and when considering the harsh operational conditions of FOSWEC in high sea states, over a broad range of frequencies defined by irregular wave spectra. Here, we perform experiments in a wave tank to investigate the effectiveness of particle damping in reducing the motion of the platform while increasing the flap's response as desired to enhance the energy generation. The results are used to characterize complex nonlinear effects and nonlinear couplings among the different degrees of freedom.

Experimental Setup

The experiments were performed in the wave tank of the Davidson Laboratory. The tank is 100 m long, 5.4 m wide and 2.1 m deep. The waves are generated by a dry-back, six-paddle, electrically driven, flap type wave-maker capable of generating regular and spectral waves with periods between 2 and 5 seconds and heights up to 0.65 m. Each paddle has an individual servo-drive with purpose-built digital controller. The tests were performed on a scaled floating oscillating flap mounted on a platform positioned 0.79 m below the water surface. The 1.2 m wide, 0.95 m high and 0.127 m thick oscillating flap (Figure 1) was composed of an aluminum frame filled with foam. Its total mass and mass moment of inertia were respectively 21.5 kg and 5.5 kg.m^2. The flap was hinged to the (1.5 m x 1.17 m) platform, which was built using T-slotted framing rails attached by corner brackets. The platform was held by four strings at the corners that extended underwater and connected to extension springs with loop ends that were firmly held in position by heavy weights on the bottom of the tank. The particle damping system consisted of four 5-cm PVC tubes that were 0.53 m long. These tubes were partially filled with low carbon steel spheres having a diameter of 1.9 cm to yield 18% mass ratio. A displacement sensor was placed on top of the flap frame to measure the relative linear displacement between the flap and the platform. A 3-phase accelerometer and a 3-phase gyroscope IMU were mounted on the platform to measure all rotational and translational accelerations. One wave wire, placed at 5 m upstream of the flap, was used to measure the incident wave height. All data were acquired at the rate of 100 Hz. Tests were conducted for different wave heights and periods.

Particle damping

Figure 2 shows that particle damping yielded a 73% reduction in the platform's surge displacement when the period of the excitation 4.5 cm-wave was set to 4 seconds. This reduction percentage was not, however, consistent. Damping particles did not cause any reduction in the surge displacement when the wave period was set to 4.5 seconds. Furthermore, the platform surge displacement increased by 150% at the lower wave period of 2.85 seconds. Analysis of the pitch and yaw motions showed similar responses, pointing to the complex nonlinear dynamics of particle damping and the coupling between the different degrees of freedom.The impact of reducing the surge motion on the rotational displacement of the flap is deduced from figure 3, which shows that particle damping of the platform's surge motion increased the angular rotation of the flap by about 40%.

In the full paper, we will evaluate and discuss all mechanisms contributing to particle damping of the surge response of the platform. These include collisions between the particles and the container, inelastic particle-to-particle collisions, and frictional losses. These depend on different factors including mass ratio defined as the ratio of the mass of the damping particles to the total mass of the platform and flap; void ratio defined as the ratio of volume not occupied by particles to volume occupied by particles; porosity defined as the ratio of volume not occupied by particles to bulk volume of the particles; clearance defined as the distance particles can travel before impacting the wall, rolling friction; and coefficients of restitution among the particles and with the enclosure. We will also elaborate on the coupling between the different degrees of freedom and energy transfer between the flap and platform motions.

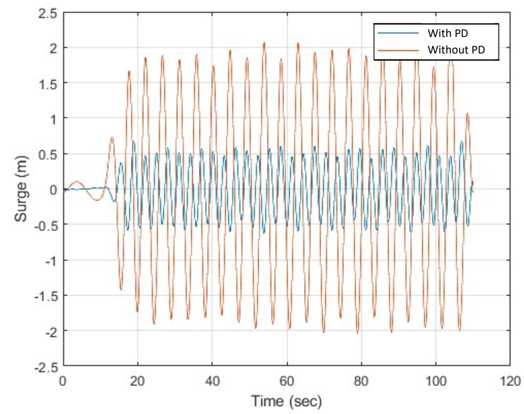

Figure 2: Reduction in surge amplitude induced by particle damping for a wave period of 4 seconds and amplitude of 4.5 cm.

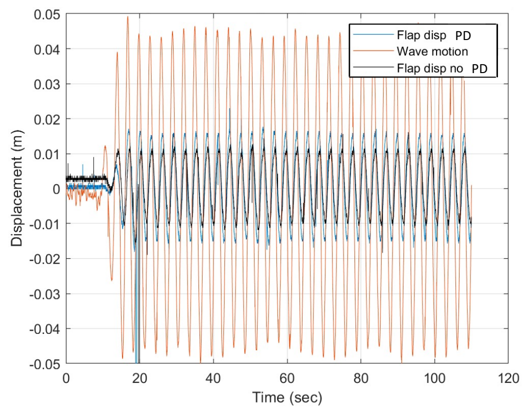

Figure 3: Increase in angular displacement of the flap under particle damping of the platform's surge motion. Wave period 4 seconds.

Conclusions

We tested in a wave tank the use of particle damping to control the surge motion of a near-surface platform supporting an oscillating surge wave energy converter. The data showed effective damping and enhanced flap oscillations under specific excitation conditions, but less effective or even increased motions under other conditions. These observations point to the complex nonlinear features of particle damping.

References

[1] Henry, A., Folley, M., Whittaker, T. (2018) A conceptual model of the hydrodynamics of an oscillating wave surge converter. *Renewable Energy* **118**: 965-972.

[2] Masri, S. F., Ibrahim, A. M. (1973) Response of the impact damper to stationary random excitation. *The Journal of the Acoustical Society of America* **53(1)**: 200-211.