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Analysis of the equilibrium conditions of a double rotor turbine prototype designed for the exploitation of the tidal currents

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ABSTRACT

For several years the Department of Mechanical, Energy and Management Engineering (DIMEG), in collaboration with SintEnergy Srl, has been performing researches for the exploitation of tidal currents. An innovative turbine has been developed, anchored to the coast, which does not require the supporting structures on the seabed and should reduces installation costs and environmental impact. This machine, in its latest version, proposes the use of two concentric and contra-rotating rotors, in order to require a small, or non-existent, stabilizing torque.

In the present work the machine equilibrium conditions have been defined and, by a CFD analysis, the lift and drag coefficients of the central deflector have been calculated, together with a final machine design procedure.

As a case study, applying the above procedure for a machine installed on the Messina strait, the energy output and the payback period have been estimated.

1. Introduction

The exhaustion of traditional energy resources (e.g., fossil fuels), in addition to the environmental pollution as a result of the fossil fuels consumption, urge the global community to seek alternative energy resources, especially renewable ones (wind, sun, ocean waves, and tidal currents). Among these, tidal currents are an energy source very interesting for several reasons [1]. The tidal current high energy potential is used only for a minimal part, unlike the wind ones, even if they are completely predictable [2], generated by gravitational interaction moon–earth.

Several projects have been developed, mainly characterized by a high costs [3] and environmental impact as well as a low energy production [4]. The main challenge is the installation of the plant, not requiring high skilled personnel, special equipment and very long time for completing the job.

The machines actually working by tidal currents are moored to floating structures, or a wide supporting pylons like the Kobold [5], Darreius [6], Cormat [7], Seagen [8] turbines. Recently hydrokinetic turbines [9] are gaining ground thanks to their simpleness.

Dealing with these issues, a long last collaboration between the DIMEG (Department of Mechanical, Energetic and Management Engineering – University of Calabria, Rende, CS, Italy) and the company SintEnergy (TechNest Incubator Rende, CS, Italy) is aimed to the development of innovative turbines able to harness tidal resources. Thanks to their experience the authors have conceived a way to make a wide turbine operates in the sea like a kite, moored directly to the coast, by easy and cheap frames, and steel ropes subjected only to traction force [10].

Several related works have been carried out: the basic idea [11] has been to implement a central deflector which makes able the machine to be self balanced through the current, maintaining the same equilibrium position during the operating phases.

An initial design has been improved implementing two contra rotating rotors working at the same speed in opposite directions with no or low torsional effects [12].

The state of the art is an easy machine design, with a permanent magnet generator built in the stator and a level floating stabilizer, helpful for the machine equilibrium and for diving and surfacing operations, when a change of current direction occurs or a maintenance activity is needed.

The main machine operating environments are any sites with bidirectional currents (a special counterbalance device has been implemented in order to turn the machine when the current

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changes its direction [10]), but it could be possible to operate also on the rivers, or, with some tricks, through wind currents.

A key point of the design is the machine equilibrium. On the vertical plane, containing the rope, the stabilizer is responsible of the equilibrium, while on the horizontal one the equilibrium is guaranteed by the central deflector characterized by a square plant; the deflector profile is symmetric because of the bidirectional flow. For the horizontal equilibrium it is very important the calculation of the lift and drag forces.

In this paper, instead of using the easy correlations suggested by the literature [13], a CFD simulation has been performed in order to evaluate the velocity distribution around the deflector, the forces acting on them and, consequently, the lift and drag coefficients (C_L, C_D).

Finally the procedure, carried out for the optimal design of the machine, is briefly described together the main results obtained for the site of Punta Pezzo, near the Messina Strait (Italy).

2. Description of the machine

The turbine, see Fig. 1, has been conceived for collecting energy from the tidal currents near the coast.

The basic idea involves the elimination of structures, supports or foundations in water – all works expensive and hard to realize – maintaining the machine in equilibrium in water (see Figs. 1–3), by a simple rope (3) subject to a tensile stress, in a correct position which does not change during the work. The rope is driven by a rigid rod (2) hinged to the coast (see Figs. 2 and 3). The working principle is quite similar to a kite: the weight (W) – reduced by the Archimedes' thrust (T_A) – and the rate of change of the axial momentum (T), forces that would sink or aground the machine, are balanced by the lift thrust produced by the tidal current on a central deflector inserted in the middle of the blade discs. This force (L_r – see Fig. 2) pushes off the turbine, but the combined action of the forces W, T_A, T, D_r, and R (Fig. 3) puts the turbine in equilibrium in a position which does not change when the tidal velocity changes. This position depends only on the turbine geometrical configuration.

Figs. 4 and 5 show the design of a turbine prototype with two rotors, each of them equipped with 6 blades. The blades are connected by circular rings sliding through the stator (4): the two rotors – external (8) and internal (7) – rotate in opposite direction so that they produce equal and opposite torques. The vertical deflector (6) is installed in the centre of the blade discs: when the current flows around it, the lift force produced (L_r) begins to drag the turbine off. The drag force, together with the other ones (T, D_r, T_A and W), origins a resultant R (Fig. 3) stretching the rope (3) connected to the machine. The connection rope-turbine is guaranteed by a rigid frame (9). In order to maintain the machine in vertical position, a floating level stabilizer (5), aerodynamically shaped, has been introduced, connected to the stator by a vertical bar (11). The stabilizer dimensions depend on the machine net weight.

Fig. 5 shows a machine exploded view highlighting the deflector (6), the rigid frame (9) whose the rope is connected, the stator (4), the external rotor (8), the internal rotor (7), the floating stabilizer (5).

Fig. 6 shows the section of the stator with the built in magnet permanent generator (MPG). The alternator/generator will have a built-in Maximum Point Power Tracker (MPPT), able to vary the shaft's rotational speed in order to convert the maximum available power, so the turbine will work at variable rotational speed and always in the optimal (design) condition. The machine nominal operating point is defined by the tidal velocity peak related to a chosen site (maximum power condition). Fig. 6 shows how the blades are installed in the stator and how they slide on ball bearings (14). The coils (16) are installed in the stator while the magnets (15) in the blades.

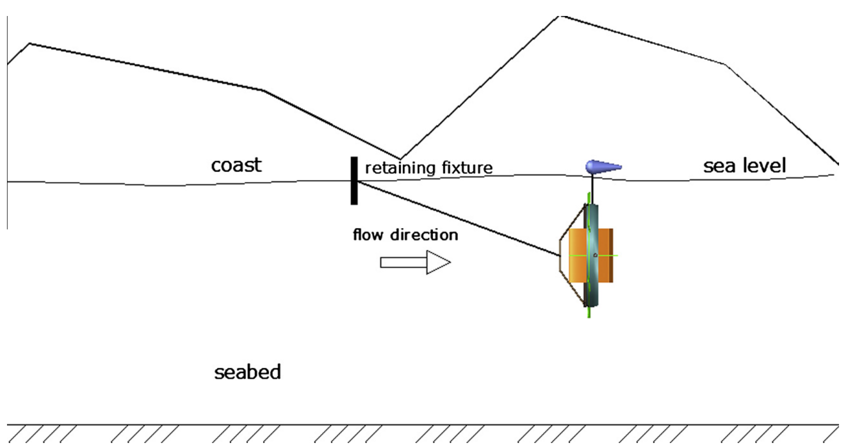

Fig. 1. Working scheme.

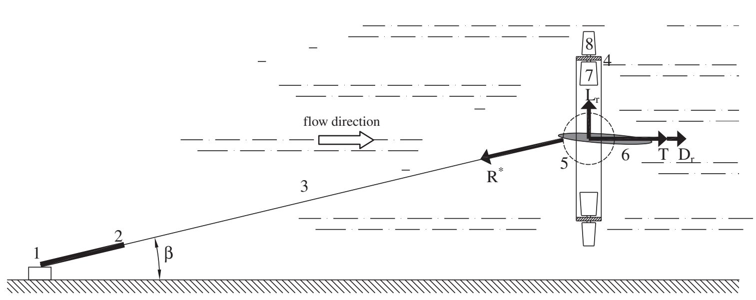

Fig. 2. View from above of the machine.