SIMULATION STUDIES OF A DOUBLE OSCILLATING WATER COLUMN

J. Falnes[1], G. Oltedal[2], K. Budal[1](†) and P.M. Lillebekken[1]

[1]Division of Physics, University of Trondheim,
N-7034 Trondheim-NTH, Norway

[2]MARINTEK, P.O.Box 4125, Valentinlyst, N-7001 Trondheim, Norway

One of the early proposals of wave power devices by Masuda[1] is a system of two nearby oscillating water columns (OWCs). Cf. fig. 1. The air chambers above the water columns are connected through an air turbine, and two check valves are used to rectify the air flow through the turbine. If the valves of such a system are operable through, for instance magnetic, hydraulic or pneumatic means, it should be possible to utilise the valves to obtain optimum oscillation (phase control) of the OWCs in order to maximise the power converted by the device.

In the process of designing such a wave-power converter it is useful to make simulation studies on a computer, in order to see the effects of changing the system in various ways. The simulator is a mathematical model of the total system, including waves, hydrodynamical coupling and pneumatic power take-off. We shall assume the hydrodynamic part of the problem to be linear. However, we allow for nonlinearities in the power take-off system. For this reason the simulator works in the time domain. Hence, in this analysis the hydrodynamical parameters are represented by impulse response functions which enter as kernels in integration operators.

In the present state of the simulator we model each OWC as an imaginary piston at the OWC mouth. Hydrodynamically this surface is considered as an oscillating rigid body with a mass which corresponds to the mass of the oscillating water inside the mouth of the OWC. Although this is only an approximation, it has the computational advantage that the effect of the OWC resonance is not included in the above-mentioned kernels. If the hydrodynamically more correct applied-pressure model[2] were used, then the resonance effect would have been included in the

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†) It is a great loss for our research group and for the wave-energy community that Kjell Budal passed away on 9th February 1989.

hydrodynamical parameters, and thus the impulse response function would have "lasted" much longer. As a result a much longer computation time would be required to determine kernels and convolution integrals.

For an axially symmetric double OWC system in the open sea published hydrodynamical parameters for sphere sections in heave[3,4] may be applied in an approximate mathematical model as mentioned. Alternatively, we may also apply hydrodynamical parameters[5] for a double OWC with rectangular mouths flush with a fixed vertical plane wall.

The above-mentioned kernels, which for a given system comprise a 2×2 matrix, are computed as the inverse Fourier cosine transform of the radiation resistance matrix.

In the simulator there are various choices for the pneumatic power-conversion device: an orifice (for simulating a laboratory model), a self-rectifying Wells turbine or a conventional axial turbine. The air valves may be open or closed all the time, they may be passive check valves, or they may be controllable to obtain maximum converted power.

For the geometry of the OWCs there are different choices. The structure may be placed in a fixed vertical plane wall. The water plane area of those OWCs may be rectangular or triangular. Alternatively, the geometry may be axisymmetric with one ringshaped OWC outside a circular OWC. The air in the chamber above the latter OWC has the higher average air pressure. The mouths of those OWCs are faced downwards. This geometry applies to a model of a wave power device in the open sea, for instance, in a floating structure. However, the simulator is not yet developed to a stage where the structure's own oscillation in the sea is taken into account.

The simulator has been run for either of the geometies. Some results for the first mentioned geometry are shown in fig. 2. For some parameter values there have been problems with numerical stability, in particular if the valves are controlled and the turbine constant (turbine admittance) is not relatively small. By extrapolation, it seems that the optimum turbine constant is within the region of numerical instability.

However, even for non-optimal turbine constants it has been shown that a phase controlled double OWC device produces more useful power than a simple tuned OWC with optimum turbine admittance (where the simple OWC has a cross section equal to the cross section sum of the double OWC). The improvement in power conversion is by a factor 1.6 to 1.8 for long wave periods (above 9 s), but more negligible for shorter wave periods (down to 6 s, when the resonant period of the OWC is approached). We believe that with optimum turbine admittance even more power may be converted by the double OWC at the larger wave periods, but it remains to demonstrate this by means of the simulator.

Moreover, it seems that the optimum turbine admittance is smaller for the double OWC than for the simple OWC. This has the advantage that the turbine may be of smaller physical dimensions, since the pressure drop is relatively larger and the air flow relatively smaller.

The preceding reveals that it is desirable to improve the simulator. Firstly, in order to avoid the above-mentioned numerical instability, there is a need to devise an alternative method to the Euler integration, which our present SIM program applies. Secondly, it is desirable to develop the hydrodynamic part of the simulator in order to replace the rigid-piston model of the OWC mouths by the more correct applied-pressure model.

Acknowledgement

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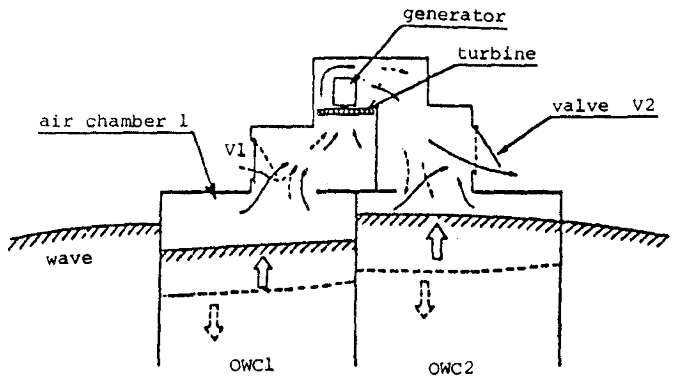

Fig. 1.

Wave power converter with two osc
lating water columns, two air ch
bers, two check valves and one c
mon air turbine run by the air f
from the high pressure chamber
the low pressure chamber. (The d
ted lines indicate the situation
falling water level.)

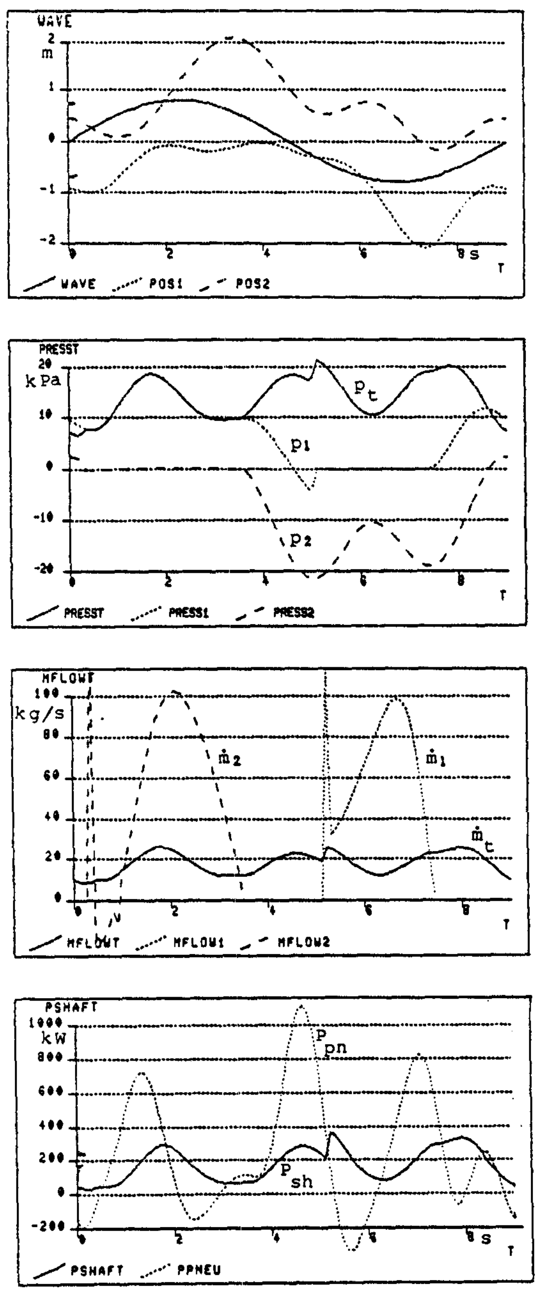

Fig. 2.

Simulation results versus time fo
double OWC in a vertical wall.
incident regular wave is of ampl
tude 0.8 m and period 9 s. Furth
curves represent the vertical pos
tion (water level) of the two OWC
the air chamber pressures p_2 and p
the pressure difference p_t acro
the turbine, the mass flow, m_1 a
m_2, through the two controlled va
ves and m_t through the turbine, t
pneumatic power P_{pn} and the pow
P_{sh} delivered through the turbi
shaft. A Wells turbine of admittan
0.001 $(m^3/s)/(N/m^2)$ and of effic
ency 0.8 is assumed in this simul
tion. Valve V1 is opened 1.1 s b
fore the wave trough. Valve V2
opened 1.6 s before the wave cres
The water plane in each chamber
25 m^2. The mouth of each OWC in t
vertical wall is of width 5 m a
height 3.5 m (between level -7.0
and level -3.5 m with respect
mean water level).