MARINE RENEWABLE ENERGY

Energy from marine currents and the experience of Kobold Turbine

Eng. Alberto Moroso

Studio Tecnico Navale e Meccanico

Moroso - Starita

Ravenna, 2nd December 2019

alberto.moroso@morosostarita.it presidenza@atenanazionale.it

RENEWABLE ENERGY: A LONG STORY!

Man has always tried to extract mechanical energy from wind and water, endless and very familiar sources of energy.

Windmills and watermills have been successfully used for centuries in many applications.

SAME PRINCIPLES, SIMILAR ARCHITECTURE

Wind turbines and tidal turbines work on the same physical principles therefore for the two environments, with the necessary differences, there are similar devices.

There mainly are two classes of turbines:

Horizontal Axis Turbines

Wind

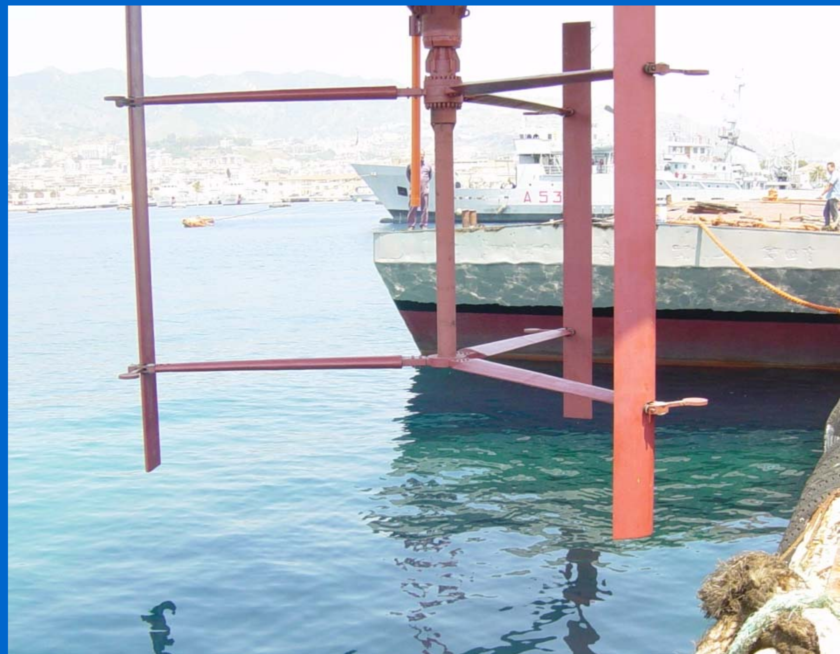
Tidal

SAME PRINCIPLES, SIMILAR ARCHITECTURE

Vertical Axis Turbines

Wind

Tidal



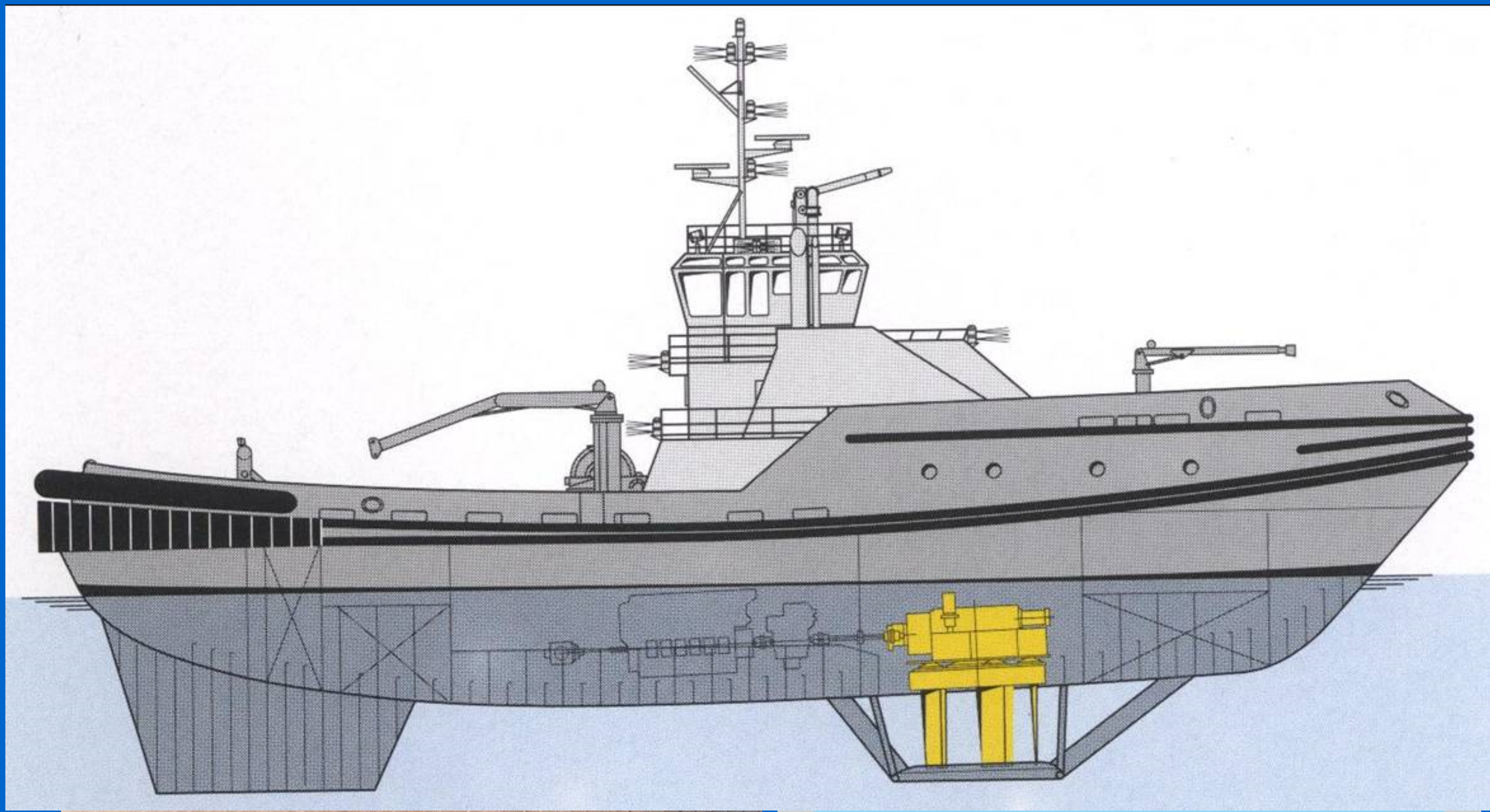
THE KOBOLD TURBINE

The *Kobold* is a hydraulic vertical axis turbine with free oscillating blades, patented in 1998 by Ponte di Archimede S.p.A.

Its main characteristics are:

- ✓ Rotation independent of current direction.
- ✓ High starting torque, thus self starting.
- ✓ High efficiency.
- ✓ Reliable, sturdy and simple.
- ✓ Self adjusting blades.
- ✓ No moving mechanisms.

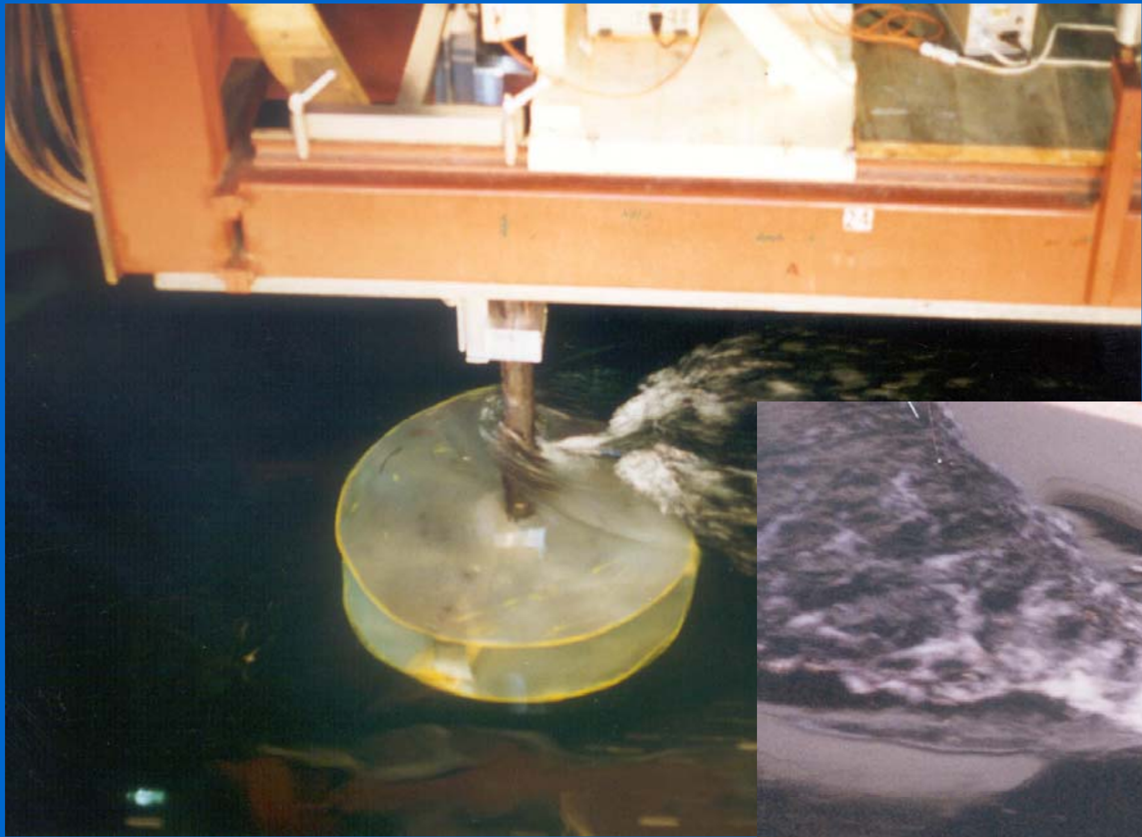
The architecture of the *Kobold* turbine was inspired by the Voith-Schneider marine propellers, often used on particular type of ships such as tugs and bidirectional ferries instead of the classical screw propellers.

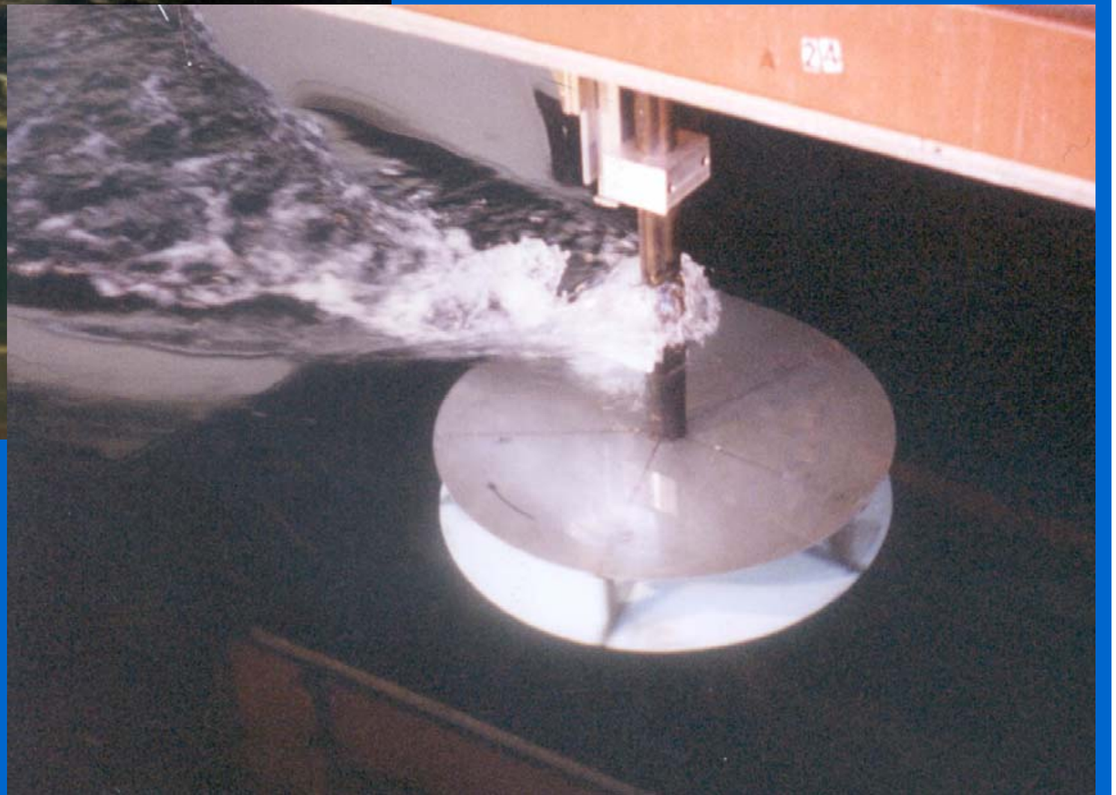


Many studies and laboratory experiments (towing tank and wind tunnel tests) have been carried out in order to arrive to the actual state of the art.

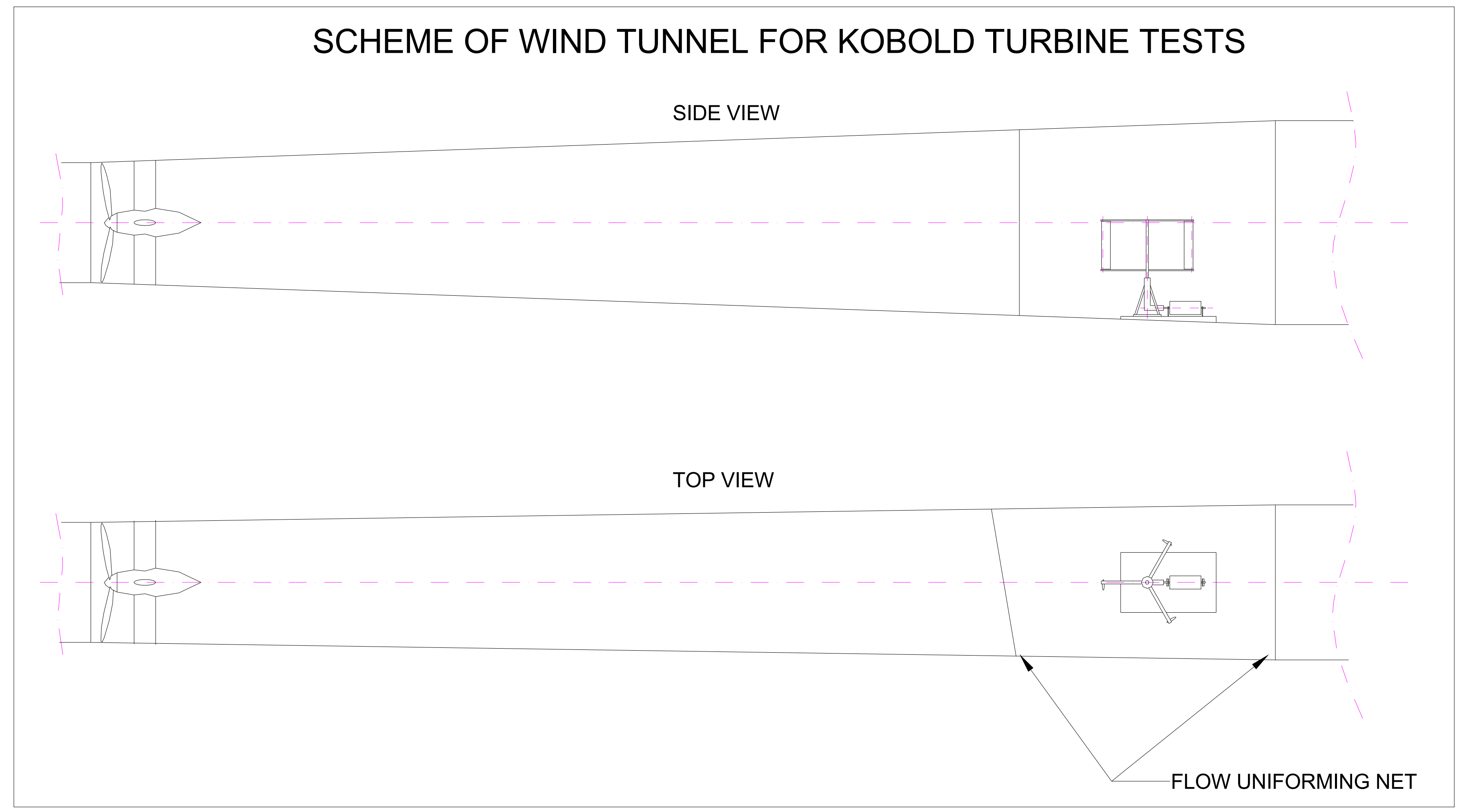
TOWING TANK TESTS

TOWING TANK TESTS

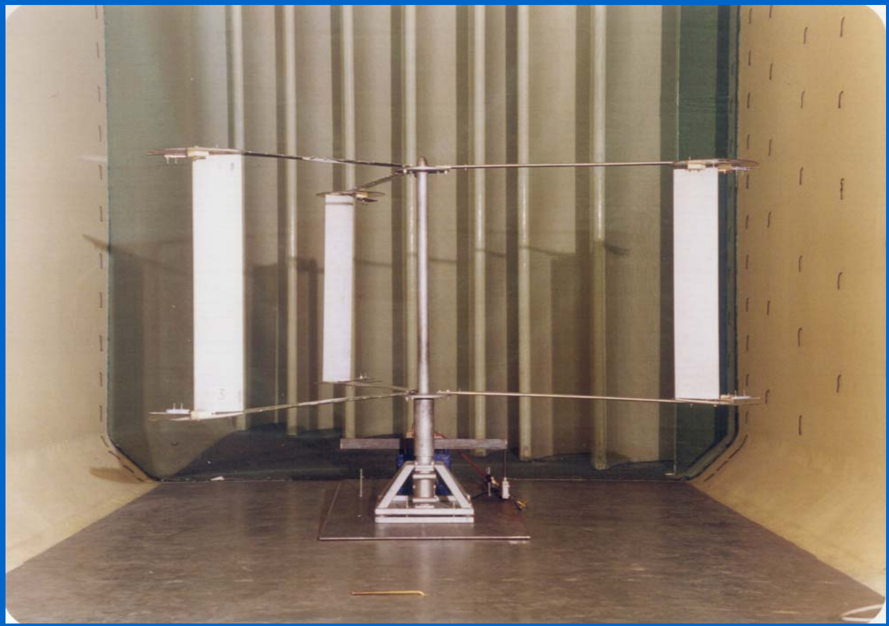




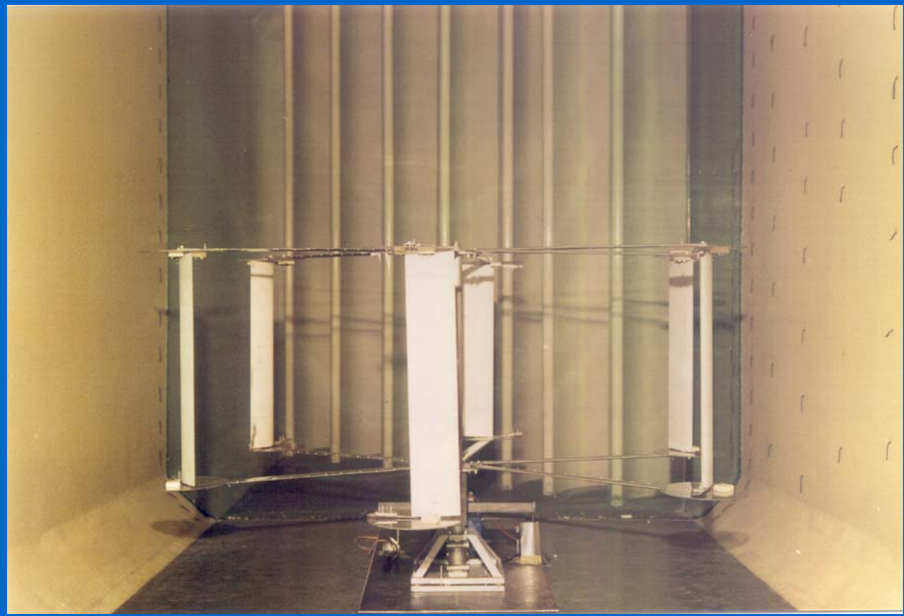
WIND TUNNEL TESTS



WIND TUNNEL TESTS



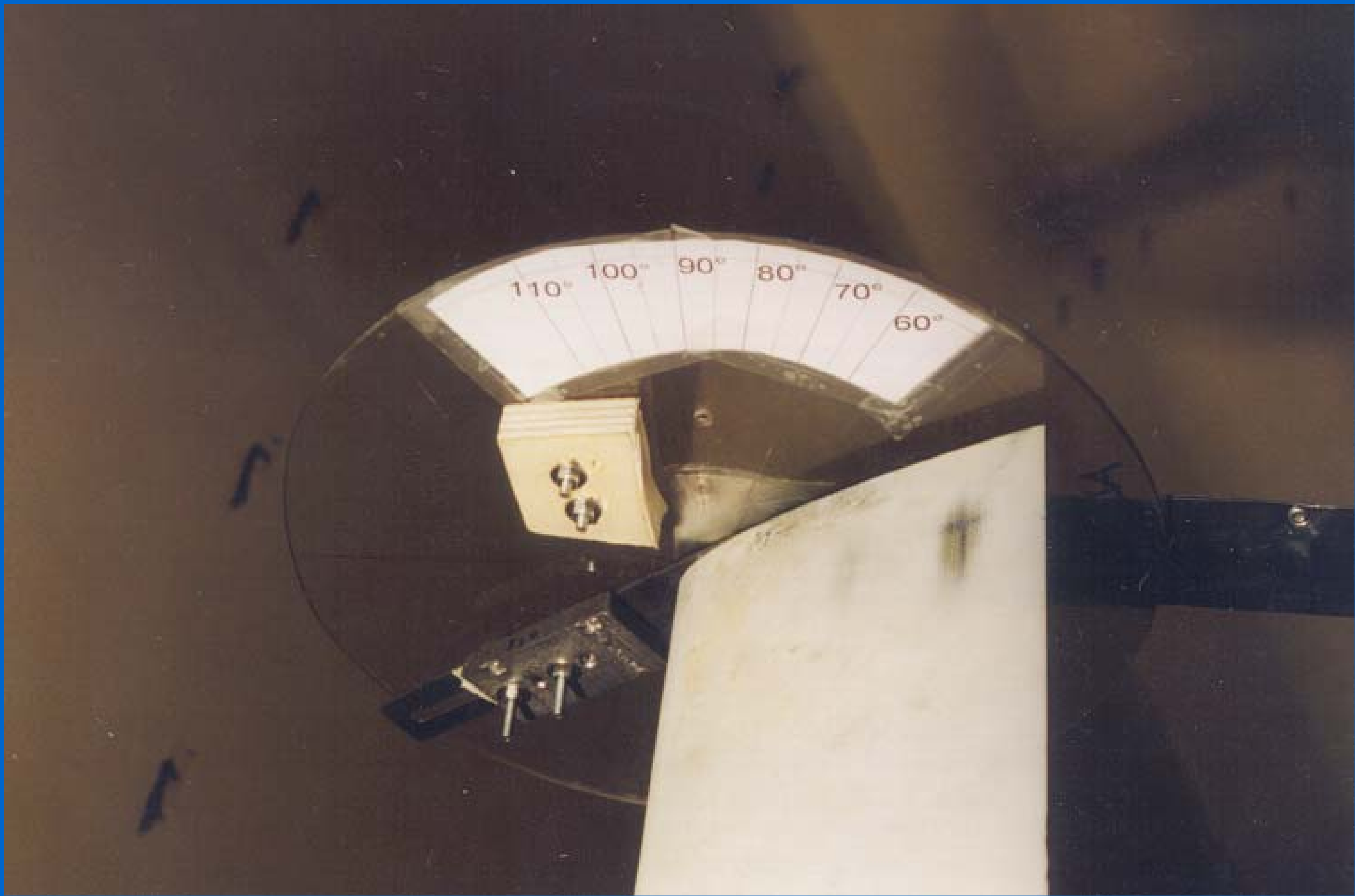
3 blades model



6 blades model

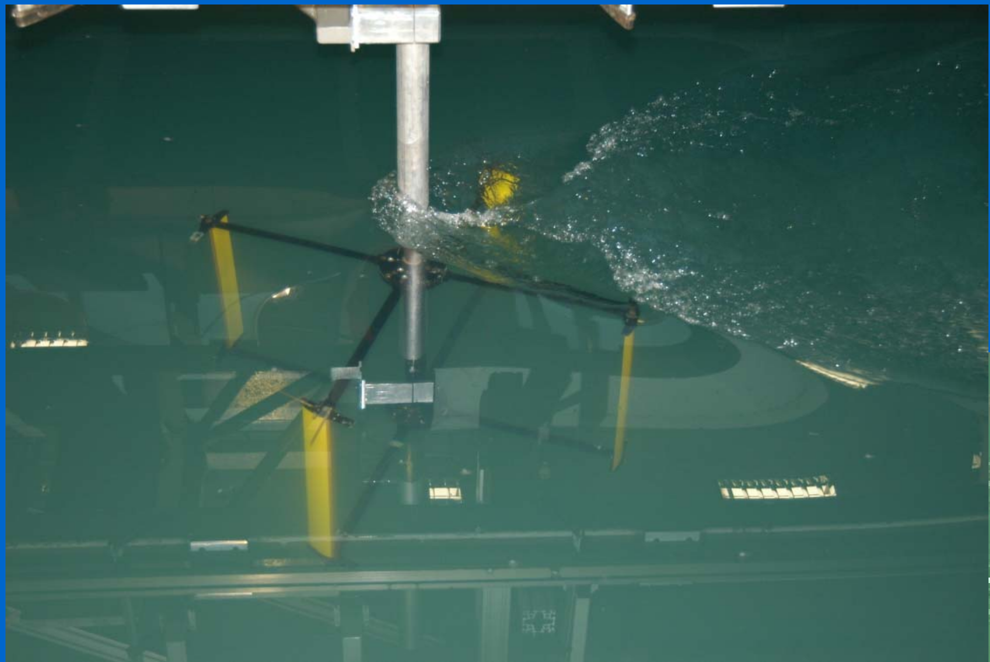
Hundreds of tests were performed, changing the main turbine parameters, such as number of blades and blade oscillation angle.

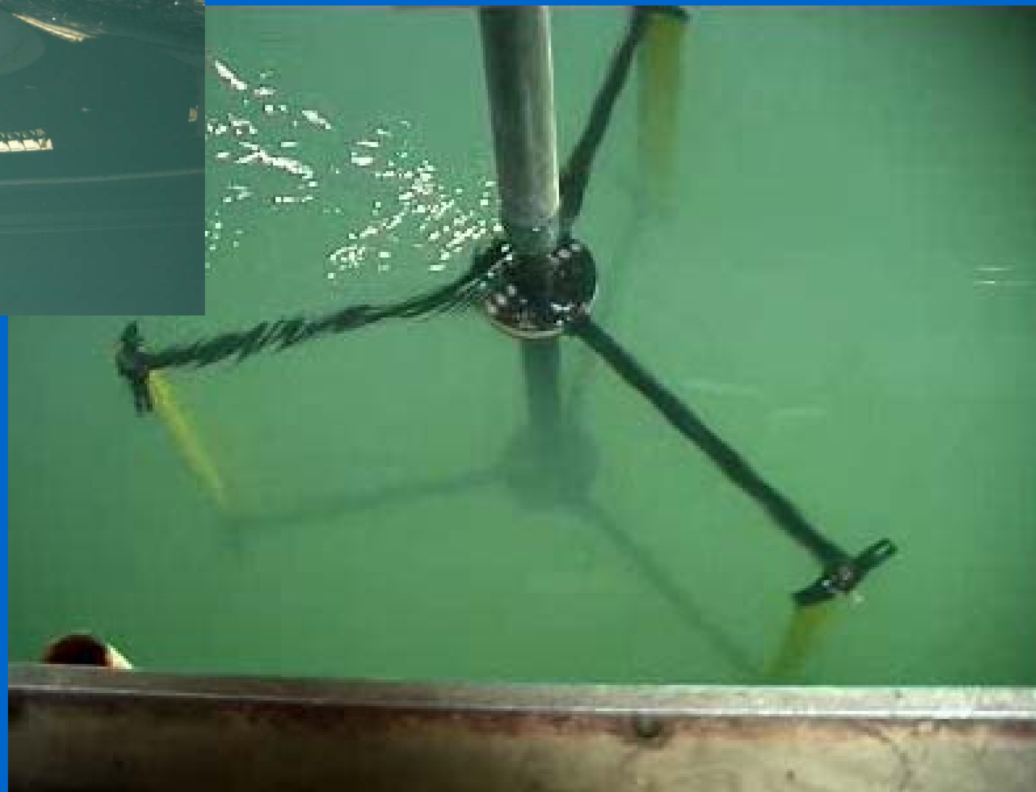
WIND TUNNEL TESTS



Model arrangement to evaluate the influence of the blade oscillation angle

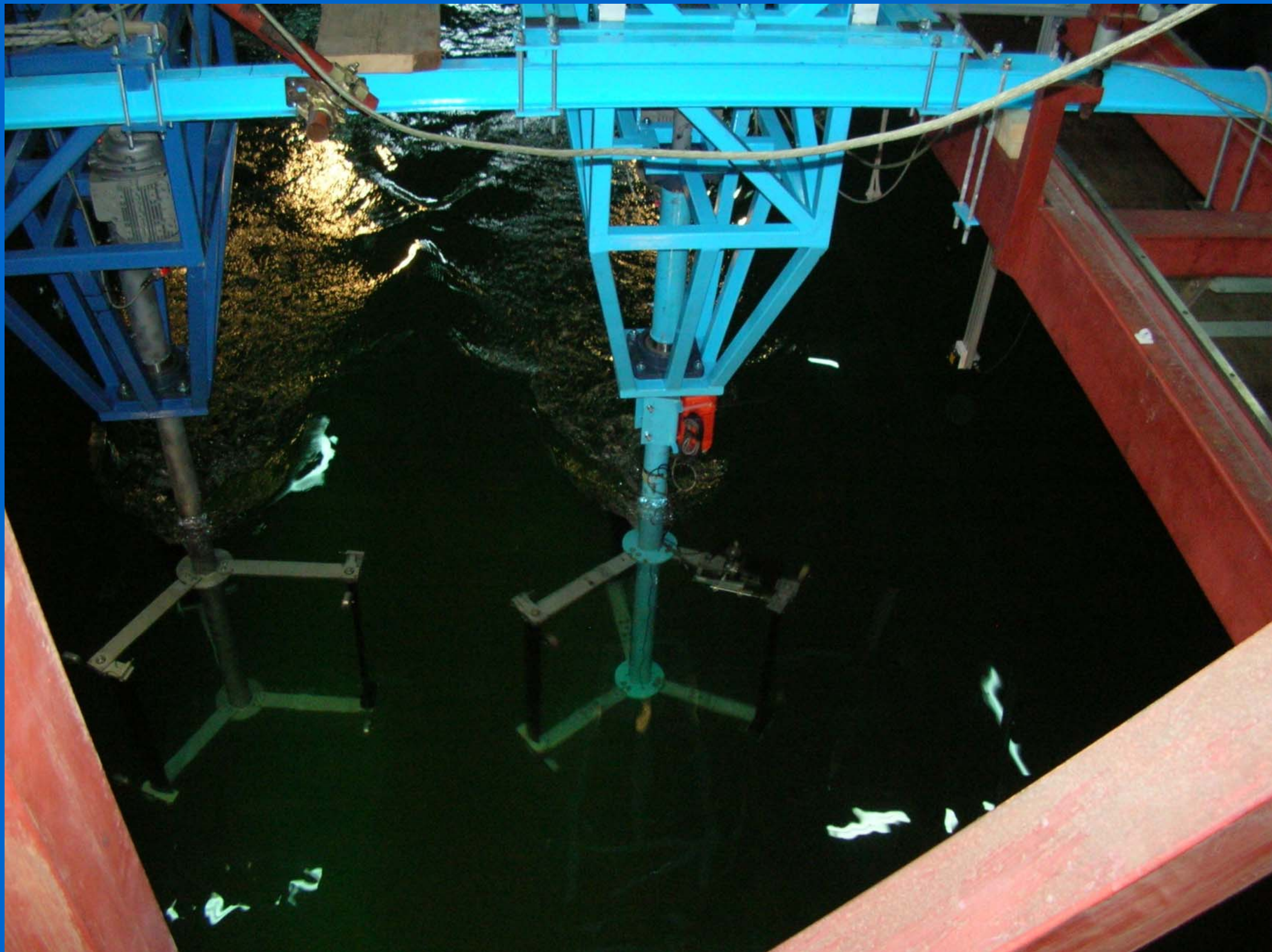
TOWING TANK TESTS



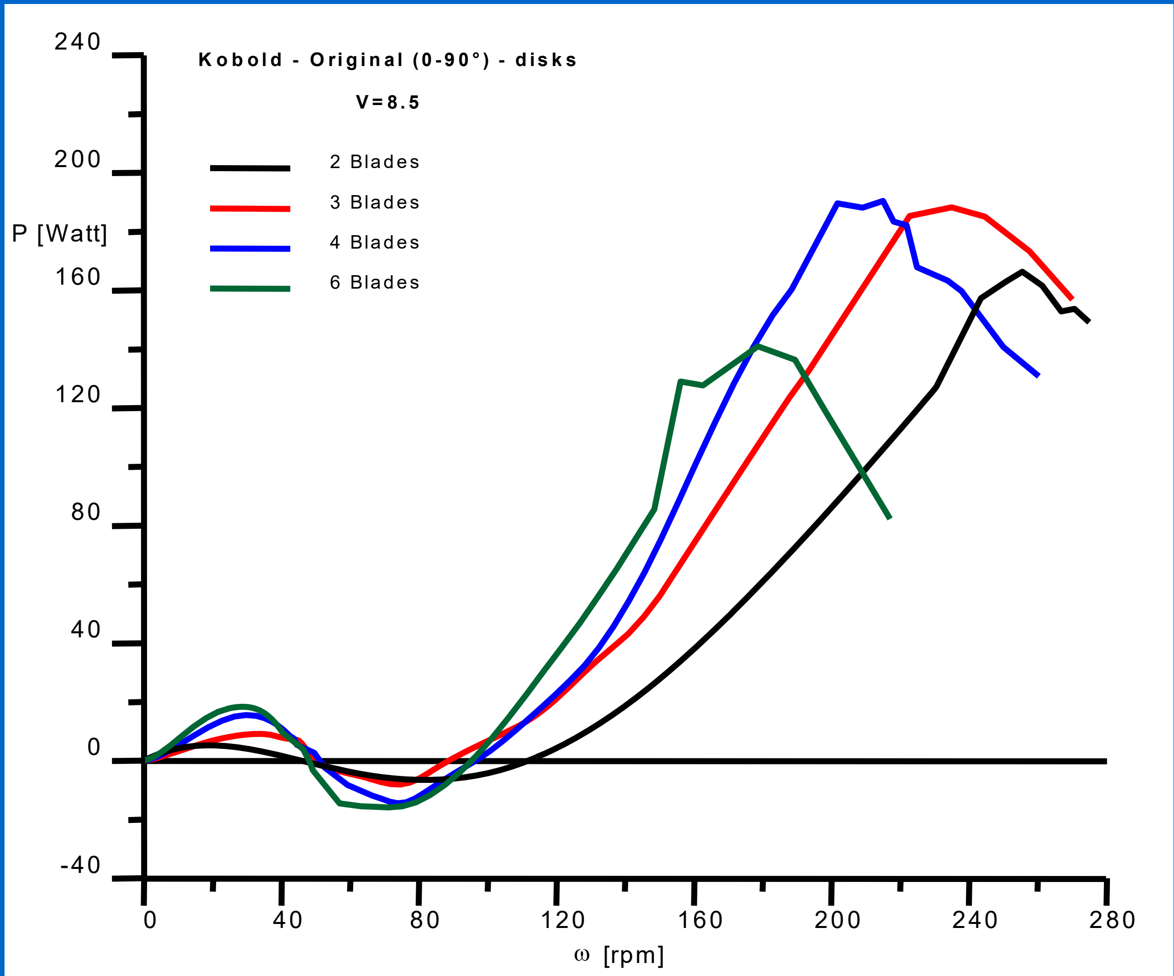


WIND TUNNEL TESTS

TOWING TANK TESTS

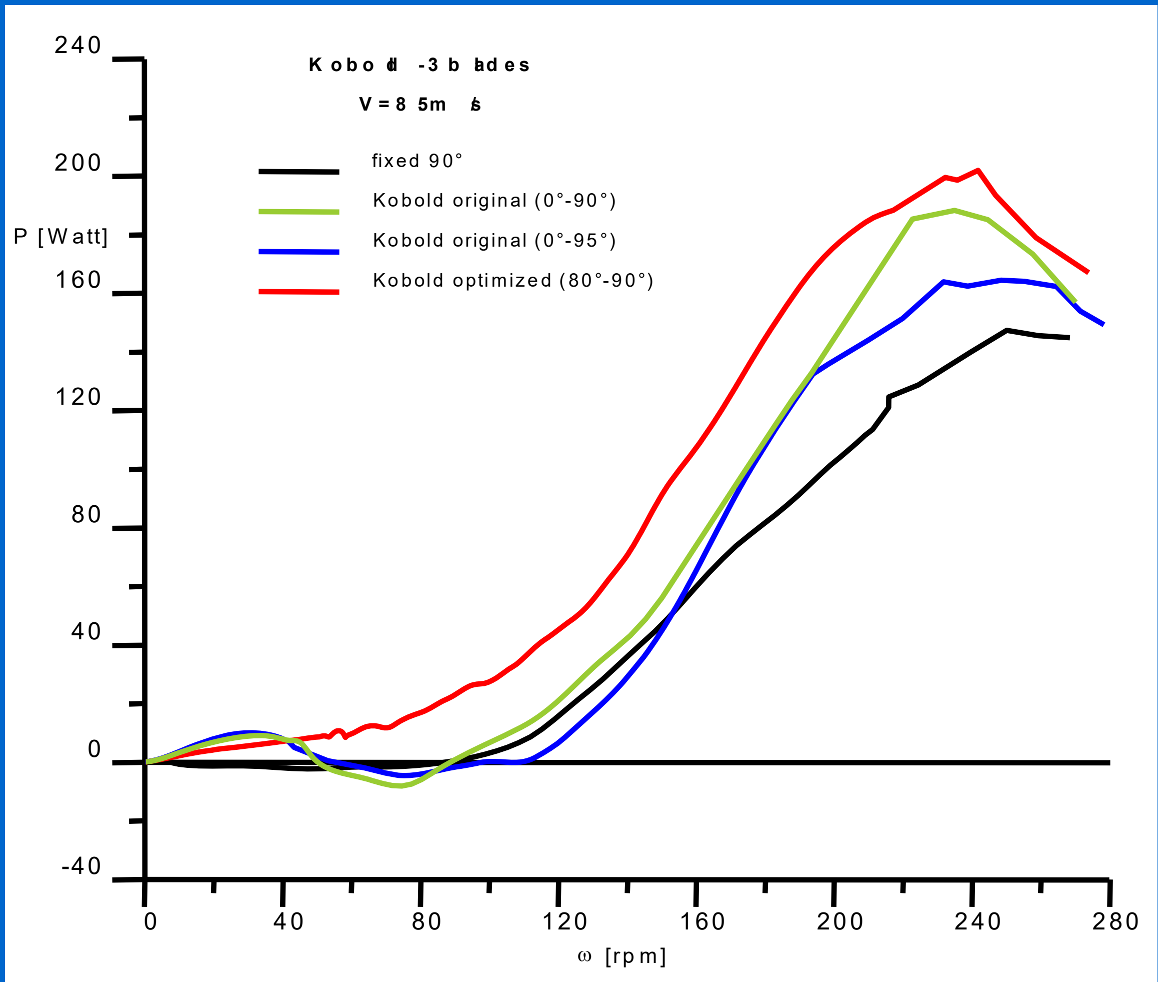


TESTS RESULTS (blades free oscillation)



- 3 blades model gave the best results. (*red line*)
- In all tests, excellent starting torques were observed.
- All models showed to suffer of lack of acceleration.
- In a small rpm interval a negative power was measured.

OPTIMIZAZION (blades limited oscillation)



- The blade oscillation was confined in a sector between two angles.
- A further increase of starting torque was reached.
- Turbine characteristic curve is all contained in the positive power zone.
- Turbine power was improved.

Kobold Turbine Working Principle

When rotating at the angular velocity ω, the blade of every vertical axis turbine is interested by a current which changes in intensity and direction at every angular position.

At each point of the rotation the total velocity of the "apparent" current is given by the vectorial sum of the two components:

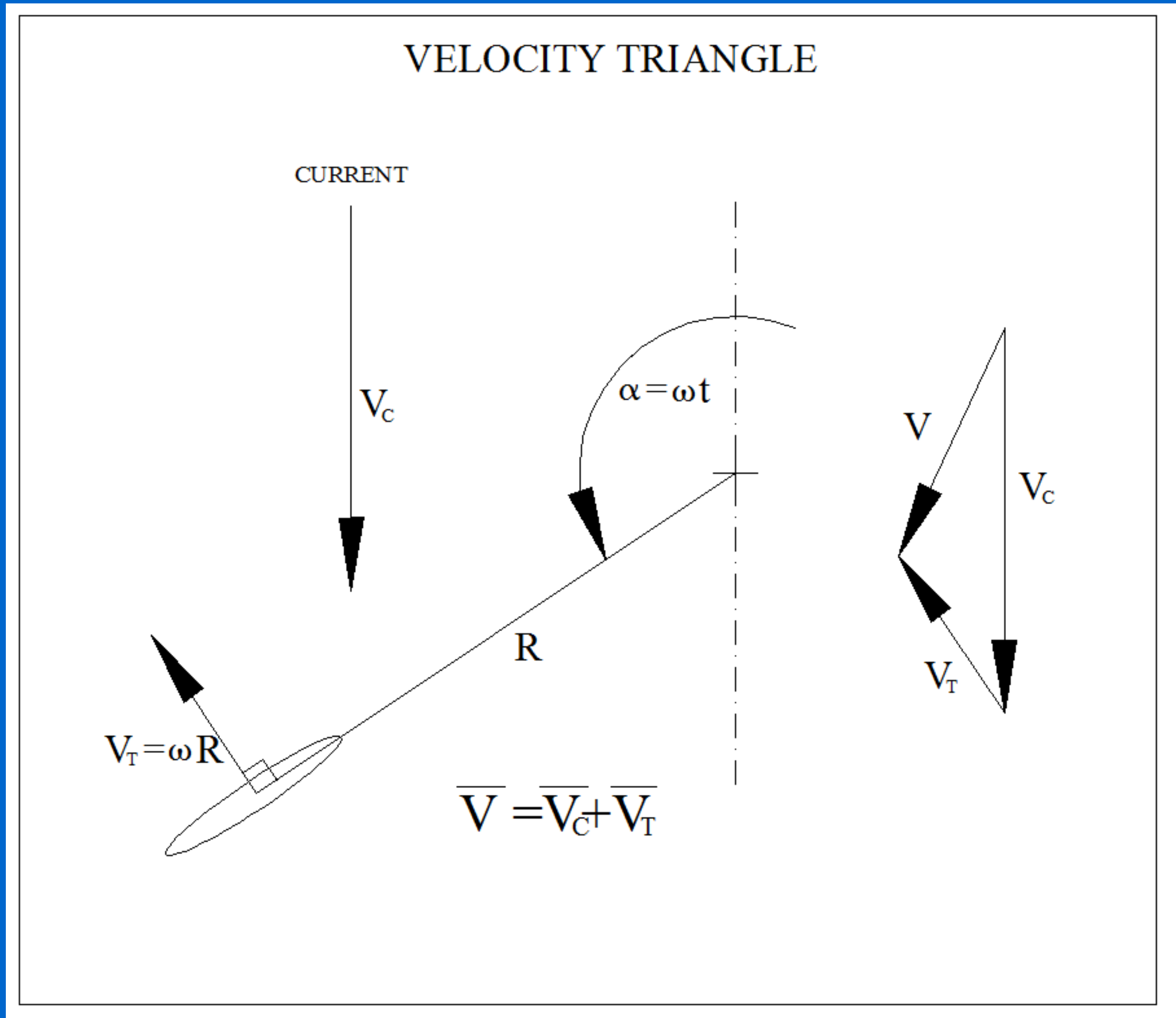
- The velocity of the current V_C – constant in both modulus and direction
- The peripheral velocity of the blade $V_T = \omega R$ constant in modulus and but not in direction

Therefore at each point of the blade path it is:

$$\vec{V} = \vec{V_C} + \vec{V_T}$$

Kobold Turbine Working Principle

It can be summarized by the following picture



Kobold Turbine Working Principle

Therefore all the Hydrodynamical forces on the blade (lift and drag) are generated by the total velocity V that changes continuously in modulus and direction when seen by the blade.

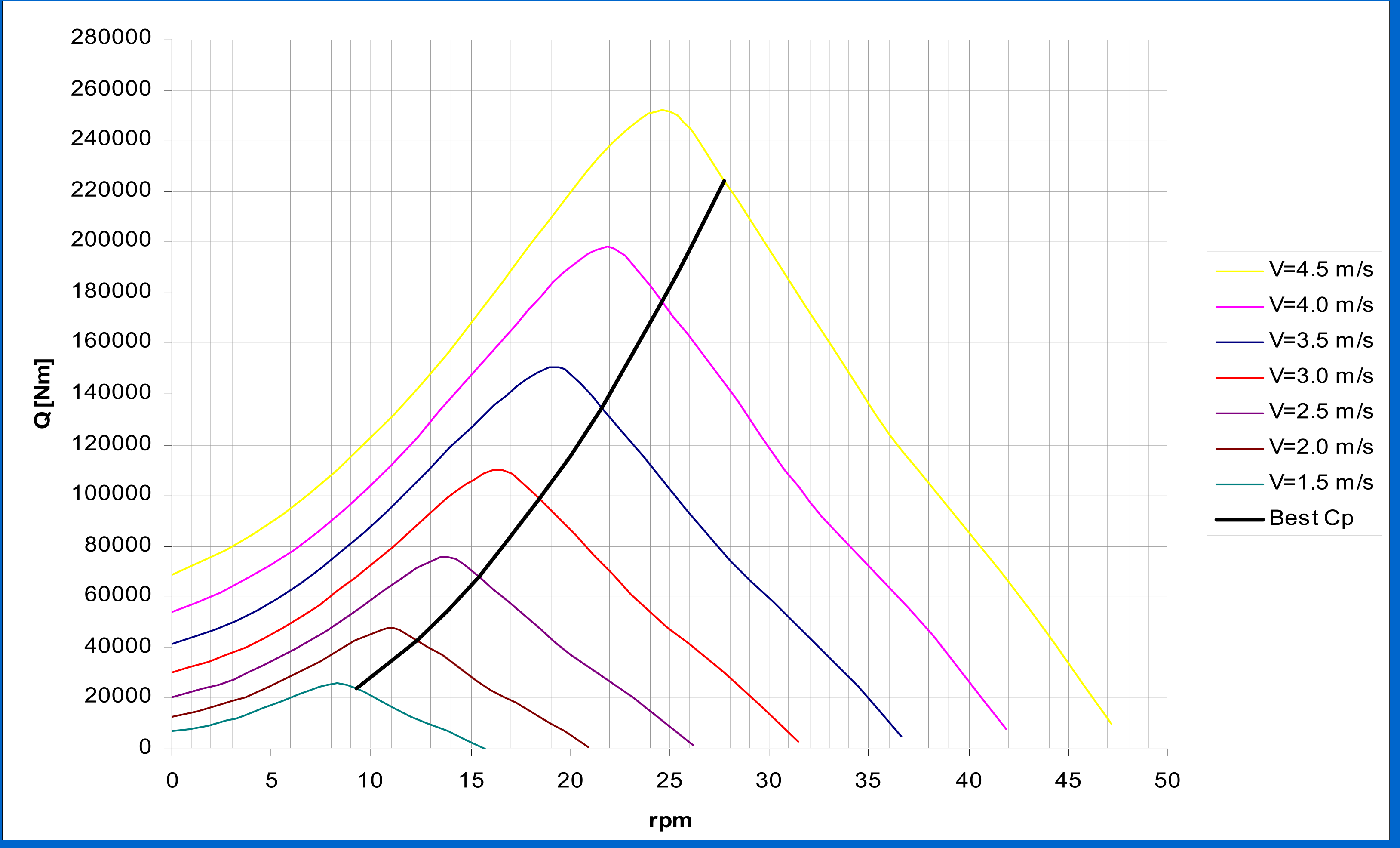
Changing the rotational speed of the turbine means to change all the velocities that the blade will meet during a revolution (the velocity triangles) and mainly:

- The intensity of the velocity
- The angle of attack between blade profile and velocity

$$L = \frac{1}{2} C_L \rho S V^2 \qquad D = \frac{1}{2} C_D \rho S V^2$$

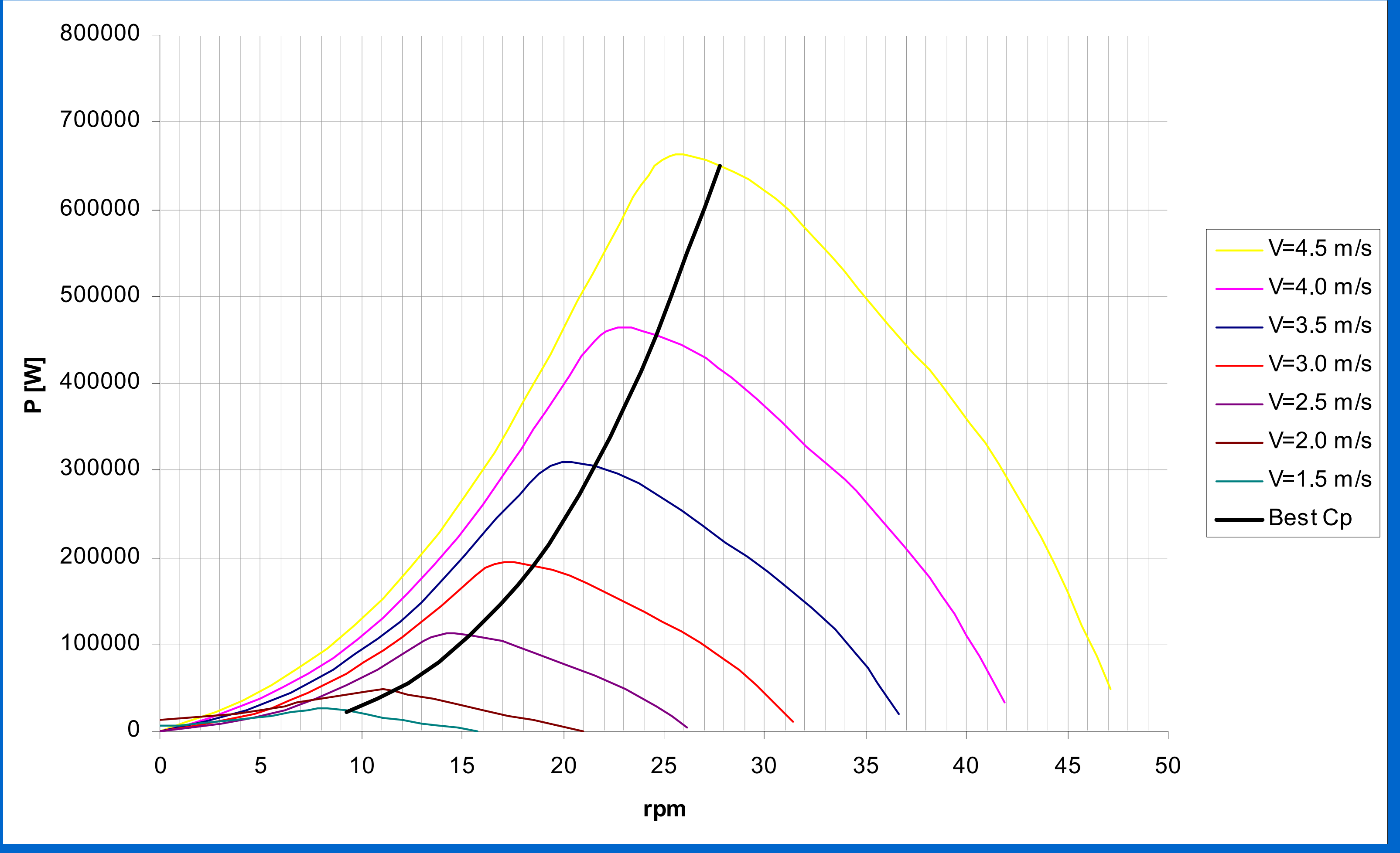
Kobold Turbine Working Principle

At the same current velocity we calculate the turbine performances (Torque and Power) at different rotational velocities.



Kobold Turbine Working Principle

At the same current velocity we calculate the turbine performances (Torque and Power) at different rotational velocities.



Kobold Turbine Working Principle

To better characterize the turbine behavior, all the turbine performances can be calculated not as function of the absolute angular velocity but in function of the ratio between peripheral velocity and current velocity:

$$\lambda = \omega R / V_C$$

This adimensional ratio is called "**Working Point**"

At any current velocity the turbine gives the maximum power (or, reaches the maximum C_P) when

$$\lambda = 2$$

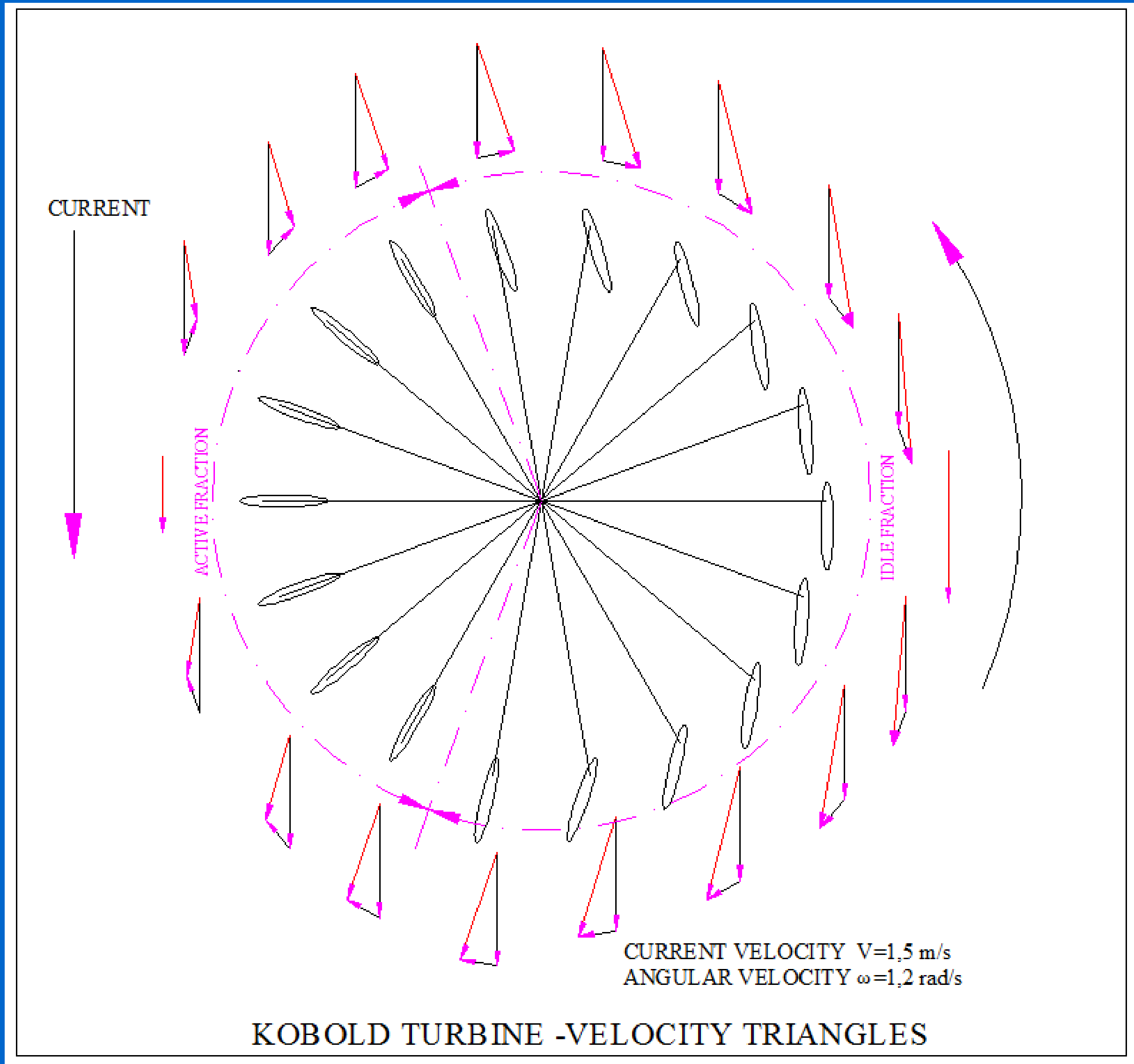
i.e. when the peripheral velocity of the blade is 2 times the current velocity.

Kobold Turbine Working Principle

To work at the same Working Point λ means that all the velocity triangles during the revolution will be the same or, better,

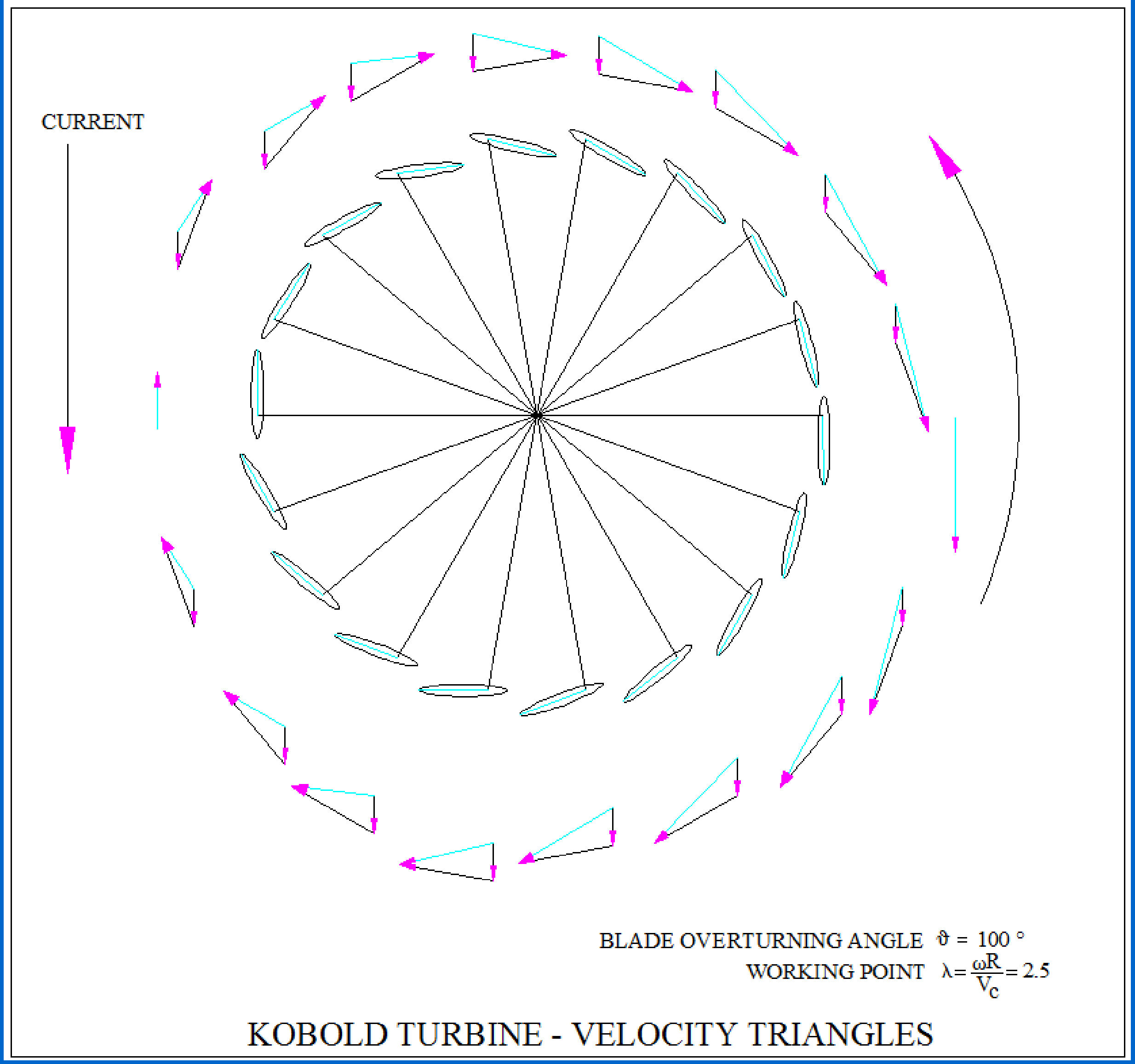
- that in each angular position the blade will have always the same angle of attack, similar velocity and,
- in each angular position the blade will have the same hydrodynamical behavior (same C_L and C_D coefficients)

Kobold Turbine Working Principle



Velocity triangles – λ<1

Kobold Turbine Working Principle



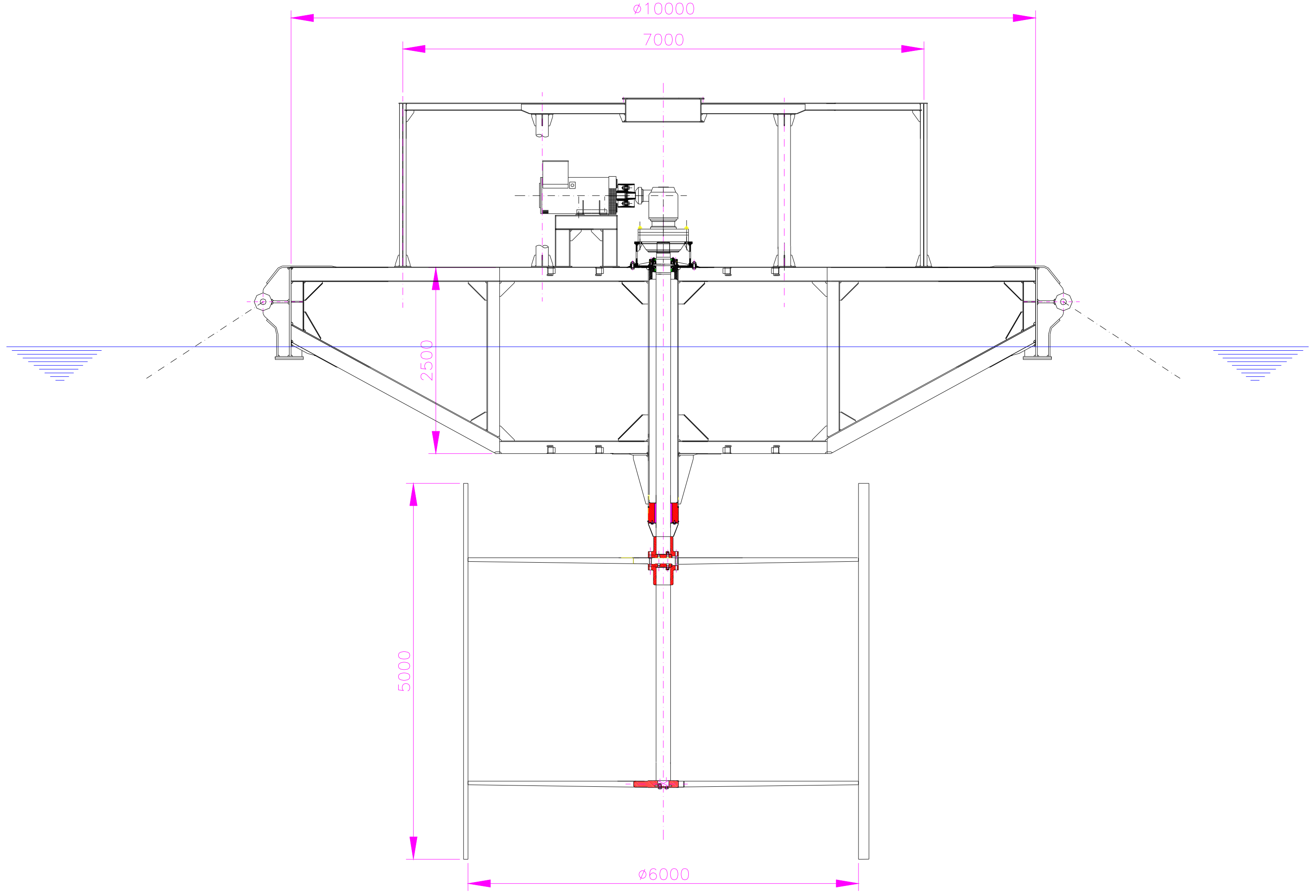
Velocity triangles – λ>1

THE ENERMAR PLANT

The *Enermar* pilot plant was launched in 2001 in the Strait of Messina, financed by Ponte di Archimede S.p.A., the Regione Siciliana Government and the European Community.

A Kobold turbine is fitted under the bottom of a cylindrical floating platform of 10 m diameter, moored at the sea bed in 4 points.

The turbine is a Kobold 3 blades type, which was the optimum one, according to all the experiments.



Enermar **Plant in Messina – General Arrangement**

Enermar **Plant in the Shipyard**

Enermar **Plant in the Shipyard**

***Enermar* Plant in Messina – Above and under the water.**

Enermar **Plant in Messina – While working.**

PLANT CHARACTERISTICS

TURBINE	
Rotor diameter	*6.0 m*
Blades height	*5.0 m*
Chord	*0.4 m*
Blades number	*3*
Blade profile	*Hilift 18*
Blades material	*Carbon Fibre*

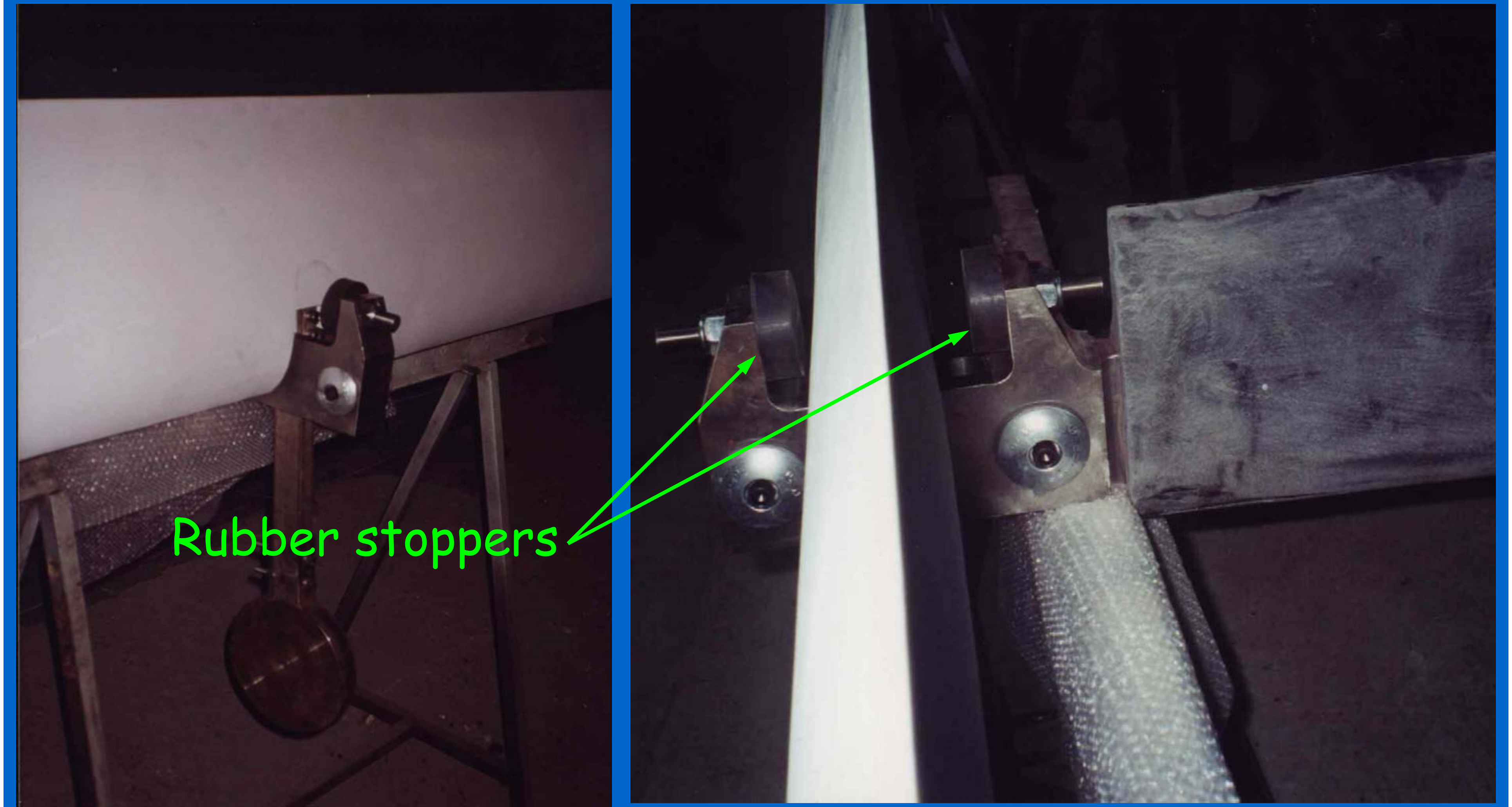
FLOATING PLATFORM	
Diameter	*10.0 m*
Depth	*2.5 m*
Displacement	*35 t*
Mooring blocks	*4*
Block material	*concrete*
Blocks weight	*35 t each*

Turbine revolutions	18 rpm (max)
Syncronous generator (3-phase brushless)	80 kW at 1500 rpm.
Epicycloidal reduction gear	ratio 90:1

SOME BUILDING DETAILS

Blades and arms in workshop

Blade-Arm Connection



Blade-Arm Connection

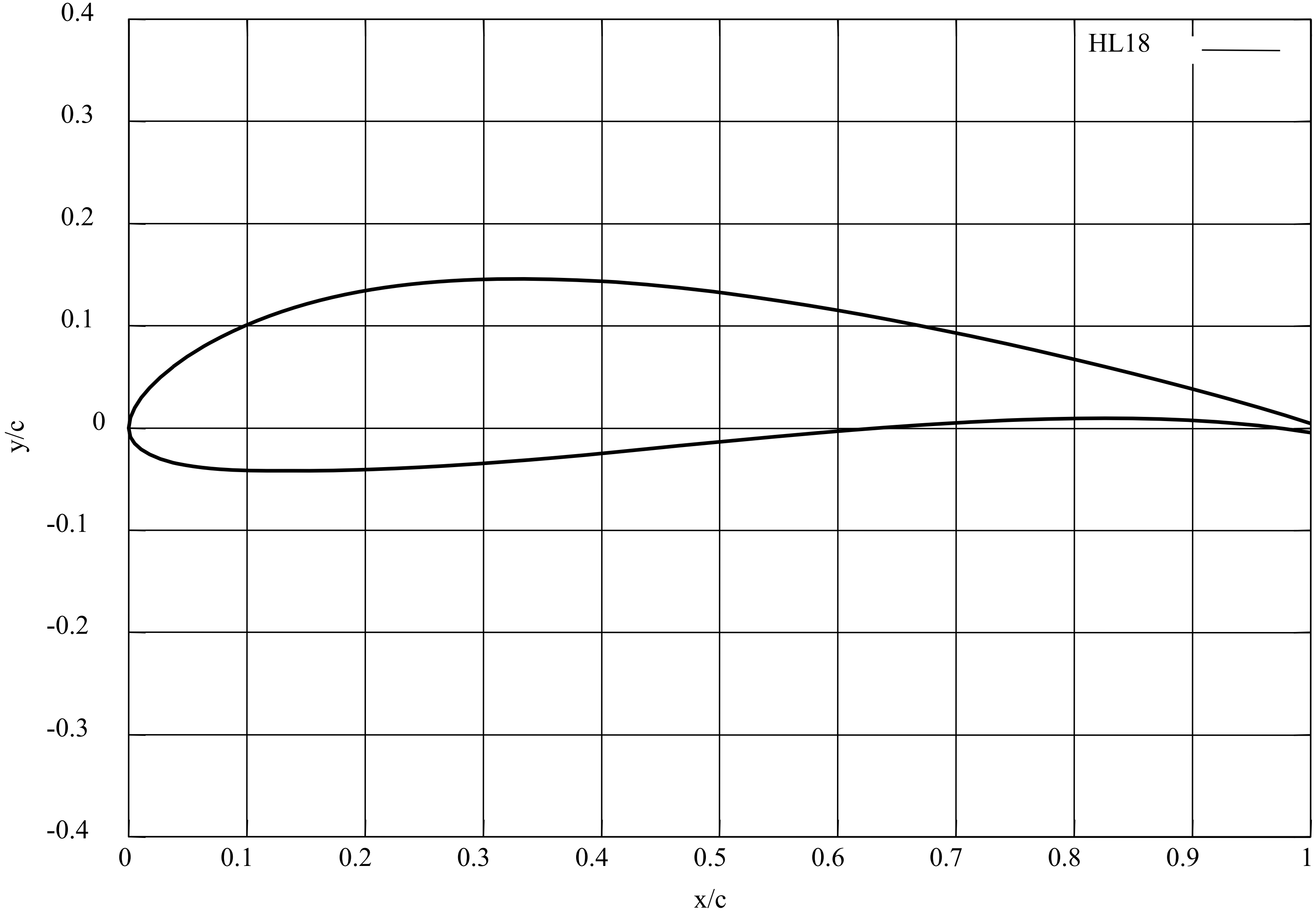
The most “sofisticated” parts of all the plant are the turbine blades.

The blades are 5 m long and have a chord of 0.4 m. The airfoil used is a completely new one (Hilift 18) purposely designed by Università di Napoli Federico II for this application.

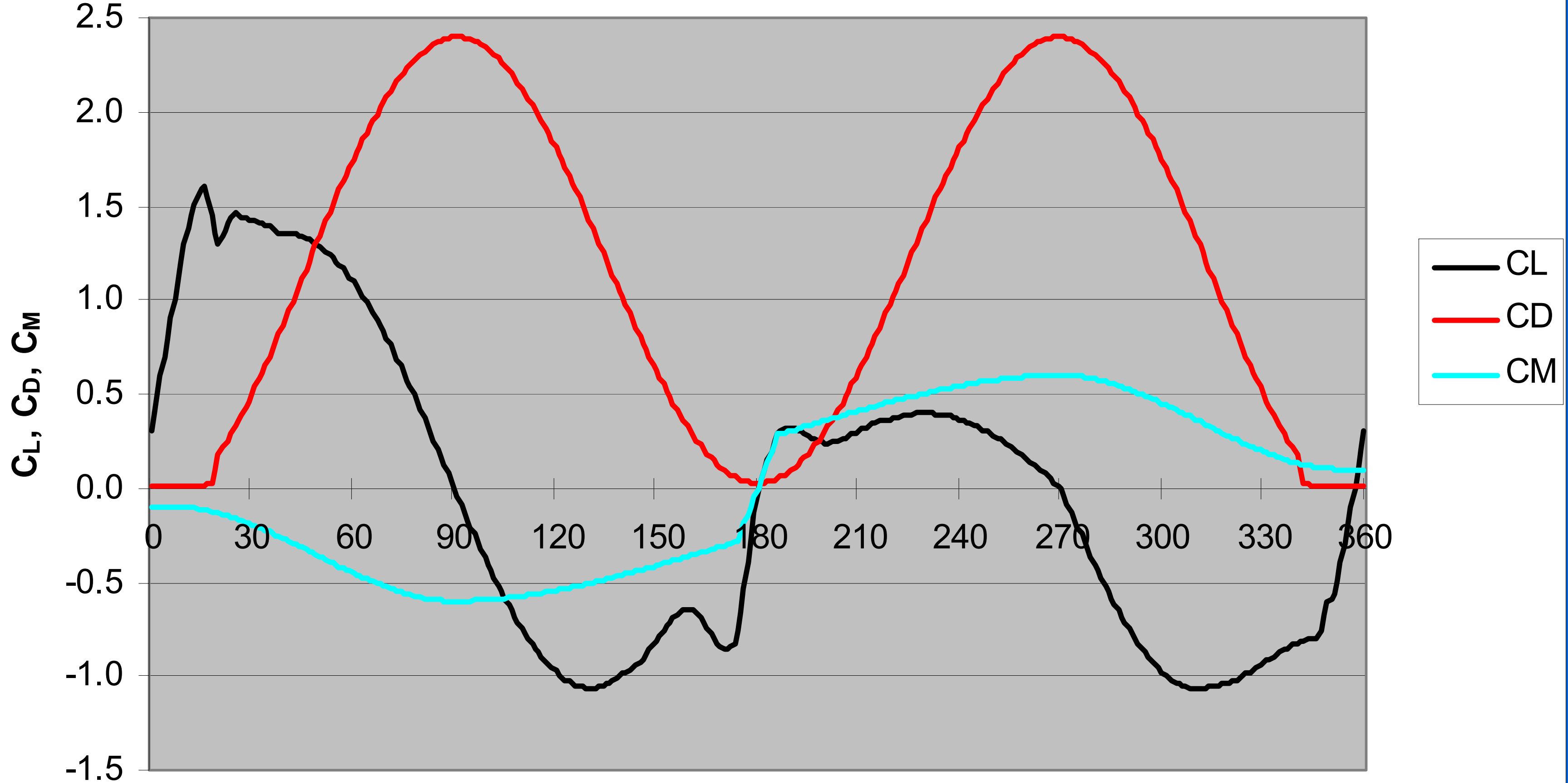
Due to the high stresses, the blades are made of carbon fiber and epoxy resin.

The inner structure is in a very light closed-cell foam also to prevent the ingress of water and there are 3 stainless steel (AISI 316) spars for the whole lenght of the blade and ribs every 500 mm.

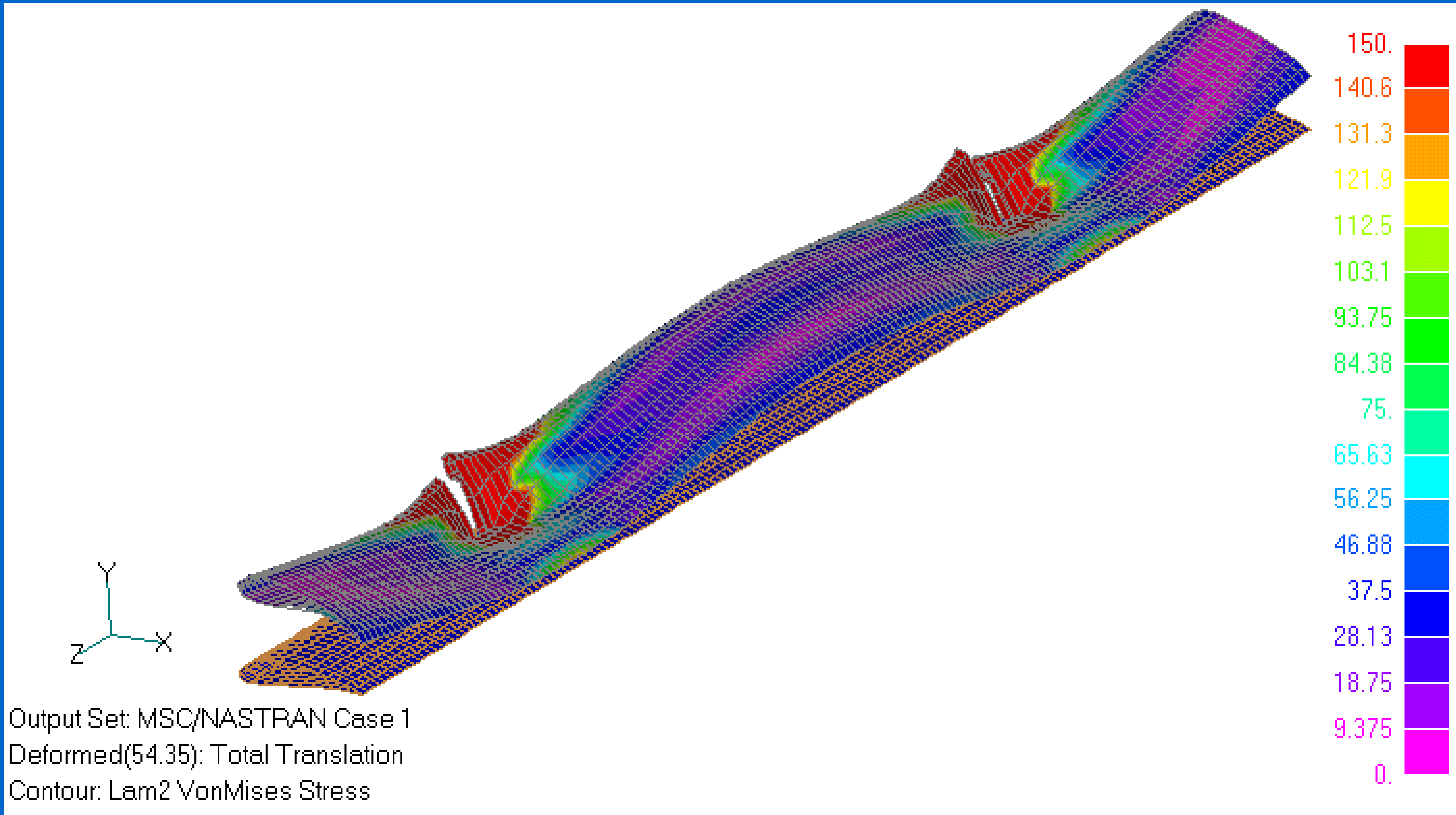
“HILIFT 18” Foil – Maximum thickness 18% at 28% of the chord



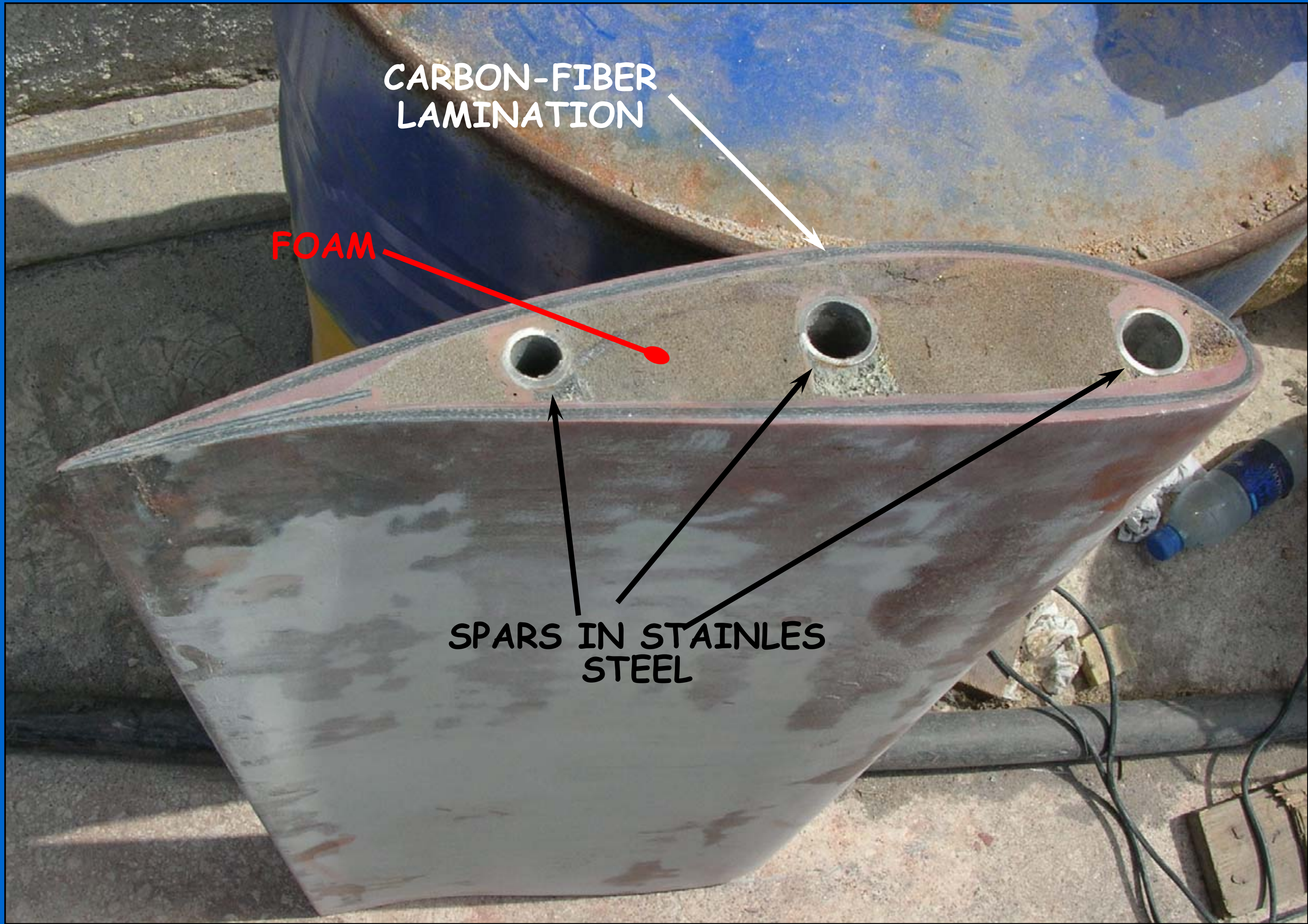
HILIFT PROFILE - AERODYNAMIC CHARACTERISTICS (0 - 360°)



ANGLE OF ATTACK (°)

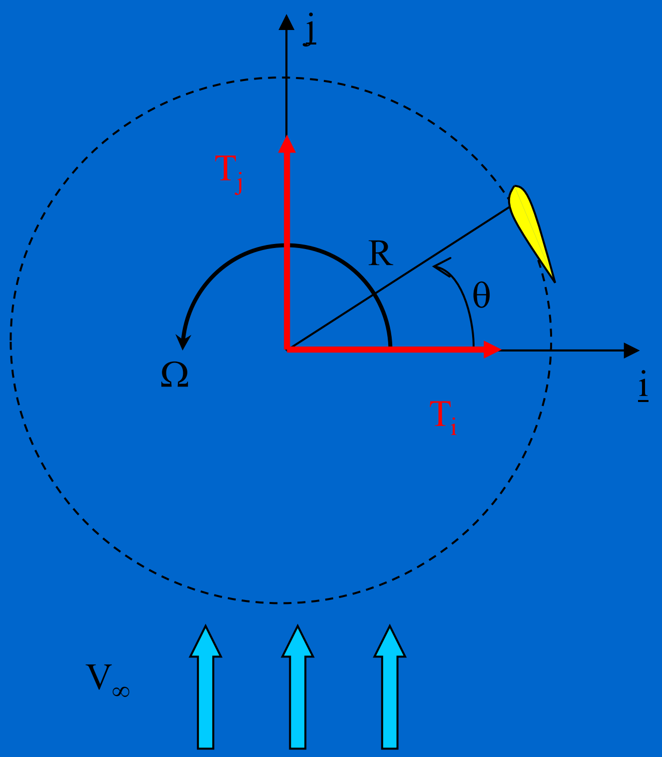


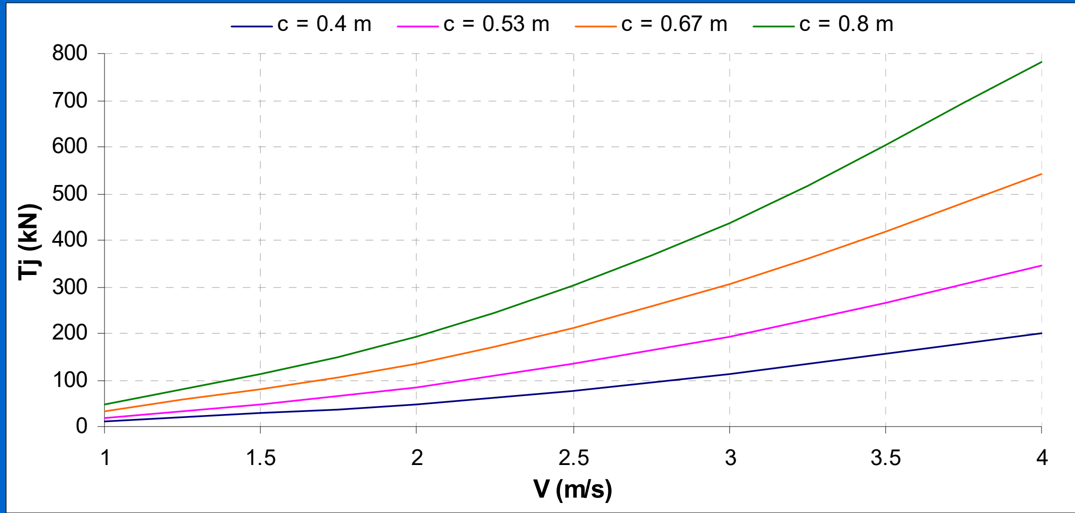
FEM structural analysis of the blade

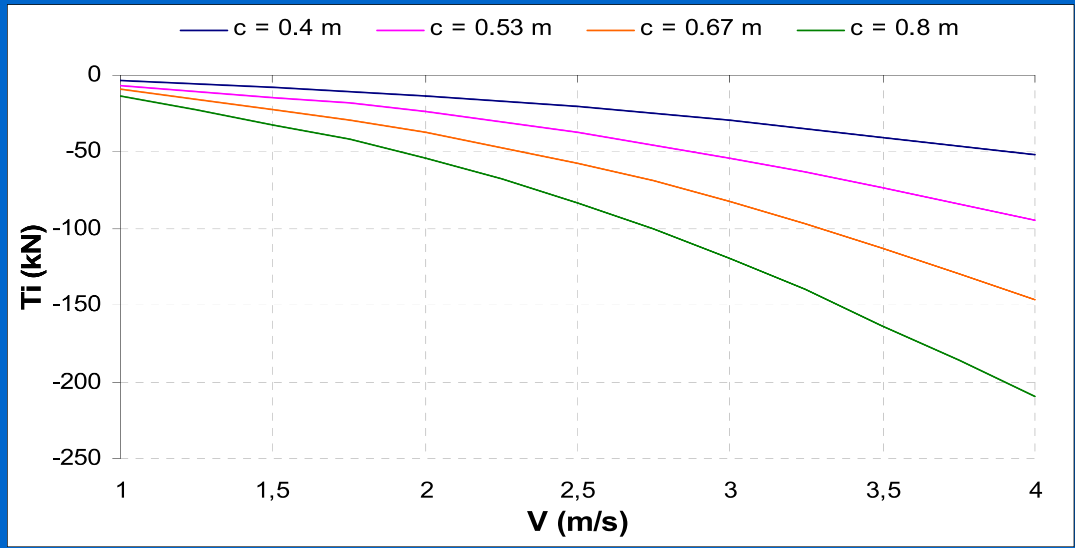

CARBON-FIBER LAMINATION
FOAM
SPARS IN STAINLES STEEL

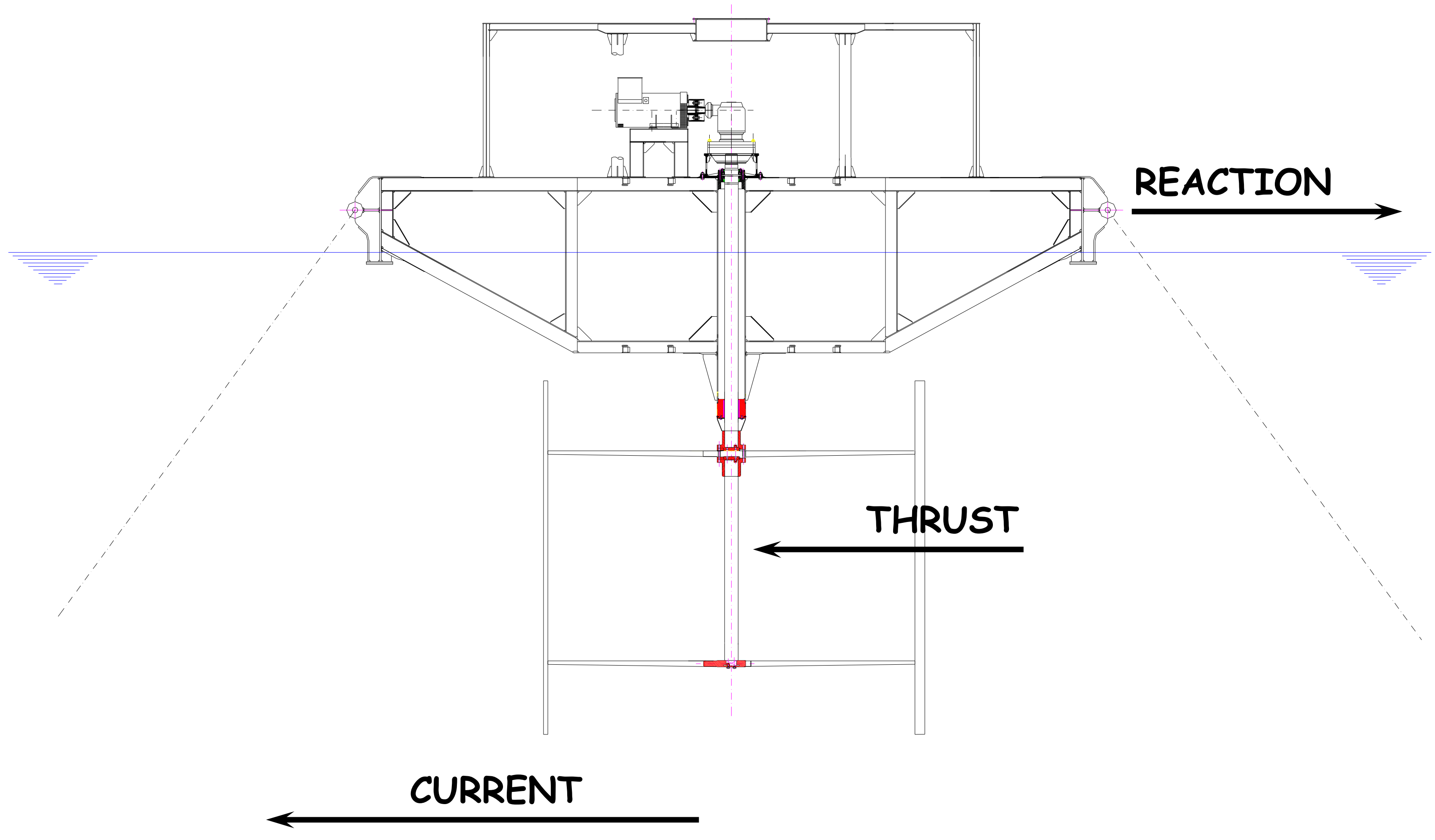
The turbine generates a thrust while working, which approximately has the same direction of the current.

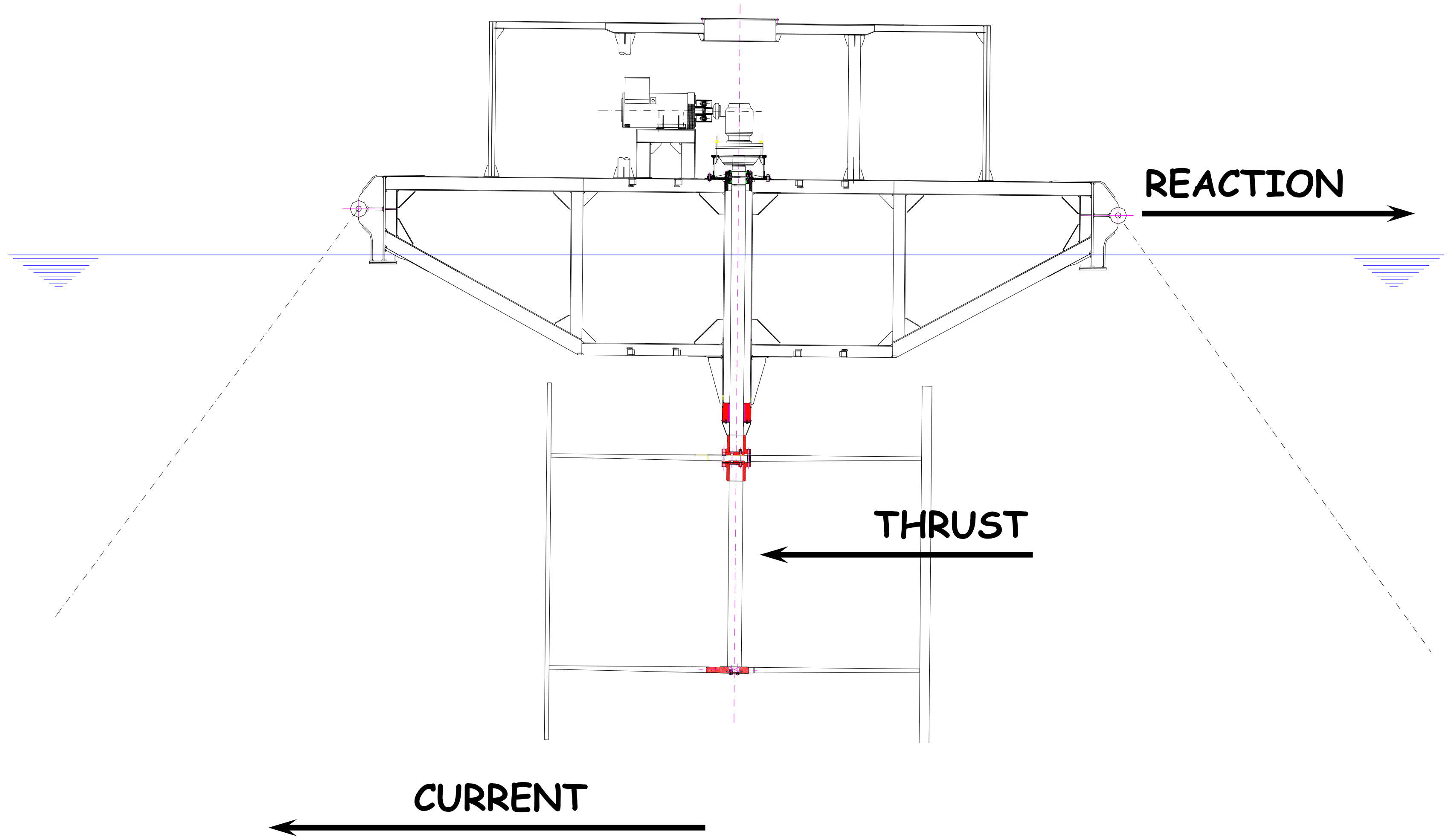
In standard working conditions this thrust is about 10 t.

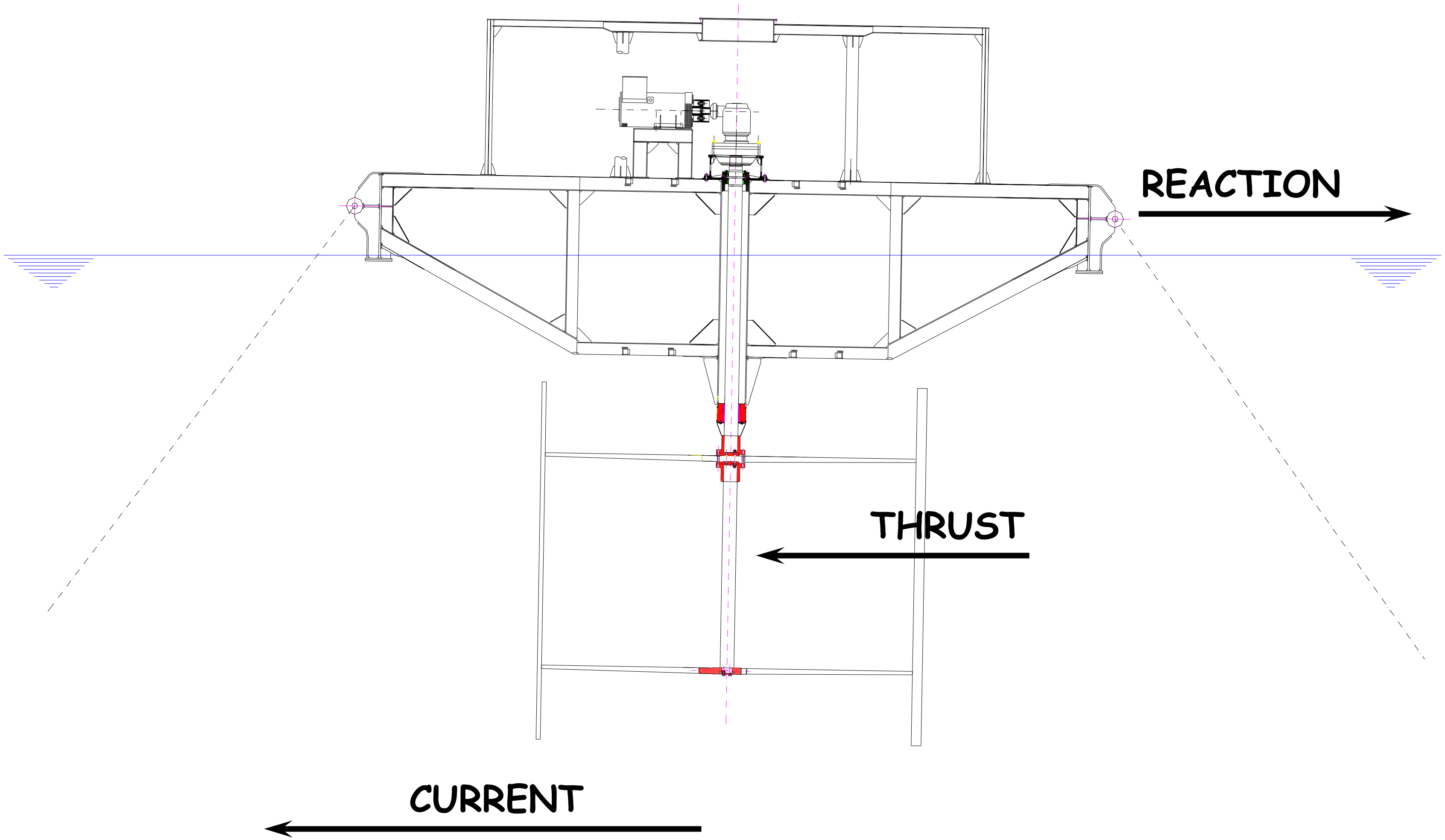


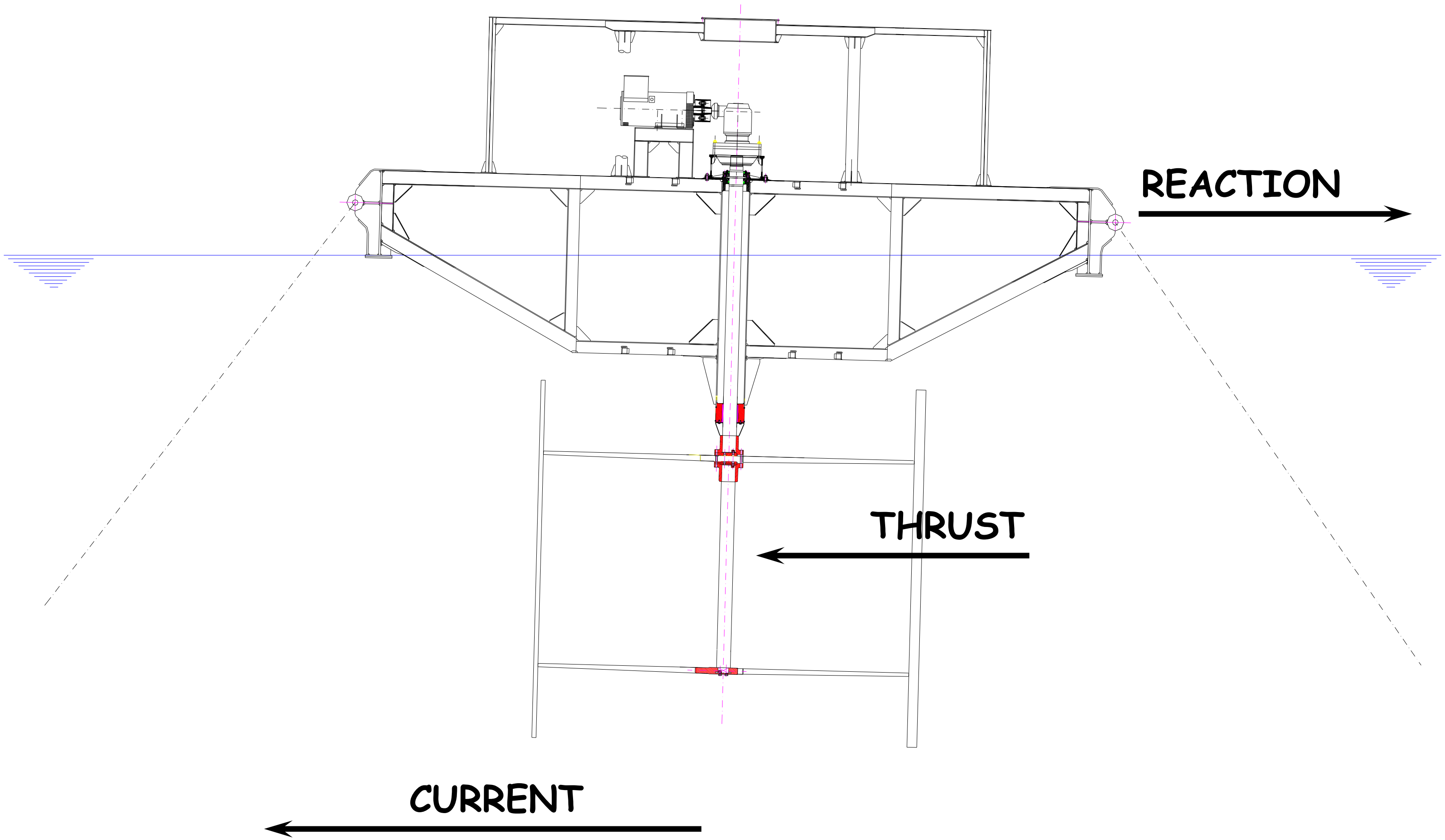


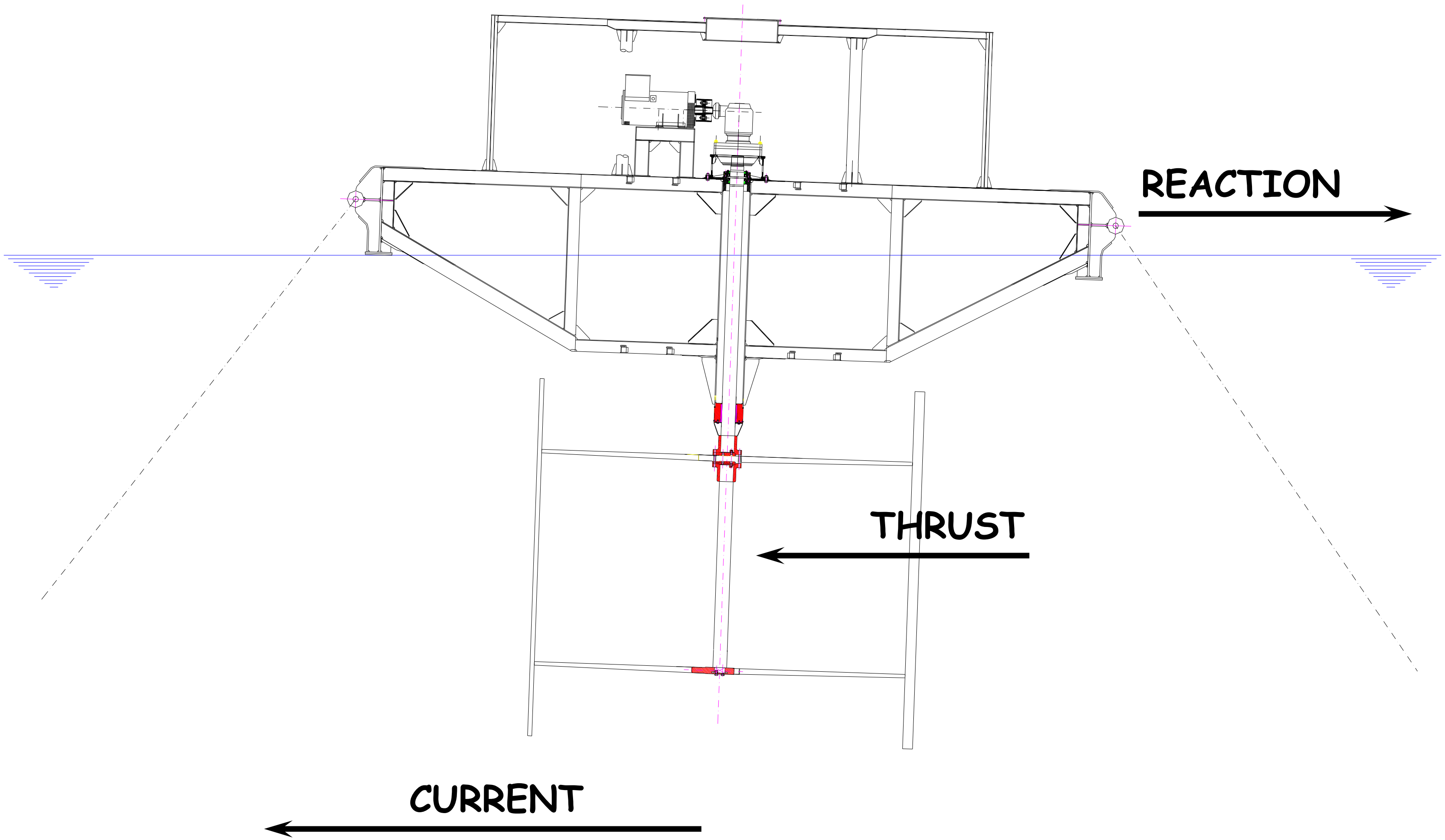



REACTION
THRUST
CURRENT

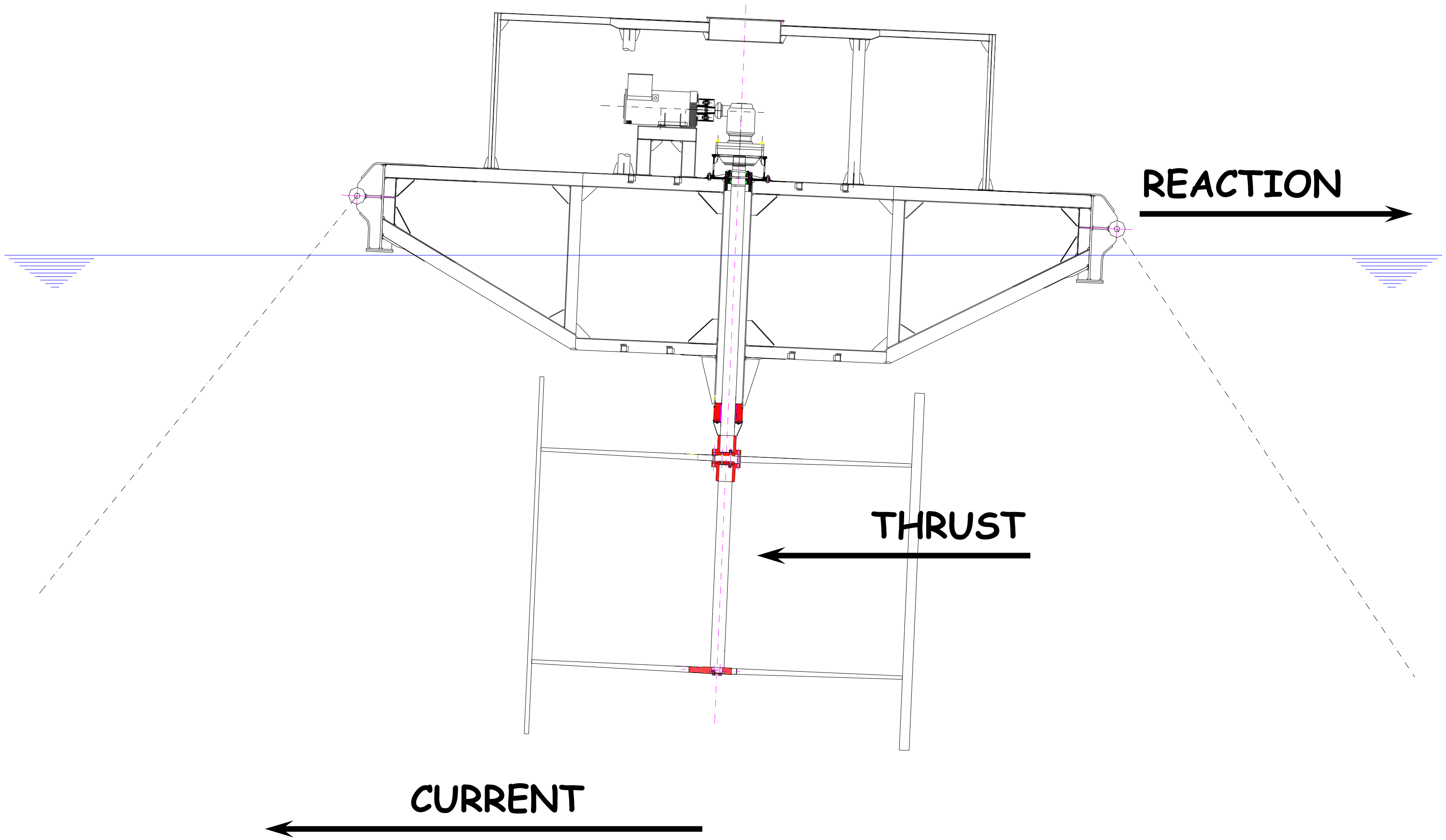

REACTION
THRUST
CURRENT

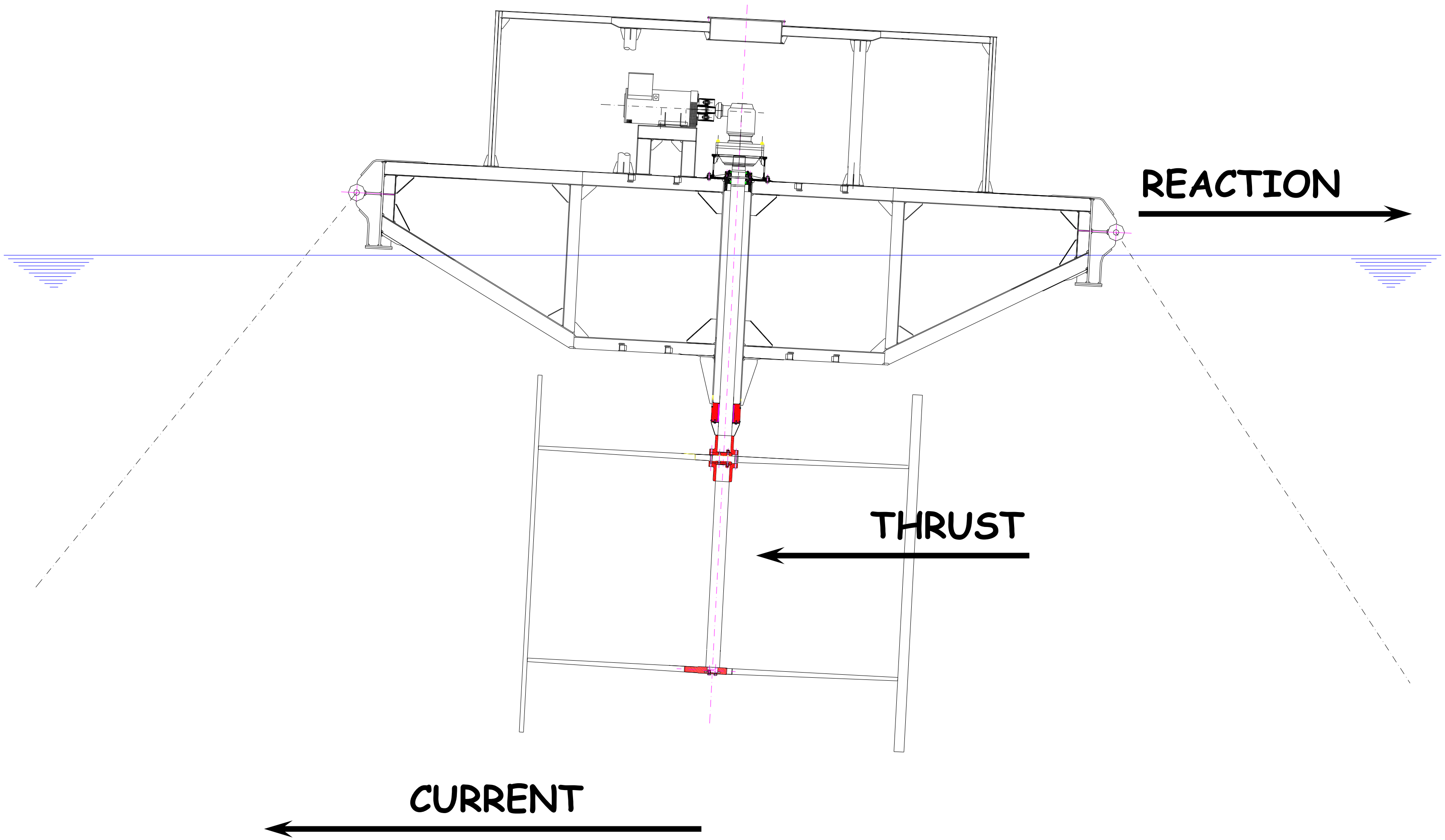

REACTION
THRUST
CURRENT

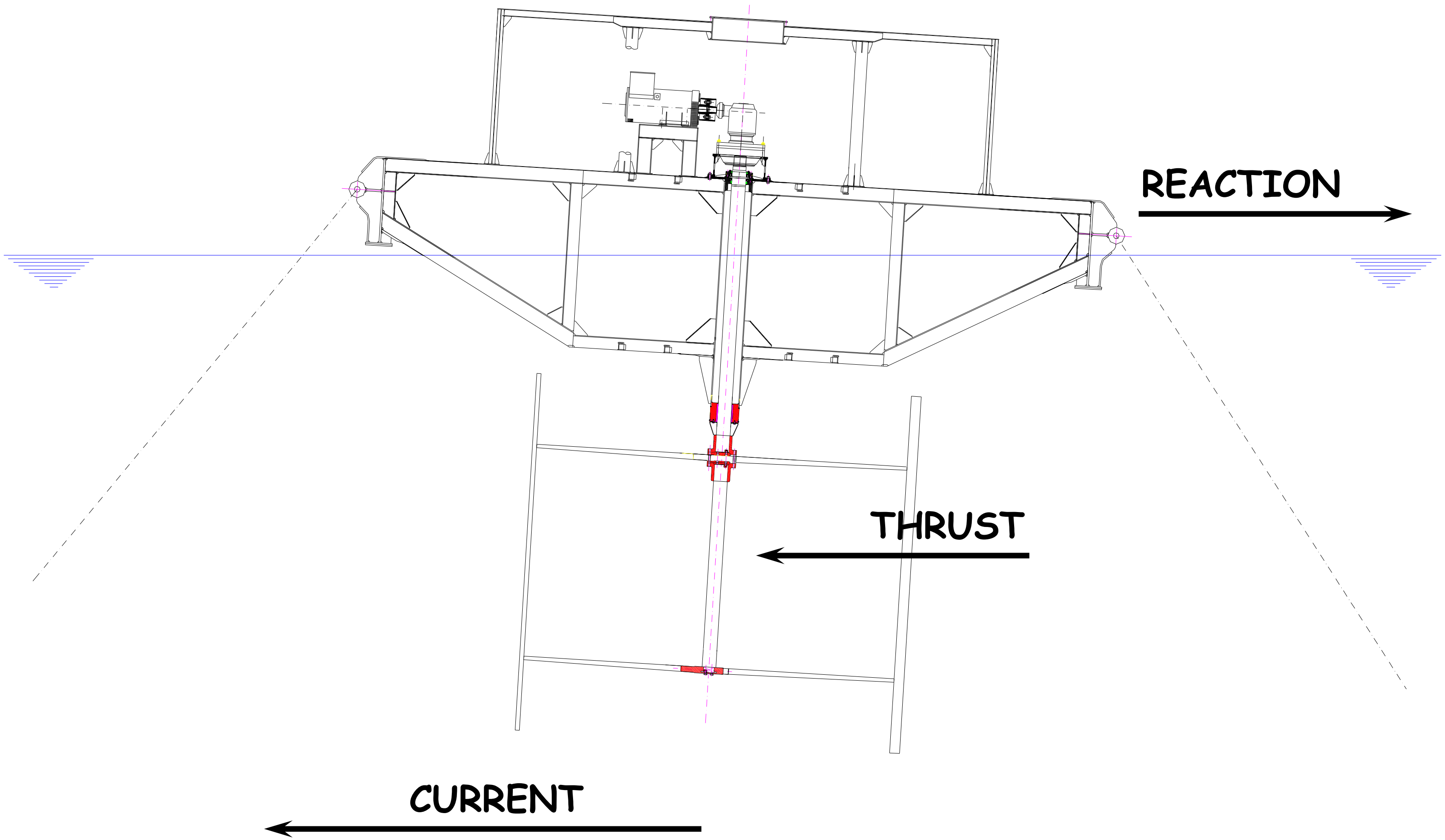

REACTION
THRUST
CURRENT

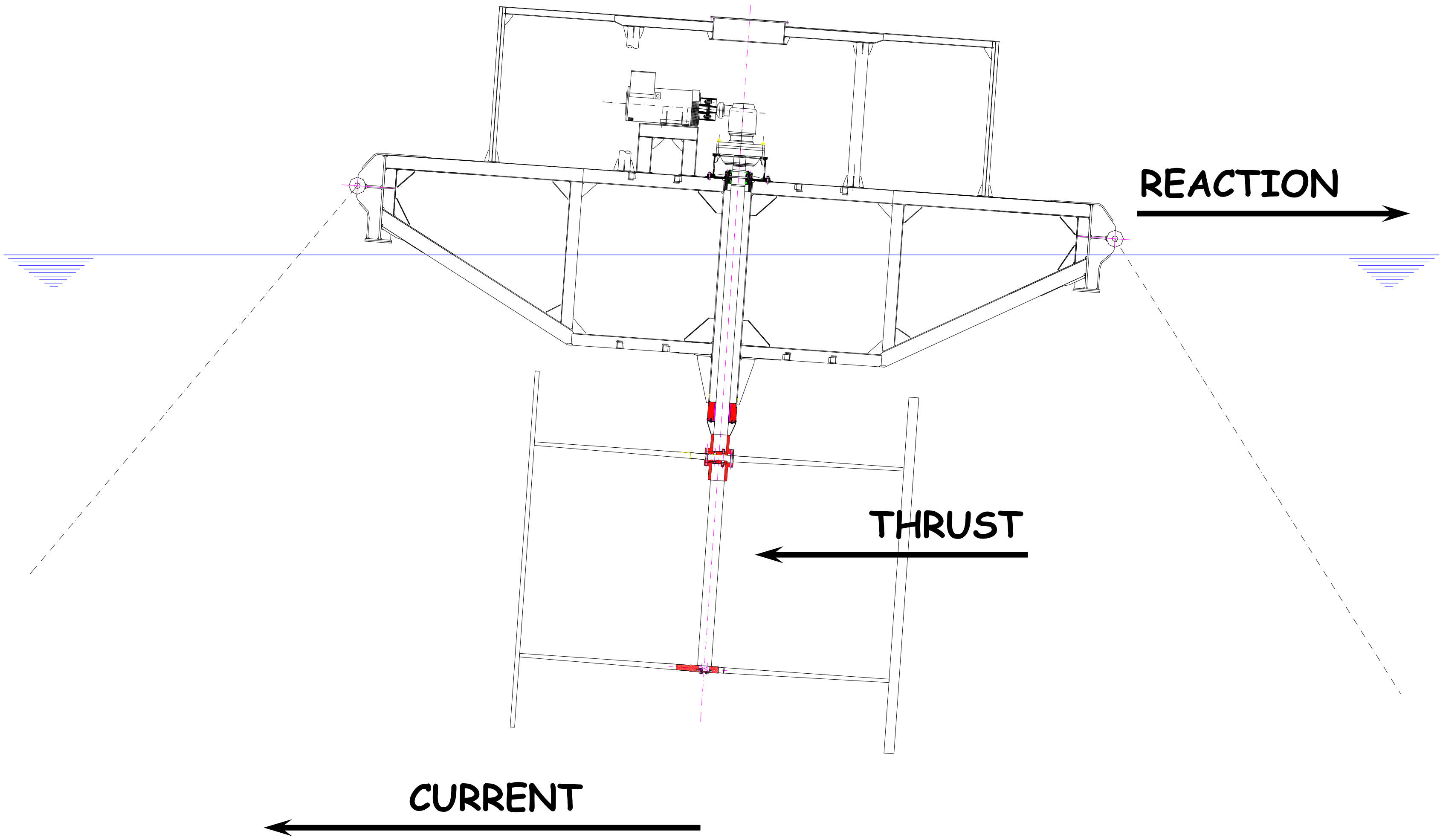


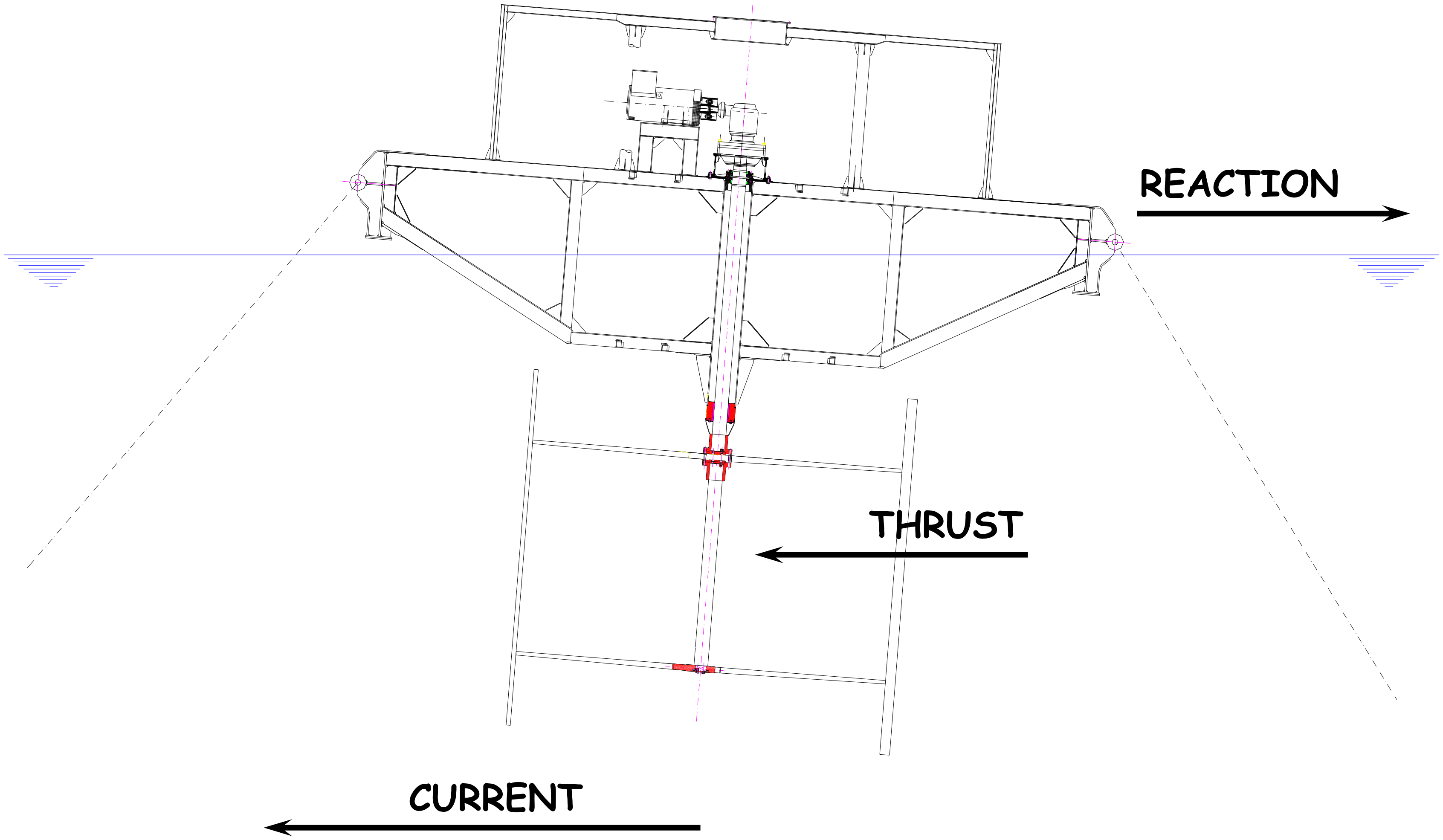
REACTION
THRUST
CURRENT

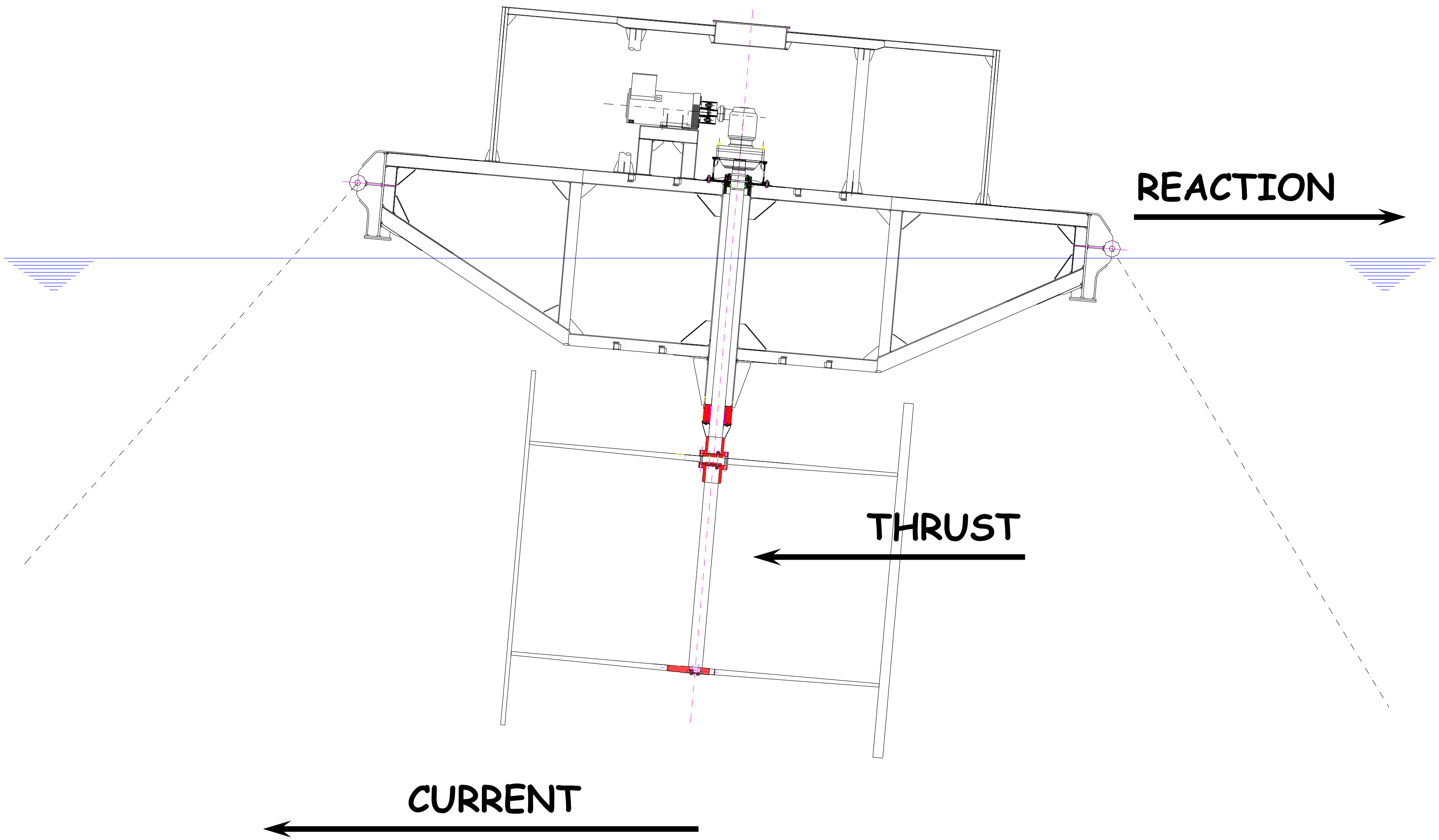

REACTION
THRUST
CURRENT


REACTION
THRUST
CURRENT


REACTION
THRUST
CURRENT


REACTION
THRUST
CURRENT


REACTION
THRUST
CURRENT


REACTION
THRUST
CURRENT

For reasons of both efficiency of the whole system and safety for the on-board personnel, the angle of trim has to be as small as possible.

Actually, during the normal operational conditions this inclination is about 5 – 6°.

It is not advisable to have a bigger angles mainly for two reasons:

- It is difficult to work on board.
- The arms fairings produce an added resistance and can stall.

The stability of the platform is therefore a primary characteristic for the floating plant.

The main parameter used to evaluate the stability of a floating object is the "**Metacentric Height**"

According to IMO Regulations a ship must have at least 0.15 m of metacentric height.

A passengers ship usually has around 0.70 – 1.20 m

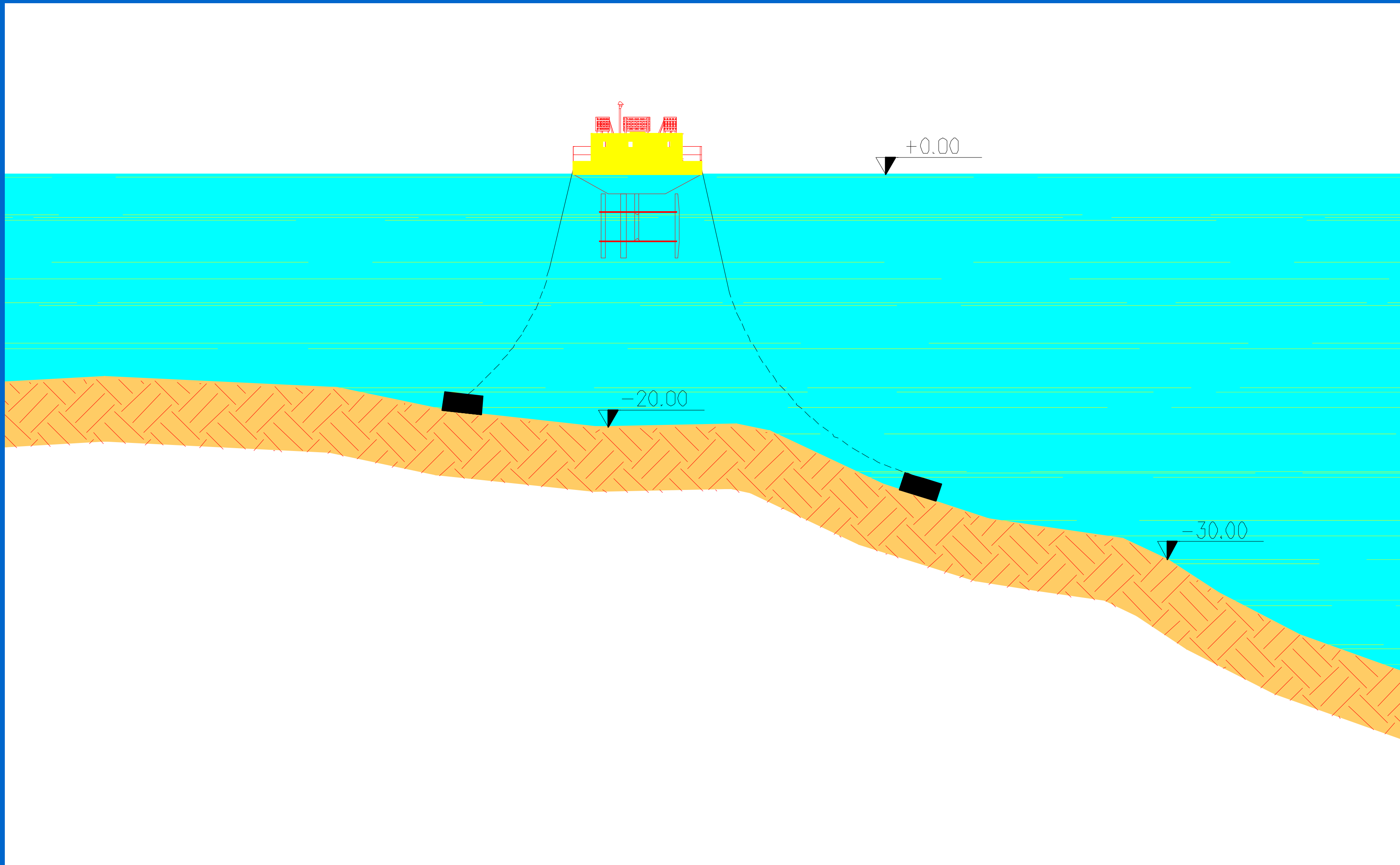
The Kobold floating platform has a metacentric height of about 5.0 m

The Mooring Arrangement

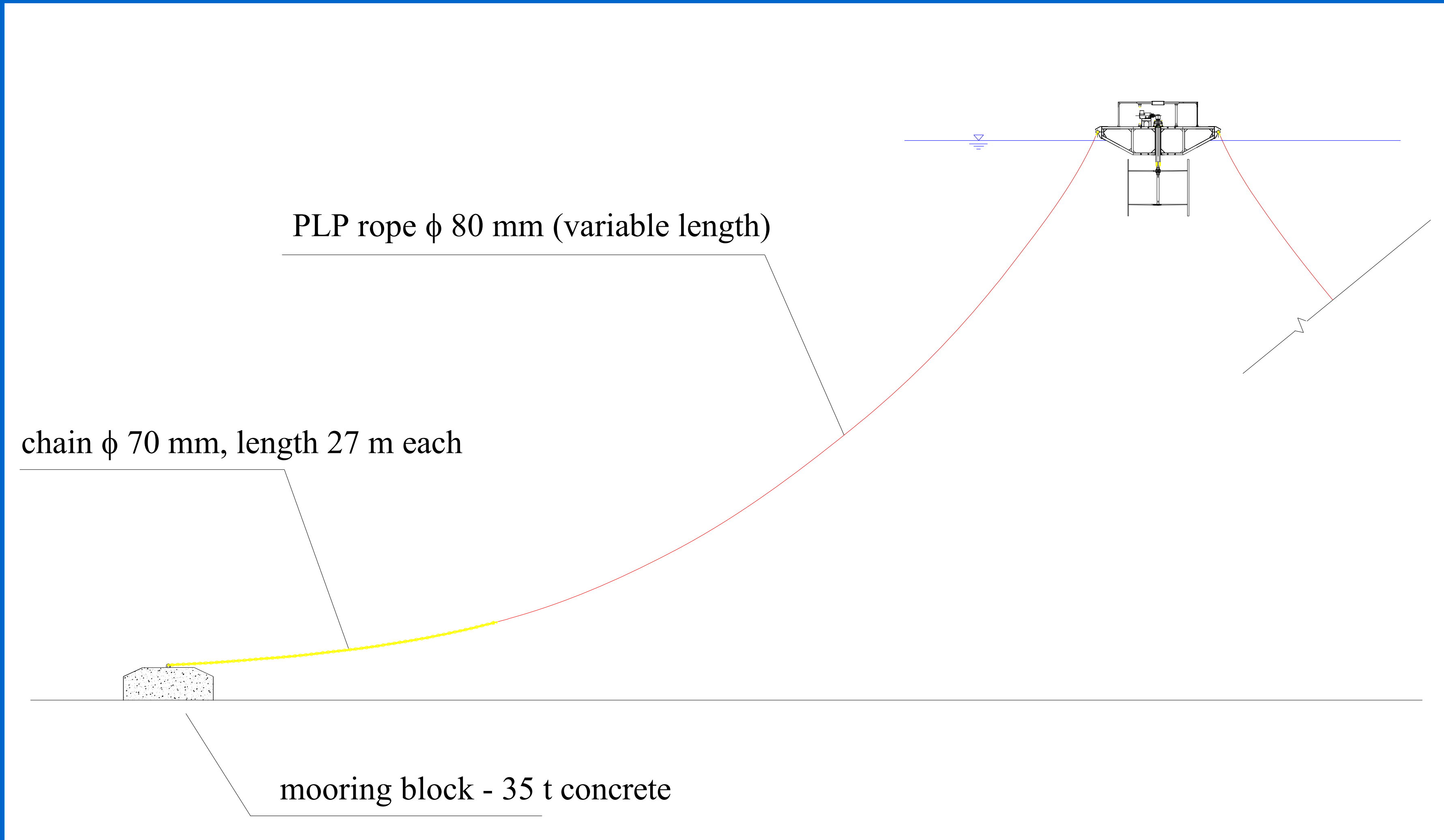
The *Kobold* floating platform is anchored to the sea bed by means of four mooring lines disposed at 90° from one another.

The platform is positioned 150 m offshore and moored to the seabed with depths going from 18 m to 35 m.

Each mooring line is composed by a concrete mooring block, by a chain and by a textile rope attached to the mooring eyebolts of the platform.

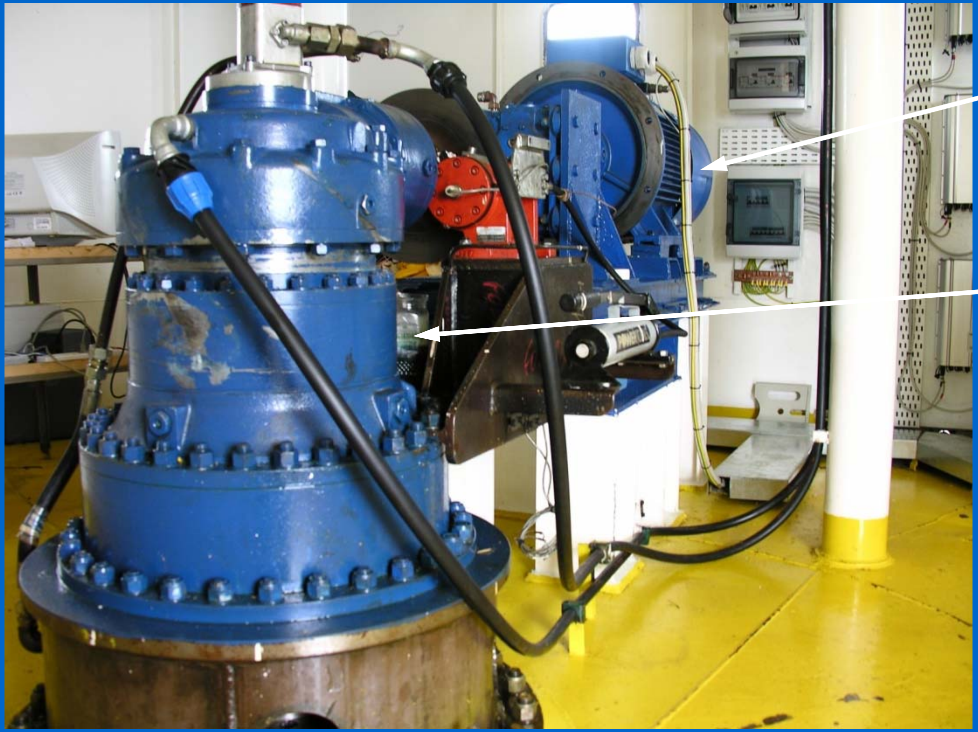


Mooring arrangement



Mooring arrangement

ELECTRICAL PLANT



Electric generator

Epicycloidal gear

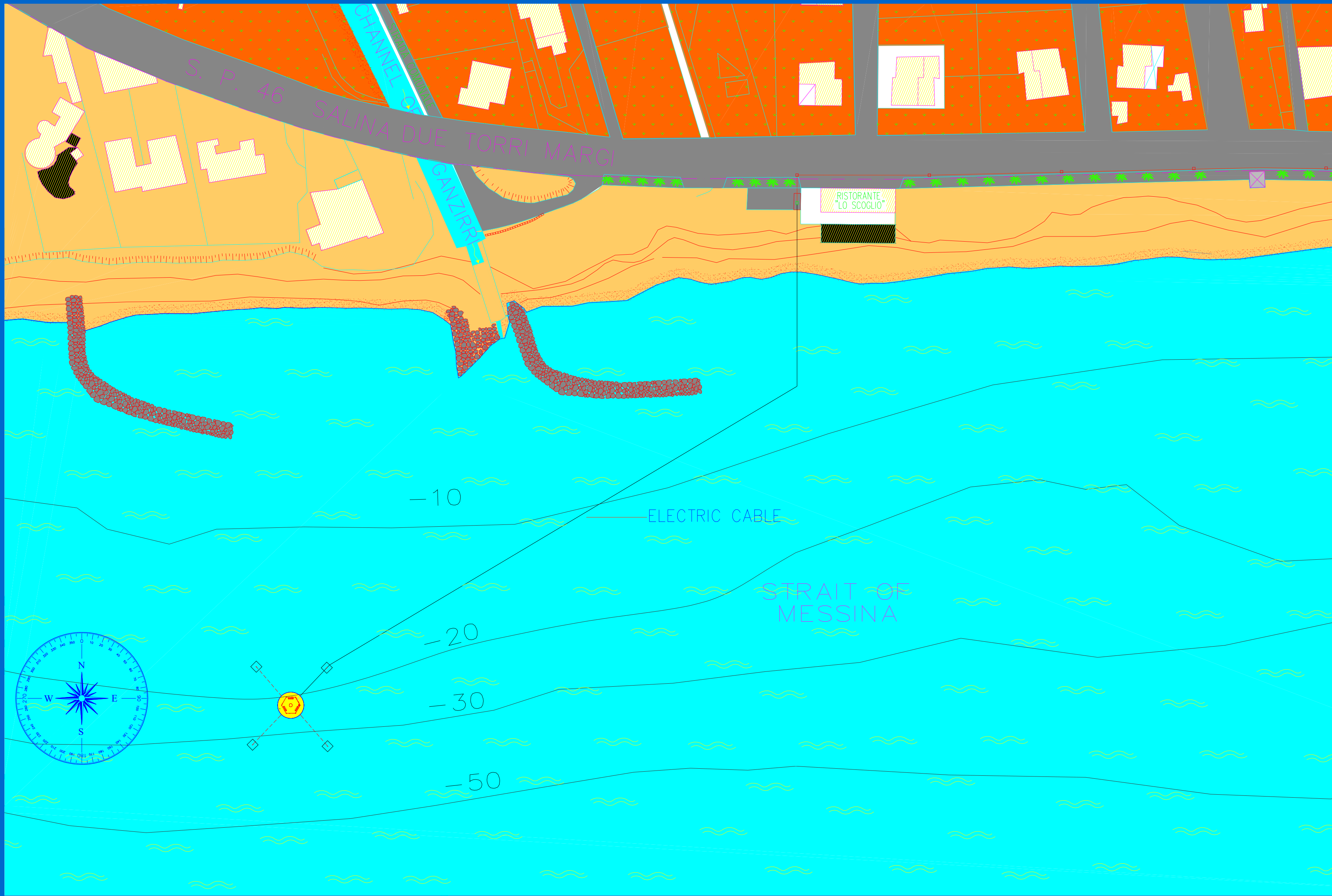
Rectifier - Inverter

CONNECTION TO THE ELECTRICAL NATIONAL GRID

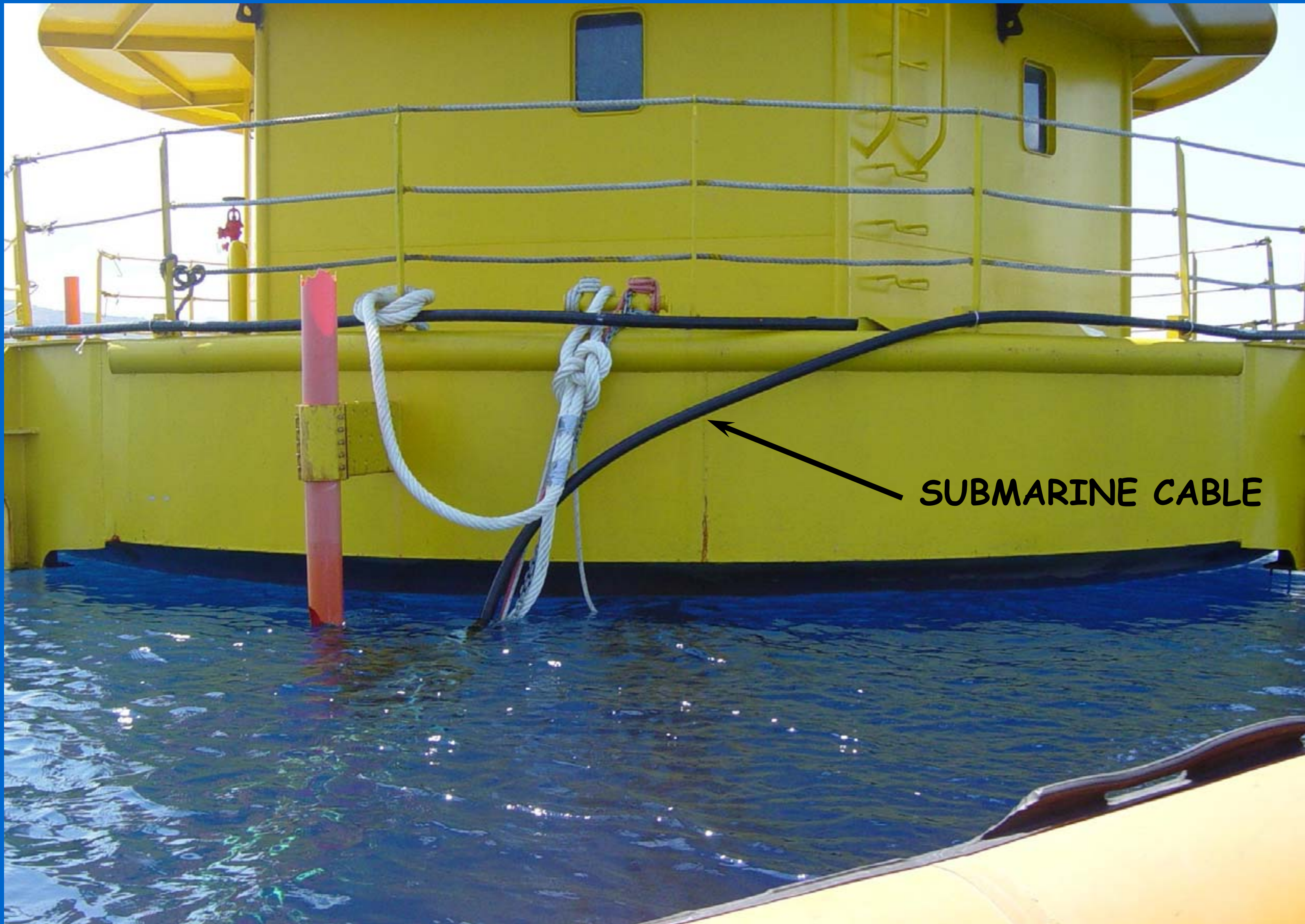
In the first phase the energy was used on board for experimental purposes, giving power to 1 kW floodlights and to a 6 kW “fire-fighting” pump.

In 2006 the turbine was permanently connected to the national electric grid by means of a submarine cable.

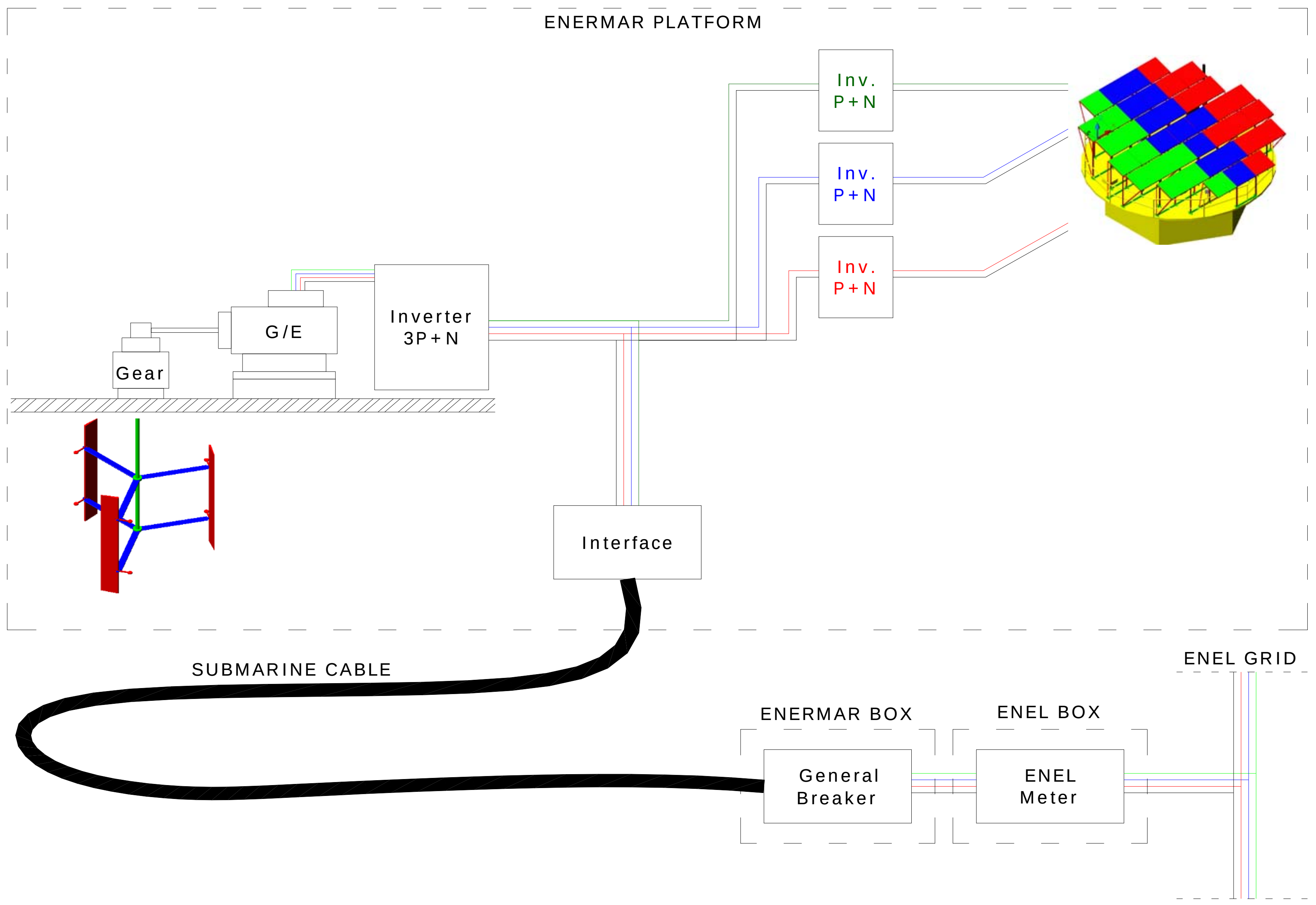
The electricity, generated at variable frequency, is converted at 50 Hz by means of a rectifier-inverter which constantly adjusts the load on the generator in order to have the turbine always at its maximum efficiency.



Submarine cable layout


SUBMARINE CABLE

Electrical Scheme



SOME RESULTS

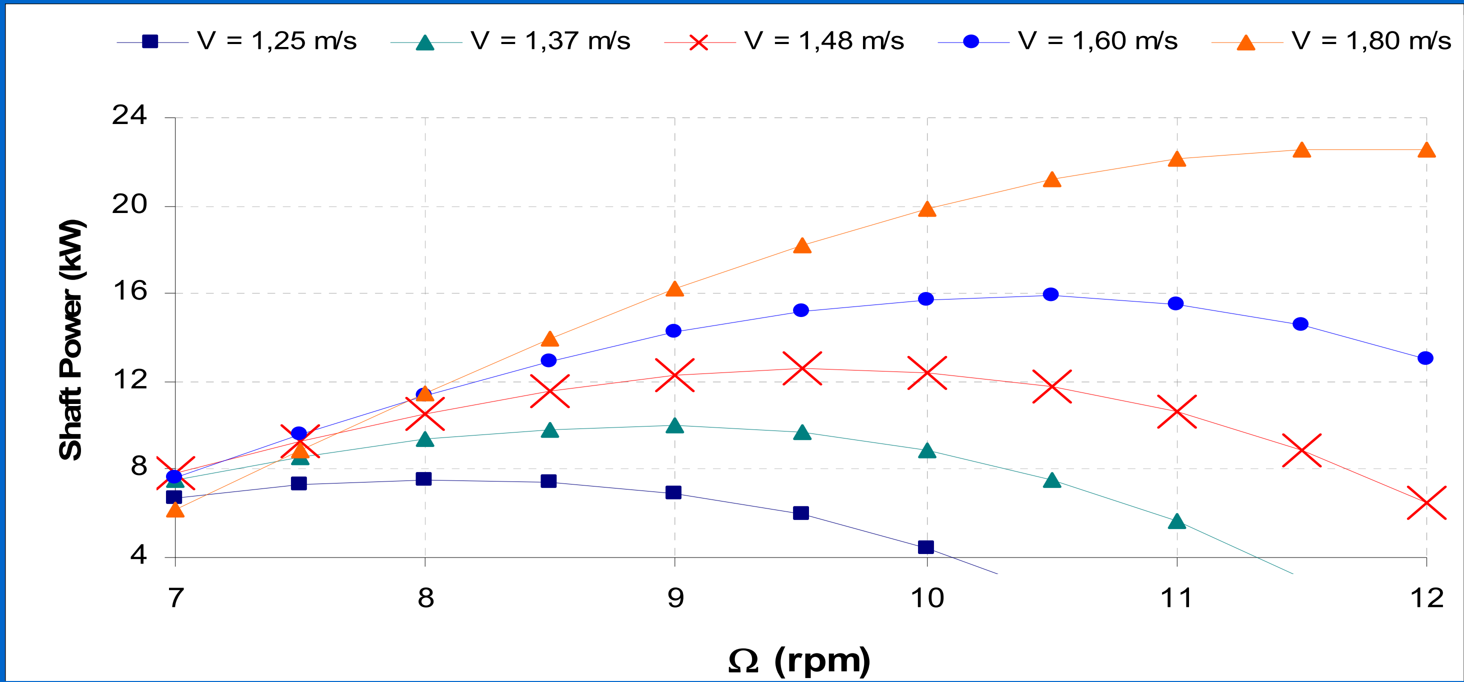
- The tests were carried out in a range of current velocity between 1 and 2 m/s.

- The global net efficiency, defined as :

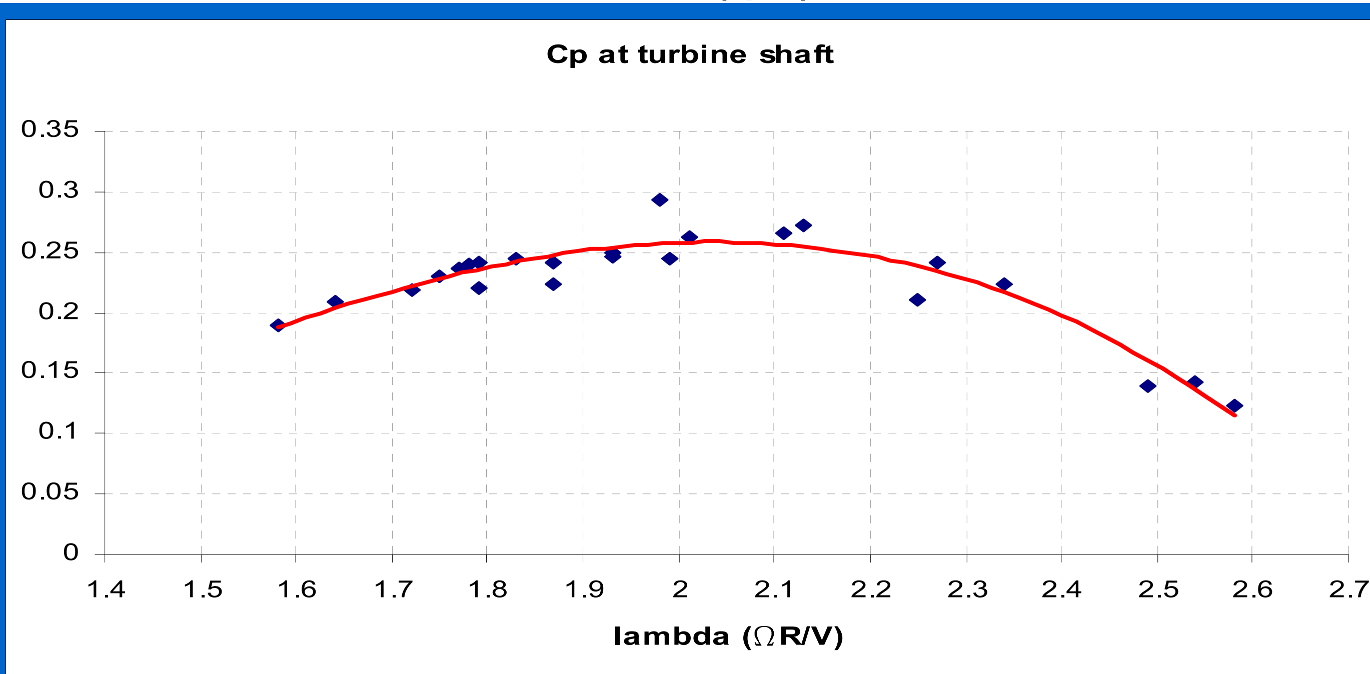
$$\eta = \frac{\text{Electric Power}}{\frac{1}{2}\rho S V^3}$$

inclusive of electric and mechanical losses, was estimated in roughly 23%.

- At 2 m/s the power produced was about 25 kW



V = 1,25 m/s
V = 1,37 m/s
V = 1,48 m/s
V = 1,60 m/s
V = 1,80 m/s
24
20
16
12
8
4
Shaft Power (kW)
7
8
9
10
11
12
Ω (rpm)



Cp at turbine shaft
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
lambda (ΩR/V)

AFTER MORE THAN TEN YEARS AT SEA…

The Enermar plant is at sea since 2001 and probably it is the first real scale plant for the exploitation of marine currents ever launched in the world.

During these years we have experienced the reliability of the several components of the plant and proved the design choices.

We had no relevant problems in the main components reliability; the global behaviour of the plant, taking into account that it is a first prototype, can be considered satisfactory.

During this running period we got a lot of data concerning details to be improved in the plant’s design and maintenance.

The main problems we found mainly regarded:

- Blade – arm connection.
- Thrust bearing.
- Galvanic currents.
- Biofouling.

BLADE – ARM CONNECTION

The weakest point of this part is the rubber blocks used to set the blade oscillation angle.

Other problems are given by fishing lines and nets which have to be removed by scuba divers.

THRUST BEARING

The original thrust bearing was made of Ertalon, material normally used for the propeller bearings.

The Ertalon gave two kind of problems: water absorption and stress weaknesses in the radial direction.

A new material was chosen for this component: Orkot.

		ERTALON	ORKOT
Rockwell hardness	R-M	87	100
Tensile stress	N/mm2	83	60
Compressive stress (Par.)	N/mm2	92	92
Compressive stress (Perp.)	N/mm2	92	347
Water absorption	%	6.5	>0,1
Max. service temperature	°C	120	130
Thermal expansion coeff.	(°K)	8,0 E-5	9,0 E-5

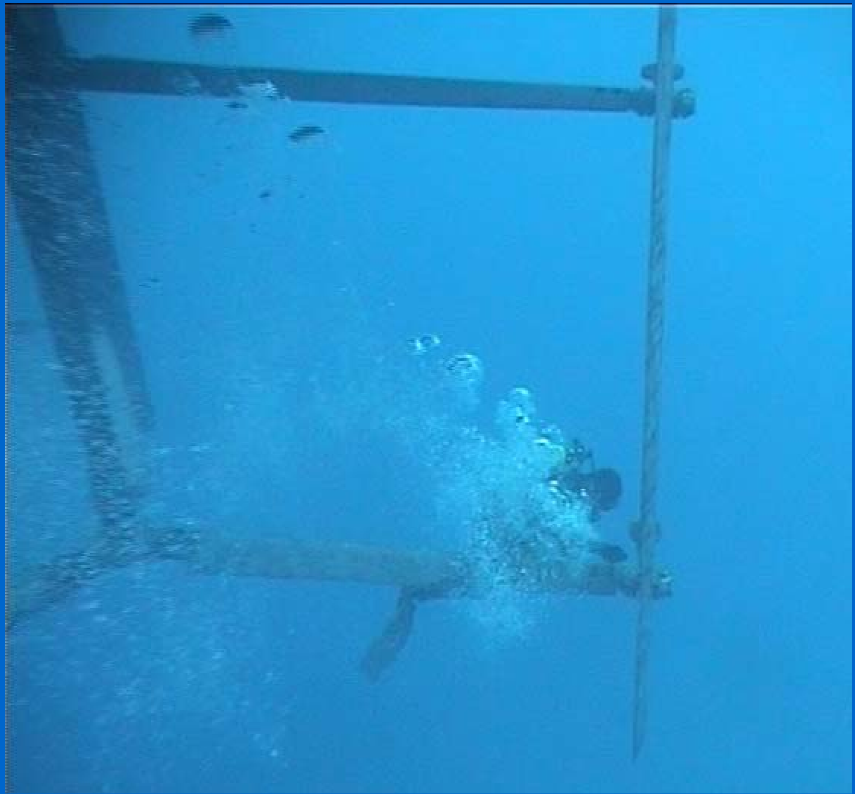
GALVANIC CURRENTS

The presence of carbon, having a very high electrolytic potential (similar to gold) generates strong galvanic currents in the steel structure and thus can cause corrosion problems if not correctly protected.

BIOFOULING

The marine environment is very active from a biological point of view.

To keep the turbine efficient it is necessary to send periodically a scuba diver to clean blades and arms.



THE *"KOBOLD II"* PLANT

Thanks to an UNIDO financing it was possible to build a *Kobold II* plant in Indonesia.

It was based on the experience gathered on the field by Ponte di Archimede Co., in designing and running the plant in Messina.

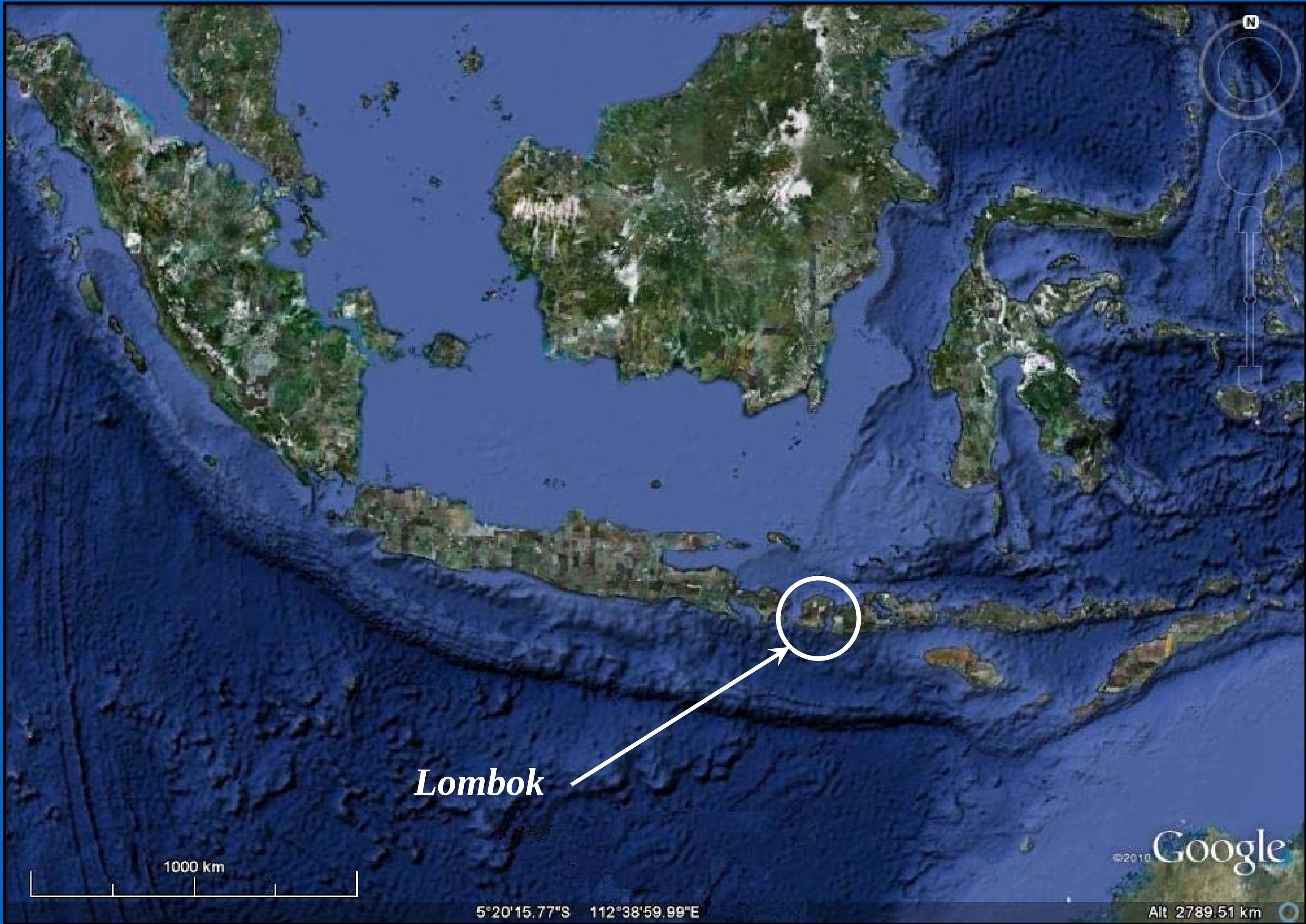
It was an evolution of what we already installed in Messina

- ✓ The plant was to be installed on the eastern coast of Lombok were there are current similar to those in the "Stretto di Messina".
- ✓ At the maximum current the rated power was about 150 kW.
- ✓ It had to give power to the village of Pringgabaya, at present not served by any electrical grid.

The plant was designed and built by the indonesian *Kobold Nusa Co.*, participated by Ponte di Archimede Co.

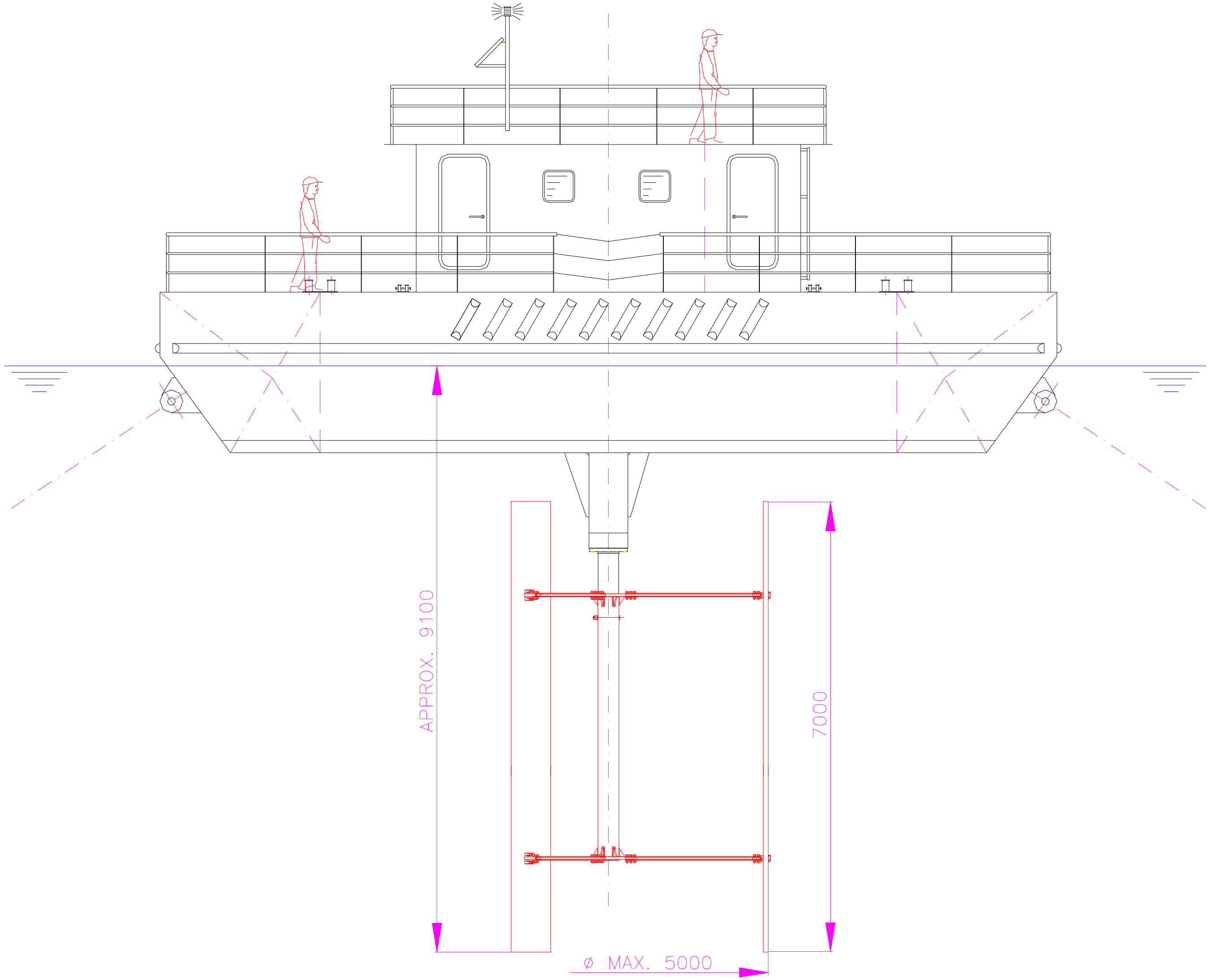
The plant was maily (both platform and turbine) built in Indonesia, getting as much as possible from indonesian market.

- ✓ The floating platform and the turbine are manufactured by PT Javasea Transnuatics.
- ✓ The mooring lines, the submarine cable, the on-land electrical distribution plant were financed by Lombok Local Government and by RISTEK.
- ✓ Blades and electrical components were coming from Italy



Kobold II **Plant in Lombok – Plant Location**

Kobold II **Plant in Lombok – Plant Location**



Kobold II **Plant in Lombok – General Arrangement**

THE *"KOBOLD II"* PLANT – MAIN CHARACTERISTICS

The plant is capable of about 150 kW with a 3 m/s current.

The floating platform is a steel barge by the following main dimensions:

Length……………………………………………………………………….14.00 m

Breadth…………………………………………………………………… 7.00 m

Depth………………………………………………………………………..2.50 m

Extreme Draft………………………………………………………… 9.50 m

Dry Weight…………………………………………………………….40.00 t

THE *"KOBOLD II"* PLANT – MAIN CHARACTERISTICS

The *Kobold* Turbine used for this application is an evolution of the turbine used in Messina.

It is bigger and it differs in some mechanical components

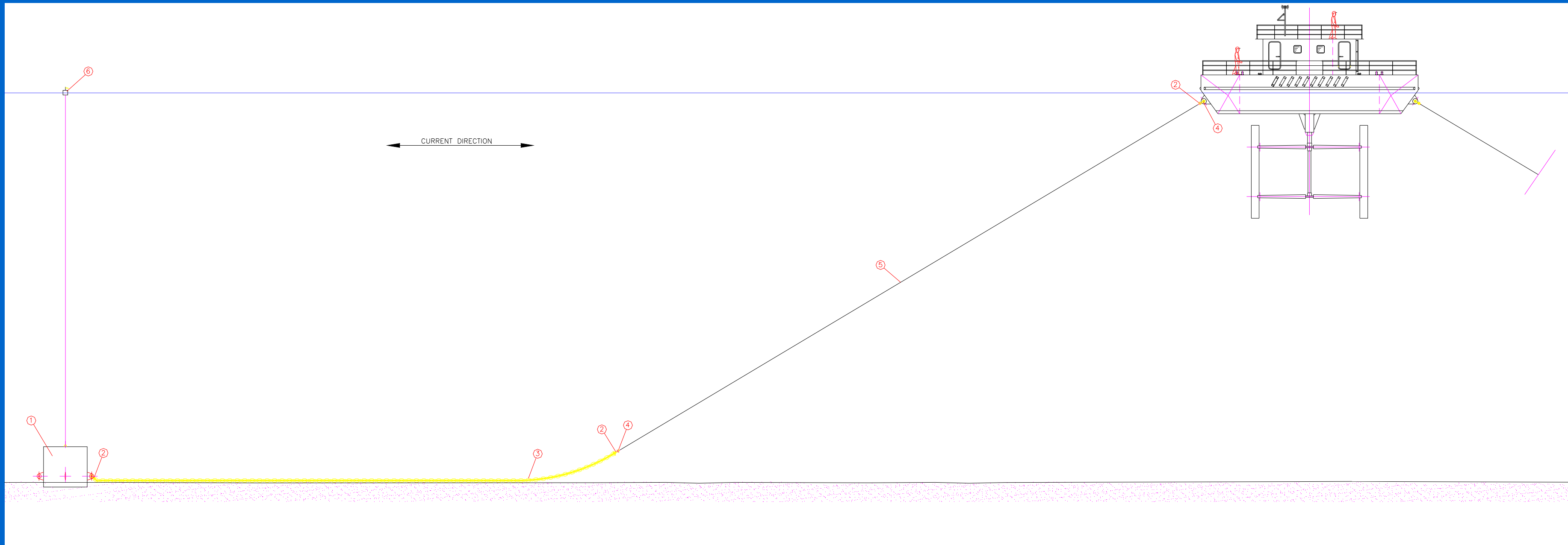
The turbine main dimensions are the following:

Diameter ……………………………………………………………… ….5.00 m

Blade length……………………………………………………………. 7.00 m

Number of blades…………………………………………………….3

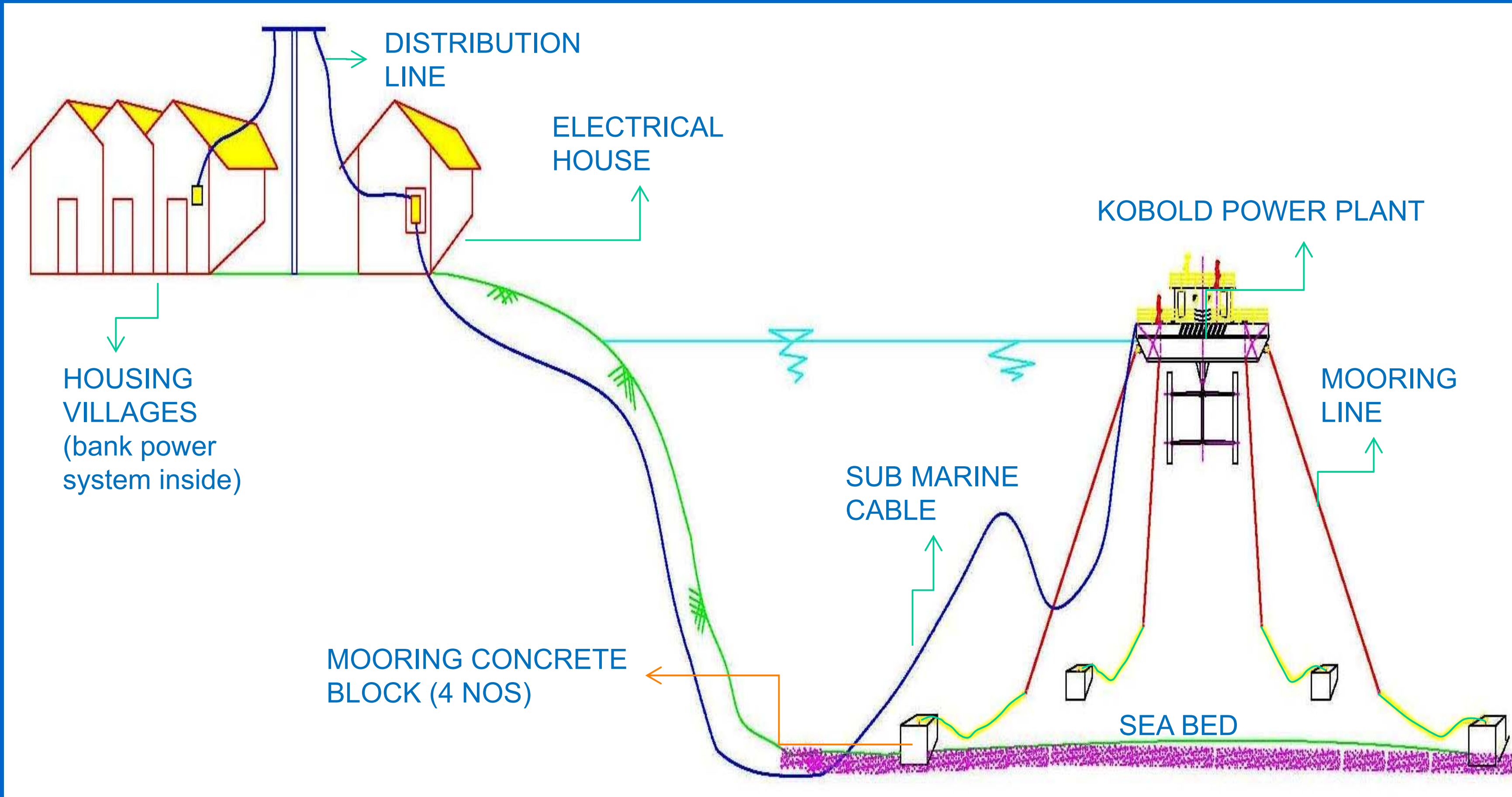
Rotational Speed…………………………………………………….25 rpm



SINGLE MOORING LINE COMPONENTS				
ITEM	DESCRIPTION	Q.TY	SWL (t)	BL (t)
1	CONCRETE MOORING BLOCK (WEIGHT=50 t)	1	==	==
2	SHACKLE DIA. 63 mm	3	55.00	330.00
3	STUD LINK CHAIN DIA. 70 mm	34 m	131.50	187.60
4	THIMBLE FOR FIBRE ROPE	2	==	==
5	POLYPROPYLENE ROPE DIA. 58 mm	45 m	==	38.60
6	POSITION MARKING BUOY	1	==	==

Kobold II **Plant in Lombok – Mooring Arrangement**

Kobold II POWER PLANT SYSTEM



THE KOBOLD II PLANT

Platform in the workshop during fabrication

THE KOBOLD II PLANT

Platform in the workshop: outside and inside

Transportation from the workshop to Lombok

THE KOBOLD II PLANT

Upper and Lower shafts during fabrication

THE KOBOLD II PLANT

Lower shaft bushing and blade arms

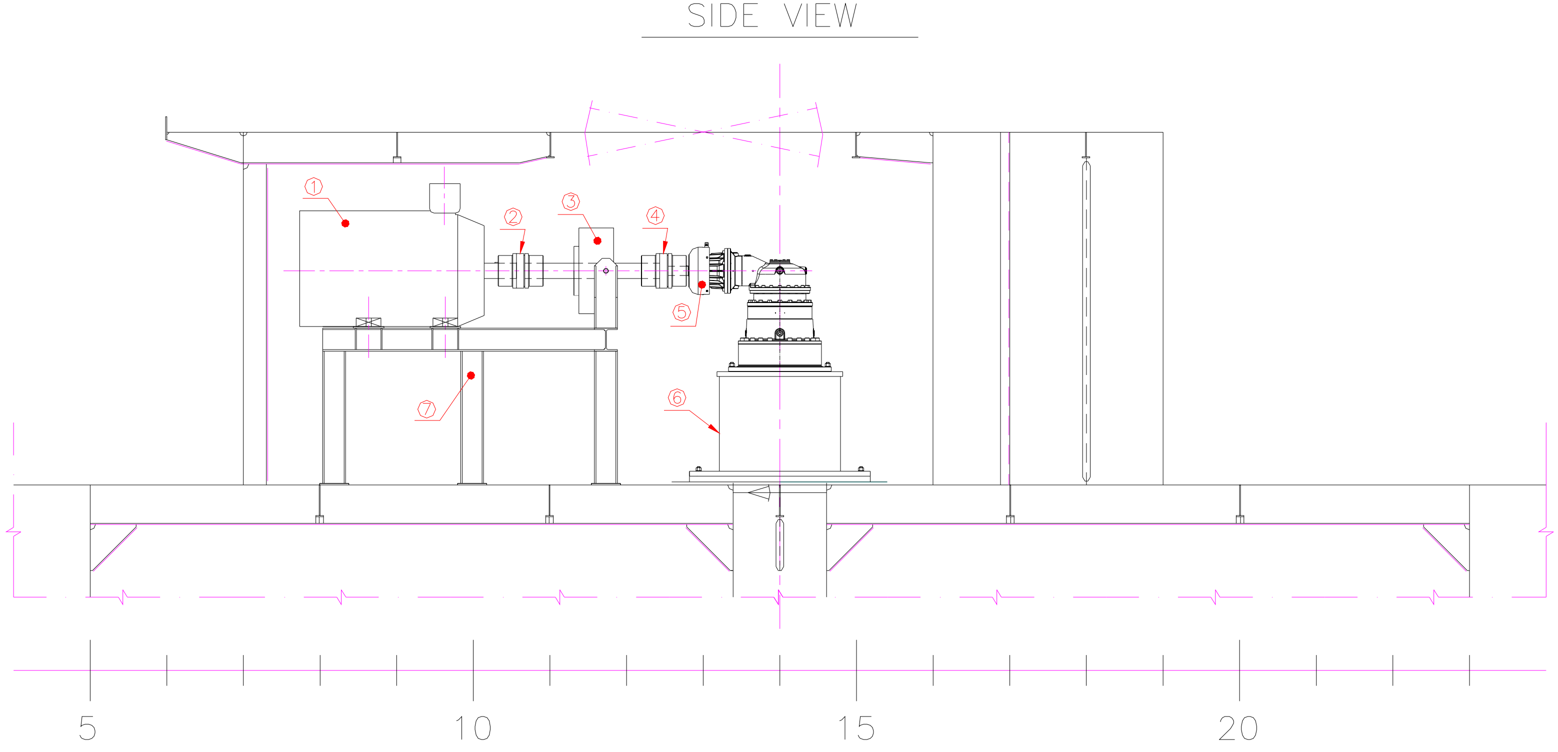
THE KOBOLD II PLANT

Blades in the workshop

THE KOBOLD II PLANT

Blades in the workshop

THE KOBOLD II PLANT



N.	DESCRIPTION OF COMPONENTS
7	Foundation for generator and hydraulic brake
6	Gearbox Foundation
5	Gearbox
4	Rotex110 92 Sh–A, D60 H7NnD D100H7NnD
3	Hydraulic Brake
2	Rotex 110 92 Sh–A D100
1	Generator

Machinery room

THE KOBOLD II PLANT

The Platform


Thank you!