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A RENEWABLE ENERGY SYSTEM FOR THE UTILIZATION OF SEA AND RIVER CURRENTS

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Abstract: *Utilization of sea and river currents, where high flow rates are present despite the lower speeds has been attractive area for renewable energy engineers. In oceanside countries with coastlines where the tidal currents are high, several projects have been realized. However, countries in inner seas, for example, Mediterranean and Black Sea coast countries, the currents are driven by salinity gradients and are often restricted to a limited surface layer. Therefore, large diameter water turbines or tidal dams are not viable methods for energy conversion. Instead, devices with drag-driven elements are deemed more appropriate to exploit the energy in such currents. The concept proposed in this paper is based on a number of tandem “drogues located on a closed chain loop. The paper includes a hydrodynamic analysis, based on a recent experimental research on tandem drogues. Conditions for an optimum efficiency and power output analysis shall be included. A configuration shall also be proposed, involving anchored or bottom-fixed platforms. The system is deemed to be appropriate both for sea and for riverine applications.*
Key-words: *Drogues, sea currents, renewable energy, hydrodynamic drag, tandem object drag*

1. INTRODUCTİON

Large masses of water moving in seas are a perpetual source of energy. Higher speed currents, especially those created by tides, have been successfully exploited, for example, well-known La Rance power station in France. Other systems aimed to obtain energy from open seas are based on current turbines, usually of horizontal axis type, reminiscent of wind turbines.

However, inland seas do not have significant tidal currents. Sea currents in those seas are salinity gradient or wind-driven, and often restricted to a surface or a subsurface layer. Therefore, large diameter current energy turbines are not applicable in such seas. Instead drag-driven elements can be used. As shown by practical data and also theoretically byGorban et al [1], the efficiency of horizontal axis current/wind turbines are restricted to about 30 percent, about half that of the classical approach by Betz. Drag driven elements, on the other hand, have efficiencies that are dependent on the drag coefficient and by the usage of tandem drag elements, the efficiencies can be significantly increased.

This paper discusses such a system in which a number of tandem drogues are used to drive a large wheel. It is a development of the system previously proposed by the same authors to produce powers at a larger scale[2]. It can be used in sea areas with strong surface currents and also in rivers. It can either be bottom-fixed or moored.

2. EFFİCİENCY ANALYSİS OF ENERGY FROM DRAG

A drag element moving with a velocity *v* in a current of flow speed V_c , such that $v < V_c$ shall experience a relative velocity of $V_c - v$. The drag force on this drag item shall be:

$$F_D = \frac{1}{2}\rho\left(V_c - v\right)^2 C_D A \quad (1)$$

where ρ is the density of fluid, C_D is the drag coefficient and A is the frontal area (area of the drag element in the direction perpendicular to the flow). The power (energy per unit time) which this drag element extracts from the fluid flow shall be:

$$P = F_D \cdot v = \frac{1}{2}\rho v\left(V_c - v\right)^2 C_D A \quad (2)$$

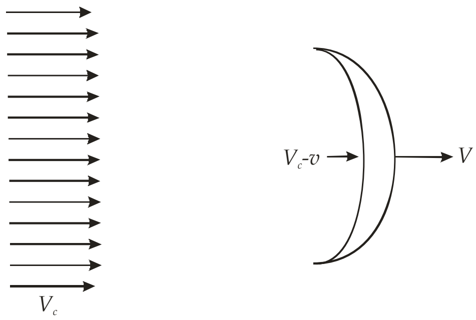

Figure 1. Current velocity (V_c), element velocity (v) and current velocity relative to the element (V_c - v)

The power available in the stream tube of coss sectional area A is:

$$P_{av} = \frac{1}{2}\rho V_c^3 A \quad (3)$$

Thus, the efficiency of a device operating with the power extracted by the drag element from the current shall be:

$$\eta = \frac{P}{P_{av}} = \frac{v\left(V_c - v\right)^2}{V_c^3} C_D = \zeta\left(1-\xi\right)^2 C_D \quad (4)$$

where $\xi = v/V_c$. As can be seen, efficiency is highly dependent on the drag coefficient, with optimum value being when $\xi = 1/3$ and $\eta_{opt} = 0.148\ C_D$. Therefore, such an energy system should seek for maximizing the value of the drag coefficient, C_D. A feasible way to increase the drag coefficient for a given frontal area is to use tandem drag elements.

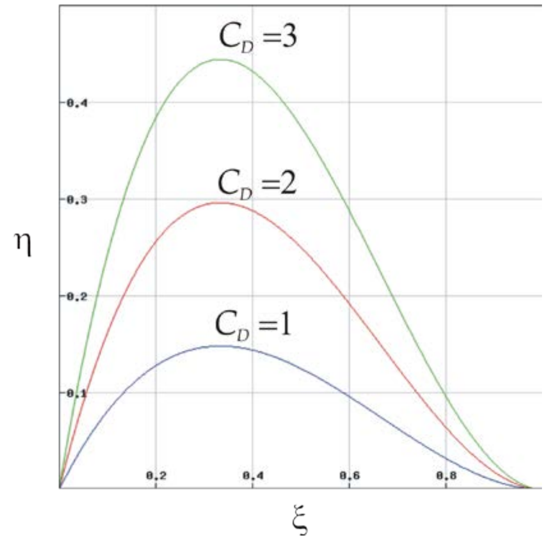

Figure 2. Efficiency of a drag-based energy system versus $\xi = v/V_c$ for various values of drag coefficient, C_D.

3. PROPOSED SYSTEM

The system is based upon using drogues (underwater parachutes or underwater windsocks) in tandem along a chain-sprocket system. Figure 3 is a representation of the system. Although a number of drogue types have been designed for being used in the marine field, a conical drogue configuration is selected for being used in tandem configuration, per the findings by Holler[3]. Drogues are attached to the endless chain by swivel mechanisms to give them a three-dimensional freedom of operation. The sprockets shall be inside groves in both of the wheels such as to protect the drogues from the sprocket teeth. Synthetic Kevlar-woven cloth shall be the material for the drogues, and the ropes to connect the drogues are also made of Kevlar. The lower part of the chain shall be above the free water surface, and the drogues shall operate such that the upper rim being virtually tanget to the free surface. The nominal dimensions of the system are as diameters(d) of the drogues are 2 m, that of the wheels (D) 5 m and the total length of the system (length between the centers of two wheels) about 100 m. Power takeoff shall be made from the front wheel, by a generator operating nominally about 2 m above the water surface- an advantage over other wave/current energy systems since there are less problems of maintaining watertightness and due to the convenience for maintence and repairs.

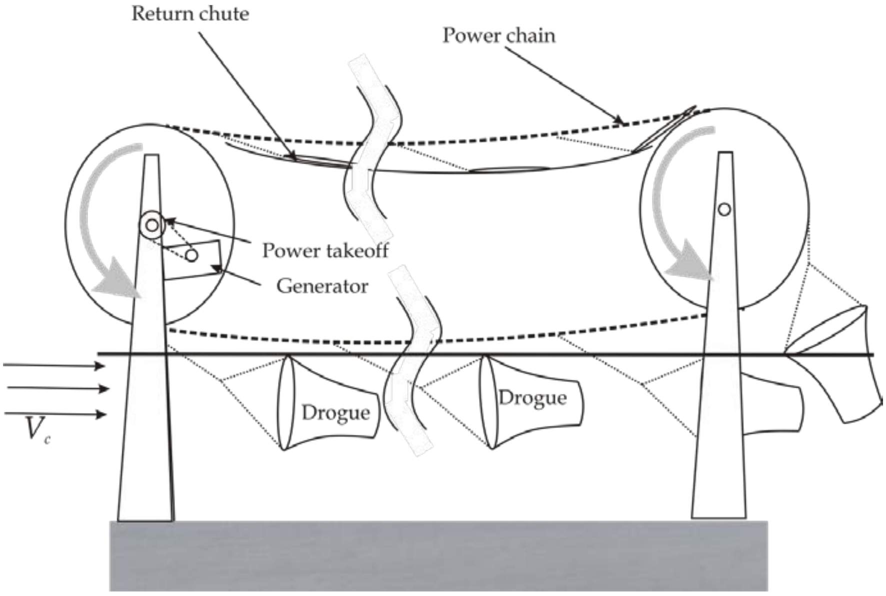

Figure 3. The proposed system

4. ANALYSİS OF THE SYSTEM

Holler[3] has presented data for the drag coefficients of so-called cross-chute and conical drogues used as sea anchors. The drag coefficients of conical drogues, together with their geometry, is presented in Figure 4.

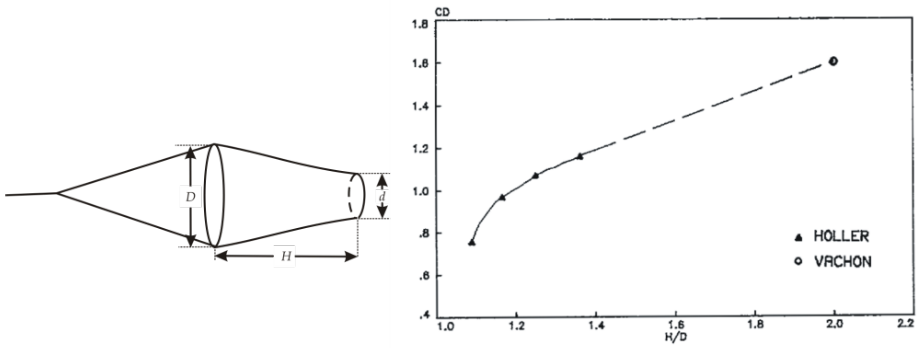

Figure 4. Drogue geometry definition and drag coefficient as a function of *H/D* (Holler[3])

Holler[3] has also presented the drag coefficients of two drogues towed in tandem: For a standard drogue with D = 2.72 m, d = 0.34 m and H = 3.72 m, drag coefficient is reported to beC_D =1.17. Two such drogues towed in tandem with a nondimensional separation S/D = 6.73 shall have a total drag coefficient of 1.98 times that of a single anchor-indicating virtually no effect of the drogue forward to the rear one. Data for cross-chute type drogues (drogues with no central opening) also presented in that paper implies that a separation of $S/D \approx 15$ is required for such a case, suggesting that conical drogues are a proper selection for such an application. A similar conclusion can be inferred from Chiang and Dunker[4], although no information about the drogue geometry is given. Unlike the parachutes, which require a significant time for their opening from the folded position, conical drogues shall "open", i.e., take their operating geometry within less than one length of travel within the current.

If $K = C_{D(tandem\ couple)}/C_{D(single\ drogue)}$, then a tandem cluster of n-such drogues shall have:

$$C_{D(total)} = C_{D(\text{singledrogue})} \cdot \left[1 + (K-1) + (K-1)^2 + \ldots + (K-1)^n\right]$$

$$C_{D(total)} = C_{D(\text{singledrogue})} \cdot \sum_{j=0}^{n-1} (K-1)^j$$

For a sufficient separation, say, S/D = 7, $C_{D(\text{total})} \approx n\, C_{D(\text{single drogue})}$

As an illustration, let us assume a system described above, with:

D= 2 m.

d = 0.25 m

H = 2.75 m

C_D = 1.17

If 10 such drogues are present, on the tow leg of the chain, the distance between the two wheels shall be nominally 150 meters. Assuming no interference (K = 2) between the tandem drogues, C_D(total) = 11.7 and η_{opt} = 1.73. Although thic result at the first sight seems to violate the energy conservation laws, it is logical since the momentum in the wake of a drogue is recovered from the adjacent streamlines, thus making the effective area larger than the frontal area of a single drogue. If the system is operated in the optimal condition, in a current with a 4 knot (2.06 m/s) speed, then the ideal power output shall be164 kW, with wheels rotating at 13 rpm, indicating the feasibility of such a system.

5. CONCLUSİONS

It is believed that such a system has been shown to be feasible. However, a series of model tests involving towing or circulation channel tests and site-surveying including the effects of possible adverse weather and oceanographical conditions should be made before the prototype saz installation of such a system.

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