Utilization of Wave Energy

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When looking upon an aroused sea, many wonder how this seemingly large energy resource could be used. Inventive minds have gone to work on devices of all kinds — pumps and bellows, buoys, barges, and ramps, surface and subsurface siting, using alloys and plastics, etc. — generally based on mechanical or hydraulic principles. They would probably all work (if somebody would build them), but none thus far have been shown to do so profitably.

With the cost of energy rising steeply, one often assumes that previously uneconomical alternatives become more favorable. That may be so to some extent, but rarely enough so. Material, labor and capital that go into the new systems also cost more, and the economic break-even point is raised.

What has made the use of fossil fuels attractive is the high energy density they provide which permits a boiler, engine or turbine to be compactly sized. Alternate sources of energy, for the most part, offer low energy density or "head" — solar, wind, ocean waves and currents, tides, ocean thermal, for example. Components in systems designed for their use have to be large, requiring more costly construction than conventional systems, the interest on which keeps operating cost high even though the "fuel" is free.

Waves and swell, dynamic features of the sea surface generated by local, respectively distant winds, fall into the low-head category. They are often irregular and represent a broad range of frequencies and height. Many wave-energy conversion devices, however, are tuned to one frequency and become ineffective at all others.

Professor John Isaacs at Scripps Institution of Oceanography has developed a system — a wave pump — that mitigates the constraints of this resource. It is detuned and responds to a wide range of wave frequencies. It also can amplify wave height or "head" by accumulating water in a tank under pressure.

The design is extremely simple. A long pipe, containing a check-valve at the bottom, is suspended vertically from a float, as shown in Figure 1. When the float moves down in a wave trough, water enters the pipe. When the crest lifts the float, the check-valve closes and the entrained water is raised. It continues upward due to its larger inertia when the float/pipe descends into the next trough. The valve opens when the pipe begins to decelerate and it fills with more water. In repeated strokes
WAVE POWERED PUMP

Fig. 1.

water is carried as high as pipe length and acceleration forces permit. A 200-ft long model has amplified the pressure head of 6-ft waves nine times, a 300-ft long model has amplified 2-ft waves 20 times. Figure 2 shows the 200-ft model during tests.

Fig. 2.
Calculations based on these performances indicate that a 500-ft long, 3-ft diameter pipe should produce 50 kw in the tradewind belts. These belts and the high latitude oceans are highly energetic areas, particularly in winter. Twelve-foot waves may be present as much as half the time, 5-ft waves as much as three-quarters; they may come from 5 to 15 seconds apart. Observations and compilations of sea states the world over are, however, quite sketchy.

How large is this energy resource? I have estimated available power at $2.7 \times 10^{12}$ watts. This is steady-state power and may be considerably less than is theoretically extractable. Waves are generated by wind stress on the ocean surface. They grow with strength and duration of that stress—up to an asymptotic level, the fully developed sea, when no additional energy is transferred. Power harvest returns the wave to an immature state which the wind builds up again to a mature one. This is analogous to the growth rate in organisms which declines to zero in adulthood. Thus, harvest of the ocean waves would represent the elusive fountain of youth, at least for the ocean. Repeated harvest is possible perhaps every 50 km yielding 10 to 100 times the steady-state figure of $2.7 \times 10^{12}$ watts. Presently in the U.S., electricity generation is approximately $3 \times 10^{11}$ watts.

Wave power is clean power, no environmental debits occur. There are, however, a number of problems associated with wave-energy extraction. Floats must be small lest they average out the waves; they could form arrays as in Figure 3. If very many floats are deployed, conflicts with shipping and fishing arise. Although the wave pump can be made incorrodible, its befouling by marine organisms is difficult to control. Lifetime of the mooring and the even-so-simple check-valve thus are a matter of conjecture.
Of all difficulties the greatest perhaps is the power harvest itself. Since the sea is sometimes still, wave power will be sporadically produced. Thus energy storage has to be built into the systems. This can take many forms — batteries, elevated water, spinning masses — but one of the most promising forms is hydrogen gas. Gas storage and transmission at sea is relatively far advanced through the offshore activities of the oil and gas industry.

An alternative to continuous energy transfer by cable or pipe is the batch collection by ship or barge. In recent years tankers for natural gas (in liquid form) have been put into service. From these it is but a step to the hydrogen tanker when this form of energy becomes abundant. There are, moreover, numerous other ways of transporting the energy produced at sea to shore, namely in the form of products manufactured with this energy on site. Aluminum smelting from bauxite, fertilizer production from atmospheric nitrogen and phosphate ores, processing of fish to meal, refining of petroleum products, manufacture of plastics, are some examples.

In addition to the direct production of energy or some finished good, there is a by-product in the form of artificial upwelling. Upwelling is an important natural process that accounts for high biological productivity in parts of the ocean. It returns nutrients trapped in deep water into the surface waters for renewed photosynthetic assimilation by marine plants (algae, diatoms, etc.) on which the chain of life in the sea is based. Thus high nutrient recycling means high seafood harvest. As wave pumps of our design gain in efficiency with length (depth), artificial upwelling becomes more effective as nutrient concentration generally increases with depth.

It appears thus that a wave energy conversion device that can multiply energy density, respond to a wide range of wave frequencies, and withstand large and destructive waves could be a useful source of energy. Where energy costs compare favorably, as in remote settlements along wave-swept coasts, this source of power may soon be employed. Widespread use, however, will hinge on resolving the key difficulties of product transfer and conflicting uses.

References