OFFSHORE WAVE ENERGY DEVICES

L.J.Duckers F.P.Lockett B.W.Loughridge
A.M.Peatfield M.J.West P.R.S.White

Energy Systems Group,
Coventry Polytechnic, Coventry,CV1 5FB,U.K.

INTRODUCTION

There is an enormous offshore wave energy resource to the west of the United Kingdom. Exploitation of this resource is technically feasible, economically sound and environmentally benign. The major thrust of wave energy development around the world is concerned with shore mounted devices [1], this paper deals with a floating offshore device.

The Energy Systems Group based at Coventry Polytechnic has been working on Wave Energy since 1975. This work has been funded both by the United Kingdom Department of Energy and by the commercial sponsors, Sea Energy Associates. Theoretical considerations, scale model tests in tanks and Loch Ness, and full scale design studies have led to a device called "S.E.A. Clam". We confidently expect that the latest variant of the Clam concept, namely the Circular Clam would cost around £1M per installed MW and so should produce electricity for less than 5 p/kWh; prices competitive with the U.K. grid generation and very competitive with diesel based generations on remote islands.

THE CLAM

The Clam device currently envisaged is a rigid floating torus some 60 m in diameter consisting essentially of 12 interconnected air cells with rectangular membranes on their outer faces separating the sea from the air system. The device would weigh about 1500 tonnes and be moored in water some 30m or more in depth, and this may be found fairly close to the shore in many places.

This circular configuration , can accept wave energy from any direction, and provides a very stable frame of reference and thus allows the use of the membrane air bags whose low spring rate characteristics most nearly match the incident wave energy. Cell spring rates of the order of $1kPa/m^2$ are found to give the optimum characteristics to match the incident wave energy [2].

World Renewable Energy Congress, Reading, September 1990

The air system is partially inflated to about 15 kPa with the membranes approximately 3/4 submerged. Differential wave action around the torus then causes air to be pumped back and forth between the cells. This flow is resisted by Wells turbines, one per cell, which power the generators. A subsea flexible cable brings the electricity ashore. With compliant mooring and low freeboard, the device experiences moderate mooring and structural forces, even in storm conditions. Figure 1 shows a 1/15th scale model during tests on Loch Ness.

MEMBRANE DEVELOPMENT

Waves produce a force on the rubber membrane which compresses the air and drives it through the turbine. The membrane has to be strong enough to support the forces acting upon it and yet has to be able to flex and accommodate the shape changes as it moves from an inflated to a deflated state, on each cycle. The membrane has to be strong in the vertical direction to resist buoyancy forces , but rather elastic longitudinally in order to avoid buckles and kinks during operation. We are proposing a membrane construction with two plies of reinforcing cords laid close to the vertical orientation to provide the anisotropy in properties necessary to satisfy these requirements. A covering of 2mm of blended rubber to both surfaces makes it airtight and resists wear and abrasion .

Low head hydro-electric sites , where the pressures due to water heads of less than than three metres are similar to those produced by waves in the North Atlantic, offer a large resource of energy. A novel device has been installed by the group on River Derwent, Borrowash, in Derbyshire and this device shares some of the technology of the Clam; particularly the Wells turbine and membrane [3]. As with the Clam the Borrowash membrane needs to be strong in one direction and elastic in the other. In fact the duty required of this membrane is more arduous than that envisaged for that of the Clam, and its physical size approximates to two Clam membranes.

TURBINE

A vital component of the Clam design is the Wells air turbine which has a symmetrical blade arrangement permitting it to extract energy from air flowing through it in either direction. It does not, therefore, require rectifying valves. It also has a linear relationship between pressure drop and air flow which leads to ideal wave matching. Running at high speed (for example 3000rpm) the pressure drop across the turbine is equivalent to between 2 and 4 metres of water head, depending on the blade specification.

A Wells air turbine is fitted to each cell and is coupled to the common air system. An electrical generator is mounted directly onto the shaft of each turbine. The electrical output, which can be synchronous with the mainland grid or asynchronous and producing a controlled frequency via a power conditioning unit, is brought to shore by a flexible subsea cable. A six bladed, 1.08m diameter, 150kW Wells turbine has been incorporated into the prototype hydro electric device built by our group in 1987. We are currently refining the manufacturing process for a replacement turbine.

CLAM MODEL TESTS

A fully instrumented 1/15th scale model of a 60 m diameter Circular Clam has been tested at the Group's wave energy test site, at Loch Ness in Scotland, to determine the capture efficiency and structural loadings of the device in a wide range of sea states.

Two air system configurations were tried in the model. In the parallel connection each of twelve Clam cells was connected via a linear damper to a common air duct running round the torus. In the serial connection, each pair of neighbouring Clam cells was connected by a damper located in the duct. (The specially constructed dampers are described in [4]) Figure 2 shows measured efficiency, defined as the air power captured divided by the wave power incident on a device diameter, for the series case, plotted against energy period of the test sea. The parallel case results are very similar, with some advantage for the serial connection around Te=7 seconds.

THEORETICAL MODELLING

A theoretical model [5] has been developed to give monochromatic results for a single incident wave direction; integration of the results for spread mixed seas will follow. The surge, heave and pitch responses of the device in a range of wave periods from 3 to 13 seconds have been computed.

In Fig 3 we plot an example of device efficiency against wave period to show its sensitivity to damping rate for serial connection. The Wells turbine damping coefficient EPS is the ratio of flowrate to pressure drop at constant running speed. At Loch Ness the full scale equivalent figure for the damping used was around 0.015 $m^3/s/pa$. The linear model results suggest 0.02 is a desirable compromise figure providing good capture and manageable membrane motions. Sensitivity to spring rate is less pronounced and serial connection does seem to be particularly successful around T=7 seconds, which ties in well with the experimental results. The signs for further validation and use of the theoretical model are promising.

COSTS

These costs are based on model results obtained in the tests described above and an initial structural design. The higher capital cost reflects contingencies to strengthen the circular structural design.

System rating for one device	2.0 MW
Annual average electrical power output	0.6 MW
Annual energy output per device	5.2 GWh
Capital cost per device	1.5 to 2.5 £M
per installed MW	0.75 to 1.25 £M
per average MW	2.5 to 4.1 £M

At a discount rate of 10%, over a 20 year lifetime, and assuming a 3% maintenace cost this leads to electricity costs in range 4.2-7.00 p/kWh.

THE FUTURE OF THE CLAM

A moderate amount of further research work is required to refine and optimise the structural design of the Clam and to investigate methods of improving its performance by tuning the device to the predominant wave climate. The mathematical modelling is now a powerful tool which we will apply to indicate the design requirements for optimum performance and economy. Further work on the design of the torus structure and development of the key components is necessary but we believe that within 3 to 4 years a prototype could be designed, manufactured and deployed. Refinements to the design, components and performance would follow the testing of the prototype.

A successful prototype programme could lead to the construction of further devices on either a "one-off" basis or in moderate batches. The fact that each device can be deployed and operated independently of others means that investment in wave energy can be made on the basis of successive packages of a few million pounds. Contrast this with the need to complete a billion pound nuclear power station or a tidal barrage before any energy is delivered. There is a limited financial risk associated with wave energy.

A successful development programme could lead to arrays of Clam devices deployed around the UK and abroad, making a substantial contribution to the electricity demand of the UK and Europe.

CONCLUSION

The Circular Clam is potentially a cost effective and non polluting wave energy device that could be deployed in extensive numbers to deliver a substantial proportion of the electricity demand of the UK. Some development of the critical components of the Clam has taken place under the hydro-electric programme pursued by the Group. Further work on these and several other aspects of the design are needed but a prototype could be produced at an early stage. It is to be hoped that the UK Department of Energy review of wave energy, due for completion in 1991, recommends vigorous support for the Clam and wave energy generally.

REFERENCES

[1] See for example.
The Solar Energy Society Conference on "Wave Energy Devices" ,C57, Coventry , November 1989.

[2] Duckers, Lockett, Loughridge, Peatfield, West and White, Reinforced rubber membranes for the Clam wave energy device, Polymers in a marine environment 1987

[3] Bellamy, Duckers, Lockett, Loughridge, Peatfield, West and White
The Novel Pneumatic Hydro-Electric Device at Borrowash,
UK-ISES Conference on Low Head Hydro-Electricity, C52, pp 41-47
June 1988.

[4] White, Berry, Duckers, Lockett, Loughridge, Peatfield, West
Wells turbine simulation using a rotating disk, WESC Feb 1985

[5] Lockett F.P., Wave Forces on the Toroidal Clam Device, Proc. Euromechanics Colloquium 243, University of Bristol, Sept. 1988.

Fig.1

Clam Model on Loch Ness

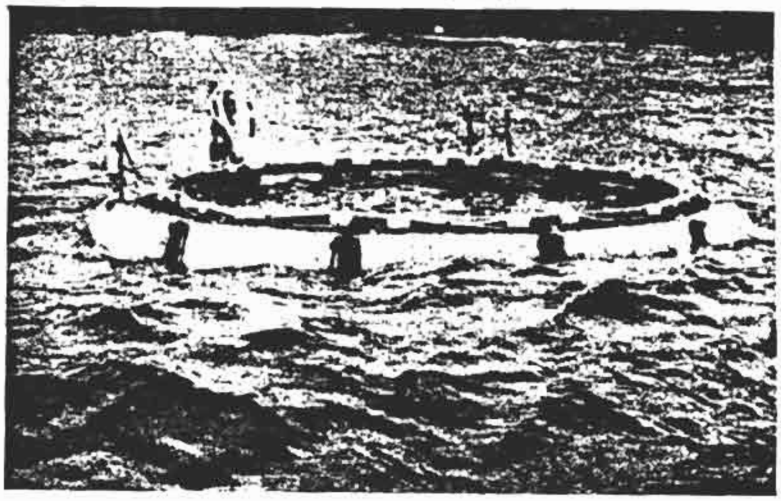

Fig.2

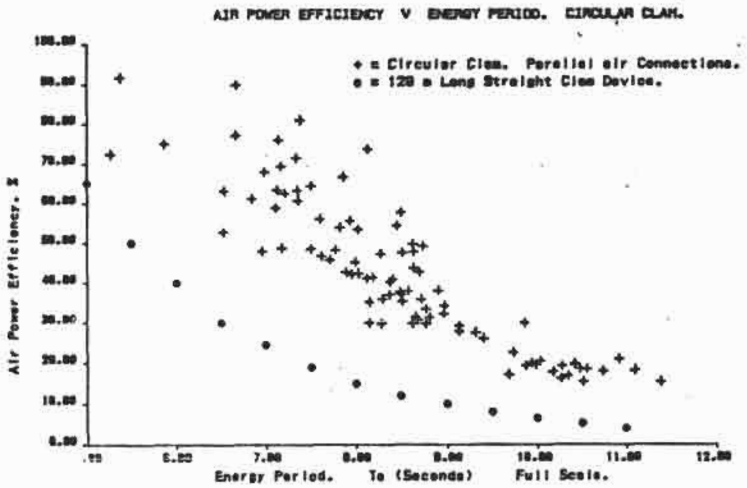

Fig.3