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STATUS 1983 OF THE NORWEGIAN WAVE-POWER BUOY PROJECT

Introduction

Three years ago we brought forward a particular proposal of a wave-power buoy,[1], [2] which has been a substantial part of our research topic during recent years. The project has received financial support through Olje- og energidepartementet (The Royal Ministry of Petroleum and Energy). The engineering aspects of the project have been coordinated through the research consortium OTTER (Offshore Technology Testing and Research) in Trondheim.

Design of a power buoy in full scale

The OTTER project coordinator T. Hals has produced a report (STF88-F82060) "Prosjektering av bølgekraftbøye type N2" ("Projecting wave-power buoy of type N2") with 14 appendices. The report (which is restricted) contains details on the design, on laboratory testing of mechanical components, on reports from technical consultants, and on offers from industrial firms. This document would form the basis for asking for tenders with the purpose of constructing a test buoy in full scale. It is expected that the buoy would function with a reasonable degree of reliability during a testing period of two to three years, provided the functioning of the critical components are sufficiently tested before installation. However, it is emphasised that substantial development and testing of components have to be carried out before reliability and lifetime have reached a level which is acceptable for a power plant.

Economic assessment

In 1981 an official assessment[3,4] of a 200 MW wave-power plant off the western coast of Norway was made in four different alternatives. It was based on the state of industrial construction and enterprise in Norway in 1981. The estimated cost of produced energy was in the region 1.20 - 1.40 kr/kWh (£ 0.11 - 0.13/kWh) for three different Norwegian device proposals and 2.30 kr/kWh (£0.21/kWh) for a British proposal (the bottom-standing NEL oscillating water column). Note that independent British assessments present much lower cost estimates for the NEL device. The reason for the discrepancy may be, firstly, the high cost of labour in Norway, secondly, the lower figure of average incident wave power per unit length of the Norwegian coast, and thirdly, that future developments of the device and of the construction technology were not taken into consideration.

For a 200 MW plant consisting of 410 wave-power buoys the official assessment[2,3] gave an energy cost of 1.40 kr/kWh (£0.13/kWh). A breakdown of the cost is shown in Table 1 (columns marked "EVA2"). We have made an alternative assessment[1,5] which results in lower cost as shown in the same table (columns marked "TEAM"). We present cost figures in a range, where the higher figures correspond to the first generation plant, while the lower figures indicate cost reduction after many large wave power plants have been constructed. The given cost figures are commented and justified elsewhere[1,5] . We shall, however, present some additional comments to Table 1.

In 1981 a Norwegian ship yard informed us that the construction of one unit of the hull in welded steel would cost 14 kr/kg. For our highest figure we assumed 20 % reduction for construction of 410 units, whereas the EVA2 figure is based on 22 kr/kg. An updating[6] of the official assessment for one piece of an oscillating-water-column structure in welded steel indicates a normal cost of 14 kr/kg, but with the depressed market situation in 1983 a cost of 9,50 kr/kg seems now realistic. Under these circumstances it is believed that the TEAM's highest figure in Table 1 is rather conservative.

The above-mentioned updating[6] claims that small units of wave-power devices in Norway can deliver energy at half the cost given in the former assessment[3,4].

Half of the EVA2 figure for miscellaneous and contingency is due to cost of facilities for construction of anchors and for assembling and cost for levelling the sea bed. We did not include such costs in the TEAM figures since our cost figure for the gravitation anchor was based on an offer from a Norwegian firm, and since gravitation anchors can be used also in locations where the sea bed is naturally flat.

A report "Elsystem för vågkraftverk, utforming och kostnadsberäkning för ett bojkraftverk vid Bremanger" ("Electric system for wave-power plant, design and cost estimate for power-buoy plant at Bremanger") by Å. Kinnander, (report no. 82-112 from Technocean AB) in 1982 states that a DC transmission system for the power plant would cost approximately 0.1 Gkr. This indicates that the higher figures in Table 1 are conservative, in particular since AC transmission was assumed in the former assessment[3,5].

Finally, we mention that the official 1981-assessment[4] has been commented both by us[1,7] and by an independent Swedish consultant[8].

Energy recovery and labour

Energy and labour are resources which are required in order to make a product. The energy associated with 100 ton of steel is approximately 1.1 GWh. Thus, during approximately one year each buoy will recover the energy contained in the steel of the hull and the strut (cf. Table 1). We expect[7] that the total recovery time for the energy invested in the power-buoy plant is less than two years. This is much shorter than the energy recovery time for other proposed wave-power devices. For two other proposed Norwegian devices the energy recovery time is estimated[3] to be 10 to 14 years.

However, the labour invested in the power-buoy plant is relatively large. Also since the phase-controlled power buoys contain some critical moving parts, it is believed that relatively much labour is required for operation and maintenance, compared to the other assessed devices. This may have a positive effect for the employment in the coastal areas where the power-buoy plant is located.

Future development and full-scale testing of the power-buoy device in the sea are required before we know decisively that the maintenance will not be excessively expensive.

Model tests

A model in scale 1:10 has been tested[9,10] in the sea near Trondheim, during six periods between September 1981 and June 1983. It was in the sea 170 days altogether. After the first periods modification had to be made, in particular on the guiding rollers, the latching mechanism and the measuring equipment. The system functioned satisfactorily during the two final test periods. Between those two periods the opening in the bottom of the buoy was modified in order to reduce viscous losses at the entrance.

Results from 14 different records taken during the sixth testing period are summarised in the diagram of fig. 1. The corresponding wave heights and periods are in the regions 0.08 - 0.4 m and 2.8 - 3.6 s, respectively. The measured input power is the sum of pneumatic power in the pump chamber and a relatively small contribution, the power lost in friction between the buoy and its mooring strut.

Conclusion

Several official assessments[3,4,6] of wave-power plants in Norway show decreasing figures for the estimated cost of wave energy. The latest updating[6] seems to confirm some of the points in our own assessment[1,5] of a phase-controlled power-buoy plant, where we estimate the energy cost to be roughly 0.6 kr/kWh (5 pence/kWh) which has prospects to be reduced to 0.3 kr/kWh (3 p/kWh) in the future. This cost would be competitive on national energy supply markets.

Among many different assessed wave-energy devices the phase-controlled power buoy is outstanding in having a rather low investment of energy, materials and money in relation to the produced energy per year. On the other hand, relatively much labour is required to construct and maintain the plant.

Since the device contains some critical moving parts, more development work and full scale testing in the sea are required in order to obtain acceptable lifetime and reliability.

Such a development program should be started as soon as possible. The program may result in knowledge on how to design a reliable device.

Our project has been pursued with design work to a stage where the next step is to construct a full-scale test buoy. However, since funds for such work are not yet available, our research team now continues its work on other aspects of wave power, i.a. work on mini-power devices and on phase-control of oscillating water columns.

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Table 1. Cost estimate for 200 MW power plant consisting of 410 wave-power buoys. The left-hand columns give estimated cost and the right-hand columns give corresponding cost per unit of produced energy in kr/kWh (1 kr = 9 pence), assuming an energy production 1 GWh/year per buoy. Columns mared EVA2 are based on refs. 3 and 4., while columns marked TEAM are based on the higher and lower cost figures given in ref. 1 or ref. 5.

	EVA2	TEAM	EVA2	TEAM
A. Estimate of construction cost				
per buoy in Mkr = £ 9.10^4	Mkr	Mkr	kr/kWh	kr/kWh
Hull of buoy, steel, 45 tons	1.5	.6 - .3	.14	.06 - .03
Mooring strut, steel, 53 tons	.4	.32 - .22	.04	.03 - .02
Universal joint, ± 30°	.3	.14 - .1	.03	.01 - .01
Mechanical components	1.0	.9 - .5	.10	.08 - .05
Electrical components	.2	.2 - .16	.02	.02 - .02
Anchor	1.3	.8 - .2	.12	.07 - .02
Installation	.7	.6 - .3	.06	.06 - .03
Miscellaneous and contingency	1.2	.3 - .2	.11	.03 - .02
Installed wave-power buoy	6.6	3.8 -2.0	.62	.35 - .19
B. Cost estimate for 200 MW				
plant in Gkr = £ 9.10^7	Gkr	Gkr	kr/kWh	kr/kWh
Construction and installation				
of 410 buoys	2.7	1.5 - .8	.62	.35 - .19
Electrical transmission	.24	.12 - .07	.05	.03 - .02
Interest and other costs	.4	.1 - .05	.09	.02 - .01
Investment tax, 10 %	.3	.16 - .09	.07	.04 - .02
Invested capital for power plant	3.6	1.9 - 1.0	.83	.44 - .24
C. Annual costs in Gkr = £ 9.10^7	Gkr	Gkr	kr/kWh	kr/kWh
Capital 9.44 % (7 %, 20 years)	.34	.18 - .10	.83	.44 - .24
Operation and maintenance	.23	.06 - .03	.56	.14 - .08
Total	.57	.24 - .13	1.39	.58 - .32

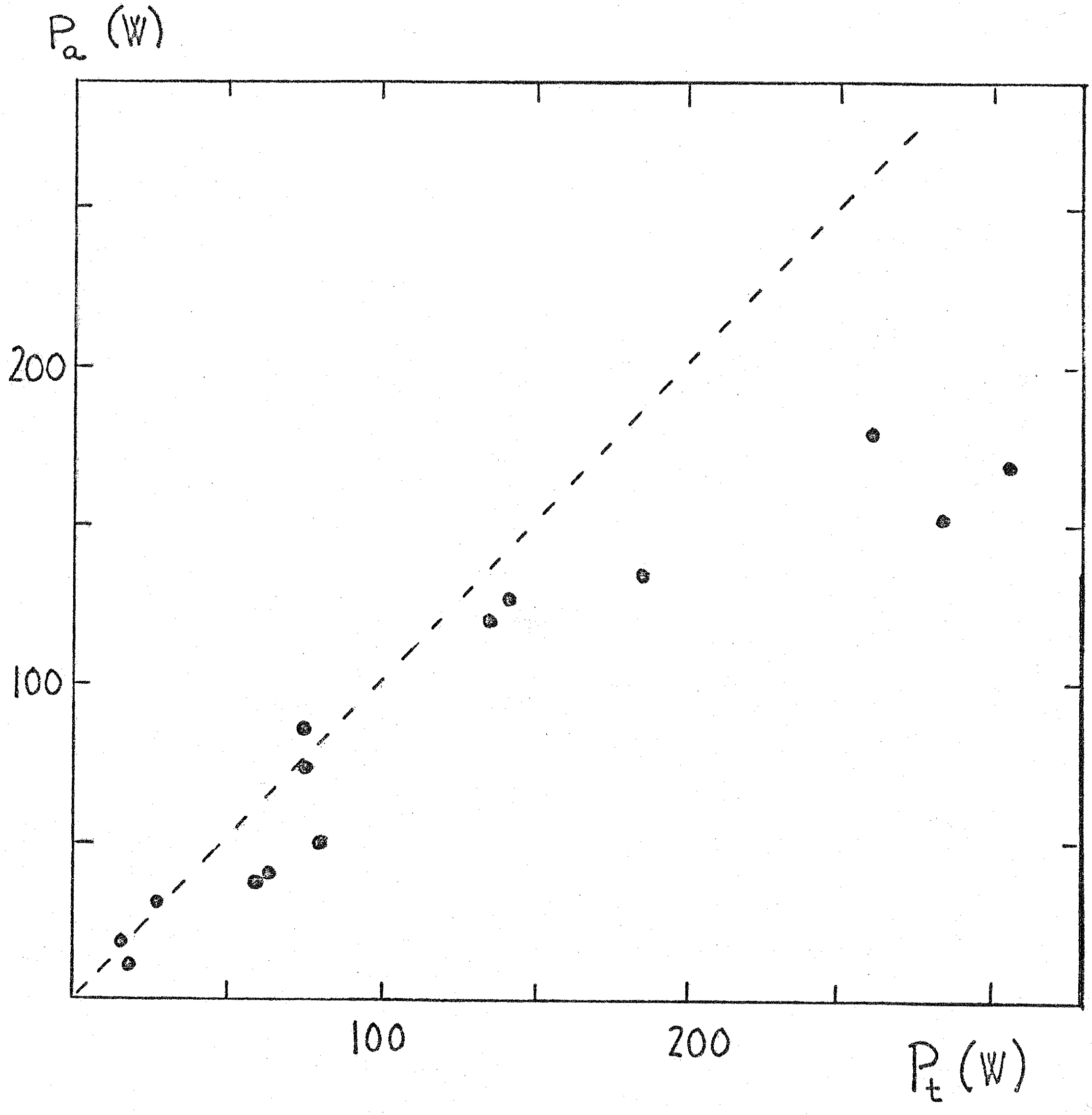

Fig. 1. Results from sea tests[9,10] of power-buoy model in scale 1:10. The vertical scale gives the measured input power P_a to the buoy. The horizontal scale gives theoretical values as given by using measured values of the wave and of the heave motion in a theoretical formula. For input power below 130 W (corresponding to 0.4 MW in full scale) there is reasonable agreement between theory and experiment since the experimental points are fairly close to the inclined dashed line.

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