ARRAYS OF WAVE-ENERGY DEVICES

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Any large-scale wave-power station will have a number of devices operating in relatively close proximity to each other. Consequently, the hydrodynamic interactions between neighbouring devices may modify significantly the performance of a given device relative to its performance when in isolation. This possibility was recognized early in the development of wave energy devices and Evans[1] and Falnes[2] independently derived a theory for power absorption by an array of devices.

The calculation of the absorbed power requires knowledge of the exciting forces and the radiation damping matrix for the array and, in general, these are difficult to calculate even for an array of modest size. However, by adopting the so-called 'point-absorber' approximation (this essentially says that the wavelength is much greater than the device dimensions) both Evans and Falnes were able to derive simple expressions for the maximum power that may be absorbed by an array of heaving, vertically axisymmetric devices. This theory has subsequently been extended to include any combination of translational modes (McIver[3] and G. Singh, private communication). An important feature of this theory is that no knowledge of the device geometry is required.

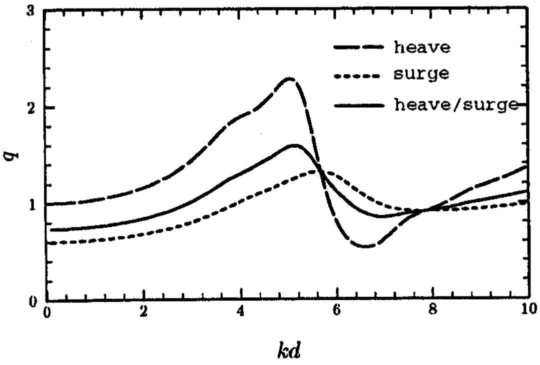

Figure 1: Optimum q factor v. kd for a line of 5 equally-spaced devices.

The results displayed in figure 1 are for a line of five devices, each with a vertical axis of symmetry, and spaced a distance d apart. The incident waves have wave number k and propagate in a direction normal to the line of devices. Curves are shown for devices that are able to move and absorb power in heave, in surge, or in both of these modes. Here q is the mean gain factor defined as

$$q = \frac{\text{power absorbed by the array}}{\text{power absorbed by 5 isolated devices}}.$$

The results in figure 1 are for the optimal q factor where the power has been maximised at each value of kd. If there were no hydrodynamic interactions, then q would be identically equal to one for all values of kd. Values of q in excess of one indicate that hydrodynamic interactions between devices increase the power absorption capabilities of the array while

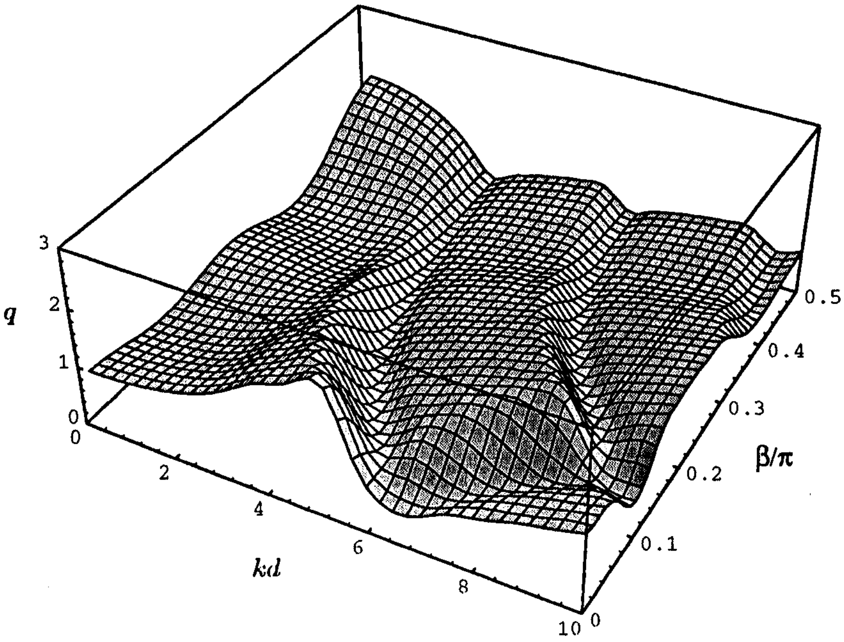

Figure 2: The optimal q factor v. non-dimensional wave number kd and angle of incidence β for a line of five devices absorbing in heave.

values less than one indicate a decrease. Such oscillations are particularly evident for the case of heaving devices while devices that surge perpendicular to the line interact weakly. It is interesting to note that the curve for combined heave and surge motions always lies between those for heave or surge alone.

As well as a sensitivity to the wavenumber kd, the optimal q factor changes quite rapidly with the angle of incidence β, here measured from the normal to the line of devices. This is illustrated for heaving devices in figure 2 where the optimal q factor is plotted as a function of both kd and β. Clearly, the array spacing could be chosen to give significantly increased power absorption capability for a small range of wave numbers and wave directions. However there a number of difficulties with this approach. Firstly, small changes in the predominant incident wave length or direction may give a very much reduced q factor that is less than one, indicating that the hydrodynamic interactions now result in destructive interference from the point of view of wave power absorption. McIver[3] has suggested that a possible remedy for this extreme sensitivity to wave conditions is to choose an unequal spacing of the devices and this idea is now under further investigation.

A second difficulty is that the large q factors are usually associated with unrealistically large device motion amplitudes. Some calculations of the maximum power absorption when the device motion amplitude is constrained to be less than some multiple of the incident wave amplitude (this turns out to be easy to implement) have been made by Thomas & Evans[4] and McIver[3]. With this type of constraint imposed, the large peaks in optimal power absorption, evident in figure 2 are much reduced.

A problem that arises with calculation of constrained or non-optimal motions is that the point absorber theory of Evans and Falnes no longer gives a consistent approximation. Hence, a more complete hydrodynamic interaction theory that accounts for scattering within the array, and without restriction on individual device size, must be used. Such a theory has now been used for array calculations of non-optimal power absorption. The individual devices are modelled by surface-piercing, truncated, vertical cylinders of radius and draught a and in water of depth $8a$. The power take-off mechanism and the moorings are modelled by linear springs and dampers. As before, the results given here are for a line of equally-spaced devices a distance d apart.

The results in figure 3 compare the optimal q factor for heave with the non-optimal q factor for an identical array of tuned devices. To achieve the optimal performance the device characteristics must be varied with frequency. In the non-optimal case the device characteristics are fixed and correspond to optimal performance at $ka = 0.4$ for a device placed in isolation. A device tuned in this way will have an actual power absorption capability that falls off as the wave frequency moves away from the tuned value. The array spacing is chosen to be $d = 12.4a$ so that the tuned devices perform best at the peak in the optimal q factor which occurs at about $kd = 5$. With this coincidence of device and array tuning, the optimal q factor does give a useful guide to the array performance of the tuned devices. When the device and array tunings do not coincide (not illustrated here) then the non-optimal q factor can be quite different from that predicted by the optimal results.

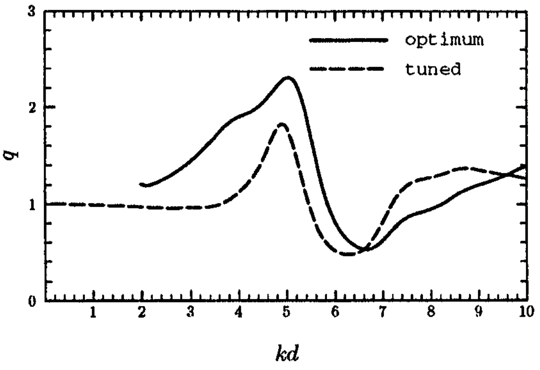

Figure 3: The q factor v. kd for a line of 5 equally-spaced devices absorbing in heave.

An absolute measure of the array performance is the mean capture width per device which compares the absorbed power with that available per unit crest length in the incident wave. This is given in figure 4 for the configuration just described. It is apparent that hydrodynamic interactions can be exploited to improve the peak performance, when compared with that of an isolated single device, but the closely-associated performance trough leads to a narrowing of the band width. It is desirable to avoid this narrowing, particularly as the peak performance is unlikely to be obtainable because of non-linearities and other effects

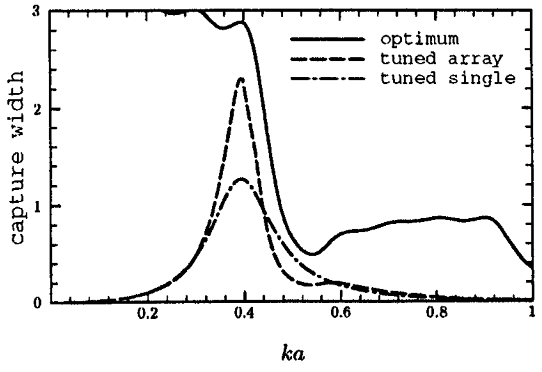

Figure 4: The capture width v. ka for a line of 5 equally-spaced devices absorbing in heave.

not accounted for in the present work. Methods for assessing and improving array performance are currently under investigation. As already mentioned, one possibility for improving the performance is a judicious choice of array configuration[3].

Future work

Work on a number of extensions of the above work is currently under way and these are outlined below.

1. A systematic numerical approach to the reduction of destructive hydrodynamic interactions by 'optimal' choice of the device spacing is being developed.
2. Rather than constrain device motions in the way mentioned above, it is more realistic to constrain the devices to a maximum motion amplitude that is independent of the incident wave amplitude. This type of constraint is now being considered.
3. To fully assess the capability of a wave power station irregular seas and directional spread of the incident waves are being considered.

Acknowledgment

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DISCUSSION

Palm, E.: If the existence of trapped modes has been established in a problem, is it still possible that the modes are only generated by extremely special initial conditions?

McIver, P.: I don't think very specialised initial conditions are necessary. Prof. Evans has reported that he is able to generate them fairly easily.

Evans, D. V.: Presumably you used a wide-spacing approximation to calculate the added mass and damping. How good is the approximation for the spacings of interest?

McIver, P.: Detailed comparisons have been made with accurate calculations made by Spiros Mavrakos (National Technical University of Athens, Greece) using a multiple scattering method. For all of the relevant hydrodynamic coefficients and for the range of spacings of interest, excellent agreement was obtained.

Falnes, J.: You state that with calculation of constrained motion the point absorber theory no longer gives a consistent approximation. The approximation refers to the neglect of multiple scattering, since the excitation forces are assumed to be the same as for isolated single bodies. Why is the validity of the approximation dependent on the oscillation amplitude?

McIver, P.: The point absorber theory assumes a typical device size is much smaller than the wave-length and neglects all scattering within the array. Thus, the exciting forces are assumed to be what they would be if the devices were in isolation and only the phase of the incident wave leads to differences from device to device. Interactions occur through the radiated waves and, in particular, through the off-diagonal terms in the damping matrix, but these are calculated without any multiple scattering taken into account.

Consider the simple case of two devices. The power absorbed will depend on the waves incident on each device. Leaving aside the incident wave, the waves incident on device 2 will result from scattering and radiation by device 1. The amplitude of the radiated waves will depend on the amplitude of oscillation of device 1. For large motions of device 1, such as occur when optimal power absorption takes place, the amplitude of the radiated waves is much lager than that of the scattered waves and the point-absorber assumptions outlined above are consistent. For non-optimal motions of device 1 it may be shown that the scattered and radiated waves are of similar magnitude and it is no longer consistent to include radiated waves but neglect scattered waves when calculating hydrodynamic interactions.