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Coastal Sea Power. A proposal for Exploitation Wave Energy

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Abstract

This paper presents an alternative to the converters that currently are being used to harness the energy in the waves of the sea. This is a floating structure, with two dead-anchored to the seabed, suitable to be located near the coast in an area with or without the existence of tides. The floating cylinder arranged horizontally following the oscillations of the sea surface and transmitted through arms, the movement of the machinery fitted inside a house mounted on the structure. In the machinery converts the reciprocating motion of the arms in an unidirectional movement to impulse along the axis of an elastic accumulator allows continuous rotary motion of the rotor of an electric generator, as a permanent magnet alternator.
Being a floating structure can be accessed maintenance or repair from a boat into the house. Another characteistic of this proposal is that it does not possess elements that will work submerged due to this, watertight components do not need necessarily more difficult to maintain and more expensive.

Key words

Wave energy converter, Synchronous Permanent Magnet Generator (PMG), Permanent Magnet Linear Syncronous Machine (PMLSM), renewable energy, WaveSwim.

1. Introduction

Today, in addition to the economic crisis are suffering a crisis of energy resources causing oil prices exceed $ 100 per barrel. The situation today is very different from the energy crisis of the 70, at the time, for political reasons, the oil producing countries voluntarily reduced the flow rate from wells, but now the extraction capacity is at a maximum. Many oil producing countries, as in the case of the USA or Great Britain, surpassed peak production and are in a progressive decline. On the other hand, emissions from the combustion of fossil fuels, mainly coal and oil, with the consequences of acid rain and emission of greenhouse gases, make it urgent to obtain energy from renewable energy sources at the same time not harm the environment. Within the renewable energy the percentage that occupy the energy from the sea is derisory.
It should be recalled that the directive 2009/28/EC of the European Parliament sets a target of 20% of energy consumption from renewables by 2020. Spain, according to the National Action Plan 2011-2020 Renewable Energy estimates that energy from the sea on three possibilities: hydrokinetic, tidal and wave, followed by an evolution as shown in Figure 1. It is considered that until 2016 the power installed, and output power is zero.

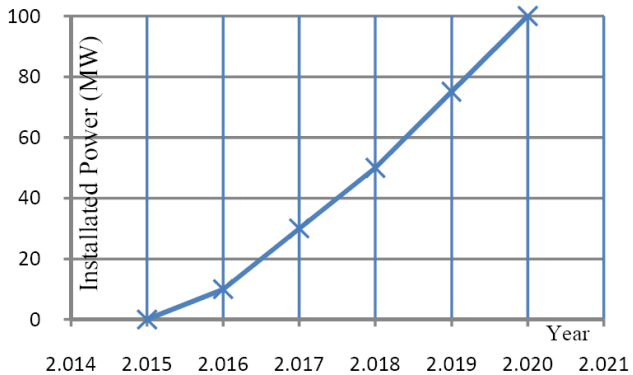

Fig. 1. Estimated installed power with wave generation.
Source: PANER 2011-2020 [1]

Currently in Spain is initiating the development of the first pilot projects for harnessing wave energy, with different prototypes.
The development of national technology for different

types of prototypes, and development projects of various testing centers suggests a major industrial development in the area of ocean wave energy. Projects are currently in the demonstration phase and is expected by 2016 is set the best technology to capture energy from the sea, allowing the commercial development of the sector with the launch of the first commercial plants producing electricity from the sea.[1]

Among the various ways in which the sea acts as an energy accumulator, through tides and currents, thermal gradients and waves, the latter presents some interesting advantages.

Is widespread and related with the energy demanded, and that about 40% of the population lives on the coast, and has a greater predictive power than wind. It is also an energy that is highly concentrated (5 times more than wind and between 10 and 30 times more than solar). [2]

Despite the large number of patents involved in obtaining energy from the sea, are very few the installations that are being tested worldwide.

2. Exploiting existing wave in Spain

In our country, in the small port of Mutriku , Guipuzkoa, began operating in July 2011 the first installation, pre-commercial wave power, based on the Oscillating Water Column technology, OWC, its implementation took advantage to build a coat dock with the central integrated in this. It has 16 cameras, each housing is fixed to a pitch turbine type Wells, of 18.5 kW rated power, a total of 296 kW, capable of producing annually an energy of 600,000 kW • h. In this case the turbines are driven by compressed air wave effect.

While already producing energy is still too early to know which is the result. No other plant is producing energy and fed into the network.

Other more or less advanced projects are being tested. This is the case of "WaveCat" in Galicia, which is composed of a floating device with two converged hulls to form a "V" to concentrate the increasing wave height, overflowing with some side tanks from where it flows to a turbine designed to work with little height. The Canary Islands are studying the usefulness of the model Wave Dragon, Denmark. It is based on a water-storage tank located about 2 m above sea level, which includes a ramp wave water exceeding a certain level. The tank discharge operated at a Kaplan turbine.

Swell data obtained from WANA points and by means of the different beacons placed along the Canary Isles coast which measure the height and period of swell, demonstrate its potential [3]

Both, Pasajes and Santoña, as experimental buoys have been installed that use the vertical motion of waves to drive hydraulic pumps to transfer mechanical power to an alternator. The results were not expected. Hydraulic system failures and damages arising in temporary halted the project.

3. Description of proposed converter.

In Figure 2, top, shows the profile of the device represented in the resting condition, sea state calm. At the bottom shows a volumetric view. This is a floating structure with two parallel prismatic floats with their axes situated at the front of the waves. This is mounted on a stand which houses the machinery and electrical generator.

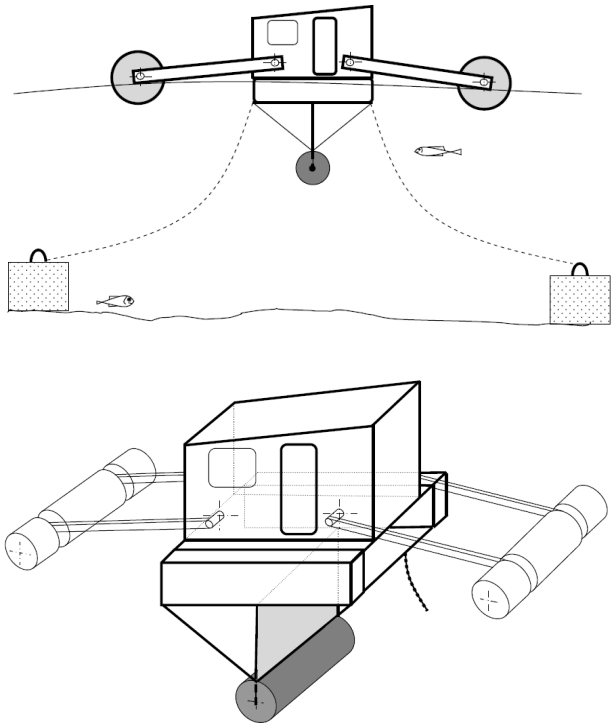

Fig. 2. Proposed structure for power converter

Structure located in an area with waves, suppose that the waves move in the direction from left to right, the cylindrical floats follow the movement of waves and transmit the alternative angular displacement of the arms to the machinery located in the house. When the left float is pushed up it creates a torque tending to rotate all the structure in clockwise. To mitigate this effect is so in the bottom of the submerged structure is fitted as a keel plate that opposes the rotation by acting as a hydraulic brake.

Moreover, the displacement of the wave incident on the plate creates a counter clockwise torque. To prevent failure of the solder from the top of the keel bars are placed, represented a 45 º, from the bottom of the keel. During the rotary one bar will work at tension and the other in compression. From the bottom of the keel also provides a fixed ballast of cylindrical shape to oppose any rotation, clockwise or counter clockwise.

The ballast is welded to the bottom of the keel but is suspended from that and fastened with a bar or cable to its shaft.

This prevents fatigue or by an excessive bending stress could break the solder joint. To keep the structure is drawn, there are two dead, one left and one to the right, coupled with the structure in its plane of symmetry, by heavy chains. The mission of these anchors is treble. First, as mentioned, keep the structure is displaced in the direction of the waves, secondly keep everything aligned for all waves move parallel to the floats. An angular displacement (in the horizontal plane) in one direction or the other creates a misalignment between the forces that create a torque in the direction of undoing the

disturbance. Third, help to prevent the rotation (in the vertical plane) as it was explained above. If the structure is rotated clockwise, the chain will be further strained the left side and weaker on the right side of what the torque will be counterclockwise. An alternative to chain link between dead and structure is join them with a rope and place a weight in the middle of the structure.

In order to provide to the flotation sufficient resistance to the deformation caused by the impacts of waves without metal reinforcements, it is advisable that its lateral surface is wavy. If it is also filled with polyurethane foam achieves two purposes: 1 increase their non-deformability (similar to what happens in the manufacture of sandwich panels) and 2 in case of loss of watertight (e.g. due to corrosion) is avoided the flood to be already occupied the interior of the float.

The bars connecting the floats with the machinery are carried out as security, a rotation limiter, for example with an appendix soldier in the bar (not shown). When the bar reaches a certain angle of rotation would stop the appendix with the house. One positive consequence of having these caps is that even with the large storms would dump the structure because to do so should turn on one of the floats.

Since energy can be obtained is proportional to the length of the cylindrical floats can have these for longer than the structure. Similarly, to give the whole greater buoyancy the prismatic floats can be made longer. This solution also contributes to increased resistance to the above turns clockwise or counterclockwise. In any case, be chosen for the weight of ballast and keel size appropriate to the worst sea conditions that is expected to go to work.

The name “WaveSwim” responds to the object to moving on the waves surface with a movement of lack of coordination with the arms, swim, as per a swimmer would de done.

4. Machinery inside the house.

Figure 3 shows a simplified schematic of the machinery.

The reciprocating motion of each float-arm assembly is transmitted to the equipment housed inside of the building, which protects it from inclement weather, through two semiaxes can rotate inside two separate bearings, marked with number 2 simplicity in Figure 3. The other bearings were not represented to simplify.

Each bearing shall be firmly seated on the inner side of the bulkhead, and it will be radial design and must be overdimensioned to can support the overload proceeding of the impact from the waves on the floats during storms. This is of particular interest to the two bearings located at the side the front of the wave (left side).

To transmit the motion from the shaft axis 8 to 21 can be used gear drives, that is to say, assembly teeth wheel (the technical solution more reasonable when it comes to high power) or, as is shown in the figure, an initial chain drive, more economical solution, but subject to breakdowns and increased maintenance and reduced efficiency and otherwise admissible only when efforts are not high. To simplify the description we assume that the initial transmission chain are made.

If the left float is moving up, also the arm 9 will move up. The drive shaft 8, turning anticlockwise, transmits motion to the gear wheel 7 which also rotates counterclockwise, and through the chain will be turn the pinion counterclockwise also.

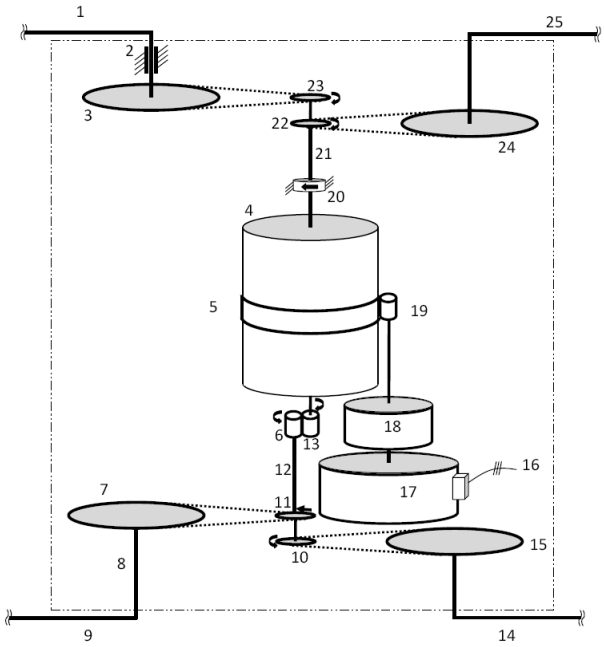

Fig. 3.Machinery inside the house

The pinion 11 includes a retention mechanism (ratchet) so that if the Nº7 wheel rotates counterclockwise (when the left float is rising) the Nº 12 shaft rotates counterclockwise and the Nº6 wheel will return counterclockwise also, and the Nº13 wheel engaged will return clockwise and the Nº21 shaft is rigidly will return clockwise also. If the Nº7 wheel return (that is, when the left float is lowering) the Nº 11 gear pinion will return clockwise also, but due to the internal mechanism of ratchet movement is not transmitted to the Nº12 shaft. As just seen. only during the upward movement of the left float transmits motion from the arm shaft 9 to 21.

The downward movement of the float is used through the arm marked 1 in Figure 3. The process is as follows: lower arm 1, the Nº 3 wheel rotates clockwise, the gear 23, like 10, 11 and 22 is equipped with ratchet mechanism and the shaft 21 rotates clockwise.

Block 4 is an elastic accumulator constituted, for example, a flexible metal strip (by way of the "rope" of traditional watches). Figure 4 shows a possible constitution.

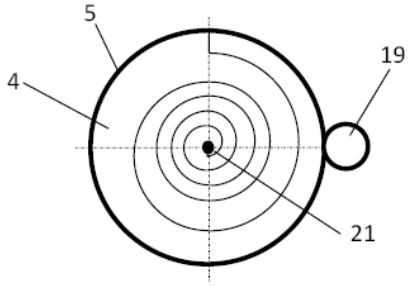

Fig. 4. Mechanical energy accumulator.

The function of this accumulator is multiple. First, since the ascent and descent speed of the floats will not be constant, the speed of rotation of the shaft 21 will be neither, and yet the output speed, the speed of the generator, it will be constant. It is similar, following the

analogy of the clock, with, we give a quick return and another more slowly to the clock wheel. This does not a effect to the more slowly of rotation of the needles. Although the speed of rotation of the input is not constant, the output speed is constant.

Following to an electrical analogy, it acts as a similar manner as you would be a filter capacitor, high capacity, fed by a current source: large variations supply power do not affect the terminal voltage. The second mission of the accumulator is to avoid high mechanical loads that would be subject to the teeth of the gear if the transmission were rigid. Think of the high inertia of the oscillating mass arms and floats, and also in the inertia of rotating parts, mainly outside of the accumulator multiplier and generator, with the couple faced.

The gears 6 and 13 are chosen with the same number ofteeth so that during movement up and down of the float the mechanism works the same way.

The shaft 21 is a thru-axle on the inside of the ratchet 20,ratchet whose "stator" is firmly attached to the fixed structure. Its mission is to prevent a partial discharge of the accumulator via mechanical through the arms and float assembly.

As the accumulator is charging will grow the torque required to prevent the discharge of energy itself, which is to say that grows the tangential force exerted by the teeth of the outer ring of the outside accumulator, represented with the number 5 in Figure , 3 on the teeth of the pinion 19. At one point the pinion 19 begins to rotate, as the input shaft speed of the multiplier 18, whose output shaft is the input shaft of the electric generator represented by the number 17.

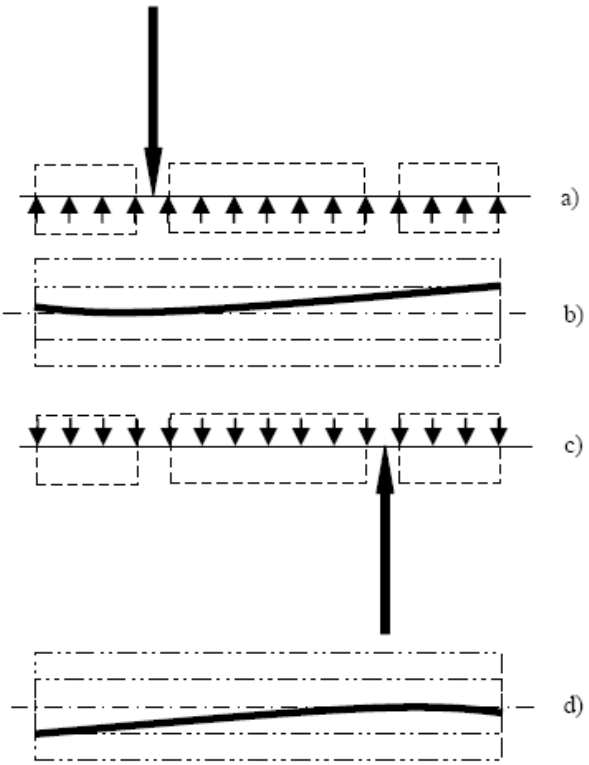

Fig. 5.- Distribution of forces and deformation.
a) and b) float up, c) and d) float down.

What has been said about the performance of the left float with his arms 1 and 9, applies to right float with his arms 14 and 25. The arm 1 works when the left float is down and arm 9 when the left float goes . With respect to the right float the arm 25 works when the float rises, and the arm 14 works when the right float down. Therefore, assuming that the structure does not rotate, except for the moments in which one of the floats is on the crest or in the valley of the wave, we see that there will be two arms (each float) via of which energy is transferred to the accumulator.

That offers resistance to the displacement of each float only one of the arms means that the shaft that supports the floats will be subjected to bending stress not symmetrical on the other hand, the arm is subjected to torque, both efforts have be taken present for the proper dimensional according with the effects of fatigue. Figure 5 shows the vertical thrust of the water due to buoyancy, evenly distributed, and the reaction of the arm at the junction counteracting the resultant. Will also be represented as the deformation of the shaft. The graphs a) and b) in the case of the float up and c) and d) for when the float is down. Distributed forces represent the difference between the thrust forces (for buoyancy) and the forces of weight**.**

5. Selection of the electrical generator.

The study of alternative electrical generators suffered a heavy impulse due to the development of renewable energy, wind and water, wind turbines and little hydraulic advantage.

Certainly, from electrical engineering will have to answer to the question of finding the best alternative for wave energy converter. The differentiating factor for this type of conversion is the nature of drive: linear, alternate, low speed and low frequency. Important steps are ready taking with respect to the direct drive linear generators. In effect, linear is not necessary to transformation of the type of movement required, and direct drive, that is, without intermediate gears. Direct consequence of this is the enormous size of the generators are being tested. [4]

Recent studies suggest that the Synchronous Linear Permanent Magnet Machine, PMLSM, are the most suitable type for wave energy conversion. [5]

In our case, where small powers, taking the view of the limited development of linear generators and prices, it does not reasonable to think as first choice a linear generator and so they departed, as designed data, of o rotary generator.

It is desirable that the machine is robust and maintenance is as small as possible. With the above seems to discard the use of direct current machine, although it must be borne in mind that today's brush replacement intervals can be many months. Conceivably then, as more appropriate, in a synchronous generator with a high number of poles as part of a very slow speed before the accumulator. The inconvenient of small generator speeds involved is heavy and bulky machines. An alternative that may be of interest is that of permanent magnet synchronous generator, which carries a rotor of lighter weight and diameter, while the price is considerably higher than its counterpart in rotor winding.

This option reinforces the fact that the Permanent magnet excitation system has cornered the market is small medium size generators due to its simplicity improved

feasibility and the elimination of energy losses in the rotor [6]. It is advantage the experience gained by manufacturers in the development of such low-speed generators for other use of renewable energy: wind power.

6. Maximun Power convertible.

It is the maximum importance to do an estimation of the maximum power that can be transformed with a converter. To do this we will get some results based on some simplifications.

Come from the assumption that the wave height is reduced when understood as the difference in elevation between crest and valley is lower than the available travel of the floats that results when the arms are located between its two extreme positions. This would be the case shown in Figure 6.

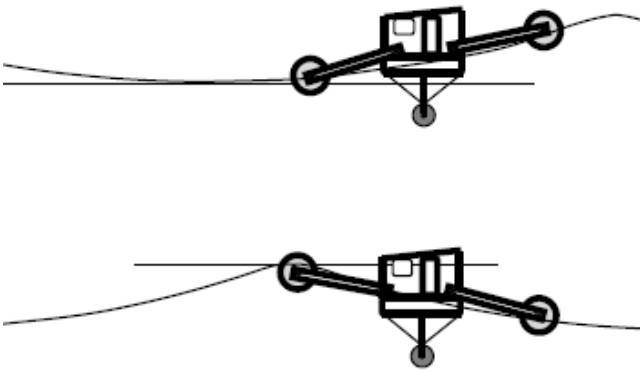

Fig. 6. Working with small waves converter

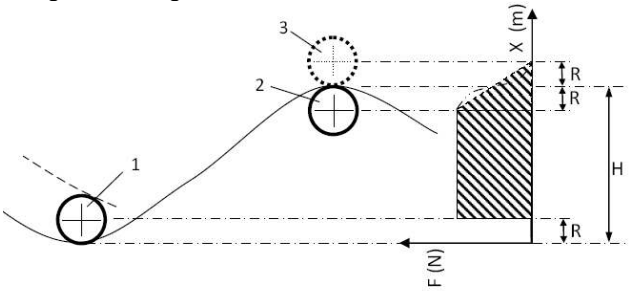

Fig. 7. Power optimization

Figure 7 represents primarily with the Mark 1, the position of one of the floats when the wave passes to the valley (we neglect the weight of the float and arms). When the wave crest passes with the float position is the 2, if the arm is passing its maximum torque, or if it makes the most of their energy, ending at position 3.

Since energy is expressed by

$$W = \int F \cdot dx \qquad (1)$$

as it is to get the most interested in energy than the value of force, all the way, so it is, and for the present case this happens when the float has all its volume in water, peak evicted. That is, interest not to start the upward motion until the surface is covered by water (as depicted in position 1, the surface wave dashed). The maximum travel this buoyant force exerting constant, ends when it reaches just below the crest of the wave, position 2. From here, as will can provide a boost emerging gradually smaller, up to float on the crest, position 3, with zero thrust. The force between position 2 and 3 shows a trace, but to have symmetry, the area under the graph of force is the same as if the variation was linear. As said, represented by R the radius of the float, and H the height of the wave, the maximum energy obtainable by float meter in length and per cycle, W_M*, given that the converter will have two floats will be

$$W_M^* = 2 \cdot \pi \cdot R^2 \cdot \rho \cdot g(H - R) \quad J/m \qquad (2)$$

As the density of seawater, ρ, about 1028 kg/m^3, and g the acceleration of gravity.

If we call T the wave period, the number of cycles per second is 1 / T and therefore maximum power convertible, P_M *, will be:

$$P_M^* = \frac{2 \cdot \pi \cdot R^2 \cdot \rho \cdot g(H - R)}{T} \approx 63{,}34 \frac{R^2 (H - R)}{T} \quad kW/m \qquad (3)$$

From the above expression shows that the optimal radius float, depending on the wave height is:

$$R = \frac{2}{3} H \quad m \qquad (4)$$

To obtain energy and power has been taken into account on utilization from the float began to emerge, but this use is technically very difficult to carry out and it is unrealistic to consider it. Therefore, without taking it into account, the energy gained per cycle is:

$$W_M = 2 \cdot \pi \cdot R^2 \cdot \rho \cdot g(H - 2R) \quad J/m \qquad (5)$$

And the power convertible top, P, is:

$$P_M = \frac{2 \cdot \pi \cdot R^2 \cdot \rho \cdot g(H - 2R)}{T} \approx 63{,}34 \frac{R^2 (H - 2R)}{T} \quad kW/m \qquad (6)$$

And this expression shows that the optimal radius is:

$$R = \frac{H}{3} \quad m \qquad (7)$$

If we design a converter of this type, for a wave height H prevailing in the area, with the optimal float radius R, ie, substituting the result (7) in expression (6), we obtain the following approximate expression:

$$P_M \approx 2{,}35 \frac{H^3}{T} \quad kW/m \qquad (8)$$

As mentioned, this would be the maximum power that could theoretically develop this converter, in reality, of course, would be lower.

Now we justify the graph of push the float during the overexploitation, as Figure 8.

The volume of water displaced by one meter of float when it reaches the crest of the wave, before beginning to emerge is:

$$V_0 = \pi \cdot R^2 \quad m^3 \qquad (9)$$

When the float above water height "h" the erupted volume is:

$$V = \pi \cdot R^2 - \int_0^{\phi_1} (2R\,sen\phi) R\,sen\phi\, d\phi$$

Solving,

$$V = \pi \cdot R^2 - R^2 \left[\phi_1 - \frac{sen2\phi_1}{2} \right] \quad m^3 \qquad (10)$$

Since the thrust is proportional to float submerged in Figure 9 shows the evolution of the thrust, expressed as a one, vs angle function of immersion, 0 ° corresponds to all the float submerged and 180 degrees around the float on the wave.

The dashed line represents the linear variation gives rise to the same energy transformed

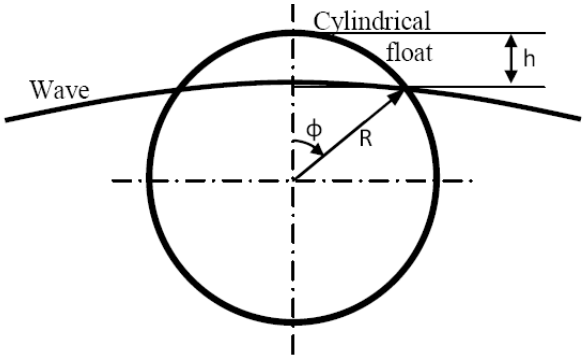

Fig. 8. Float emerging

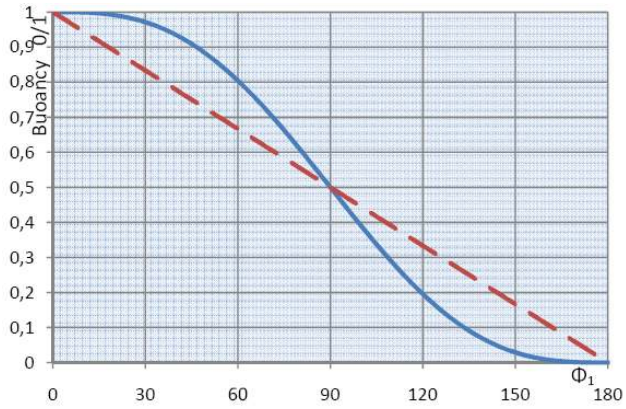

Figure 9.- Evolution of pushing

Previously, it was indicated that, by design, the arc rotated by the arms that support the floats should not exceed a certain limit. That is, to design a converter must be fitted to the specific area of work. For a given angle of maximum displacement, the larger the wave height greater must be the length of the arms.

Figure 10 shows the evolution of the wave height as recorded by data from the buoy Langosteira, outside next to the Port of A Coruña, in the month of December 2011. Height observed, except for the case of temporary day 14, oscillated in the range of 2 to 3 m.

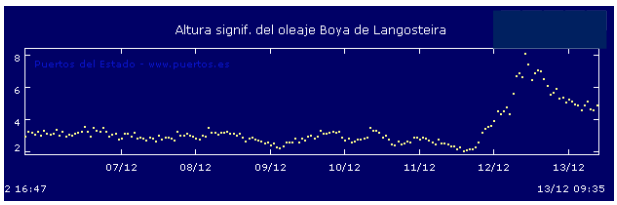

Figure 10.- Registration of wave height in the outer Port of A Coruña.

7. Conclusions

Energy from the power of water represents large amounts of clean, Renewable Energy. The World Energy Council estimates the energy that can be harvested that from the world's oceans is equal to twice the amount of electricity you produce that the world now. This simple fact shows that within the energy sources in the immediate future be developed to replace fossil fuels, because they are exhausted and so environmentally friendly, energy from the sea in each of its three components will be a serious option. The types of converters will be most appropriate to each condition.

The presented here, low power, low cost and low maintenance can be suitable for areas with low population density and to be placed in areas of no great waves.

It should be remembered also that, due to economic social cohesion, the European Union is promoting to improve the production of electrical energy from renewable energy sources. Construction of wave parks should be made in areas of moderated or lower environment sensibility, using safe technologies. The European Union estimates a wave energy cost of about 5€/kW·h.[7]

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