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New steps in the development of the second generation TEC GESMEY

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***Abstract*—The paper shows the results of the new steps that have been done in the development of the tidal energy converter GESMEY. These are the design, construction and trials into the sea of a 1/10 scale prototype and also the construction with the same scale of the buoy BOSCEM, that anchors the device and lets it in the correct work position and depth, along the two directions of the flow that the daily tidal cycle have. Inside the paper is described the objectives and the methodology of the experimental trials that were carry out the last summer with the scale prototype.**

GESMEY is a new type of tidal energy converter (TEC) that has the capability to exploit currents in waters over forty meters by itself and it gets only using its internal ballast system the necessary equilibrium between hydrostatics and hydrodynamics forces to make the emersion and the immersion procedures without any other help.

Finally the paper shows the description of the results obtained over the performance of the devices along the immersion, emersion and floating transport manoeuvres and afterwards the results, that were obtained along the generation power tests that were carried out, are shown

***Keywords*— Marine renewable energies. Exploitation of marine currents energy. Marine and Tidal currents energy converter. Exploitation in deep water of the marine current energy.**

I. INTRODUCTION

Marine current´s energy is one of the most important marine renewable energy resources but nowadays the technological developments for its exploitation are still in the beginning of their life and there are only devices used mainly as a test to learn more and improve the technology and not to generate or sell electricity [1].

At present time there are over seventy devices into this technology, they are in different stages of development but not in industrial exploitation and only a small number of them are suitable for depths over 40 m and constitute the second generation of TECs and one of them is the generator GESMEY and the results of the new steps that have been done in its development are the object of this paper and into it the objectives and the methodology of the experimental trials that were carried out with the 1/10 scale prototype are described and the results of them to and so several conclusions about how those results can improve the further development of the 1MW TEC GESMEY in a real size. Is also shown the design, construction and trials of the 1/10 scale prototype of the Buoy BOSCEM that anchors the generator in the correct work position and depth, along the tidal flow of water.

II. THE CONCEPTUAL DEFINITION OF GESMEY

At present time all of the devices that are developed or in development need a mean spring peak velocity over 2 m/s to be effective and into the European sole rights exploitation there are many sites where the main velocity of the stream has this condition, but some of them are in waters with more of 40 meters depth and usually over 80 or 100 meters. Several of these places are on the Gibraltar´s Strait in the south of Spain that is the natural channel to join the Atlantic Ocean with the Mediterranean Sea and it performs an energetic resource making up by a double current that it is originated by several superposing effects that are, different density between both masses of water, the different level between the ocean and the sea, these tides are generated in the Atlantic side of the Strait and go into the Mediterranean Sea [2].

The principal part of the energy associated to these currents is on the upper Atlantic waters current and there are places with maximum current's speed up 2 m/s and normally with a depth over 40 meters and it was the initial goal of GESMEY Project (Spanish acronym for Submarine Electrical Generator with Y Shape framework) to develop a TEC specially designed to exploit these deeper currents on the Strait.

Then, with a more global perspective, the main objective of the GESMEY project was to develop a generator with a low cost life cycle and designed for the Strait and other World sites with waters depths over 40 meters, where the present devices that form the first generation of TEC´s cannot operate. It would be noted that one important part of the oceans current´s energy is in these deeper waters.

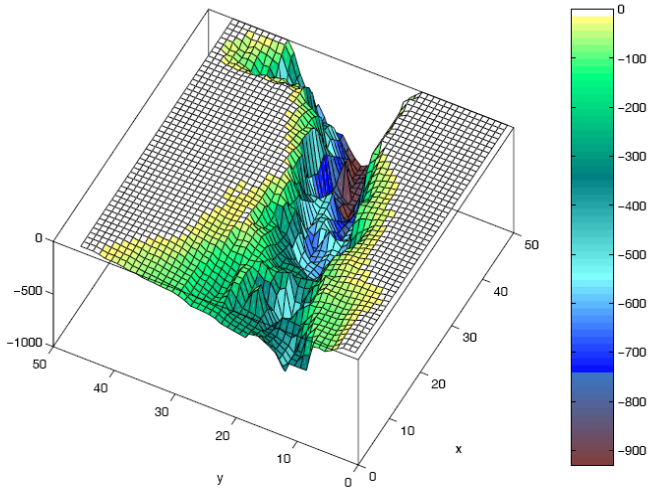

Fig. 1 Bathymetric profile of Gibraltar´s Strait

The generator GESMEY was developed with the following main characteristics:

- Simplified deployment
- Minimum environmental impact
- Robust and simple construction
- Easily scalable (depth, stream, speed, nominal power)
- Integration of mature technologies

The project was germinated from an initial idea of Professor Lopez Piñeiro, patented by the Technical University of Madrid (UPM) [3] and initially it had been developed in collaboration between two research teams, one from the UPM and the other one from the Foundation Technological Centre SOERMAR. The project was supported by funds from The National Research Program 2008/2011 of the Spanish Administration and at this end another patent was delivered by the UPM to protect the new developments [4].

During the development of GESMEY project it was used as guideline the Protocol that was delivered by the University of Southampton [5] and its stage 1 was done. As results of it two conceptual definitions of GESMEY were chosen that will be shown forward and some specific methods and tools for the naval architecture engineering process were also developed.

Along 2010, new funds were obtained from the Spanish Ministry of Industry, Tourism and Commerce to carry out the stage 2 (Construction design) and the 3 (Operation design), of the Protocol. These stages were being developed along the years, 2010, 2011 and 2012 by a consortium between UPM, SOERMAR and Astilleros Balenciaga, a shipyard with huge experience in offshore ships and at the end of the stages it got a 1/10 scale prototype with 10 kW power that was constructed and tested in the Cantabrico Sea during the summer of 2012.

The form of GESMEY generator has one rotor with three blades that propels one electrical alternator, placed into a POD and joined it there are three columns situated on a perpendicular plane with the axis of the rotor and at the end of each columns there is one float with torpedo shape that has its axis on parallel way to the rotor´s one.

At the end of this process was delivered GESMEY U1M design with 1MW of power for places where the one way flux of the stream is highest [6]. This prototype is shown on Fig.2 and their general specifications are exposed on Table I.

This concept has a rotor with three fixed pitch blades because they have a better reliability and with very improvement efficiency it the flux is unidirectional as it happens in the case of U1M generator. This case is optimum for the current´s on Gibraltar's Strait.

The other main parts of the two concepts of GESMEY are, one central pod with the power take off components and the auxiliary systems, the columns that are the main structural parts and are also used as auxiliary ballast tanks and the end torpedoes are the main ballast tanks that let the stability of the device on operation with asymmetric loads and its stability on flotation like a semisumergibles platform.

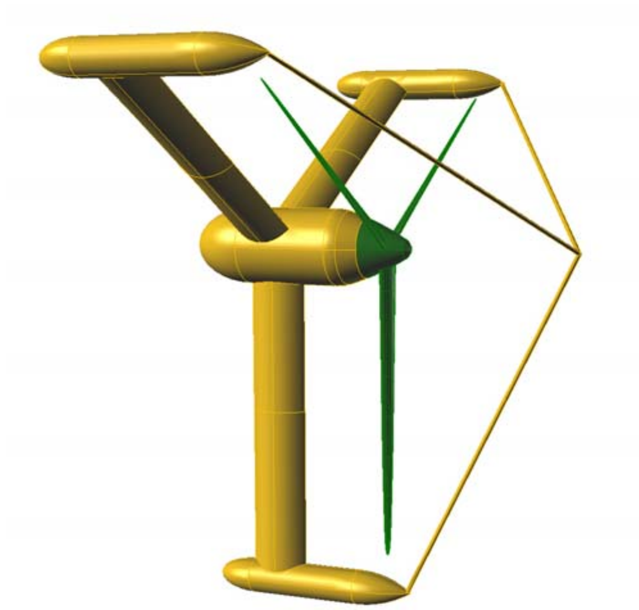

Fig. 2 General view of GESMEY U1M

Along the develop of the GESMEY project, different possibilities for the development of a computerized tool, that facilitates the several calculations that are necessary, were considered and at last the tool HACERIC (Spanish acronym of tool for the analysis of radial bodies inside current´s flow) was developed and used and it let the user enter data corresponding to the analysis of the device and adjust different ballast tanks levels obtaining as results the most significant forces, torques and orientation angles of the device in operation or in other positions.

For the hydrodynamic resistance calculation of the supporting body was used one CFD analysis and also some towing tank tests in the hydrodynamic towing tank of the E.T.S. Ingenieros Navales of Technical University of Madrid (UPM).

TABLE I
GENERAL SPECIFICATIONS

Description	GESMEY U1M
Power (kW)	1000
Stream Highest Velocity (m/s)	1,8
Sea bed depth (m)	80
Rotor diameter (m)	32
Minimum end of the blade depth (m)	34
Rotor (RPM)/Gear output (RPM)	12/750
Structure	Steel
Number of devices in a generation park	20/50

For the analysis and calculation of the device´s structure was used FEM methods and tools and also with the elements of the anchor and mooring systems [7].

To carry on the hydrodynamic design of the propeller in GESMEY Project and with the design characteristics that lets it get energy of a bidirectional flow as is usual in tidal currents, it was decided to use double symmetric outlines (two axis of symmetry) to form the annular sections of the blades and how at present time there are is not information over this type of blades working into the Reynolds Number range that a marine turbine do it a preliminary analysis was done with one thickness / chord rate of 0,21 and into the Reynolds Number range of (1×10^6 ; 8×10^6) and looking for a good resistance of the blade to the water effects by the point of sight of its structural construction.

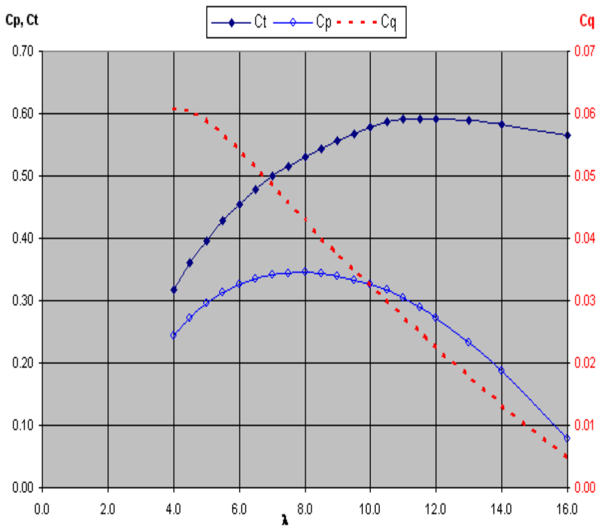

Fig. 3 XFOIL Modelling Results

Finally, by means of the use of the XFOIL tool[8] it was possible to get the C_p, C_t, C_q curves by the following performance requirements, that were chosen thinking ain a particular operation site into Gibraltar´s Strait and with one rotor´s diameter between of the GESMEY A6.7 and GESMEY U1M ones and the following curves that are shown in Fig. 3 were got as results.

TABLE II
DESIGN SPECIFICATIONS

Number of blades	3
Rotor diameter (m)	20
Rotor (RPM)	12
Current velocity (m/s)	2
Ration Kernel	15%R

It was also constructed one scale model of the GESMEY generator with the rate 1:40 and with it was doing several tests into the UPM towing tank and got good results , over C_p values of 38 % , which are similar to the obtained into [9] and [10] .

III. CONCEPTUAL DEFINITION AND CONSTRUCTION OF THE SCALE PROTOTYPE

The most important goal of GESMEY is the simplicity of the operational procedures and by this reason it was necessary to test the performance of the device very carefully during its installation, transport and maintenance on float. As it is described in [7] and [11] it is transported on float to the vertical of the place where it would be on operation and there by the immersion procedure the generator gets by itself the right depth with the correct water level into the ballast tanks and when the right depth is reached the device is fixed to the mooring buoy using a ROV or by a diver.

And the way to analyse this performance is the design and the construction of a scale prototype and with it develops several trials into the sea to confirm that the real performance of the device is very similar to the simulation one.

TABLE IIII
GENERAL DIMENSIONS OF GSY-ME10

Description	Diameter mm	Length mm
Rotor: Blades Hub	 1600 200	 270
Pod	457	1629
Torpedoes	324	1937
Columns	300	900
Total Length	------	2004
Pod + Rotor	------	1899
Beam	------	2510
Envelop	2900	------
High	-------	2260

One 1/10 scale prototype it was designed and constructed with 10 kW nominal power that is named GSY-ME10 that will work connected to other scale prototype of the rotating buoy BOSCEM.

The structure of both prototypes (Fig. 4 and Fig. 5) was constructed using stainless steel as basic material and their main characteristics are shown in the tables III, IV and V.

TABLE IVV
GENERAL WEIGHTS OF GSY-ME10

Description	**Weight Kg**
Structure	236
Equipment	91
Total Weight	330
Displacement	703 dm^3

The buoy BOSCEM is the device that lets the anchoring of the generator with only one point and has the possibility that the generator rotate over it to exploit the two ways of the tidal current.

Fig. 4 View of the structure of GSY-ME10

The scale prototype of BOSCEM that was constructed has a outline NACA 0040 and into there are three ballast tanks with one unitary capacity of 100 litres of water and the water level into them is controlled by inserting compressed air.

Along the trials the complete weight of the prototype BOSCEM was over 300 Kg, enough to keep the device in the right depth during all the tests of generation that were done with the prototype GSY-ME10.

TABLE V
DIMENSIONS AND WEIGHTS OF BOSCEM

Length (mm)	1000
Beam (mm)	400
Height (mm)	800
Weight (Kg)	80
Displacement (dm^3)	220

The generation and the control systems of GSY-ME10 were designed and constructed in The Electrical, Electronic and Systems Laboratory of the E.T.S. de Ingenieros Navales from the Technical University of Madrid (UPM) to test the control of the emersion and immersion procedures and the electrical power generation under different speed and depth conditions.

Fig. 5 View of the structure of BOSCEM

Fig. 6 shows a view of the 10 kW alternator coupled with a direct drive motor which was tested and validated into the Laboratory. It can be easily observed the three phase line and the DC excitation line (computer controlled). A complete computer-controlled system was developed for measurement, monitoring and controlling with more than 100 signals from/to the PTO and the ballast system of the reduced scale prototype.

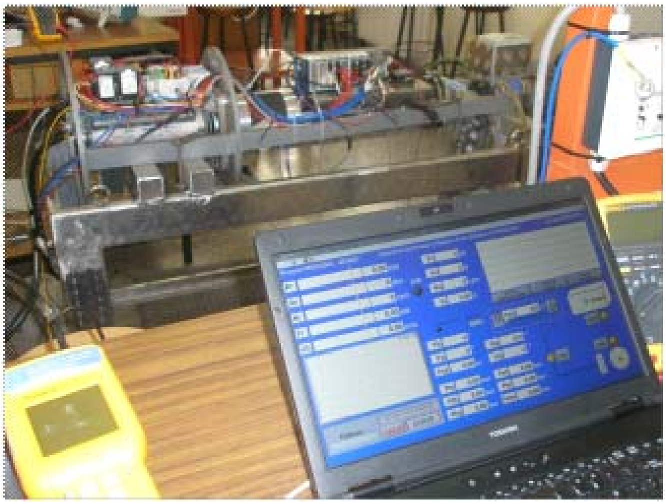

Fig. 6 View of the PTO for the 10 kW GSY-ME10

At the same time the compressed air control module was constructed and is fill with air from the compressor and then it is distributed to the different ballast tanks and other auxiliary elements.

The rotor was designed with three fixed pitch blades that had been constructed with carbon fiber material and the hub was made using stainless steel.

So all the main components of the PTO of GSY-ME10 from the side of the marine energy to the side of the electrical energy, can be resumed as follow:

- Rotor
- Low speed shaft
- Gearbox
- Mechanical power instrumentation
- Electrical Alternator
- Electrical power Line
- Pod

And all of them are into the domo over one bedplate with the adequate bearing and support set.

One external view of the GSY-ME10 ready for the development of the trials is shown in the Fig. 7.

Fig. 7 View of GSY-ME10

IV. Definition and Methodology of The Trials

The trials that GSY-ME10 prototype had been yielded had as objective to confirm that the performance of the device during the manoeuvers of immersion and emersion for its location at the correct depth for operation and also along the process of power generation is very similar to their previous simulations had shown.

The Tests were carried out into one protected marine zone in the Cantabrico Sea and along them several parameters that show the performance of the generator were measured, into them the power reached by the rotor operating with different velocities of the current.

To get the nominal power of 10 kW that GSY-ME10 has, it was necessary a mean peak velocity of the current over 2,7 m/s and because of into Cantabrico Sea the currents with these velocities do not exist it was necessary to produce them by the towing of the generator using one auxiliary vessel with different velocities.

The trials protocol demand two kinds of tests, ones are towing tests that show the efficiency and the performance of the generator on power operation and the other ones are manoeuvers tests that show the behavior and stability of the prototype during its emersion and immersion and also its situation on floating.

Fig. 8 View of the prototype on board of the tug vessel

To carry out the trials it was necessary moreover the GSY-ME10 and the buoy BOSCEM prototypes the other main devices that are following described:

- Tug vessel with towing capacity to tow along the two prototypes and one auxiliary vessel , zodiac type, with a constant velocity between 0,5 and 3,0 m/s by this reason the maximum towing velocity of the tow was 5,8 knots. This tug vessel had enough free space over main deck where all the test equipment and the going on board one technical crew of four people were displayed.
- Auxiliary vessel pneumatic boat type that was towed by the main tug and it had one double function one of them to transport hanging the buoy BOSCEM and the other one is the platform to support the connection manifold of the umbilical's wires. This auxiliary vessel is only necessary along the towing trials.
- Auxiliary security buoy with ascension throw over 150 N and with the task of impede that the GSY-ME10 prototype hit on the sea bed if one of the ballast tanks failed.
- Mooring structure that is only necessary along the manoeuvers trials of the GSY-ME10 prototype. It is

gravity mooring triangular structure, performed with three steel bars of one length of 2 m and with one concrete weight of 50 kg in each triangle vertex. This structure has the task to moor the buoy BOSCEM to the bottom on one way that lets it turn round freely and it is possible to see the mooring structure on board of the tug vessel in the Fig. 8.

- Ropes, Wires and Tackle, to let the support and connection of all the prototypes, vessels and other equipments between them two hybrid cables are that have very important tasks along the develop of the trails. One of them is the umbilical hybrid cable that has into two power wires, one network wire and four compressed air conductions, this cable is only used along the maneuvers tests and the other one is the hybrid surface cable that is only used along the towing trials and in it two power wires are and the network one, both of them connect the generator with the manifold box. There are several steel ropes to fix the GSY-ME10, the buoy BOSCEM, the mooring structure and the vessels, all joined between them.

The main characteristics of the towing to develop the trials are:

- Maximum towing velocity of 5,8 knots
- Necessary towing throw of 1 tons
- Maximum towing throw of the vessel between 1,5/2,0 tons
- Whole length of the unit to be towed:
  - Short 28,5 m
  - Intermediate 43.5 m
  - Large 58,5 m
- Weight whole unit 750 kg
- Sea condition calm weather
- Towing cable loads:
  - Maximum load 10 kN
  - Maximum load with velocity of 3, 0 m/s 8, 4 KN
  - Maximum load with velocity of 2, 5 m/s 7, 0 KN
  - Maximum load with velocity of 2, 0 m/s 5, 6 KN
  - Maximum load with velocity of 1, 0 m/s 3,8 KN
- Maximum admissible load of the towing cable 41,42 KN

The trials were defined in two protocols, one for the maneuvers tests and the other is for the power generation tests by towing. In the first case the objectives are to show if both prototypes have the same performance in the reality when they are in immersion, emersion or on floating procedures that the previous simulation showed and is necessary to remember from reference [7] that it was supposed that the generator is completely assembled in a yard or on one shore platform, near the point where it will be installed on the sea and it is transported on floating by a tug vessel and when it reaches the vertical of the place of operation the immersion procedure begins and the generator gets the right depth by itself with the correct water level into the ballast tanks and there it is connected to the mooring line and also to the electric line to transmit the energy ashore, and it is operating standing its position with a very less deviation. The usual maintenance is doing float and when it is necessary do it; the emersion procedure begins and put the generator on flotation. The ballast water is expelled out by compressed air changing the level of water into the ballast tanks and the device goes up to the surface.

The generator emerges to the surface with vertical orientation and the emersion time is over ten minutes as was probed with a simulation procedure and arrives to the surface in the same position [11] and [13].

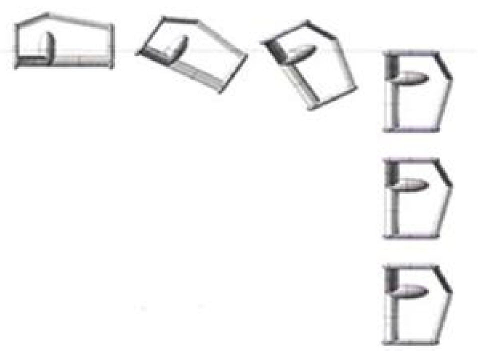

Fig. 9 Positions along the immersion procedure

On the surface it is necessary to change the main axis position from horizontal to vertical direction by expelling more ballast water in order to get this new position and the device lays floating over four meters above the surface of the sea and on this way is possible to do the necessary operations or usual maintenance tasks with the help of an auxiliary vessel. Also with this new position the device can be transported to one port or one yard if it is necessary to make especial maintenance duties [14] and [15].

V. Development of the trials

The manoeuvers trials were done along four days and with a team of six people and during them were tested the following items.

- Check out the performance of the buoy BOSCEM prototype along its immersion, its emersion and its mooring to the gravity structure on the sea bed and also the correct way of the semi automatic system to leave the buoy free.

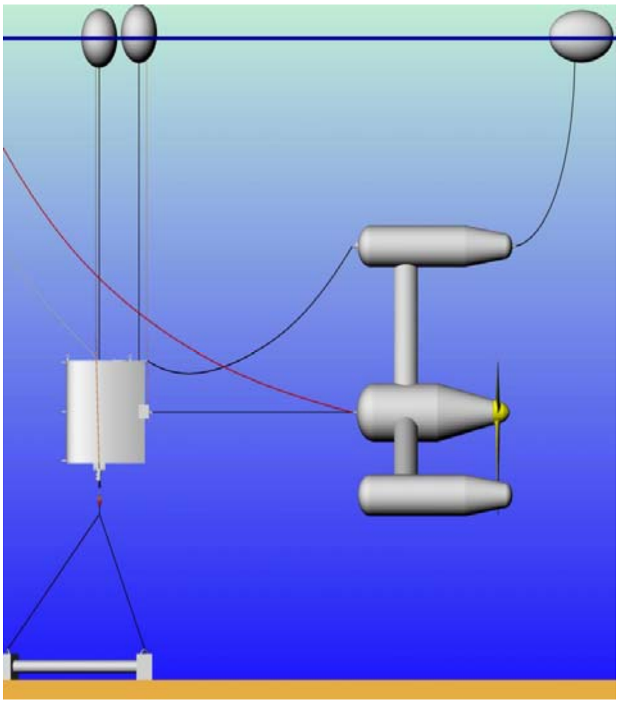

Fig. 10 Position of both Prototypes into the sea

- Check out the performance of the GSY-ME10 Prototype along the execution of several manoeuvres and were carried out tests that are described into the protocol to get the exact control of the system to feed water into the ballast tanks and over the control of the turnover in the immersion and also in the emersion and to get the stability when the device is reaches the surface of the sea and also floating

Fig. 11 Evolution of the device at the beginning of the immersion

- Check out the performance of the unit of the buoy and the generator doing the manoeuvres together.

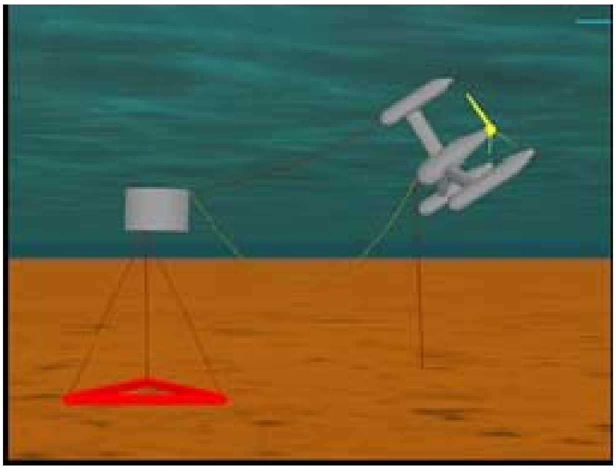

Fig. 12 Position at the beginning of the emersion

During these trials the necessary adjustments of the different elements of the control system were doing and the assessment of all the variables that conform the equilibrium position of the generator and also the buoy and it was confirmed that the device has one real performance very similar to the previous one that was simulated during the develop of the preceding stages of the GESMEY project [11].

The power generation trials and also the sea keeping of all the system (device, buoy and auxiliary vessel) were done ,using one tug vessel for five days and with the same team of six people, all the trials that conform the protocol were developed .

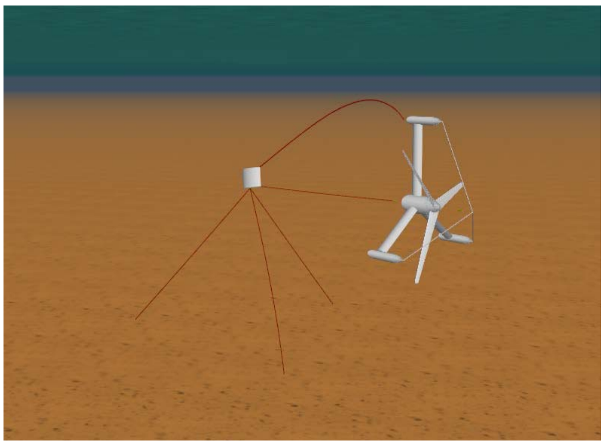

Fig. 13 Simulation of the real working position of the generator

Three double way routes were done and one by one were towed with the three lengths of the unit and in this way it was possible to make amends for effect of the marine currents over the results.

The trials were done with the following four velocities of the tug:

- 3,0 m/s
- 2,5 m/s
- 2,0 m/s
- 1,0 m/s

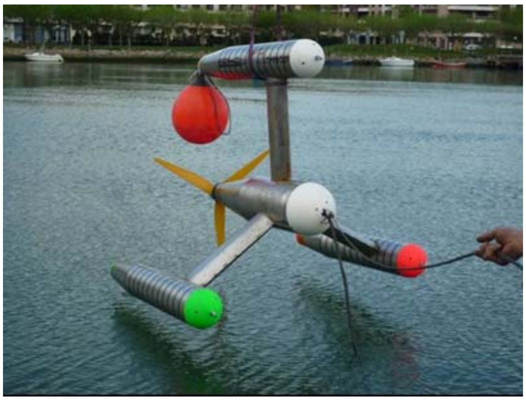

Fig. 14 Positioning of the GSY-ME10 on float

Along the trials several series of dates were taken with the following objectives:

- The assessment of the maximum power that is possible extract of the generator in function of the speed of the current and at the end of the monitoring tests that were carried out to get the electrical power/ current speed curve.

- The assessment of the trim and the list of the generator and the buoy during the electrical generation tests in function of the direction of the current and the couple forces of the rotor.

- The assessment of the real characteristics of the propeller.

In order to avoid the effect of the prop wash of the tug on the velocity of the current flow that goes into the rotor of the generator during the trials it was necessary to get the most suitable length of the towing cable to make that disturbing effect more less and were carried out several trials with different lengths of the cable and as results was chosen the more suitable of then to make the towing of the generator as it is shown in Fig 16.

Steering tests were carried out with the entire unit to determine the level of the trimmed by the head and by the stern and also the level of the shore up on both, port board and starboard.

Along the monitoring trials the assessment of the velocity of the vessel was done, the power in the rotor, its revolutions, its couple force and its thrust were determined and also the electrical power obtained and the angels of trim and of share up of the generator and other parameters that had provided large and important information necessary in order to carry out the following stage of the GESMEY project that consists in the development and construction of one industrial prototype of 100 kW power and it will be tested into the sea for one year.

Fig. 15 View of all the unit carrying out one power trial

By means of the analysis of the data it is possible to say that the performance of the generator during its operation has a high stability and its trim is very short and its list is negligible and when the velocity of the current is larger the trim goes to cero. The reason of it is that the device has the possibility of self orientation as the previous simulation of its performance showed.

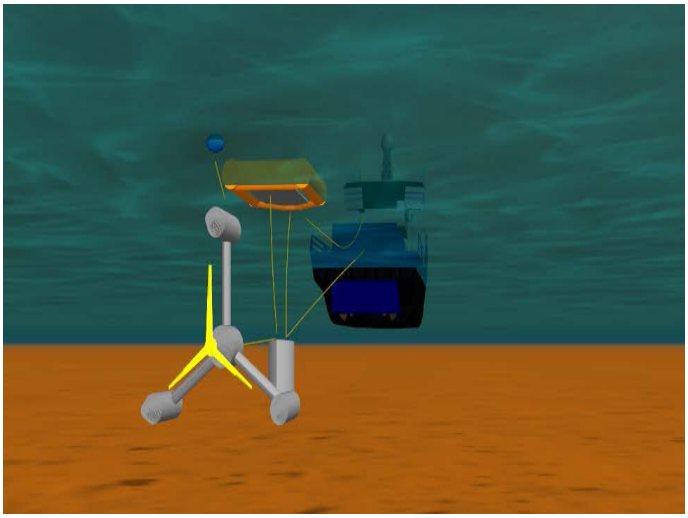

Fig. 16 Underwater simulating view of the unit carrying out the trial

Over the result of the power trials it is possible to explain the following assertions:

- On the basis of the numerical hydrodynamic model of the rotor that was realized by CEHINAV (UPM) the C_p is over 0,48 that is into the interval [0,4;0,5] as it is shown in several published papers [9] , [10] and [12].

- With one Cp over 0,48 one rotor of 1,6 m of diameter would give power on the axis of the rotor of 13,3 kW with a current velocity of 3,0 m/s and a power of 10 kW with a current velocity of 2,7 m/s

The numerical model that was used, it was supported by the set of data obtained from the curve Cp=F(λ) of the tested rotor. The operating point was adjusted as function of the measured velocities and the rotor rotational speeds. As result of the tug trials, the comparison between the results of the numerical modelling of the power that the rotor translated to the shaft and the measurement of the real points of this parameter along the towing tests that were carried out with GSY-ME10 prototype were done and the coincidence is very high as it is shown in Fig. 17. In it is possible to see that is very exact the adjustment of the curve on the cloud of real points.

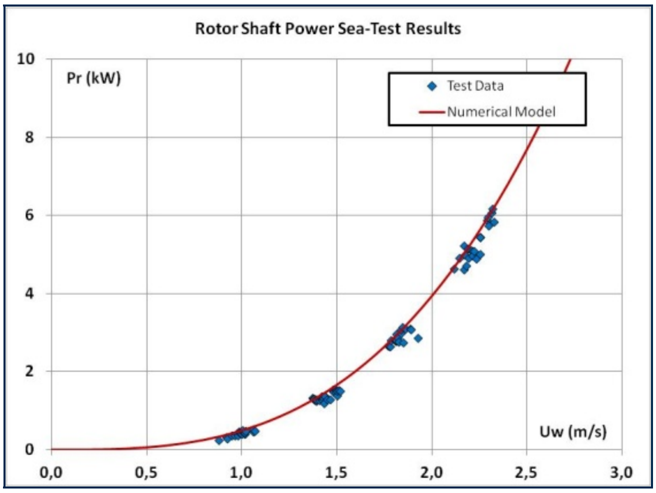

Fig. 17 Rotor- Shaft Power towing tests results

VI. Conclusions

- GESMEY is a new concept of generator that will be able to exploit marine currents energy on sites with rotor depth over 40 m and it has the possibility to exploit currents with stream speed below 2 m/s
- GSY-ME10 prototype trials show that the previous modeling emersion and immersion manoeuvres only with hydrodynamics forces become into a reality
- GSY-ME10 prototype shows that GESMEY will have a robust and simple construction with less weight than the devices of the first generation of TECs have.
- GSY-ME10 prototype shows that GESMEY does not need special and expensive vessels or offshore artefacts to transport it or positioned in the operation sites and so to emerge and removal
- GSY-ME10 and Buoy BOSCEM, prototypes show that it is possible that GESMEY works with a simple mooring and anchor system and also with a minimum environment impact because it works submerged but not lies over the sea bed
- The design of the mooring system with the Buoy BOSCEM lets that the Generator exploit the two way of the marine tidal current with propellers with fixed pitch blades
- The unit GSY-ME10 and Buoy BOSCEM shows that GESMEY has low life of cycle cost because the installation, maintenance operation and the final remove will be cheaper than other devices that at present time exist.
- The results of the trials show that the real performance of the prototypes is very similar to the previous numerical modeling of GESMEY were demonstrated.

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