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Synchronous and subharmonic resonance of an array of curved wave energy converters in a channel

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We analyse the nonlinear behaviour of an array of curved surge-type wave energy converters (WECs) in a semi-infinite channel of constant depth. Surge-type WECs have attracted interests by researchers and industry, mainly because of their capability to absorb energy with potentially large efficiency when excited by incident waves.

The vast majority of the theoretical models developed so far on the dynamics of this kind of devices neglect nonlinear contributions. This can be unjustified when nonlinear resonances of trapped modes occur. Indeed, Michele et al. (2018b) recently showed that subharmonic resonance and mode competition of trapped modes can increase energy production of a system of surging WECs. Moreover, recent investigations on curved flap-type gates suggest that using curved structures could further improve wave energy extraction efficiency. Motivated by these new aspects, in this work we investigate the effect of gate surface curvature on the nonlinear dynamics of an array of surge-type WECs.

We show that a small horizontal deviation of the gate surface produces significant changes in the dynamical behaviour of the system. Using perturbation-harmonic expansion up to the third order, we decompose the nonlinear governing equations in a sequence of linearised boundary-value problems of order n and harmonic m. The gate shape effects resonate the first harmonic at the second order, so that three timing with two slow time scales is necessary.

First, we consider the synchronous excitation of a single trapped mode. Products between the gate shape function and the second-order terms force the first harmonic at the third order. We point out that this particular excitation is not possible for flat gates, because in that case the corresponding evolution equation would be damped and unforced. We also show the occurrence of new terms in the Ginzburg-Landau evolution equation, which are not present in the case of flat gates. We show that nonlinear synchronous resonance of curved WECs yields constructive interactions that can be significant for design purposes.

Finally, we analyse the occurrence of subharmonic nonlinear resonance by monochromatic incident waves. Perturbation expansion of the unknowns leads to an evolution equation similar to that obtained for the synchronous case. Then we define an optimized PTO coefficient which maximises power extraction under subharmonic resonance. The capture factor reaches much larger values than the theoretical maximum of a WEC in a channel described by the linearised theory. Furthermore, we show that subharmonic resonance is associated with increased efficiency of wave power extraction, though the effects of curvature are not always beneficial as we initially thought.