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PONTE DI ARCHIMEDE S.P.A.
RESEARCH AND DEVELOPMENT

The company "Ponte di Archimede S.p.A." (PdA) is a research and development company, working in the fields of innovation engineering and renewable energy, with a particular attention to environmental issues. The company was established in 1983, then as a part of the Caronte Shipping Group. PdA carries out their international scientific researches with the support of important Italian scientists from the Italian Shipping Register (RINA), the National Council of Research (CNR), Horcynus Orca Messina, INSEAN Rome, Politecnico di Milano and the University of Naples "Federico II", together with the United Nations Industrial Development Organization (UNIDO), Chinese Academy of Sciences (CAS) and other scientific researches in China, Indonesia and the Philippines.

P.d.A has developed the ENEMAR system – with the patented vertical axis Kobold turbine as its core, for the exploitation of marine currents to generate energy. The first vertical axis full-scale marine current turbine prototype was installed in the Strait of Messina 2001. The next step is to provide renewable energy to remote islands in the Republic of China, the Philippines and Indonesia. This will be done by installing farms of the ENEMAR system. This is an ongoing project together with UNIDO and the governments of the three countries.

The Submerged Floating Tunnel concept, called the Archimede's Bridge, based on an innovative typology for fixed links across straits and lakes is also under development. A Sino-Italian Joint Laboratory of Archimede's Bridge (SIJLAB) has been originated in 1998 between Institute of Mechanics, Chinese Academy of Sciences and Ponte di Archimede. One of the main tasks of the project is to develop a 100m tunnel in the Qiando Lake, China, wide enough for cars to pass.

Moreover the project of Fuelcells (TEA) is developed together with CNR and an industrial sized prototype is operating in Messina.

The hydrodynamic tunnel is currently used for testing small models of the ENEMAR system and is to be commercialised even for other applications.

THE ENEMAR SYSTEM

Marine currents represent large renewable energy resources and have the potential to give a significant contribution to fulfill the worldwide energy demand.

The president of Ponte di Archimede S.p.A, Dr. Cav. Lav. Elio Matacena, came up with the idea of utilizing a vertical axis turbine to extract energy from the marine current in the end of the 80's. He had then been inspired by how his ships from Caronte S.p.A moved in the Strait of Messina by the means of a vertical axis propeller. The main advantage of this type of turbine, compared to horizontal axis turbines, is that no matter where the flow comes from the turbine will always turn in the same direction.

The ENEMAR system – with its core the patented Kobold turbine – was operating in the Strait of Messina from 2001 until January 2005, when it was transferred to land for maintenance. The main improvements for the prototype were a stronger rotor bearing with less friction and reinforcements of the blades. Furthermore the generator and the inverter were changed to comply with the necessary characteristics for the Sicilian electricity grid. In July 2005 the Kobold prototype was connected to the grid. This is the first marine current turbine in the world to be producing electricity to a local electricity grid, see figure 1, below.

Fig. 1. The Kobold turbine in the Strait of Messina

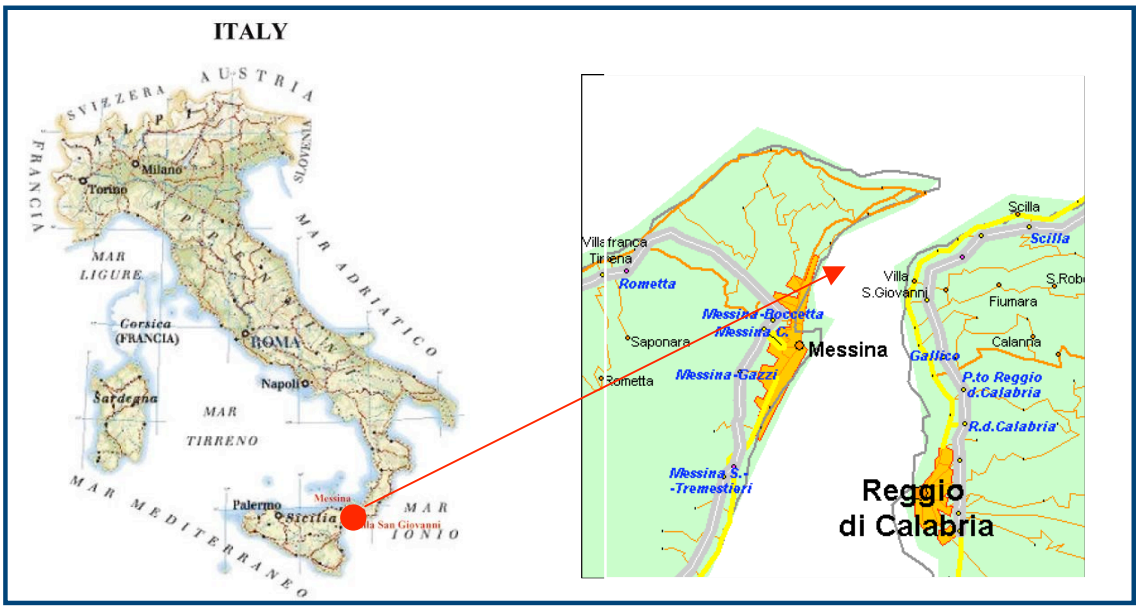
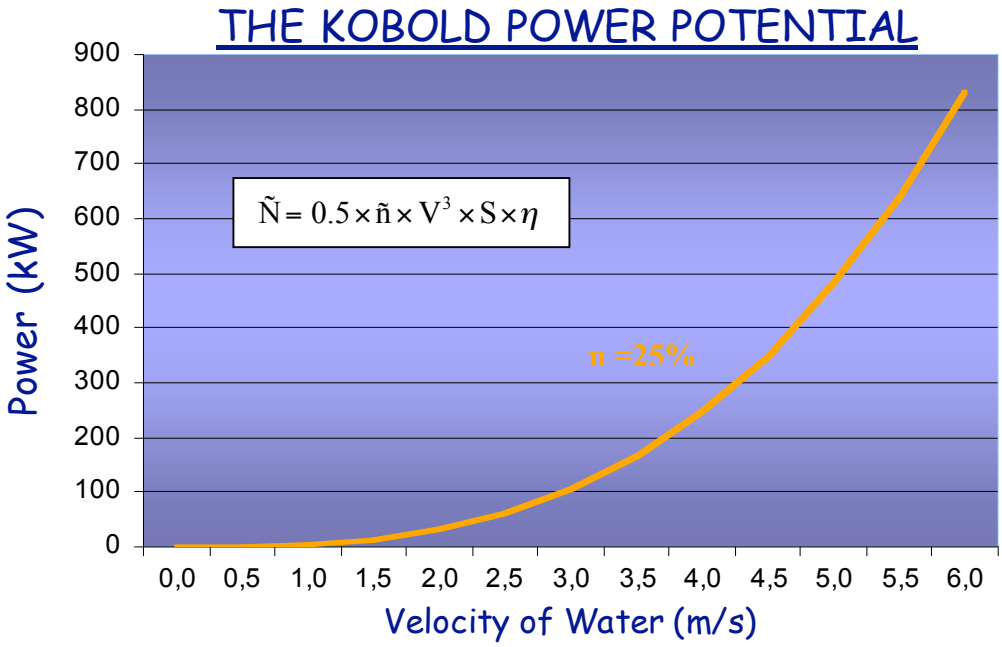


Fig. 2 – The location of the Kobold prototype

The produced electrical power is the product of the global efficiency, the diameter blade height ($S=30\ m^2$ in case of Kobold turbine), the water density (ρ) and the current speed (V). The current efficiency of the Kobold turbine is about 25%. This efficiency will be increased further with an optimized mechanical system. Note that already at this stage the Kobold turbine has efficiency comparable to the long-time developed wind turbines.



With the experience from a full scaled system in the water for 4 years of time Ponte di Archimede S.p.A has all the necessary information to develop a optimized mechanical system and is further on developing a design tool together with INSEAN, Rome and Politecnico di Milano, where it is possible to estimate different design conditions without having to do expensive model testing. This will be very helpful for future projects where the turbine can be easily optimized for specific site conditions. The computer model and the optimized mechanical system are to be finished in 2005.

The next step is to provide renewable energy to remote islands in the Republic of China, the Philippines and Indonesia. This will be done by installing turbine farms of the patented ENEMAR system - the Kobold. This is an ongoing project together with UNIDO and the governments of the three countries.

For more information about the history of the ENEMAR system, see appendix 1.

SUBMERGED FLOATING TUNNEL –
ARCHIMEDE'S BRIDGE

The Archimede's Bridge is an innovative concept: an environmentally-friendly crossing, exploiting the principles of hydrostatic thrust and based on the idea first developed by Archimedes, the scientist genius from Syracuse, in the third century BC.

With this highly advanced type of construction, it is possible to design shore-to-shore links across straits, lakes or rivers, in places where such projects had hitherto been ruled out on economic and technical grounds.

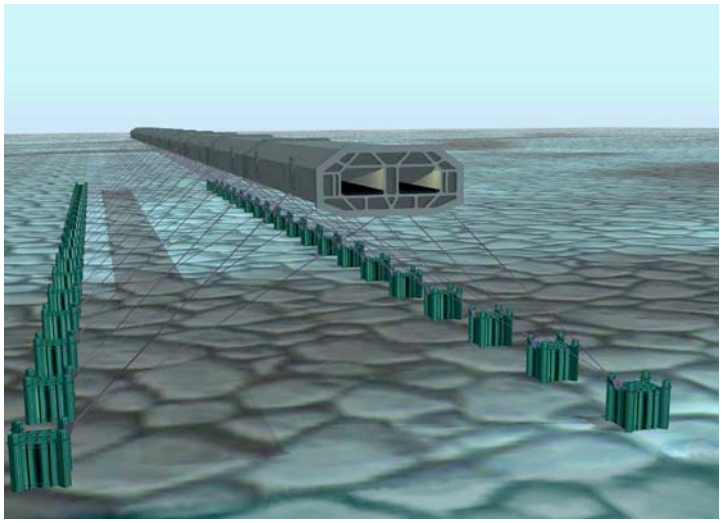


Fig. 3 The Archimede's bridge

The typology of the Archimede's Bridge overturns the traditional engineering approach to the problem of a fixed crossing in that it considers the mirror of water that has to be overcome not as an obstacle but an element to be used in its favour. To make this happen, a stable submerged link has been designed whose fundamental requisites are:

- a high level of structural performance without regard for length
- invulnerability to atmospheric factors
- a high level of performance when facing seismic effects

- competitive construction costs

The study of the Submerged Floating Tunnel concept, called the Archimede's Bridge, based on an innovative typology for fixed links across straits and lakes, was investigated in the first phase in collaboration with the Norwegian Roads Research Laboratory, the Danish Road Institute and the Italian Shipping Register, with a financial grant from the European Union and the coordination of FEHRL (Forum European Highways Research Laboratories) an International Association of 22 Public Road Administrations. Furthermore the Provincial Administrations of Como and Lecco, in Italy, have officially shown great interest in the Archimede's Bridge for crossing the Lario and the study of the submerged floating tunnel in the Strait of Messina has been promoted by Ponte di Archimede S.p.A. and verified with a feasibility analysis by the Italian Naval Register (RINA).

A Sino-Italian Joint Laboratory of Archimede's Bridge (SIJLAB) has been originated in 1998 between Institute of Mechanics, Chinese Academy of Sciences, China and Ponte di Archimede S.p.A. For this Dr. Cav. Lav. Elio Matacena received the 2004 *International and Technological Cooperation Award of The People's Republic of China*. During the First Meeting of the Steering Committee for SIJLAB in 2005 it was decided that a 100m tunnel, wide enough for cars to pass, is to be developed in the Qiando Lake, China. The next step it to build a 3000m long submerged floating tunnel in the Zhoushan Archipelagos.

FUELCELLS –TEA

The TEA Project has already been responsible for the construction of a pilot-plant for the serial production of fuel cells with gas diffusion electrodes.

This new generation of electrodes, the result of a revolutionary technique of platinum coating, has lower costs compared to those of more advanced products now on the market. The pilot-plant's radical innovations affect the technological production process of such components, with consequent lowering of costs and overheads, whilst at the same time guaranteeing a high-quality finished product.

The gas diffusion electrodes can be used in the electrical and thermal energy production sectors, having a low environmental impact in that they make up the principal element of the fuel cells. During the development of the project, research was carried out to optimise the plant, taking into account both the methodological preparation of the electrodes in gas diffusion and the technological automatism of production. This research has meant that the project is being continuously updated and the plant duly re-configured.

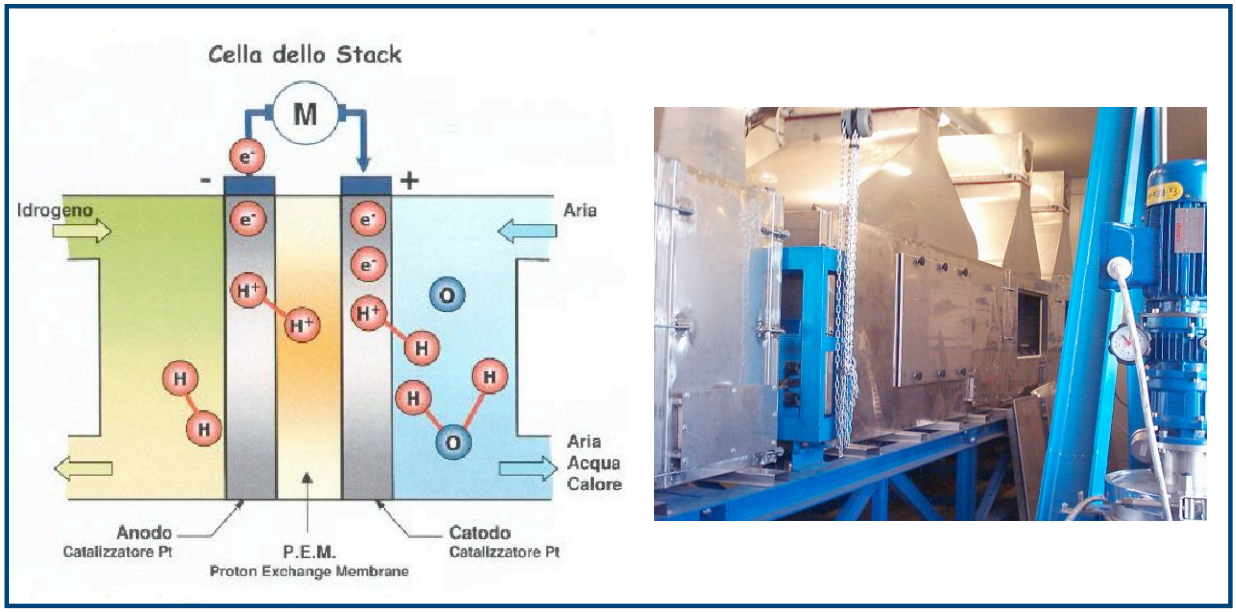


Fig. 4 The fuel cell scheme (left) and the industrial sized fuel cell prototype TEA (right)

The Advanced Electrochemical Technology Project TEA Project has been 50% financed by the regional government of Sicily (as part of their 1994-1999 POP), with the other 50% coming from Ponte di Archimede S.p.A. and the Messina CNR-ITAE Institute, with a total investment of 500 000 Euro. The project is aimed at demonstrating the feasibility of an automatic plant for the production of polymeric electrodes for fuel cells at competitive costs. A good functioning industrial plant has an efficiency of about 80% more than a manually processed plant.

The TEA Project began in March 1999 and has aimed to diffuse innovative technology in the preparation of electrodes in gas diffusion and new concepts developed by the CNR-ITAE Institute as part of a number of research programs into the use of fuel cells. The experimental plant has introduced radical innovations in both manufacture (until now never produced at an industrial level) and technological production processes.

The TEA plant has two separate automated lines, the first aimed at removing the diffusive level, the second that of the catalytic layer. Both lines consist of:

- A driving mechanism to move the electrodes, consisting of a belt activated by appropriate hauling rollers with variable speeds;
- A warehouse and distribution plant that contains tanks of appropriate dimensions to contain the suspension, a siphon feeding system of spraying heads, and all other necessary accessories.
- Cylinders that are calibrated for thickness, conducted by a system of presser rollers.
- A tunnel-shaped oven, having several thermal rooms operating at different temperatures, equipped with electrical resistance and power controlled fans.
- A control panel with the components necessary to manage automatically each of the two lines

This project is carrying out in collaboration with the National Council of Researches.

HYDRODYNAMIC TUNNEL – REVMA

The REVMA project is a hydrodynamic tunnel for the experimentation of various models of keels, hulls, propellers, turbines and all other components that need hydrodynamic testing.

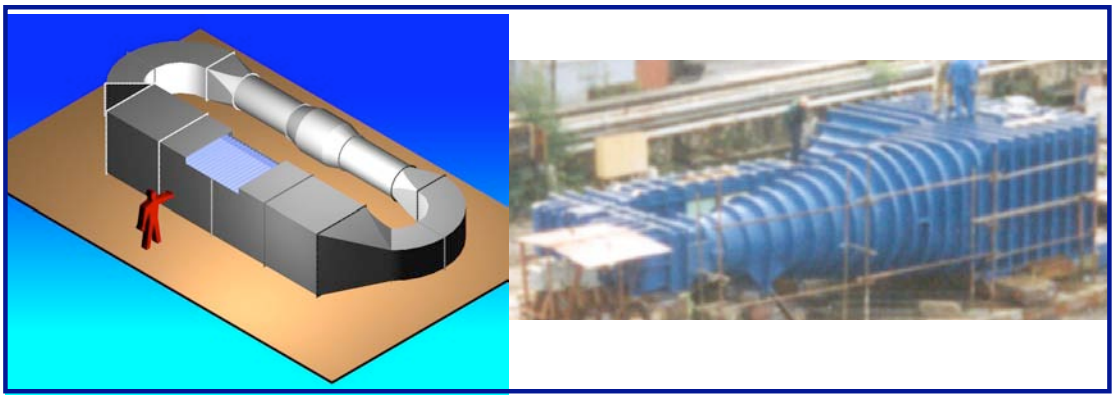


Fig. 5 The REVMA plant

In the test room (see red man pointing above) the water has a maximum speed of 4 m/s and thanks to the shape of the tunnel tests can be performed under optimal conditions.

THE DEVELOPMENT HISTORY FROM IDEA TO THE KOBOLD PROTOYPE IN THE STRAIT OF MESSINA

The first small model of the turbine was built and tested in the water tank belonging to Department of Naval Architecture of University of Naples. The blades were free to oscillate up to 90 degrees (with respect to the radial direction) and the torque was generated mainly by blades drag. A picture of the first small turbine model is shown in figure I, below.

Fig. I – First small model of turbine (Panemone type)
for tests in water tank of Dept. of Naval Architecture of University of Naples

In a second phase a numerical code "ad hoc" developed at Dept. of Aeronautical Engineering of University of Naples was used to predict the turbine behaviour and output power.

The numerical activity was coupled with extensive experimental activities consisting in wind-tunnel tests of a larger model of Kobold turbine. In fact a second model was built and tested in the wind tunnel of Dept. of Aeronautical Engineering, University of Naples (see figure II).

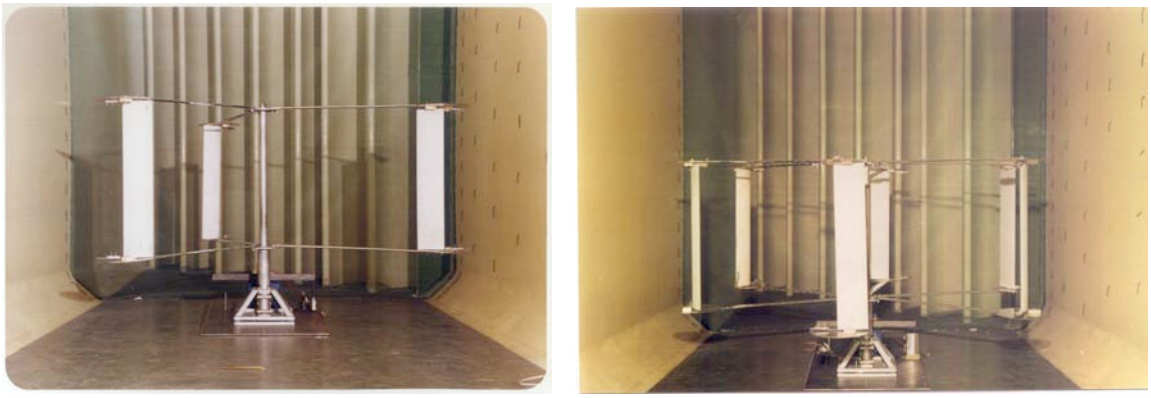


Fig. II. Model of Kobold turbine installed in the wind-tunnel belonging to Dipartimento di Progettazione Aeronautica of University of Naples (3 blades, left; 6 blades, right)

This time the torque was generated by lift on the blades. This model was built to be tested with different number of blades and to optimize the blade's articulation angles. The model had a diameter of 2.2 meters, blades height was of .8 meters and blades chord was of .17 meters. It was tested with 2, 3, 4 and 6 blades. The blade airfoil was NACA 0018 and due to the high number of possible parameters variation, hundreds of tests were performed.

The first Kobold turbine model tested had the blade oscillating between angles of 0 and 90° with respect to radial direction. To optimize the angles and the position of blade counterweight, see figure III.

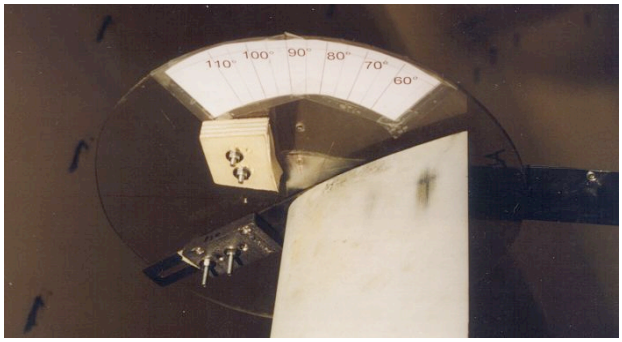
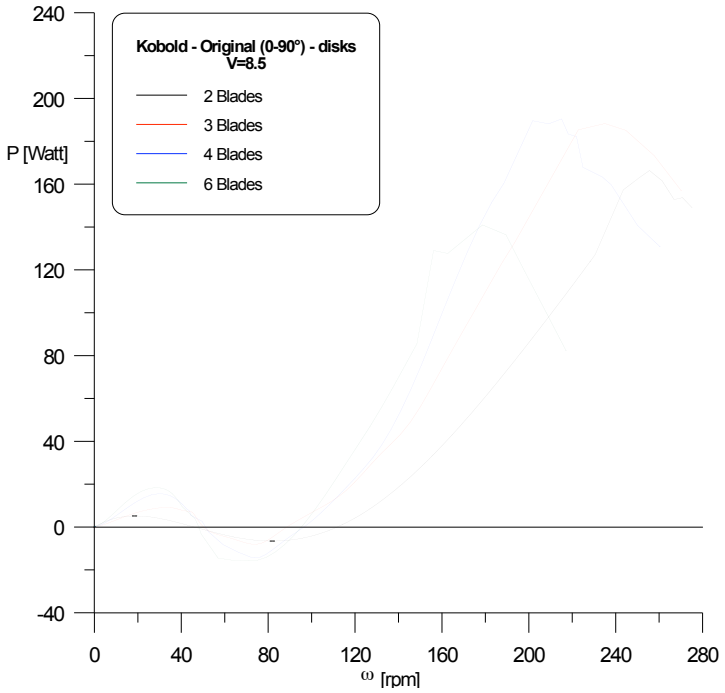


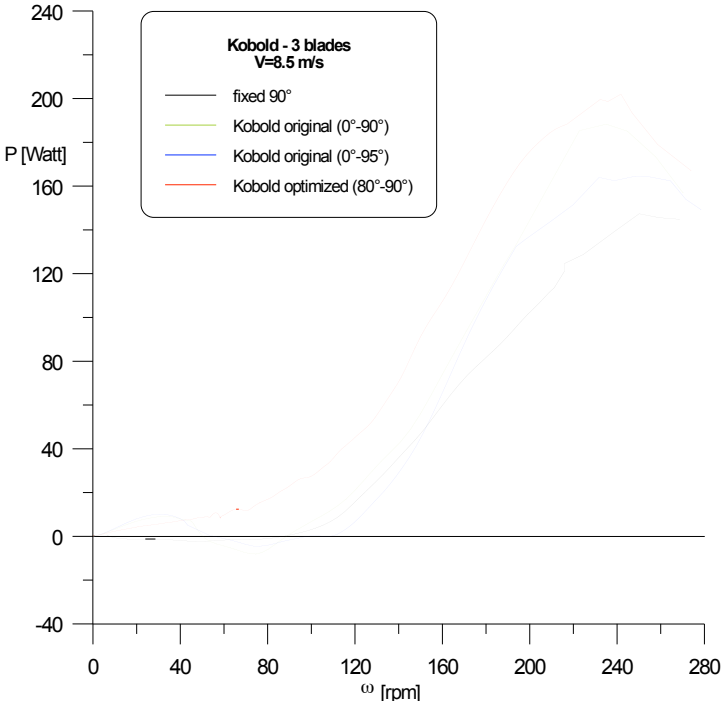
Fig. III: Details of the blade tip with counterweight. Arrangements to optimize blade pitch angle

In graph 1. below it can also be seen the effect of blades number on produced rotor gross power. This graph clearly shows why a 3-blade configuration was chosen for the real prototype (in fact the maximum rotor gross power is the same of 4 blade arrangement, but with obvious less losses due to blade sustaining arms and minor construction costs).

Optimization of blade articulation angle was then performed to solve the problem of negative power in the low rpm range. In graph 2. the gross rotor power for different blade articulation angle setting is shown.



Graph 1 – Original Kobold turbine (blade articulation 0-90°). Gross rotor power for different blade number configuration (wind-tunnel tests)



Graph 2. – Kobold turbine optimization. Gross rotor power for different blade articulation settings (wind-tunnel tests)

The turbine was tested several times, modifying its characteristics according to the numerical and experimental test results. All the investigations led to the definition of the turbine well defined kinematic characteristics.

The theoretical evaluations have taken into account various mathematical models, suitable to describe and foresee the Kobold turbine behavior both form dynamic and kinematic point of view. The final result of this was the Kobold prototype in the Strait of Messina, see figure IV.

Fig. IV – The Kobold turbine in the Strait of Messina

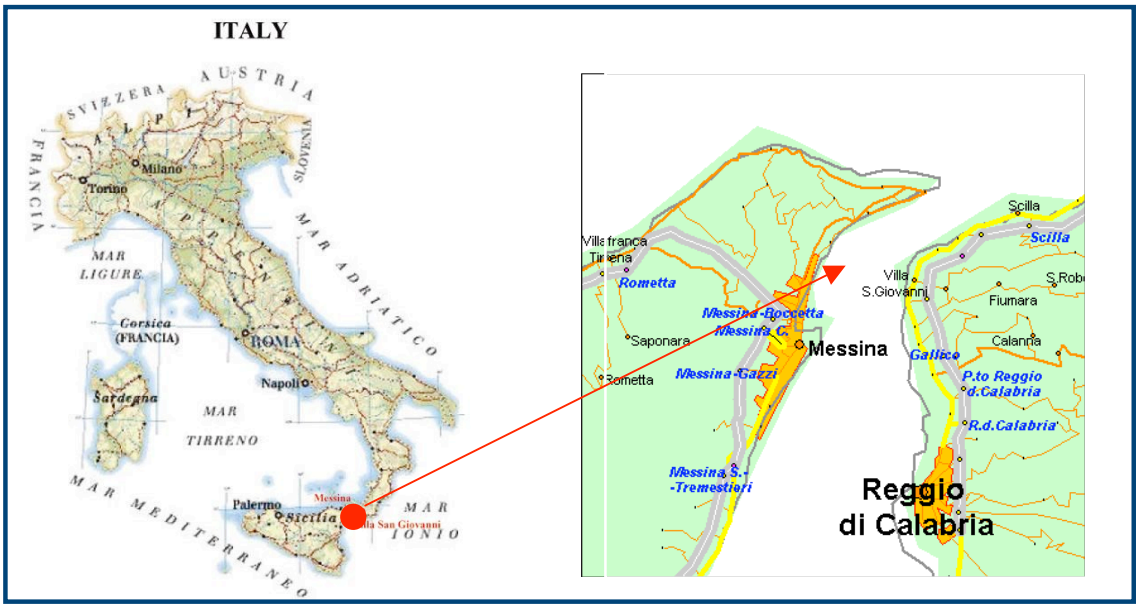


Fig. V – The location of the Kobold prototype

The Kobold turbine has been designed to satisfy, at the highest possible level, the environment safeguard and efficiency needs, as well as the necessities of low construction and maintenance costs.

The characteristics of the Kobold turbine are the following:

- direction of rotation independent of marine current direction.
- a very high starting torque, that makes the turbine able to start spontaneously, also in loaded conditions, without the necessity of any starting devices.

From the mechanical point of view, the Kobold turbine has been designed following simple and effective principles, so as to need for its whole useful life very limited maintenance interventions.

Main plant dimensions are the following:

Turbine	diameter	6 meters
	blade span	5 meters
	chord	0.4 meters
	n° of blades	3

The 3-blades turbine rotor mounted under the buoy output power curves at different sea current speed has been evaluated with the help of the numerical code.

Global efficiency of the system has been measured as **ratio** between the **produced electrical power** and the theoretical power available in the current relative to the intercepted area:

$$\text{ç} = \frac{\text{Pelectrical}}{.5\ \text{ñ}\ V^3\ S}$$

Where S = *Diameter* Blade Height* ($S=30\ m^2$ in case of Kobold turbine), ρ is water density and V is the current speed. **The measured global efficiency was (before 2005) measured to be around 23%, which is comparable to long time well developed wind turbine and then this first results can be considered excellent even because on-going improvements in the**

mechanical transmission system will certainly rise the global efficiency very soon.

Up until January 2005 the turbine produced electricity by turning on 20 lamps each of them absorbing about 1 kW of power (total produce power 20 kW) with a current speed of about 1.8 m/s and driving the electro pump (25 kW) with a current speed of about 2.0 m/s. The turbine was then transferred to land for maintenance and some minor improvements. Main improvements was the bearing of the turbine rotor and the blades were reinforced where they are connected to the arms.