Politecnico Di Torino

Mechatronics Engineering

Master's Degree Thesis

DESIGN OF A MOTORIZED SAIL FURLING SYSTEM

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Credits

I would like to take this opportunity to thank everybody who contributed to the success of my thesis and who helped me to realize this project.

I especially want to thank my tutor Carl JOSSE, head of the design office, for his hospitality, his pedagogy and his investment in this major project within *PROFURL*.

Then, I thank Thomas RETAILLAUD, project manager at the design office and Cedric MARTEL, technical manager, for having welcomed me and allowing me to realize this thesis.

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Content

Introduction

In Europe, the global boating industry's second largest market, the region's economic recovery appears to be in full flow, with low interest rates and higher employment spurring domestic consumption. Trade among EU member states grew 23% to €2.6 billion, while exports of boats outside the bloc rose 6% to €5.9 billion. With consumer confidence reaching new highs, European boating markets appear to have side-stepped the quagmire of political and economic instability of recent years, with overall revenues across European boating markets growing by 3% in 2017. [ICO17]

France is a global leader in sailboat production. The sales growth of boat production has skyrocketed to +14% in 2017 compare to 2016 to reach 4,26 billion euros in revenue [MIN18]. The country counts among one of the most important boat builders and boat hardware equipment manufacturers. This sector is constantly moving and more than ever these last decades. The introduction of 3D manufacturing, new composite materials and new electronic technologies have changed the way boats are built and perceived. Indeed, the boat industry has been for a long time quite simple and basic in its design, mainly for traditional robustness reasons. However, the increase of new boat owners, the ageing of the overage customers, the development of boat renting and the increase number of unexperienced sailors, has forced the market to adapt to be more accessible.

As part of my master's degree at *Politecnico di Torino,* I realized a 6 months thesis within the company *PROFURL* in France. *PROFURL* develops furling systems for more than 30 years for professionals such as *BENETEAU,* and a wide variety of resellers. I had the opportunity to work as project manager to design the second version of its Electrical "flying" sail furler, one of the very few on the current market. The two major tasks asking for this project are directly linked with mechatronics. On the one hand the goal was to modify the mechanical structure to improve the efficiency of the system and on the other hand we aim at introducing a controller to protect the furler and to adapt it to its very demanding environment.

This thesis report exposes the whole design cycle I conducted for 6 months. The first part will be dedicated to the analysis of the needs and of the original requirements and their evolution.
The second part is the heart of the project. It is centred on the design around three axes: the motorization, the mechanical and the electronics improvements.
Finally, the last part will detail the actions taken to test and validate the final prototype.

Company presentation

PROFURL is a company of ten people located on the Atlantic coast of France. It is part of the group *WICHARD* which was created in the Forges De La Croix De Fer factory on the 1st of May 1919 by Henry Wichard and his associates. *WICHARD* started as a cutlery sub-contractor to a globally renowned equipment manufacturer for the yachting sector and precision part supplier for the mechanical, automotive, aeronautical and medical industries. The forge is the original field of the group but since 2002 it merged with *PROFURL* to extend its range of boat hardware equipment. Then, *WICHARD* has become a group of seven companies mainly specializing in the sailboat industry. From the forged marine hardware to the sail furling systems and the carbon fibre mats, the company has become one of the five main boat equipment companies.

I have been working specifically with the team of *PROFURL* in *Pornichet*, a place selected for its proximity with the main boat builders of the Atlantic coast such as *BENETEAU*. I joined the Design office as project manager of my own system. *PROFURL* is a profitable company that makes very specific products for customers but also custom products for racing sail teams such as the "Vendée globe" or the "route du Rhum".

One of the features of the company is the proximity with the whole team. I have been working directly with the marketing and the technical department which work with us in such a way that the design of products is always linked with every contributor of the project to the customers. *PROFURL* develops, build prototypes and test their own product for more than 30 years now.

Chapter 1

Specifications

1.1. Defining the need

There are many types of different sail boats such as: Catamaran, Trimaran, Sloop, Ketch…
Here, we will consider the Sloop* (Fig. 1) as a reference example for our study. A « standard » from the 1950s, this type of rigging* is composed of a main sail, fixed on the mast, and one or more jib*. This type of boat is adapted for cruise or regatta*.

Figure 1 : The sloop

The main sail is fixed on the mast, although it's possible to reduce its surface thanks to a system of ropes and eyelets. The jib is fixed in the case of the use of a stay furling system but removable in the case on the use of a "flying" sail furling system. Consequently, when a stay furling system is used, the shroud* is structural, it's an element of the static of the mats. In this case, the sail can be furled depending on the need and the speed required. In the case of a flying sail furling system, these sails are called « flying » because they can be removed and changed for another one more adapted to the strength and the direction of the wind (Fig. 2). A stay furler will be then permanently on the boat while a « flying » sail furler can be detached from the sail.

*refer to lexical

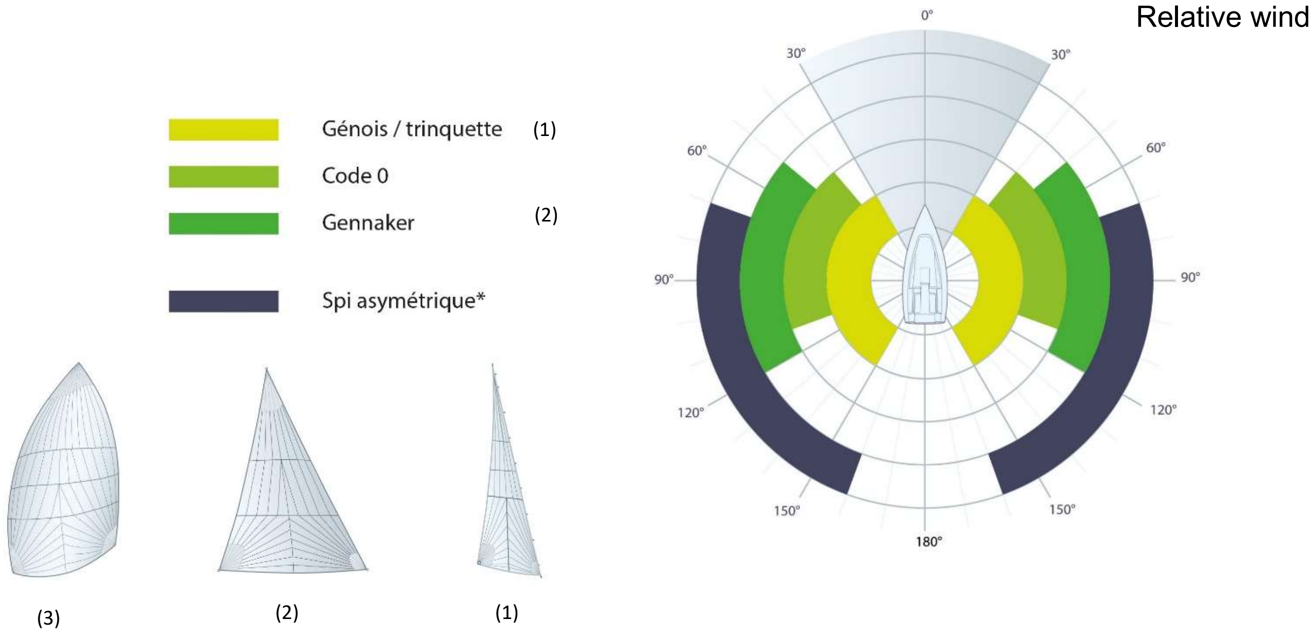
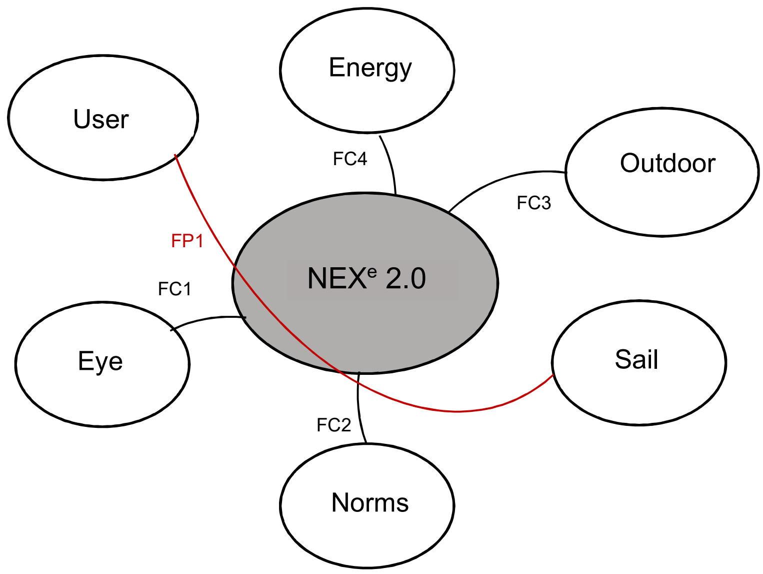


Figure 2: Different types of sails and their speed polar chart [Wic19]

These manual systems use a mechanism composed of pulleys and ropes to be actioned. The manoeuvres of big sails are complex and require a lot of strength. That is the reason why *PROFURL* has been developing electrical assisted furling systems, for more than 30 years. The brand aim at targeting a wider variety of customers who are looking for more assistance during the manoeuvres of the sails. On the other hand, the "flying" furling systems are rare and not as common as the stay furling systems. In 2018 *PROFURL* was the first brand to launch on the market the first electrical « flying » sail furling system. The motorization of this function aims at bringing comfort and aid to the user. My mission was to design the next version of the system by improving it and by adding new electronic control features.

1.2. External constraints

The « NEX^{e} » project was created to design a range of electrical « flying » sail furlers for pleasure sailboats of a size between 35 and 70 feet. The name of the project became the name of the *PROFURL's system*. The brand targets a market as large as possible. New boats market is relatively small. For example, *BENETEAU*, the world number one sailboat manufacturer produces only around 2000 units a year. Knowing that a small part of them will be equipped with an electrical « flying » sail furling system, the NEX^{e} must be adapted to the second-hand market, equipped with a usual manual furling system (Fig 3).



FP1: Allowing the user to furl the « flying » sail.
FC1: Following the brand design
FC2: Respecting the norms
FC3: Being waterproof and salt resistant
FC4: using the energy on board

Figure 3 : APTE diagram – NEXe*

The environment is an important aspect of the development. It's a major factor that must be considered to define the function and specifications of the system. On a boat, the environment is specially considered in the design because the product needs to be first, resistant and secondly, reliable. Indeed, the boat stay autonomous on the water and such a major system must be designed to reduce as much as much possible any failure problem. One the one hand, the mechanics and the electronics must resist to the mix of water and salt which will be constantly in contact with the furler. One the other hand, resources on a boat are limited. That involves a clever use of the power available on board to furl the jib. By analysing the specifications of the NEX^e, a set of criteria were qualified as invariant for the design of the NEX^e 2.0:

- **Aid with de manoeuvres of the sail of** Gennaker*, Spinnaker, Code 0, staysail type
- **Reliability**: 3 years warranty minimum
- **Service rate**: 100 days a year with an average of 10 furling a day.
- **Having the possibility to be « plugged »** to the sail as standard manual "flying" sail furling system
- **Being actionable** from anywhere on the boat
- **The sail must be fix** when the system is not in use
- Being at least **IP67**
- Being resistant to salt/ water + UV + temperature between -40/+50°C
- **Being shockproof** to all the equipment from the deck*
- **Being easy to install**, with only an additional plug compared to a manual "flying" sail furling system
- **Doing manoeuvres** in less than **1min**

To these general specifications, some other features, more technical, will be added to developpe a truly adapted system. When the function is clearly determined, the technical specifications can be set up.

1.3. Technical specifications

In this part, the main technical specifications will be presented while others will be exposed. The first thing to understand is how a "flying" sail furling system works.

The jibs are attached to three points (Fig. 4). The furler is linked to the deck by a chainplate* and to the sail by the tack*. At the other end, the head of the sail is linked to a swivel which is linked to the mats. Between those two specific points of the sail, a taut anti-rotating cable is attached, around which the sail will be furled.

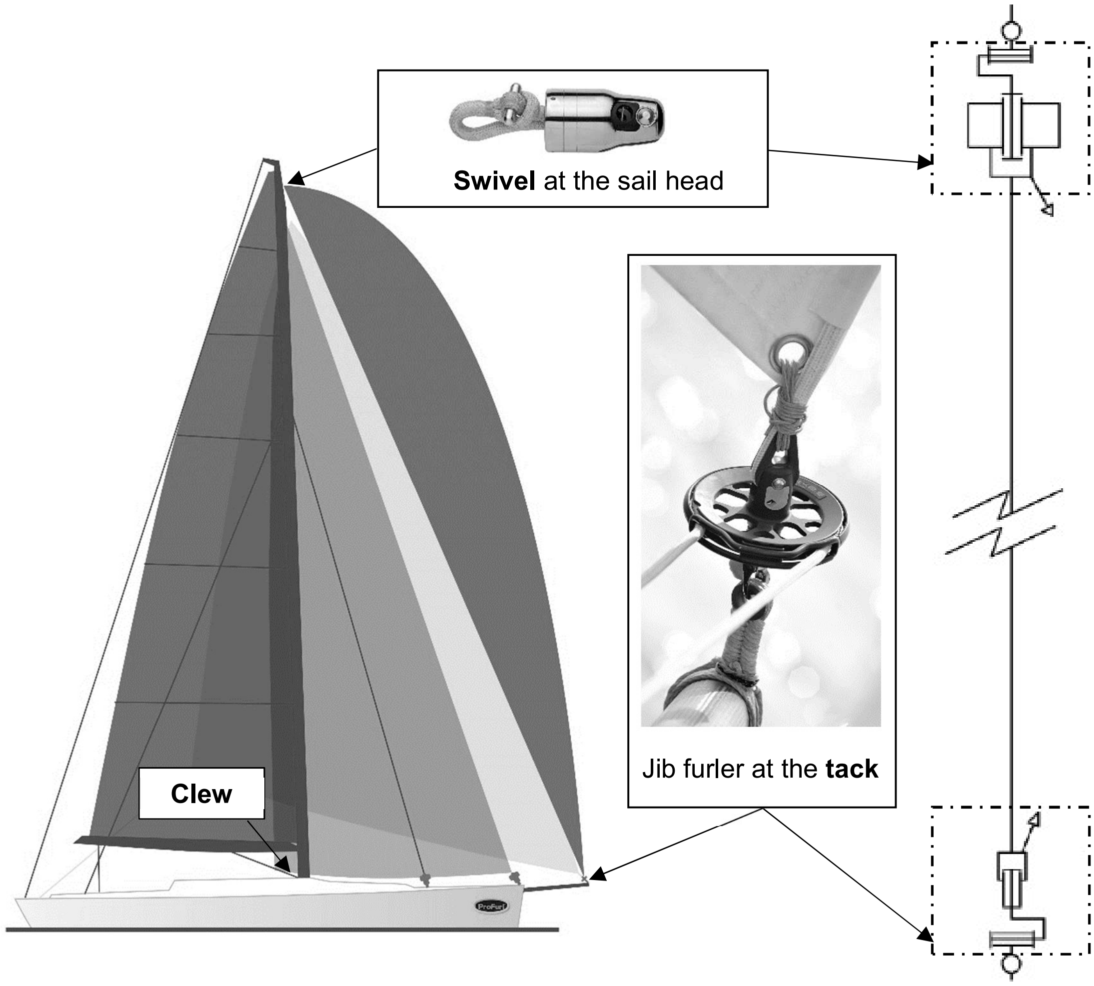


Figure 4: Swivel/Furler assembly

Two main stresses will determine the sizing and design of the created system. They will be the base of the whole following conception. Let's study the effect on the forestay* and the flapping effect:

- The first action to be considered is the tension in the anti-rotating cable (between the head sail dans the tack). The effort is due to the force of the wind that will rush into the sail with a normal direction to its frame (Fig.5).

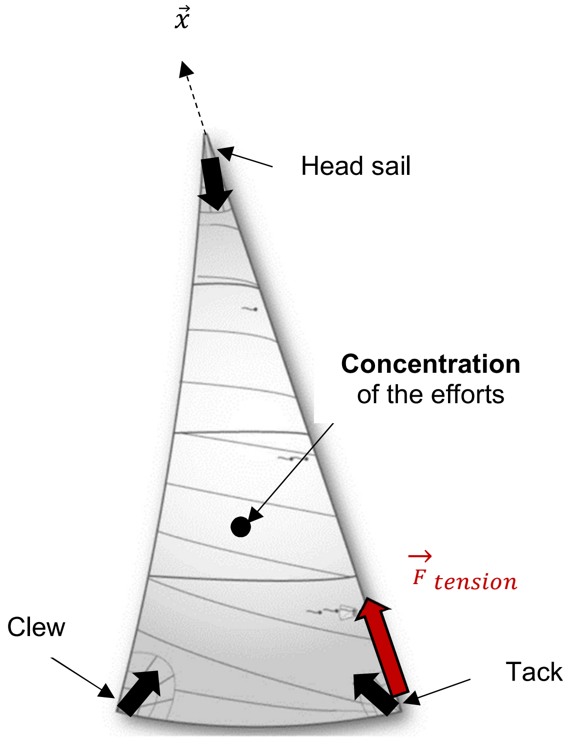


Figure 5: Efforts on the jib

Concerning the NEXe 2.0's conception, the strength at the tack will constraint the system the most. This strength depends of numerous parameters such as the boat weight, the sail area, the type of sail chosen… The tension between the head sail and the tack will be given by the naval architect and *PROFURL* imposed an additional safety coefficient:

- $F_{tension/\vec{x}} = 5.10^4 N$

- The second effort to consider is the flapping effect. When the sail is not taut anymore, an effort, tangent to the sail, is generated. It makes the sail flap under the wind and tends to let the sail unfurled. A sail not hauled in* enough is a sail which is partially deflated. This effort will allow us to set up a resistive torque which will have to be compensated by the furling system. In general, a sailor will try to minimise to relative wind by furling the sail downwind (Fig. 6). The accurate value of this strength is difficult to obtain because it's the equivalent of a chaotic system. Thanks to a lot of tests on boats, *PROFURL* deducted a torque that is enough the furl the sail in good conditions. This value has been validated with the NEXe.

- $C_{furling\ torque} = 50 N.m$

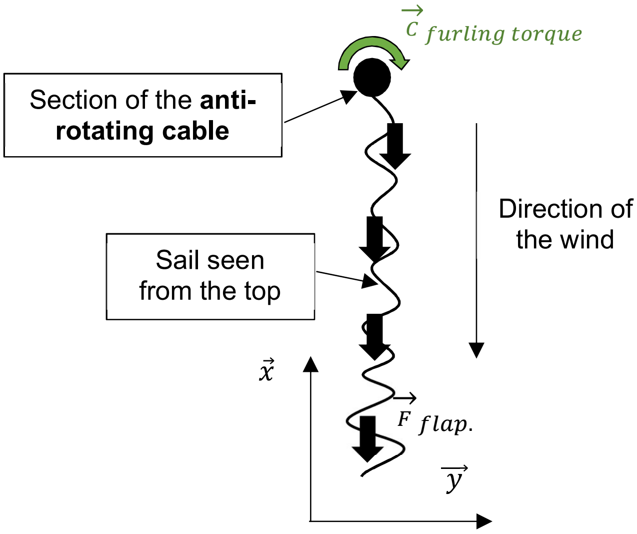


Figure 6 : Illustration of the flapping strength

These two efforts will allow us to size the system correctly. The following table (Fig. 7) gather all the technical specifications needed for the design of the electrical "flying" sail furler NEX^{e} 2.0:

Furling speed	100 rpm	Estimated thanks to the manual "flying" sail furler
Torque	50N.m	Tested and validated with the previous version
Weight	5Kg	Estimated thanks to the manual "flying" sail furler
Power	12V and 24V	Feature related to boat batteries: ⇨ *2 versions of the NEX^{e}*
Tension strength	50kN	Due to the flapping effort
Total height of the system	H<300mm	Must replace a manual "flying" sail furler easily

Figure 7: Technical specifications

After the specifications has been set up it was time to start with the conception of the NEX^{e} 2.0.

Chapter 2

Design

2.1. Reverse engineering

2.1.1 Technical solutions

The conception of the NEX^e 2.0 shares the same specifications as the NEX^e. I had the opportunity to work with the designer of the first version, my tutor. Thanks to him, I could analyse in detail the technologies used to fit the function. Reverse engineering was here, an adapted start to develop rapidly, an improved version of a product (Fig. 8). One of the advantages of this method is that some pieces can be reused for the NEX^{e}2.0 in order to decrease the production cost and the development time so the development cost.

Figure 8 : Picture of the NEX^e

From the mechanical point of view, the global system's architecture is constrained by the tension in the anti-rotating cable between the swivel and the "flying" sail furler. Important forces are transmitted directly through the crossing shaft which is made out of a high resistive material ($R_{p0,2}$=720MPa). The whole architecture will then be designed around this axe in a way to minimise the volume and the weight of the system (Fig. 9). The goal is to minimise the space used as well as the mounting order of each component. It's a balance between the technical solution and the cost of production from the creation of each pieces to their mounting in the *PROFURL*'s factory.

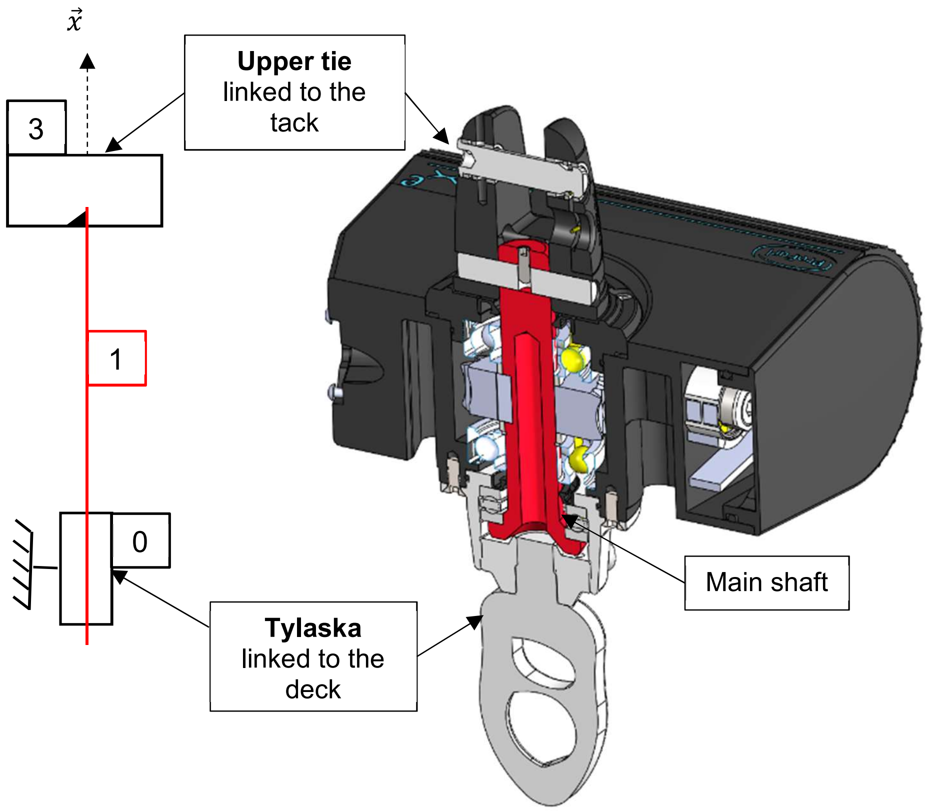


Figure 9 : Vertical sectional view of the NEX[e]

The second step was the selection of the motor. In fact, the motor size and speed rotation will determine the design of the housing and the type of reducer used. A DC brushed motor of 750W has been selected in this case. This motor can work directly connected to the 12V or 24V batteries without any controller and deliver enough power to suit the required specifications. *PROFURL* decided first to develop an electrical furling system with the minimum electronics as possible to avoid as much as possible any electronic failure on board for their first market launched electrical "flying" sail furling system. The theoretical required power is (1):

$$P_{mec.} = C_{furling\ torque}.\omega = 50.\left(2\pi.\frac{100}{60}\right) = 523W \quad (1)$$

A worm gear reducer has been selected to obtain the 50N.m needed to furl the sail (Fig. 10). The benefit of this solution is the irreversible characteristic of this type of reducer. Every electrical « flying » or « staying » sail furling system uses this type of reducer for that specific feature. Indeed, this mechanical and reliable function is required to maintain the sail in its position after a furling cycle. We don't want the sail to roll out due to its own weight but only if the motor is activated. The gear of the reducer is linked directly to the shaft and to stop it rotating a woodruff key is used. The power of the motor is transmitted thanks to a belt that allowed the designer to minimise to volume of the whole system (Fig. 10).

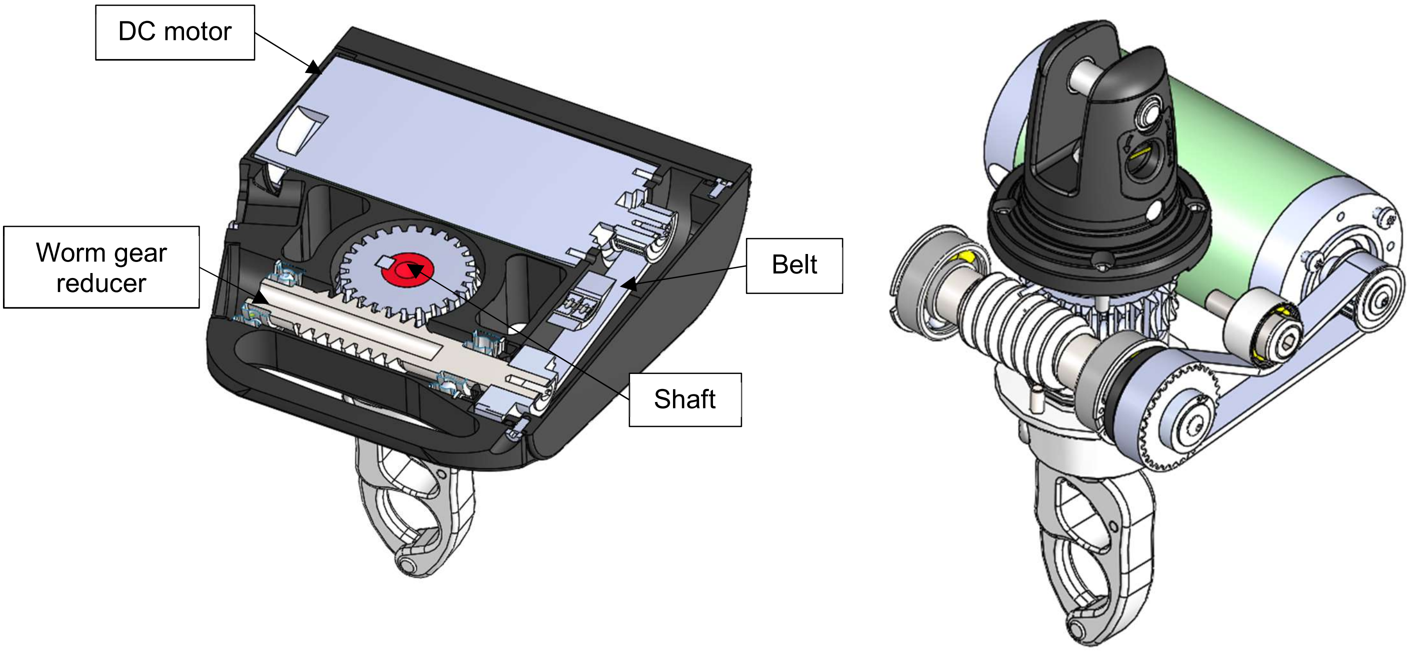


Figure 10: Horizontal sectional view of the NEX^e and NEX^e without its housing

The technical features of the DC motor are given in the Appendix 1. Nevertheless, some characteristics are particularly relevant for the rest of the study:

For the 12V version:

- ✓ Nominal speed: 4000 tr/min
- ✓ Nominal Torque: 1.8N.m
- ✓ Nominal Current: 85A
- ✓ Gear reducer ratio needed: r =1:40
- ✓ Price: 250€

Finally, the global system architecture has been optimised to be as compact as possible. The watertightness is realized thanks to an astute assembly of toric joints. The corrosion resistance is guaranteed by a clever choice of materials and adapted surface treatment with the use, for example, avec stainless steel and anodize aluminium.
From the electrical point of view, the NEX^e is rudimentary. This choice came out of a will to limit the amount of electronics exposed to the marine environment. No power control was set up on this version for example. After having analysed the technical solutions, I had to pick the drawbacks up.

2.1.2 Drawbacks

This step has been one of the most critical for the conception of the second version of the NEX^e. Weaknesses have been determined aiming at improving this first version that has been kind of a "prototype" for the brand. The following data came from a batch of tests and feedback from customers and were the corner stone of the development I conducted to develop the NEX^e 2.0.

- **The efficiency:**

  The biggest lost in the current system is due to the solution taken to create to irreversibility of the furler. The friction in the reducer is needed to have the irreversibility property but it's also the cause of a lot heating losses and so of a poor efficiency. Indeed, the worm gear reducer has one of the worst efficiencies of the range of reducers. Although, this type of reducer is one of the most compact solution for a high gear ratio. The efficiency must be reconsidered in the development of such a system. The global efficiency NEX^e is lower than 40% (2-3):

$$\eta_{global} = \eta_{motor} * \eta_{mec.} \approx 35\% \quad (2)$$

$$P_{output} = P_{elec.} * \eta_{global} = 750 * 0{,}35 = 262W \quad (3)$$

  Even though this value is very low compared to the specifications, the furling can be done with the adapted manoeuvres, with the boat correctly placed compare to the direction of the wind as explained in the section 1.3 of the chapter 1.

- **Power consumption and heating problems:**

  A batch of tests has been carried out before launching the NEX^e on the market. Because *PROFURL* is a small company, most of the tests have been done directly on boats with a prototype whose design is based on theoretical calculations. Three types of data were measured during many furling cycles: **the current** (A); **the tension** (V); **the rotation speed** (RPM). The graph (Fig. 11) represent the average value with those measurements. Up to 130A have been measured for some furling cycles. Those current draws correspond to the reaction of the motor to the movement of the sail that is opposed to the wind direction and the flapping effect. In addition of a higher electrical consumption, these current draws can damage the system if it's maintained for a long period of time because it causes heating of the electrical components and of the motor. This data will be extremely important for the following study and the creation of an adapted controller on the second version of the NEX^e.

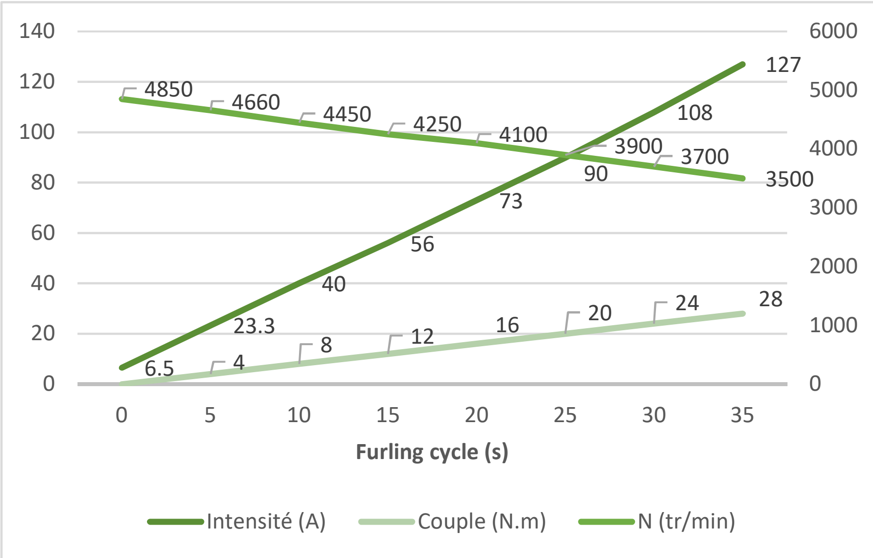


Figure 11: Measurement of the average torque / rotation speed / current during a furling cycle

To conclude, even though the NEXᵉ globally answer to the requirements and follow the references currently on the market, its conception can be improved. The main idea would be to design a furler with a better efficiency but also with an electronic control, smarter, that could preserve the mechanical components as well as the motor and all the electronical elements. Finally, the goal would be to limit the electrical consumption of the system, which is essential on a boat, where energy is limited and vital.

2.2. Design for manufacturing

2.2.1. Motorization

2.2.1.1. Types of electrical motors

The designing part of my project began with the selection of the right actuator. *PROFURL*'s design team wanted to improve as much as possible the efficiency of their second electrical "flying" sail furling system. Then, my mission was to select an efficient actuator while mastering the industrial cost. The notion of technological cost has been a major part of this project. The relation between the technical solution and the cost of it, guided me to select an adapted solution for a special need.

The motor is the heart of the NEXᵉ 2.0, it's an essential component that must deliver the required torque in a limited volume while being reliable and resistant to its environment. Three types of motors have been compared to select the best solution for our needs: The Alternating Current motors; the Direct Current brushed motors and the DC brushless motors. Four criteria have been considered to realize the selection (Fig. 12):

- **The nominal power**: The motor must deliver the required power imposed in the specifications.
- **The price:** The financial aspect is one of the main aspects of the design of the system because the project aim at being industrialized and some aspects must be considered early to limit the development cost.
- **The volume and the weight**: The NEX^{e} 2.0 must replace a standard manual « flying » sail furler so it must be relatively similar in terms of volume and mass.
- **The reliability** and the ease of installation.

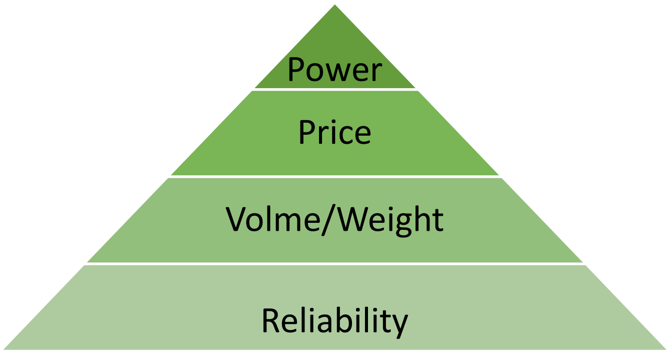


Figure 12: Motor selection criteria

Yachting is reluctant to non-essential electronics and especially the sailboat industry. Electronics are often the main reason of failure on a sailboat because of the extreme environment. That is why the actuator must be chosen accurately for our specific environment. Those motors could be:

- **AC motors:**

Firstly, AC motors will be considered here. It's the most used type of electrical motor in the industry. The AC motor consists of two basic parts: the stator supplied with alternating current to produce a rotating magnetic field and the rotor linked to the shaft that produce a second rotating magnetic field (Fig. 13).

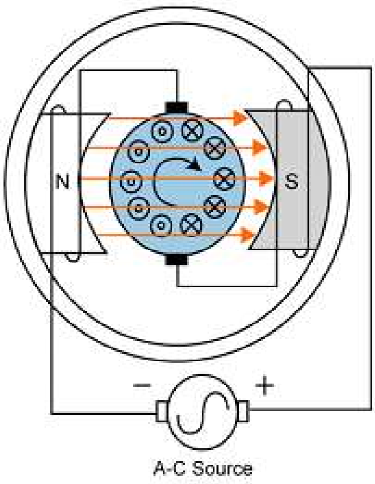


Figure 13: Asynchronous Motor (Most common AC motor) [20Ris]

They are highly reliable, relatively of a good size and but we must modify the power source in our case. In fact, a power inverter must be used to convert the power source from DC to AC in order to produce a rotating magnetic field in the stator of the motor. They are mainly used for their ability to rotate for days without being worn. The NEX[e]2.0, on the contrary, will work for a short period of time and at a medium to low frequency. The addition of a power inverter and the way we will use the motor doesn't fit the best to our application. The study will then be oriented toward a DC motors.

- **Brushed DC motors:**

The initial DC brushed motor chosen on the NEX[e] is given in Appendix 1. It has the advantage of being connected to directly to the batteries 12V or 24V, depending of the NEX[e]'s version. On the other hand, it's a very heavy and sizeable motor because of the inversional relation between the weight and the ratio power over speed rotation. In addition, the efficiency of the initial motor was only ≈60-70%. The working principle is simple: two permanent magnets create a stationary magnetic field that surround the rotor. The rotor is made up with one or more windings and it produces a magnetic field when energized (Fig. 14).

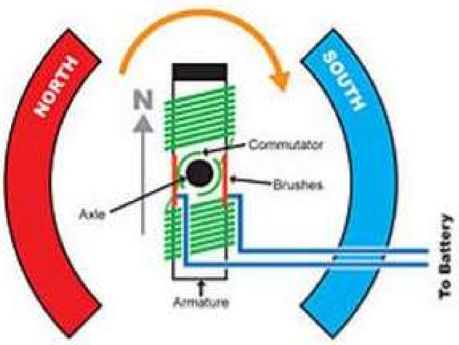


Figure 14: Brushed DC motor [Hpi]

- **Brushless DC motors:**

The last type of motor selected for our study is the brushless DC motor (Fig. 15). This actuator has an excellent efficiency, between 90% and 95%, heats up much less than a usual brushed DC motor and its reliability is comparable to an AC motor. The magnetic field of the stator is created by a control electronics. On the contrary, the rotor is made with a permanent magnet and there is no direct contact between the rotor and the stator. The main advantage for our use is the better ratio: torque over weight. Because we have a high torque and a low speed compare to the power tension, brushed DC motor magnets are heavy, and this can be solved with the brushless DC motor.

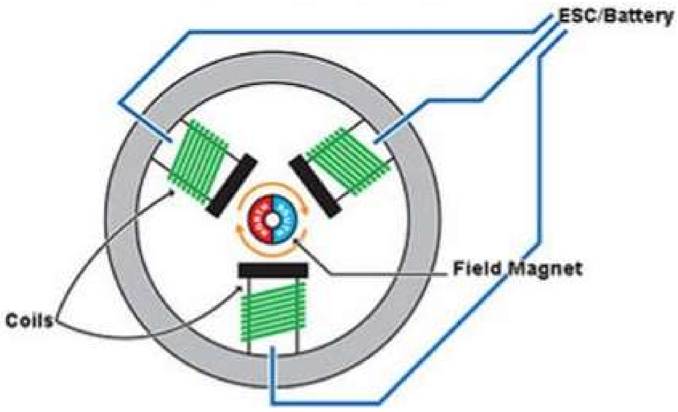


Figure 15 : Brushless DC motor [Hpi]

One key point must be considered with this type of motor. The highest is the power tension of the motor, the highest will be the output torque and the smallest will be the rotation speed, so the weight and size of the reducer needed. A step-up converter may be necessary to elevate this tension that is quiet low at the output of the boat's batteries.

2.2.1.2 Selection of the actuator

The complete assessment of the study is in Appendix 2. The following table (Tab. 16) shows the pros and cons of each type of motor for the conception of our product.

	Efficiency(η)	Heating	Simplicity for the integration	Ration weight power	Price
Brushed DC Motor	-	-	++	-	++
Brushless DC Motor	++	+	+	+	-
AC Motor	++	+	-	-	+

Figure 16 : Comparison if the actuators

Following the global analysis of the technical solutions, I've conducted a market analysis with the current suppliers of *PROFURL* to find the best actuator for our application. The Brushless DC motor was theoretically the best balance of all our specifications. Finally, my goal was to compare and to find the best Brushless DC motor in terms of technical features but also in terms of price. The ideal solution here was to use brushless DC motor with a hollow shaft that could allow us to design a furling system that transmit the efforts directly through the main shaft. This specificity will be developed further. The ratio power over weight would be excellent for this type of actuator. The idea would be close to the technical solution used for electrical bicycles (Fig. 17). In the case the compacity is maximal and the efficiency is very high.

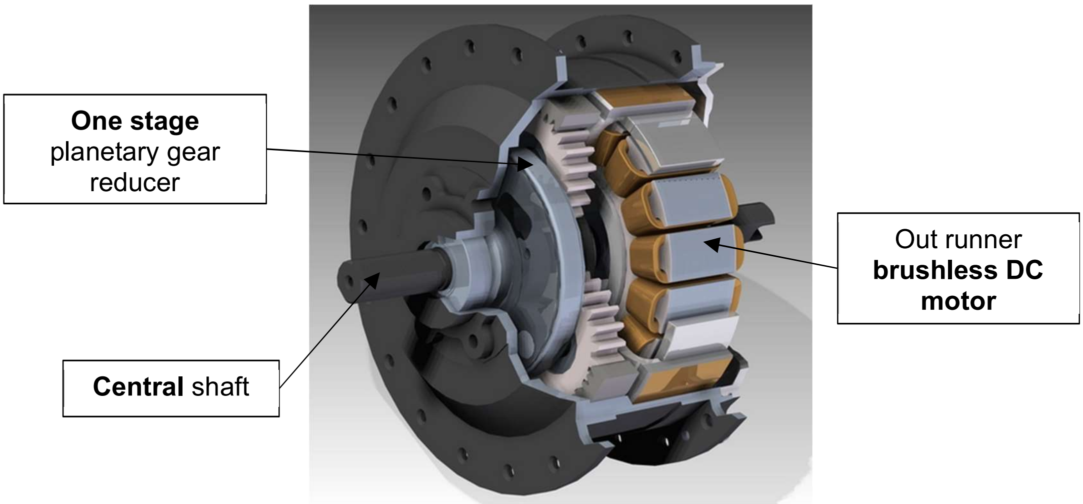


Figure 17 : Example of an electrical bike wheel hub DC motor [Avd]

After an overview of the main actuator suppliers, I contacted the company MDP and I had an interview with one of their business engineers to work on a common project with PROFURL. The idea was to develop an all new brushless DC motor or to use one of their wide range of standard ones, in order to design a very efficient and technologically new, flying sail furling system. The highest power we could find for such a motor was 300W and no more. This type of motor is rarely used for a higher power and the market is around ~0W to 300W and no more. For this reason, a tailor-made motor has been considered. The price of a tailor-made brushless DC motor has finally been calculated at a half of the technological target cost of the NEX^{e}2.0. To this price we must add the cost of the electronical controller and the step-up converter. This solution, although interesting, wasn't viable for the quantity need by the brand which was around 100 units.

PROFURL's design team and I, decided to reserve this solution for a future version of the "flying" sail furling system because the technical solution is interesting, but the market doesn't yet have a standard suitable actuator for our needs.
The brushed DC motor has then been considered because it's a known technology for the brand and reliable enough for the service rate required. My choice has been guided by *PROFURL*'s electrical furling range. I decided to select a motor used for a model of staying sail furler of *FACNOR*, a brand of the group *WICHARD*, for its technical specifications and price. The motor is used in a multi motor assembly and has a good efficiency (Fig.18).

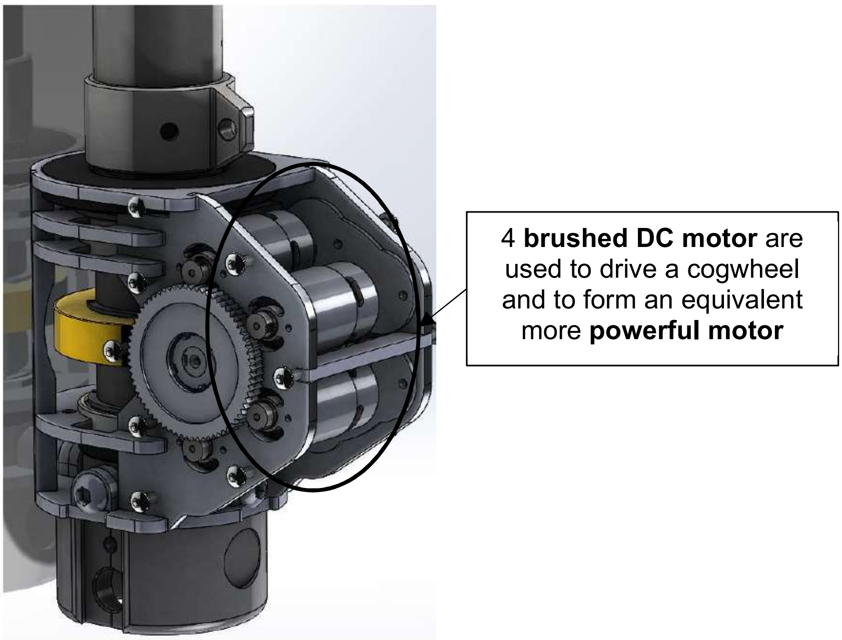


Figure 18 : CAD model of the EC electric furler of FACNOR

The solution adopted is an assembly of four brushed DC motor of 273W with an efficiency of 65% and a unitary price of 5$/unit (Appendix 3).

The main features of this motor are:

- ✓ Nominal rotation speed: 11360 rpm
- ✓ Nominal torque : 0.153N.m
- ✓ Nominal intensity: 18.7A
- ✓ Gear ratio need to obtain the specification required: r =1: 114
- ✓ price: <5€

The study of the heating and life cycle of the motors won't be developed here as it has been done in previous study conducted by the brand. However, each of these points are validated and confirmed for the use of this motor in our case. We know that that the nominal tension of the motors is 18V. The previous technical features have been calculated proportionally to the power tension 12V of boat's batteries. For the 24V batteries, the motors are simply connected by pairs in parallel to obtain a system working at 24V. In addition, no power inverter or step-up converter is required here which reduce the cost compared to a brushless DC motor and reduces maintenance costs.

After the selection of the actuator the mechanical conception, the biggest part of this project, started.

2.2.2 Mechanical structure

2.2.2.1 The shaft

Firstly, we must consider the force between the tack and the bottom tie for the design of the NEX^{e}2.0. As explained previously in the chapter 1, the tension in the anti-rotating cable must be considered as 5 tonnes and so the mechanical system must be well dimensioned. Considering the basics of mechanics, it's much easier to design a system that transmits an effort directly through the shaft, so as an extension of the cable, rather than shifted, for example by transmitting the effort through the housing. Such an option would increase the weight and obliged us to oversize the housing to transmit the force. The first step was then to design the main shaft of the NEX^{e}2.0 that will support all the tension of the antirotating cable. A thrust bearing has been added to create a pivot between the upper and lower tie of the system and allow us to create the rotational movement desired (Fig. 19).

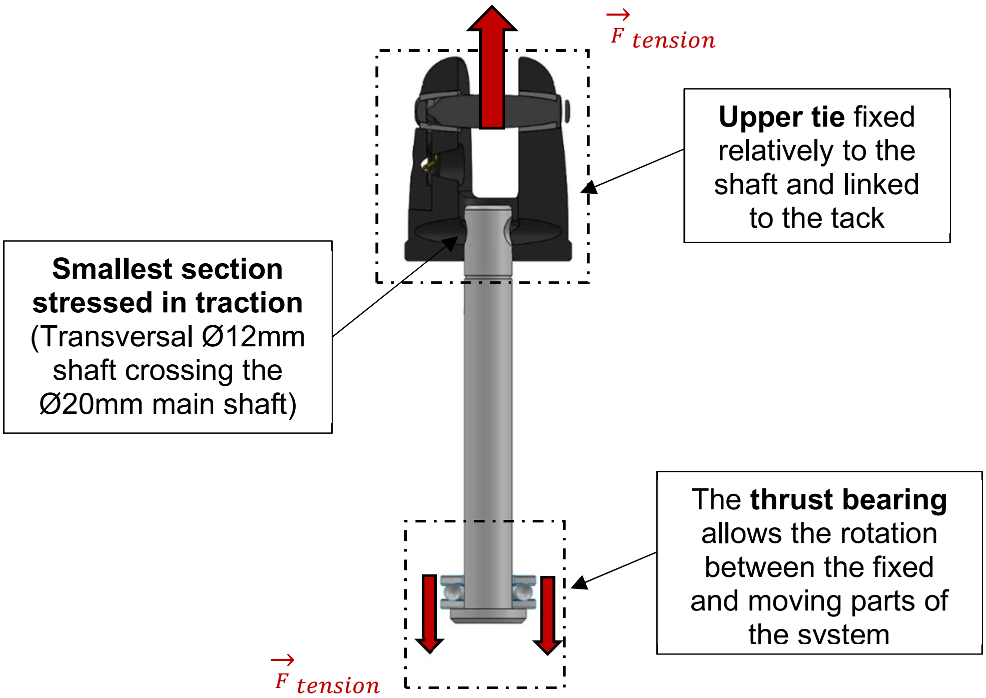


Figure 19 : Shaft of the NEXe2.0

To ensure the sturdiness of the piece, a material resistance study must be conducted:

Material: Stainless steal

17-4PH (high density and high-water resistance)
$R_{p0,2}$=720MPa
Smallest section in traction: A=74mm²

Traction resistance :

$$T = \frac{F_{tension}}{A} = \frac{5*10^4}{74} = 676Mpa \qquad (4)$$

Conclusion :

$T < R_{p0,2}$

The Diameter of the shaft can be set up at 20mm thanks to the material resistance study. Then, the shaft has been crafted to test its resistance to the 5 tonnes it must support. The following pictures (Figure 20) show a lathe and a 3-axis machine used to machine the shaft.

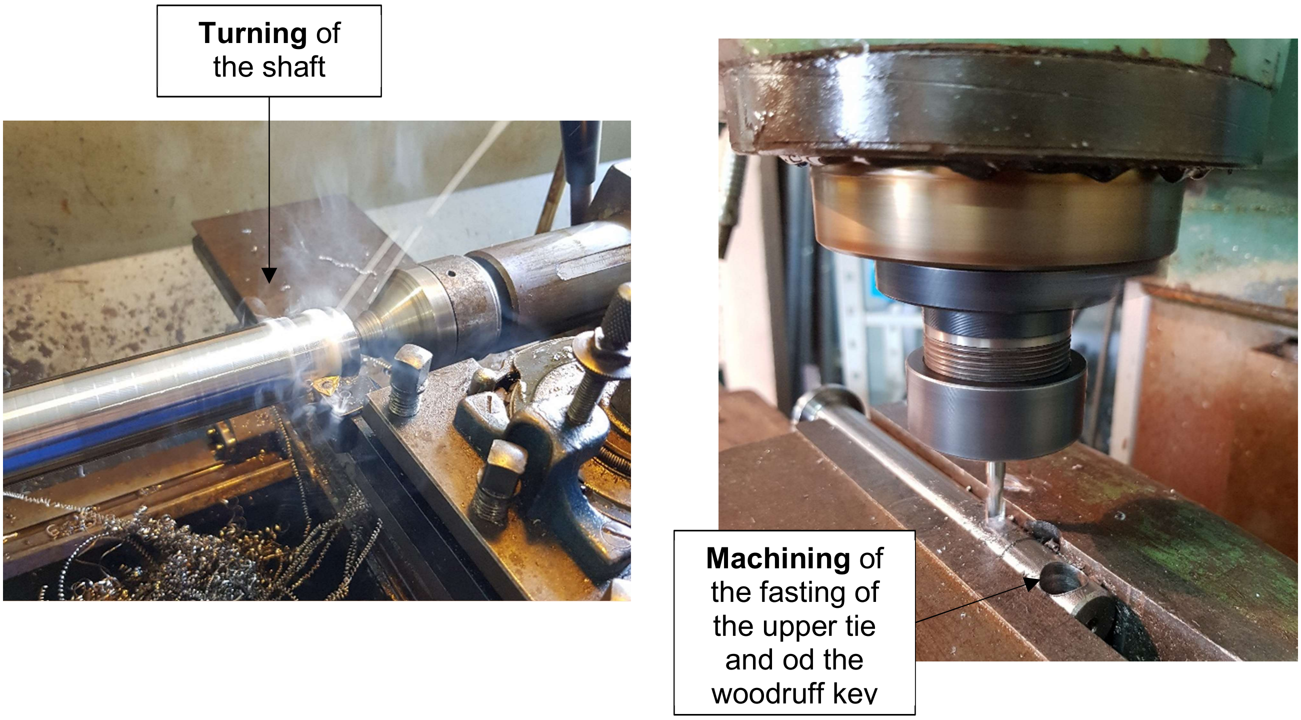


Figure 20 : Lathe and 3 axis machine

The shaft has been tested on a traction bench and the test was a success. We even reached 6 tonnes without damage. Later the piece has been reused for the protype of the NEX^{e}2.0. The second step of the mechanical conception was the reducer.

2.2.2.2 The reducer

Once the diameter of the shaft is set, the reducer can be designed in order to transmit the power of the assembly of the four motors selected previously. To optimise the reducer from the efficiency point of view, the worm gear reducer used was rejected. One of the best reducers in terms of compactness and efficiency is the planetary gear reducer. The only drawback of this solution is the reversibility of the solution that must be corrected for our system. This type of reducer is very common in industry and has the advantage of keeping the input shaft coaxial to the output shaft. For our design, a custom planetary gear reducer has been created to optimise the space and mainly because hollow shaft planetary gear reducer isn't common. The gear ratio and the dimension has been specifically designed for our needs.

I designed a two stages planetary gear reducer to keep the dimensions of the system close to a manual "flying" sail furling system. Its design started with the choice of the mechanical features needed to optimize as much as possible the efficiency. No standard element was used to design it. This choice was made in order to optimize the reducer from a space point of view and to obtain the exact gear ratio needed and the exact hollow shaft reducer for the 20mm diameter shaft calculated previously.

The epicyclic reducer has been optimized as much as possible. Some critics points were the centre of the design [For32]:

- The tooth module has been minimised to increase the efficiency
- Motor's cogs have a minimum of 17 tooth to delete the interferences with the main cogwheel
- The number of teeth of the planet gears are a multiple of three in order to be mounted correctly on the ring
- The number of teeth of each cog are prime to make a change between each tooth in contact and create a uniform wear
- The tooth width has been calculated to minimise the height of the reducer so the whole system
- Every piece has been designed to minimised to machining cost and to be conceivable with standard tools
- Materials like bronze or stainless steel were selected to limit the friction and increase the reliability and strength of the components

The next figure (Fig. 21) shows the way every tooth was made following those technical rules.

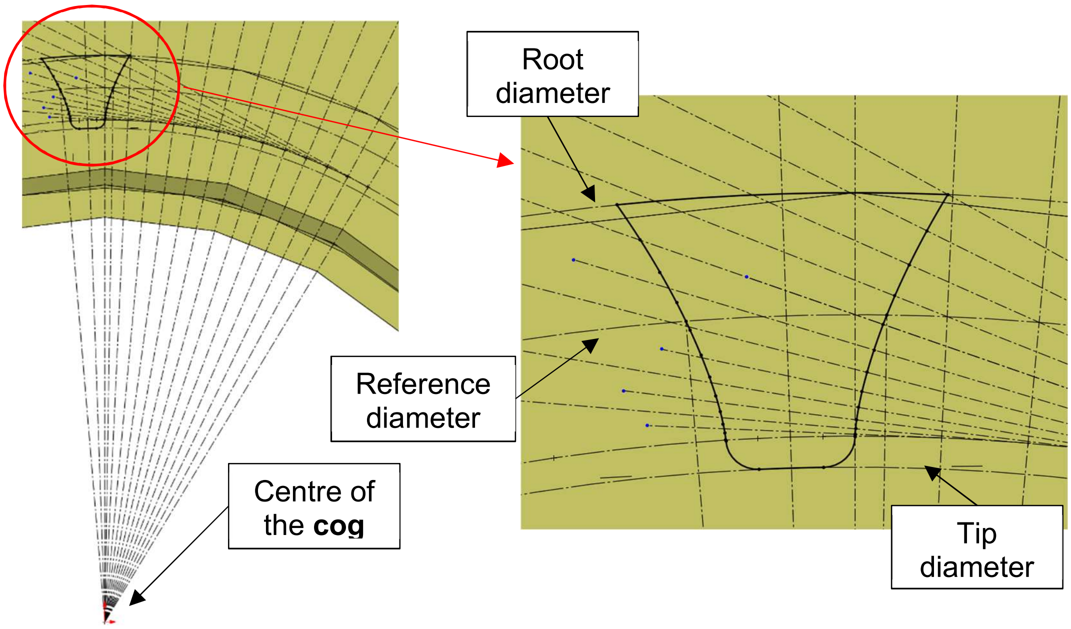


Figure 21 : Cogwheel conception

The following cogwheel is also the sun of the first stage of the epicyclic reducer. It's the CAD made with *SolidWorks* of the final piece detailed in Figure 22.

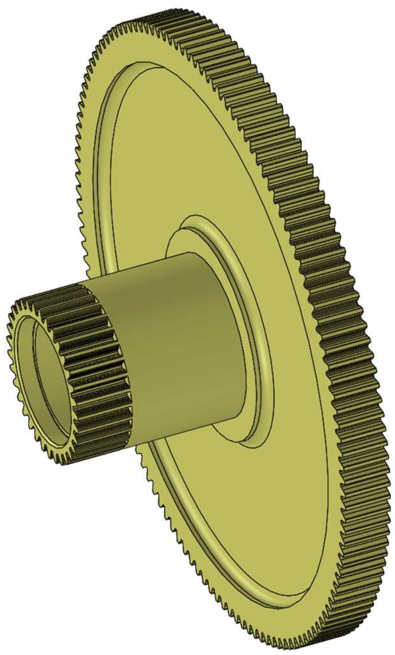


Figure 22 : CAD of the cogwheel

The global structure of the shaft and the complete reducer is shown figure 23. We can notice that a batch of bearings has been integrated between every rotating part in

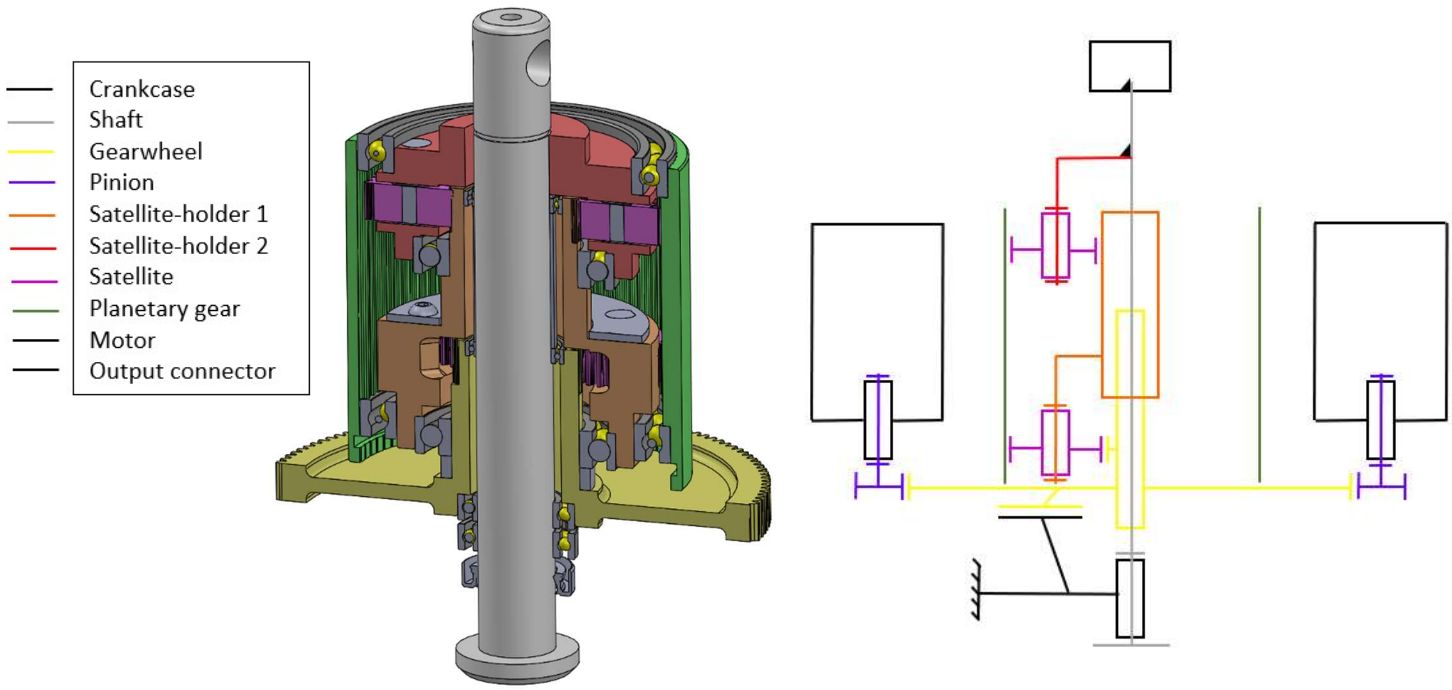


Figure 23 : Epicyclic reducer of the NEXe 2.0

a goal to optimize the efficiency. Standardized roll bearing only have been used to reduce the building cost as much as possible.
The global reduction rate is 1: 90. The height and the width will allow us to be very close the dimensions of a regular "flying" sail furling system. The next step of the mechanical design is the integration of the motors and of the irreversibility function.

2.2.2.3 Integration of components

At this stage of the design of the system, the irreversible device is still missing. As described previously, this feature was made possible by the worm gear reducer. The new reducer limit frictions as much as possible so it's highly reversible. The device used for the irreversibility is a negative brake. The working principle is simple, when the brake is powered it releases the shaft passing through and it blocks it on the contrary. This device is usually used directly on motors. To integrate this new device, I designed a flange and I found a negative brake close to the dimensions of the motors. The idea is to add it to the assembly of motors as a regular motor (Fig. 24)

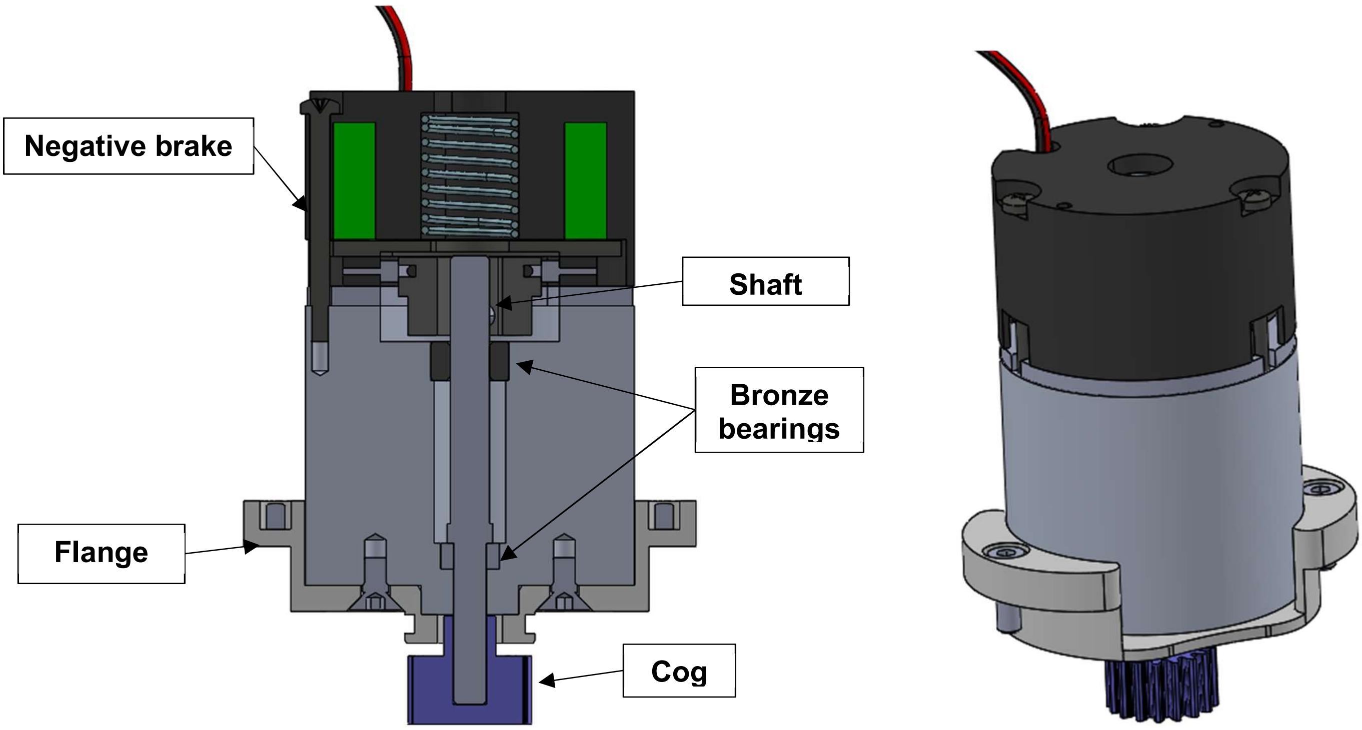


Figure 24 : Negative brake with its flange

The resistive torque of the negative brake has been selected to be exactly the equivalent of the torque of the four motors. We can notice that the shaft passing through the negative brake is guided in rotation with two bronze bearing that can be resistant to the very high speed of the motors. Indeed, because the negative brake will be linked to the main cogwheel, its rotation speed will be the same than the motors. The Next step was to place the motors and the negative brake around the main cogwheel (Fig. 25).

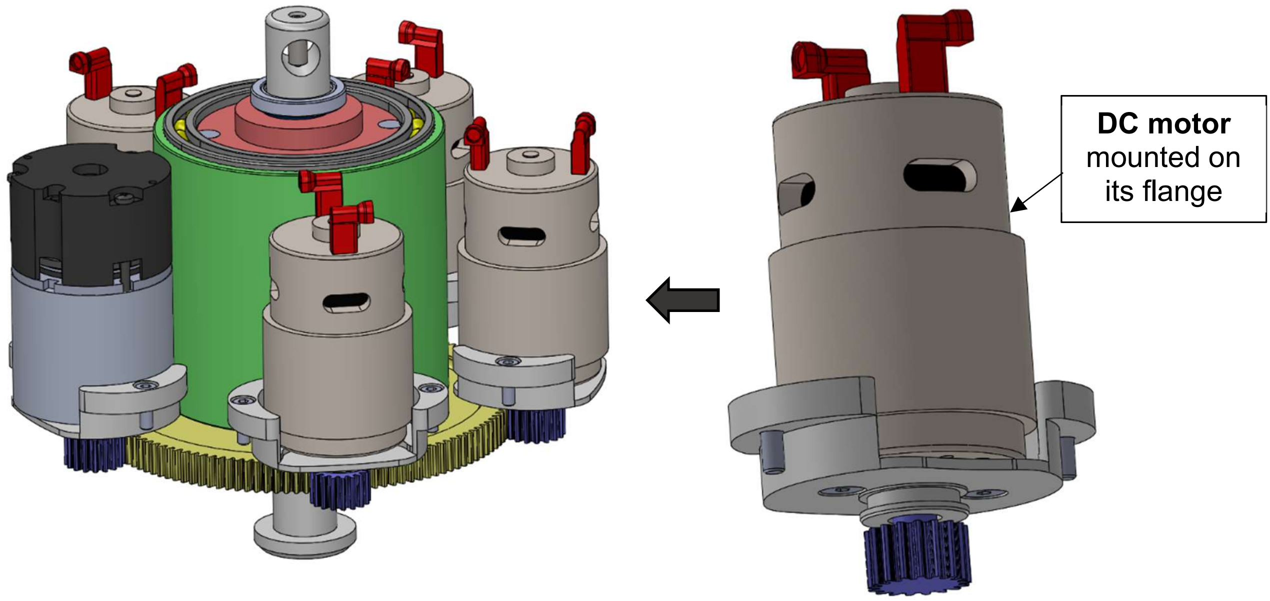


Figure 25 : Assembly of the motors and the negative brake on the left. DC motor with its flange on the right

The housing has been made to minimise the machining cost and to be easy to assemble with the rest of the system. It's made in aluminium and allow an easy access to the motors and the reducer (Fig. 26).

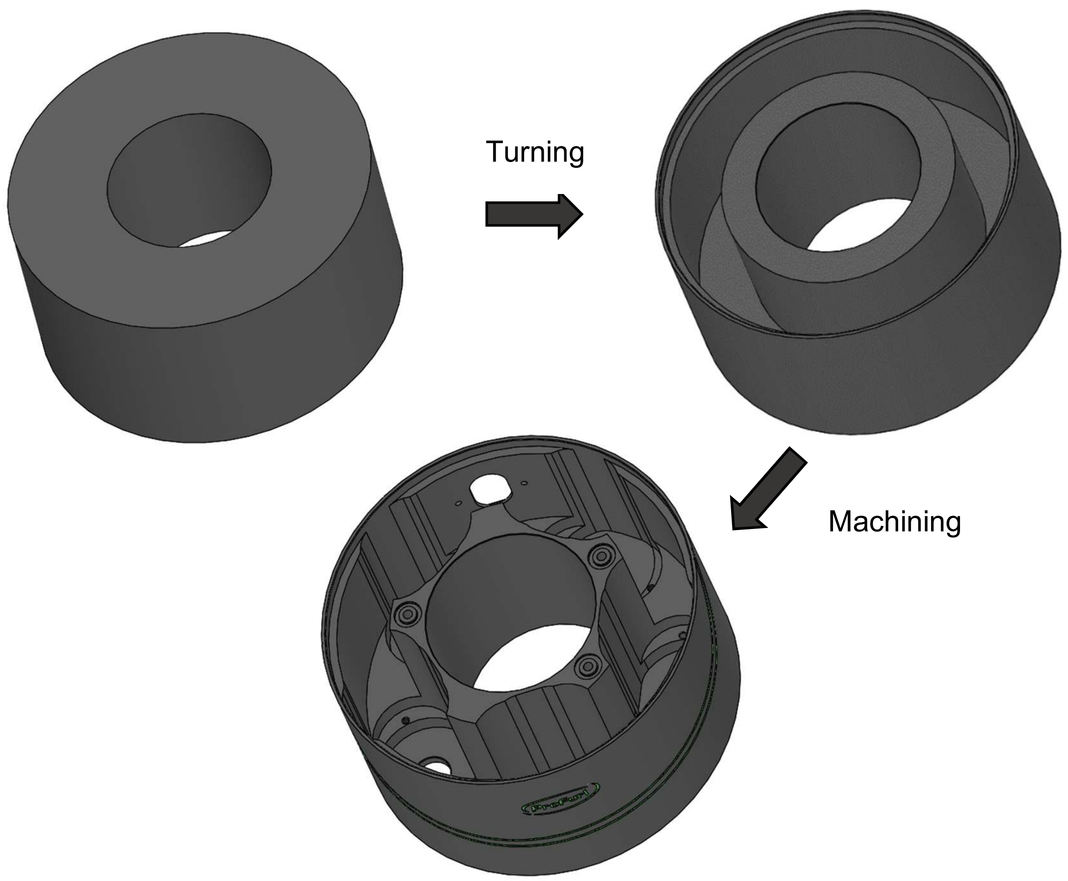


Figure 26 : Building steps of the housing

The following figure (Fig. 27) shows the final product with all the elements described previously. We can notice that the assembly between every part of the housing include a bench of toric joints with a "piston" assembly that makes a constant pressure on the joint and optimise the weathertightness and the NEX^{e}2.0.

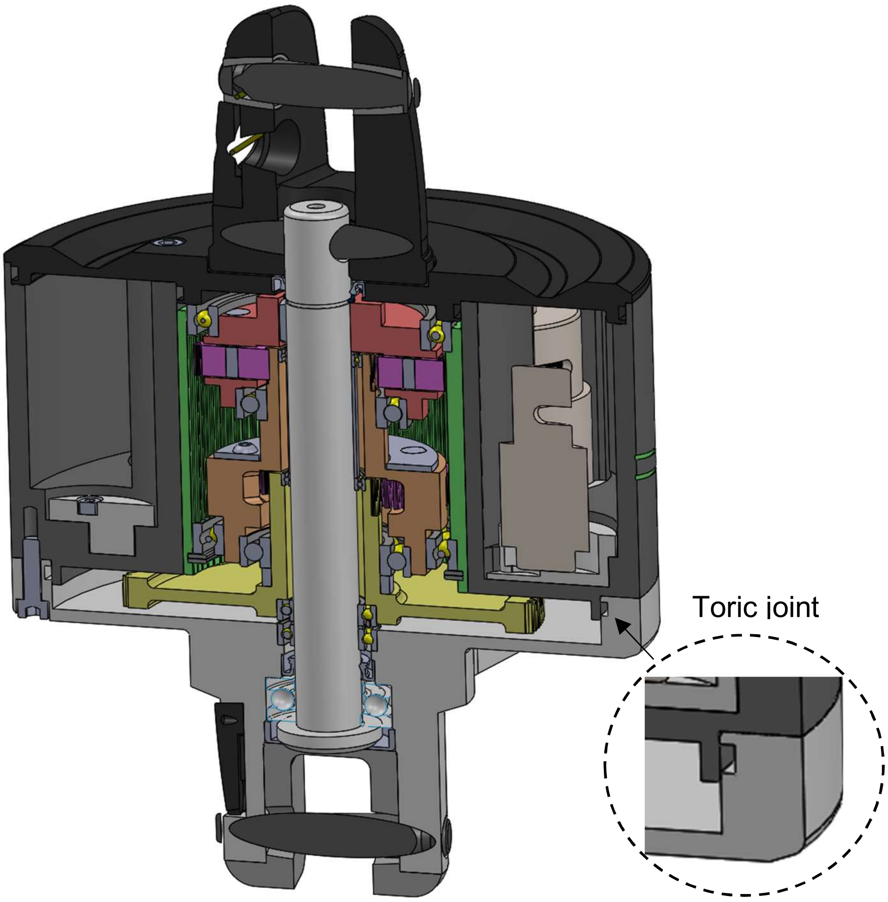


Figure 27 : Section of the NEXe 2.0

A prototype has been made with a 3D printer (Fig. 28) in PLA and with all the standard elements of the system. The goal was to test the mounting scheme of the NEX^{e}2.0 but also to have to better view of the final system. The next step will be to create a functional prototype.

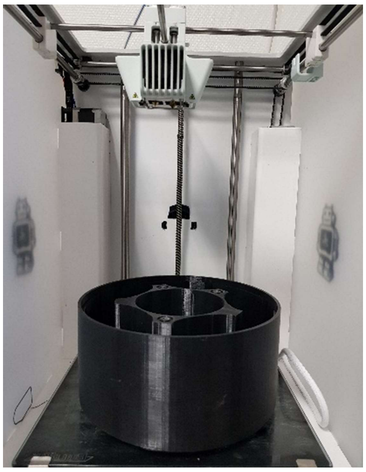


Figure 28 : 3D printer making the housing of the NEX^{e}2.0

2.2.3 Control

A second important phase of the project was to introduce a control of the motors in order to improve all the range of *PROFURL's* electrical furlers. The first step was to understand and analyse what the current electrical connection was.
From now, the brand wanted their systems to be functional more than electronically efficient. The circuit between the actuator and the batteries was composed of a simple fuse for security reason and a relay to select the direction of rotation (Fig. 29).

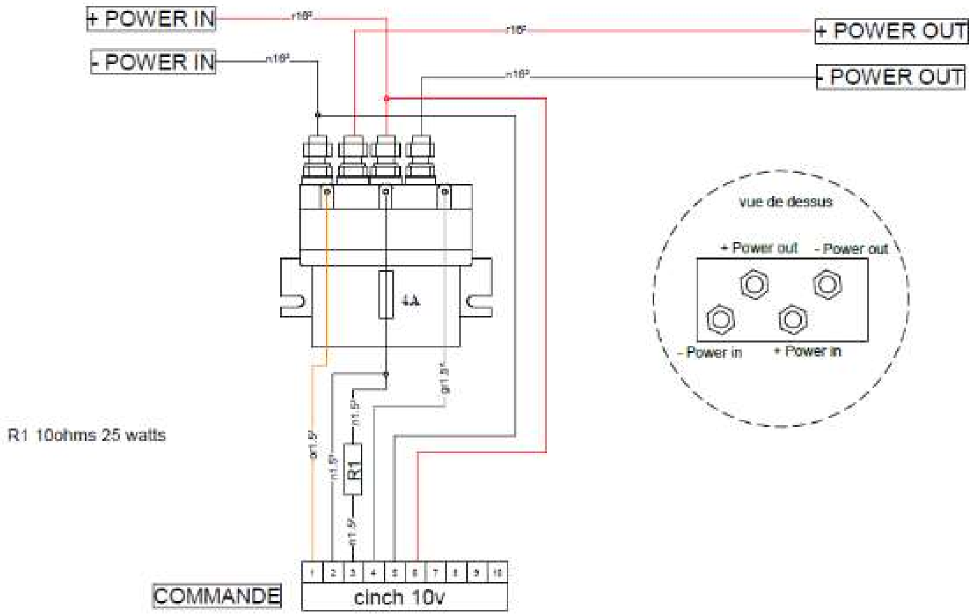


Figure 29 : Control circuit of the NEXᵉ

As explained in the chapter part 1.3, the flapping effect acts as a chaotic system and imposes the torque setpoint. In reality, the torque varies a lot and a current draw can be observed. I conducted an analysis of the tests realized during the testing phase of the NEXᵉ. As represented on figure 30, during a cycle, the motor tries to compensate the resistive torque each time there is an action due to the flapping effect and so current draws appear. Those peaks create overheating of motors and all the electrical components. The higher the current is, the hotter the electronics will be.

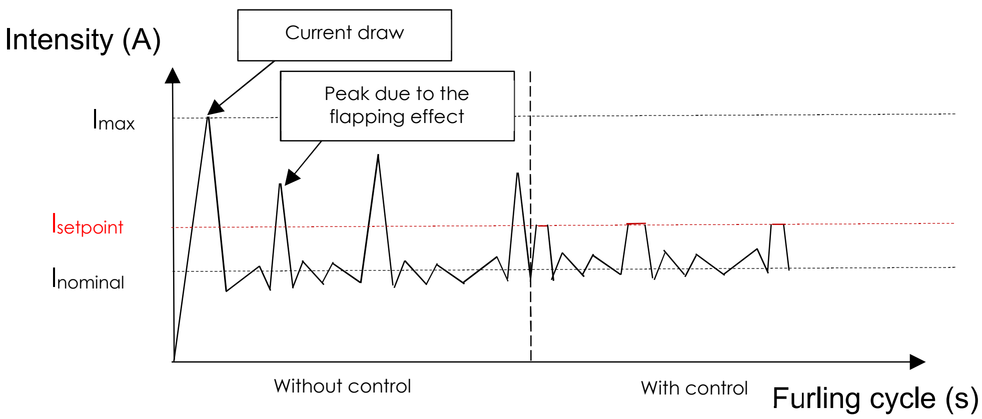


Figure 30 : Theoretical representation of the flapping effect on the actuator with and without an active control

The second part of the graph represents what a speed control regulation with current feedback aim at. The idea is to impose a maximum value of the current in order to delay the overheating of the system under the fuler's service rate. In addition of the overheating control, current peak damage the brushes of the motors and can cause other related features.
Following this analysis, I conducted the realization of the technical specifications of a controller, designed for the range a *PROFURL's* electrical furling systems. After having set up the theoretical functioning of the controller, I contacted four firms for a market analyse to start the development of a custom product for the brand.

The most common type of speed control for a bushed DC motor is the four quadrants motor control. While varying the average voltage of the power source, the speed rotation will vary too. However, because the intensity of the motor can reach up to 130A for few seconds, the controller must be designed to disperse the heat and components must resist to this high current. I "plug and play" solution has been developed based on the following specifications:

- ✓ Controlling and adjusting the speed of the motor under a limit of current consumption (that limit must be selecting/programmable by us). The tension modifies the rotation speed of the motor. If the torque increase, more current is needed for the same speed rotation. If the speed rotation is decreased in this case, the current decrease too as we have the relation (5):

$$P = U * I = C * \omega \tag{5}$$

- ✓ Integrating a receiver to control the motors remotely.
- ✓ Controlling the temperature thanks to a thermic sensor placed next to the motor and another one next to the PCB. Inform the user of overheating with a buzzer (~80-100dB) outside of the box (for higher sound intensity).
- ✓ Managing the use of one negative/parking brake integrated in the furler (impose a delay/offset).

The speed management come out if the indirect control of the torque. Le method estimates the torque from the measurement of the tension and the current powering it (Fig. 31)

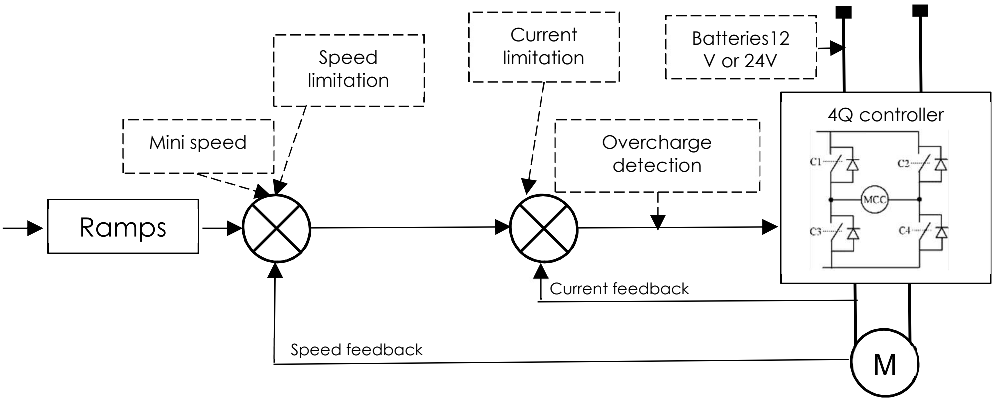


Figure 31 : Control scheme of the NEXᵉ2.0

A functional prototype has been made, all its features and technical specifications are in Appendix 4. A model of it (Fig. 32 and 33) shows the different connectors required to answer the specifications previously listed.

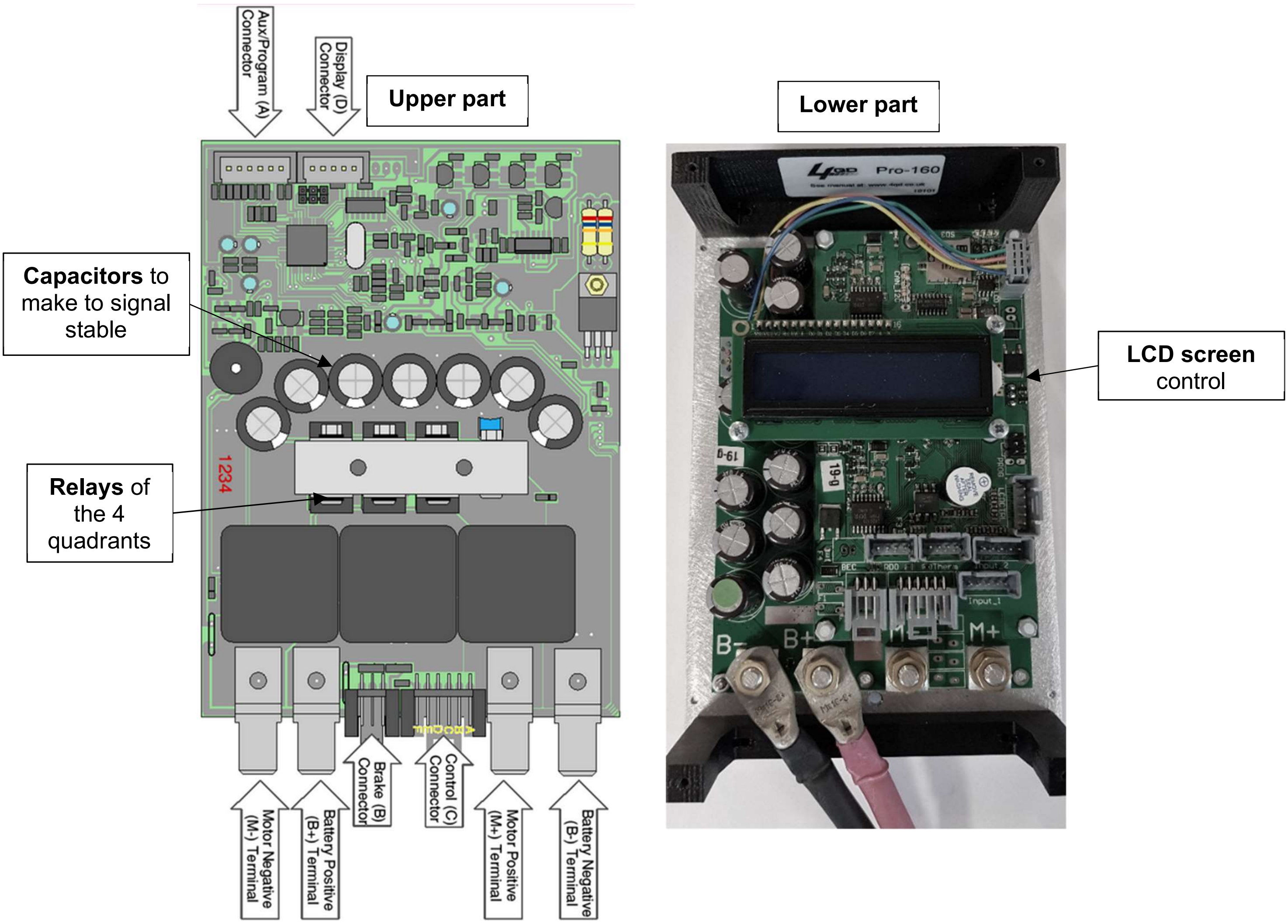


Figure 32 : Upper and lower parts of the controller's PCB scheme

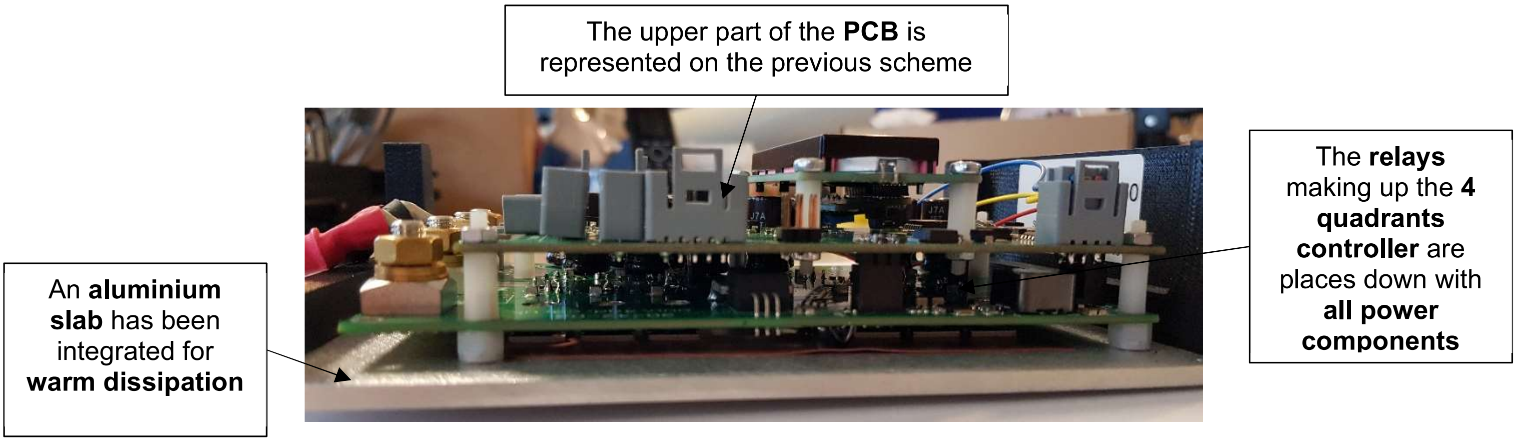


Figure 33 : Controller's PCB architecture

To test all the benefits accurately, a test bench would have been needed in order to measure every parameter accurately. Unfortunately, *PROFURL* didn't owned such a test bench. Then, the next step of my project has been to design one fully functional and optimised for all their range of furlers.

Chapter 3

Tests and validation

3.1 Creation of a test bench

WICHARD has been using two different test benches from now. Although, they lack precision and flexibility and they don't test systems as on a real boat because they are horizontal and not vertical as it should be. For the final step of my project, we decided to start the design of a functional test bench able to measure all the features related to the design of the NEX^{e}2.0. In addition, it must be adapted to the complete range of staying sail and "flying" sail furling system of the brand. The new test bench must:

- Measure the current consumption during a furling cycle.
- Give the speed rotation of the furler.
- Pick the torque value up in real time.

The first constraint in the design if the test bench was to maintain the vertical position of the furler during the tests. The goal of the feature is to be as close as the possible from the real conditions and specially to optimize the lubrication of the rotating elements. After the position determined, the gaol was to reproduce the resistant torque of the flapping effect. The technical solution chosen here is a device that is wildly used to test motors, it's the powder brake. This brake is very flexible and can be programmed easily in order to obtain the specific behaviour we want. The specs of the brake are in Appendix 4. A right-angle reducer has been added to let the brake in its working horizontal position and to multiply its braking power. Finally, a CAD model has been made on *SolidWorks* to check the global dimensions (Fig. 34).

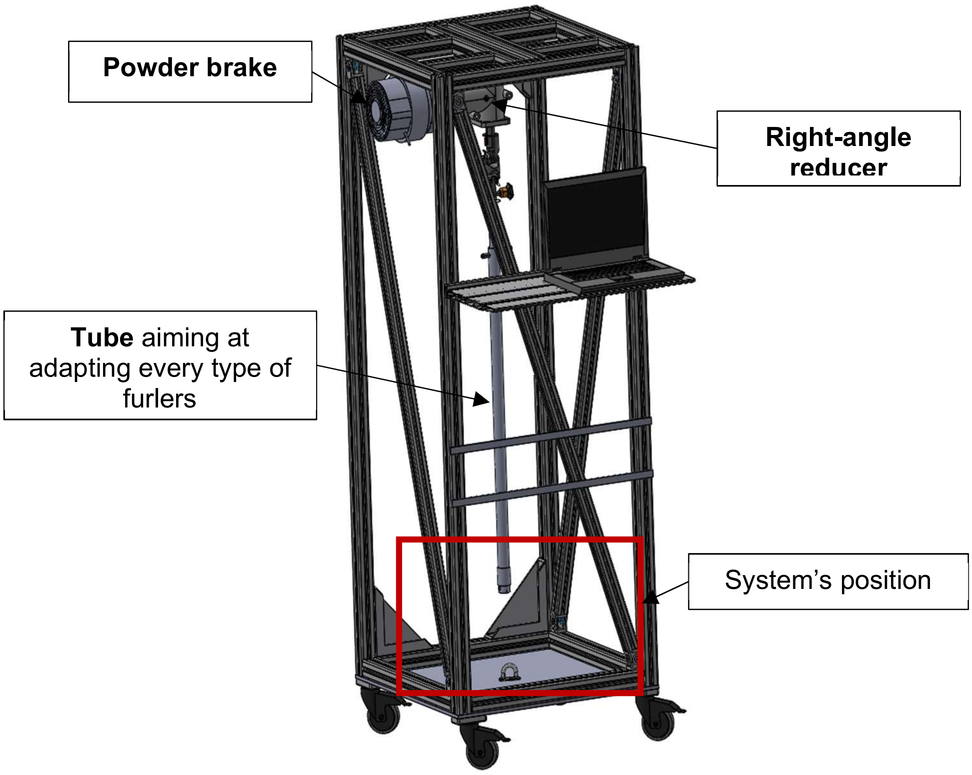


Figure 34 : CAD model of the test bench

After having determined the global shape of the bench, I started the material resistance analysis of the metal structure.

Material: Aluminium

$Rp_{0,2} = 350Mpa$
E = 70000Mpa
I=30,68 mm^4 (given by the supplier)
$\sigma_{adm} = 195N/mm^2$

The resistant torque will be concentrated in the right-angle reducer, so in the upper part of the structure as it is shown figure 35:

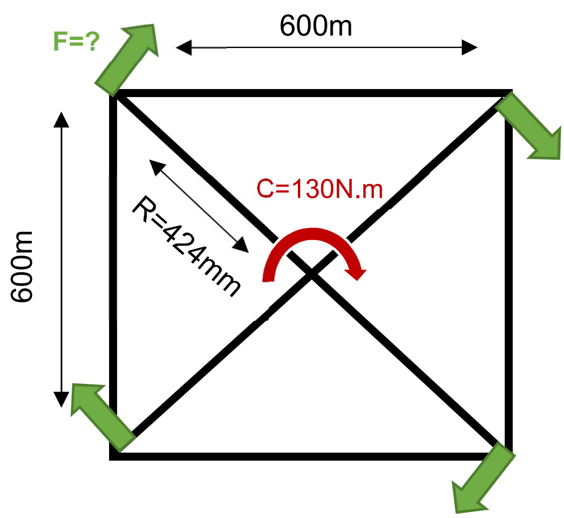


Figure 35 : Top view of the bench's structure

The goal will be to calculate the bending rate of the longest beams which are the vertical ones. We need to know the value of "F", the load, in order to be able to know the value of the beam displacement. Shear stress and compressive stress are very small compare the bending moment in this system.

$$C = F.R \quad (6)$$

$$=> F = \frac{C}{R} * 0{,}25$$
$$= \frac{130}{424.10^{-3}} * 0{,}25$$

$$F = 77N$$

Then the assembly has been considered has a simple beam with a load "F" at its extremity:

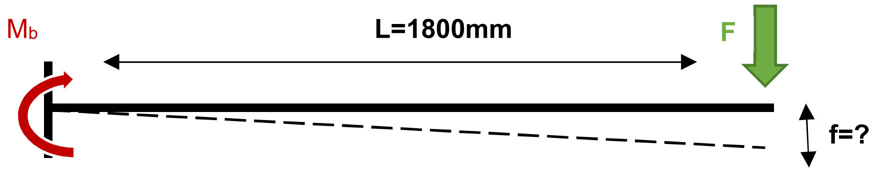


Figure 36 : Beam in flexion

Let's determine the value of "f" at maximum load "F":

$$f = \frac{F*L^3}{3*E*I*10^4} \quad (7)$$

$$= \frac{77*1800^3}{3*70000*10000*30{,}68}$$

Then: $f = 6{,}97mm$

The beam will move from 7mm from its initial position. This value is small compare to its initial position.

Finally, the stress is:

$$\sigma = \frac{M_b}{W*10^3} \quad (8)$$

$$= \frac{77 * 1800}{12{,}27 * 10^3}$$

$$\sigma = 11{,}29N/mm^2$$

So, we have:

$$\sigma \ll \sigma_{adm}$$

The beam will resist to the flexion and so the resistant torque.

Once the structure created and the components selected, the second constraint be to simulate the action of the sail on the furler. We saw on the first chapter that the flapping effect can create a resistant torque of 50N.m. The torque is proportional to the surface of the sail. That's is to say when the sail starts to be furled, the surface decrease and the flapping effect too so the resistive torque as it is shown on the figure 37.

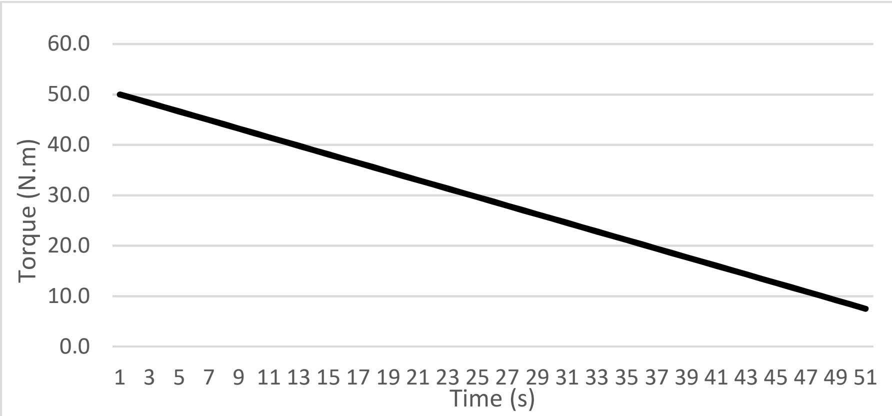


Figure 37 : Evolution of the resistant torque during a furling cycle

This behaviour will be simulated thank the powder brake to apply a progressive decreasing of the resistant torque. The resistance of the structure has been verified, the behaviour of the powder brake has been determined, it's time to develop the control part of the test bench.

The device used to simulate the brake behaviour is a PLC whose features are in Appendix 6. The control box of the bench is composed of a power inverter to power the brake and the PLC; a power block control specific to the brake and all the devices relative to the security (Fig 38).

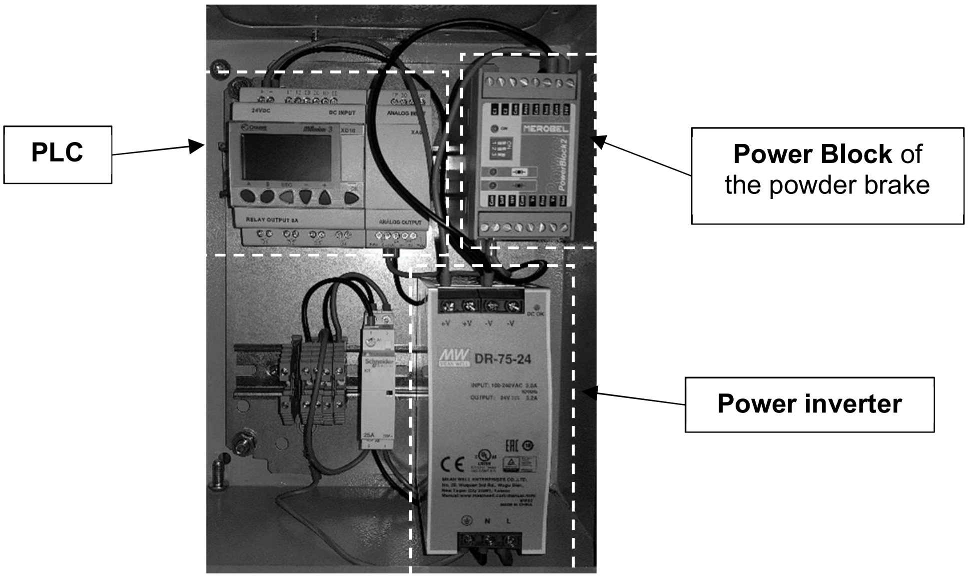


Figure 38 : Control box of the test bench

The programming of the PLC is detailed in the next part. It's the final step of the conception of the test bench.

3.2 PLC programming

The goal here is to use a PLC for the automation of the tests. The PLC bloc is paired with an analogic bloc which deliver an analogic value between 0-10V. As it is written in Appendix 5, the Power Bloc of the powder brake allow to use the 0-10V input to manage the braking rate of the of the device from 0 to 65N.m which is doubled thanks to right-angle reducer of ratio 2:1. Three "modes" will be used to test the furlers on the bench:

- ✓ An automatic « unitary cycle » mode: A complete cycle of 40s
- ✓ An automatic « cyclic » mode: X cycles of 40s are programmed in order to simulate 10 years of use.
- ✓ A manual mode: The clockwise or anti-clockwise rotation is selected with 2 press buttons and a potentiometer coupling with an LCD screen allow the user to modify the resistant torque.

The integration of the sensors has been made by another employee of *PROFURL*. This part won't be developed here. Although the PLC programming can be detailed. The Figure 39 and 40 shows the global program and the detail of one of the modules that describe the automatic "cyclic" mode. The langue used is Functional Bloc Diagram. Very similar the Ladder langue, I could integrate all the features needed.

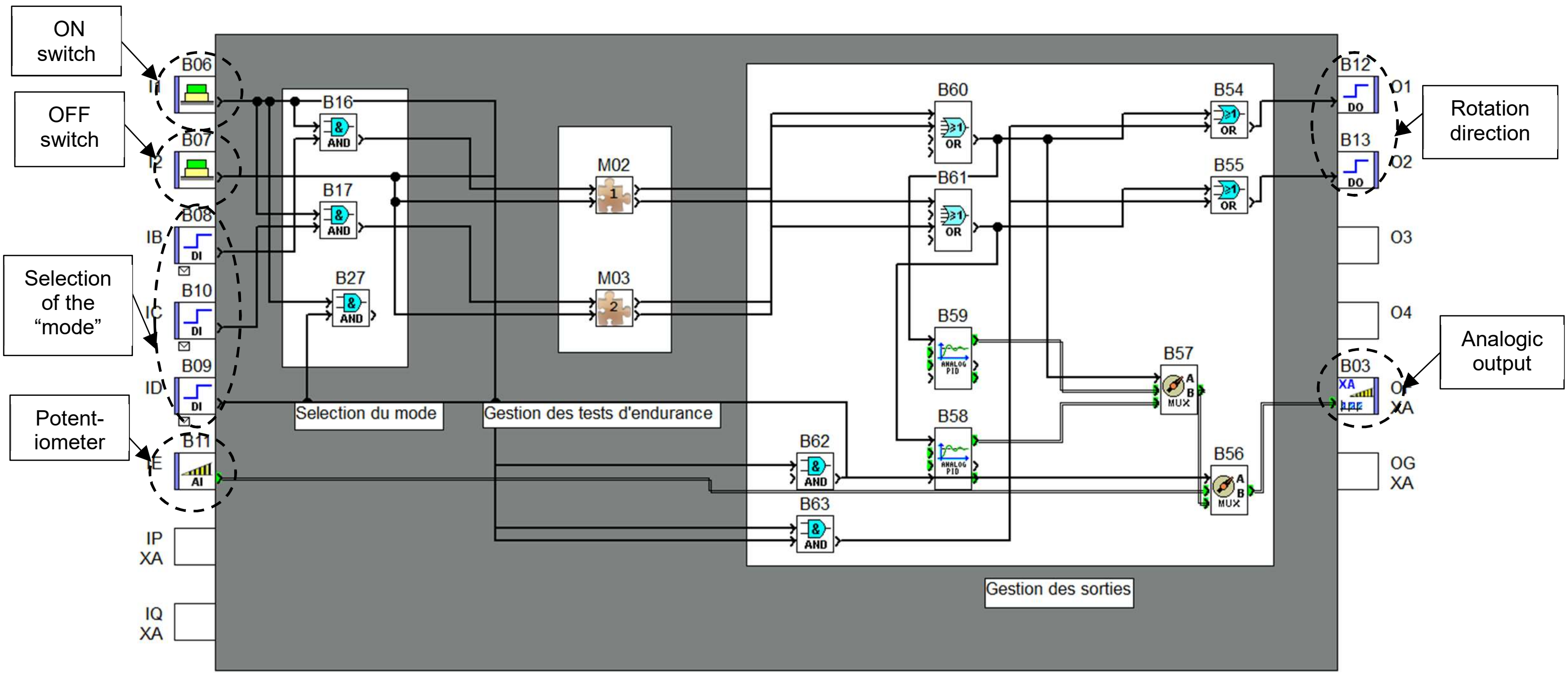


Figure 39 : PLC program

On the right part of five logic inputs deliver the order for the beginning or the end of a cycle and the order for selection of the mode. The user must, first, select the mode and then select start or stop. The analogic input aim at controlling the strength of the brake. On the other hand, we have three outputs. Two for the rotating direction of the furling, clockwise or anticlockwise and an analogic output to give the setpoint to the brake though the dedicated power bloc. Two macros are used here for gestion of the automatic cycles and unitary cycle. They are very similar and the first one is detailed next:

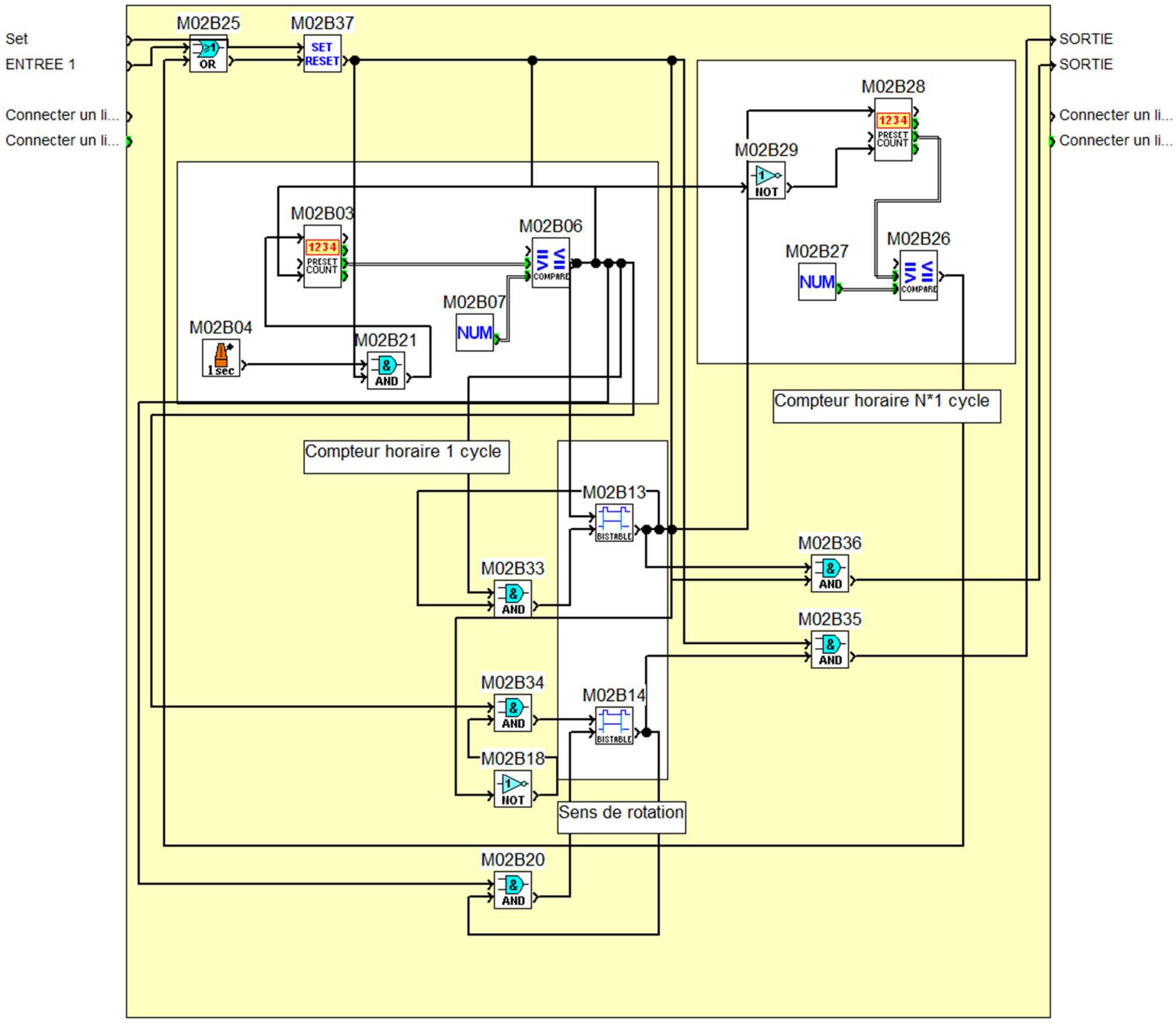


Figure 40 : Automatic « cyclic » mode macro

The only inputs of the macro are the START and STOP from the PLC inputs. The two outputs are used for both, the rotating direction and the activation of the brake. It is composed of a clock, a cycle counter and a gestion of the rotation direction changing after each cycle. The test bench hasn't been ready for the final experimentation of the controller. However, the structure has been built and all the component where ordered and mounted in the control box.

Conclusion

This project is composed of three main parts: The mechanical design of the NEX^{e}2.0, The conception of a dedicated controller and the development of a test bench aiming at testing all types of PROFURL's furlers.

The prototype of the du NEX^{e}2.0 needs to be improved from an external design point of view to start the industrialization part. However, all the suppliers, of the standard parts, have been found to developpe a profitable and efficient product. The global theoretical efficiency will be much better, even though the weight remains the same. The size of the new system develop is very close the previous version, but the shape is closer to a standard manual "flying" sail furling system. The integration of it is easier.

The controller must be tested but a protype has been made in cooperation with an external supplier. Its specifications are respected even though a "plug and play" version is still in development. The technical features have been clearly defined and the suppliers of the final product is still an actual task.

The test bench is almost functional. The structure is done, and the wiring of the control part is still on running. It must be tested before being able to test the furlers. The PLC programming is finished, and it runs perfectly on computer.

I achieved almost every tasks of my mission during this master's thesis. The lack of time due to supplier's delay forced me to optimize as much as possible my working time but I finally left an advanced "flying" sail furling system protype; a prototype of a controller made with a reliable supplier and a test bench.

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List of figures

List of symbols and abbreviations

DC	Direct Current
AC	Alternating Current
PLC	Programmable Logic Controller
FMC	Frein manque de courant
FBD	Function Block Diagram
PRT	Prix de revient technique
PLA	Polylactic acid
APTE	Application aux Techniques d'Entreprise

Lexical

Chain plate: A strong link or plate on the hull of a yacht or sailing ship, to which a shroud is secured

Code0: Type of front sail which is a cross between a genoa and an asymmetrical spinnaker that is used for sailing close to the wind in light air

Deck: A surface taking up one level of a hull of a vessel

Forestay: A rope to support a ship's foremast, running from its top to the deck at the bow

Gennaker: Type of front sail is a specialty sail primarily used on racing boats to bridge the performance gap between a genoa and a spinnaker

Hauled in: Action of making the sail taut

Jib: Front sail of a sailboat of sloop type

Regatta: A sporting event consisting of a series of boat or yacht races

Rigging: The system of ropes or chains employed to support a ship's masts

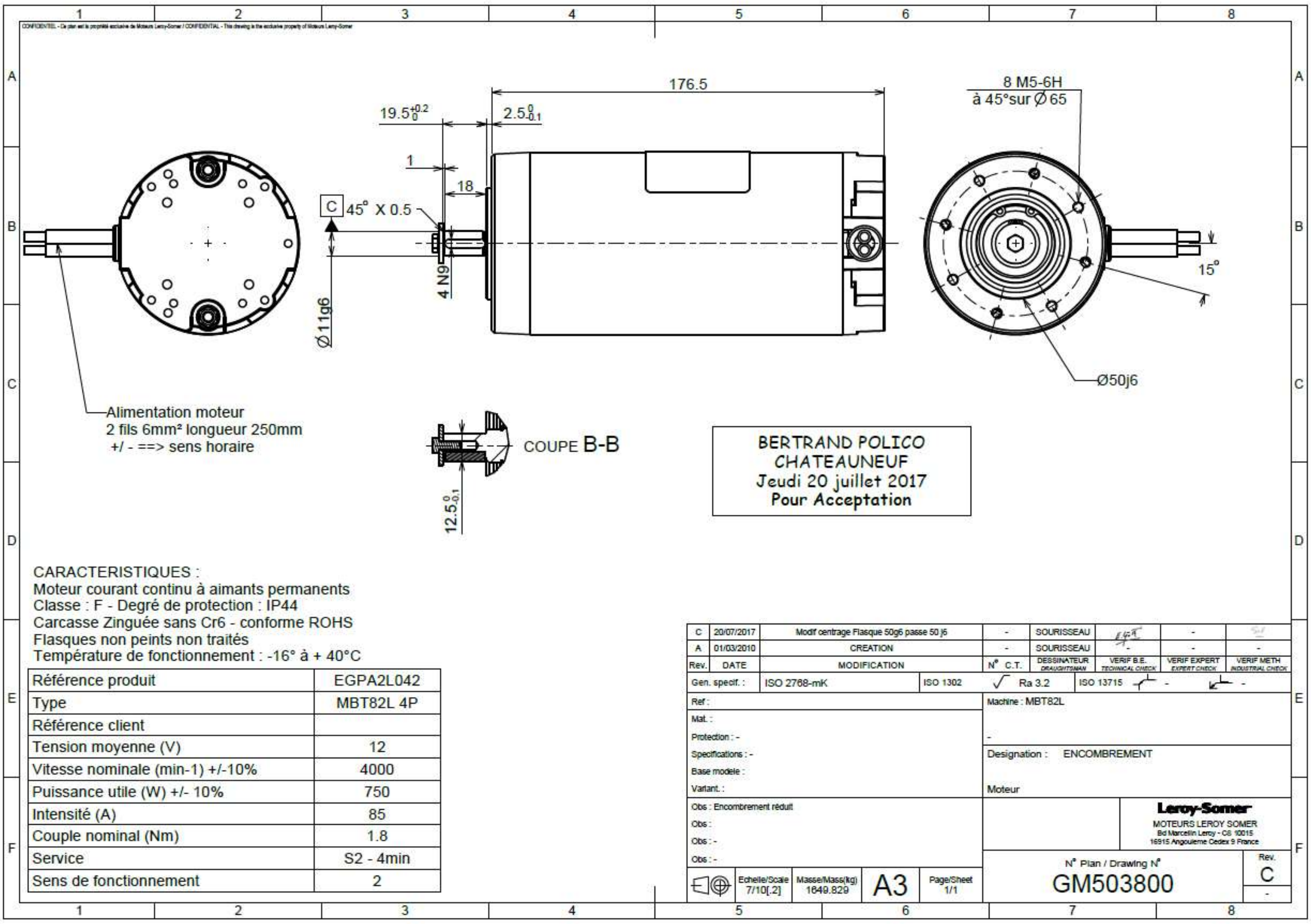
Sloop: A single-masted sailing vessel with fore and aft

Shroud: Any of the ropes or wires attached to the head of a ship's mast to keep it from swaying

Spinnaker: Type of front sail designed specifically for sailing off the wind from a reaching course to a downwind

Tack: Specific tie of the sail

Appendix 1: DC motor Leroy Somer 12V – NEXe



Référence produit	EGPA2L042
Type	MBT82L 4P
Référence client	
Tension moyenne (V)	12
Vitesse nominale (min-1) +/-10%	4000
Puissance utile (W) +/- 10%	750
Intensité (A)	85
Couple nominal (Nm)	1.8
Service	S2 - 4min
Sens de fonctionnement	2

Appendix 2: Comparison of Brushless motors

Fournisseur	Lien	Prix	Couple	Puissance	V. de Rotation(tr/min)	Dimensions(mm)	Poids(kg)	Réducteur	Tension d'alimentation	Remarque
Alien power system	[illegible]	140	7.3	3200W	Elevée	70*110	1.53		42V	>Large selection de moteurs à puissances très élévées, type moteur vélo/modélisme. >Excellent rapport dimensions/puissance. >Pas de FMC de série, ni de réducteur
Crouzet	[illegible]	1000	1.9	600W	3890	177*165	3.3		9-48V	>Smart Motor >Cout élevé (controleur intégré)
Techno indus	[illegible]	371	2.1	660W	3000	152*86*86	4.2	23.8	48V	>Possibilité d'ajouter un réducteur et un controleur adaptés >Moteurs lourds et encombrants
ebmpapst	https://www.ebmpapst.fr/media/content/info-center/downloads/catalogues_france/Plaquette_Moteurs_Ed11-15_144dpi			356W		63*178				>Gros avantage: la possiblité d'ajouter des modules avec le FMC/Le controleur/le réducteur >Puissance trop faible
FARADAY motion	[illegible]	70	2.92	2800W	9576	63*64			50,4V	>Contrôleur en option >Pas de FMC de série, ni de réducteur
Chiapha Components	[illegible]		0.88	280W	3160	102*169			48V	>Puissance trop faible
Faulhaber	[illegible]		0.4	250W	6100	90*44	0.742		48V	>Gros avantage: la possiblité d'ajouter des modules avec le FMC/Le controleur/le réducteur >Puissance trop faible
Maxon	[illegible]	722	0.501	250W	4090	131*64	2.1		24V	>Possiblité d'ajouter des modules avec le FMC/Le controleur/le réducteur >Cout de tous les éléments
MDP	[illegible]	268	0.5	524W	3600	142*62	1.8		24V	>Controleur et réducteur adaptables >Cout élévé
Flash RC	[illegible]	66		500W	54000	47*32	0.153		14.8	>Bcp de composants du type moteurs pou modélisme >Petit prix pour la puissance >Refroidissement à prévoir
Astro Flight	[illegible]	400	1.3	1000W	6000-10000	38*82	0.635		12-32V	>Controleur adaptable >Tres bonne qualité et bon rapport puissance poids/taille >Pas de réducteur adaptable
Aveox	[illegible]									>Très performant >Cher et très évolué
Miniplanes										>Moteur de modélisme

Appendix 3: DC motor MABUCHI RS-775WC-8514 – NEX^e2.0

RS-775VC/WC

MABUCHI MOTOR

OUTPUT : 9.0W～300W (APPROX)

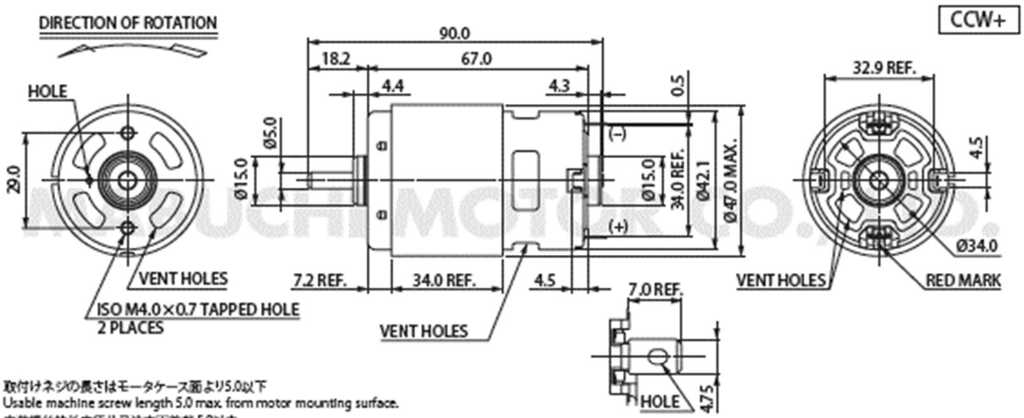
カーボンブラシ | Carbon-brush motors | 碳精电刷

代表的用途 工具：ドリル／ガーデンツール／丸のこ
Typical Applications **Cordless Power Tools : Drill / Garden Tool / Circular Saw**
主要用途 工具：电钻、园艺工具、圆锯

WEIGHT : 383g (APPROX)

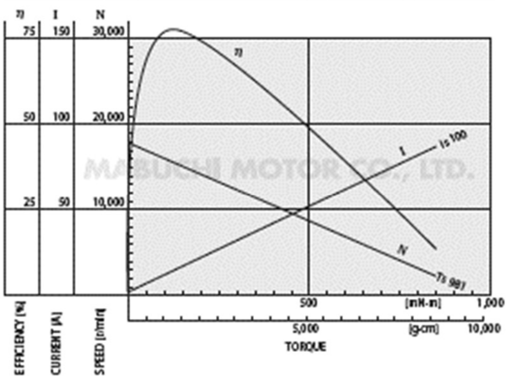
MODEL		VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY					STALL		
		OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	TORQUE		CURRENT
				r/min	A	r/min	A	mN·m	g·cm	W	mN·m	g·cm	A
RS-775VC-8016	(*1)	6～20	18V CONSTANT	18000	2.20	15680	14.8	127	1292	208	981	10000	100
RS-775WC-8514	(*1)	6～20	18V CONSTANT	19500	2.70	17040	18.7	153	1561	273	1216	12396	130
RS-775WC-9013	(*1)	6～18	18V CONSTANT	21000	2.80	18520	20.9	153	1560	296	1295	13201	156

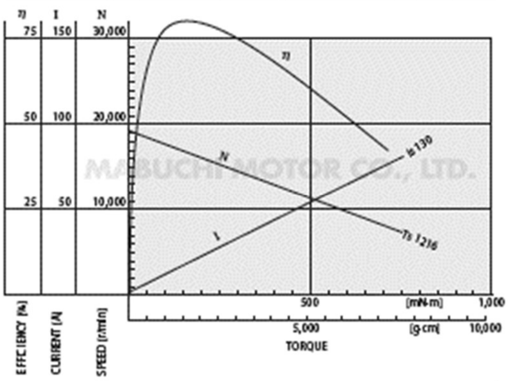
(*1) CCW進角仕様(CCW+) | CCW shifted commutation (CCW+) | CCW进角规格 (CCW+)



取付けネジの長さはモータケース面より5.0以下
Usable machine screw length 5.0 max. from motor mounting surface.
安装螺丝的长度须从马达壳面算起 5.0以内

UNIT : MILLIMETERS





マブチモーター株式会社（本社 営業部）
MABUCHI MOTOR CO., LTD.
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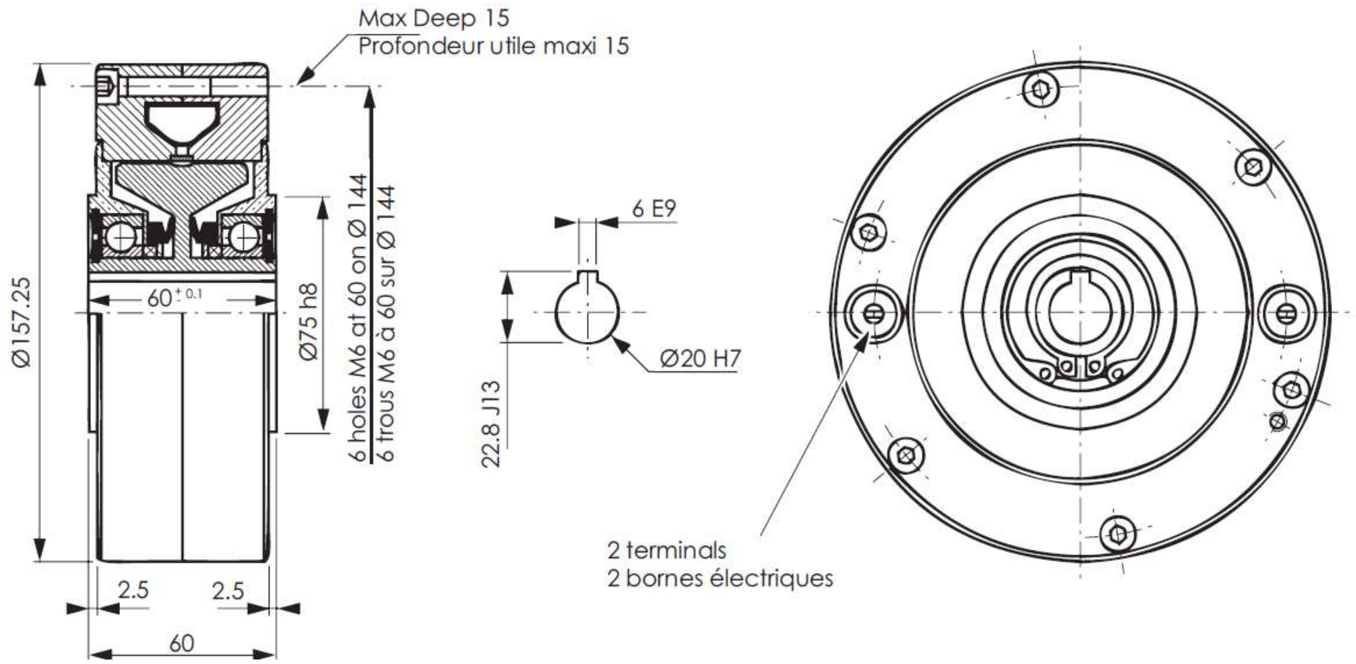
E-mail: slsinq@mabuchi-motor.co.jp

Appendix 3: Specification - Controller 4QD PRO-160

Nominal voltage range	24 – 48
Minimum / maximum voltage	16 – 55
Motor current A [max]	150
Motor current A [continuous]	60 [depends on mounting / cooling]
Reversing	Y
Half speed reverse	Programmable
Regen braking	Y
Gain adjustment	Programmable
Dimensions [mm]	145 x 102 x 38 [board], 181 x 121 x 46 [boxed]
Weight [g]	Board = 320g, boxed = 630g,
Power connections	9.5mm push-on blades
Input	1k – 15k pot, or 0 – 4.7V
Reverse polarity protection	Y
Over voltage protection	Y [60V]
Under voltage protection	Y [8V]
Pot fault protection	Y
Thermal protection	trip @95'C
Current limit – drive	Y
Current limit – regen	Y
High pot lockout	Y
Joystick / Wig-wag input	Programmable
Radio Control	Via DMR-203
Dual ramp reversing	Programmable
Ramping	Acc and decel programmable between 0.1S and 15S
Parking brake	Y [1A max] Delay and threshold programmable
Inhibit function	Y
Powerdown state (motor)	shorted
Heatsink	Integral with boxed version
Double heading	Y
Switching frequency	20 kHz
Quadrants	4

Appendix 4 : Poudre brake– MEROBEL



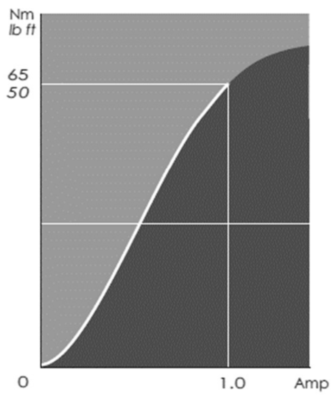
Features / *Caractéristiques*

Technical Features	*Données techniques*				
Rated torque	*Couple nominal*	Nm	65	lb.ft	*50*
Rated current	*Courant nominal*	A	1.00	Amp	*1.00*
Residual torque	*Couple résiduel*	Nm	0.63	lb.ft	*0.46*
Residual torque RR (1)	*Couple résiduel RR (1)*	Nm	1.30	lb.ft	*0.93*
Coil resistance (2)	*Impédance de la bobine (2)*	Ω	20		
Rotor inertia	*Inertie du rotor*	kg.m²	2.10^{-3}		
Min rotation speed (3)	*Vitesse de rotation min (3)*	mn⁻¹ rpm	40		
Max rotation speed (3)	*Vitesse de rotation max (3)*	mn⁻¹ rpm	3000		
Rated Outside body Temp. (4)	*Temp. ext. nominale du corps (4)*	°C	100		
Ultimate Outside body Temp.	*Limite max. de Temp. ext. du corps*	°C	120		

(1) remnant rotor version
(2) at 20°C (varies with the coil temperature)
(3) except RR versions. Any further request, please consult your supplier
(4) max for rated life

(1) version rotor rémanent
(2) à 20°C (variable en fonction de la température de bobine)
(3) sauf versions RR. Pour toute autre valeur souhaitée, consultez votre revendeur
(4) limite max pour une durée de vie nominale

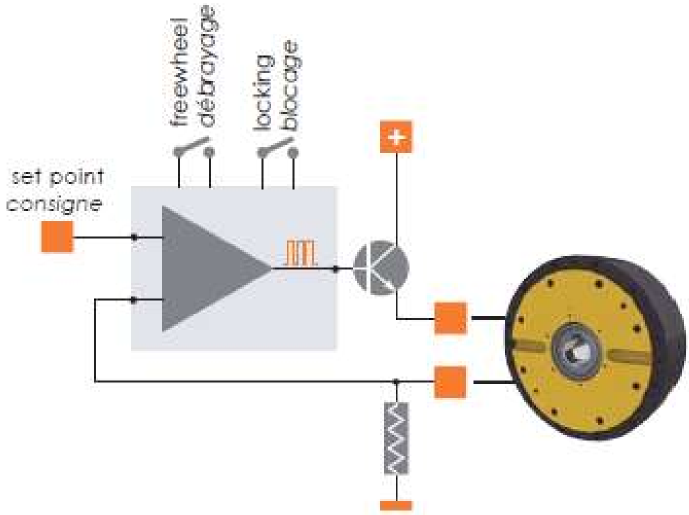
Typical torque vs. current / *Courbe caractéristique courant - couple*



Appendix 5 : Power block of the poudre brake– PowerBlock 2

CURRENT REGULATED Power Supply based on microcontroller technology.
Accurate current output control, independent of coil temperature.
High protection against transients, leading to high reliability in industrial environments.

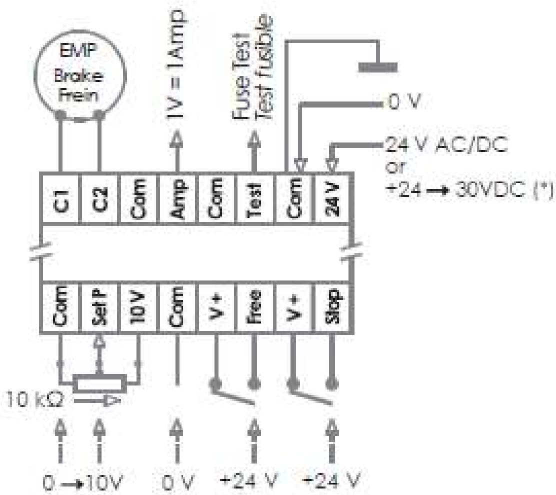
Alimentation de Puissance REGULEE EN COURANT construite autour de technologies à base de microcontroleurs.
Courant de sortie précis et indépendant de la température de la bobine.
Haut niveau de protection contre les transitoires, permettant de garantir une haute fiabilité en environnement industriel.



Features / *Caractéristiques*

			PowerBlock04	PowerBlock2	PowerBlock4 (*)
Input voltage	*Tension d'alimentation*	V	**24** AC/DC	**24** AC/DC	**24 → 30** DC
Max output current	*Courant de sortie max.*	Amp	0.400	2	4
Output load (resistance)	*Charge en sortie (résistance)*	Ω	480 max	4 → 20	4 → 20
Max. power consumption	*Puissance consommée max.*	VA	20	70	120
Remote voltage control	*Tension de pilotage*	V DC	0 → 10	0 → 10	0 → 10
Ambient temperature	*Temperature d'utilisation*	°C	+10 → +40	+10 → +40	+10 → +40

Dimensions & Connections / *Dimensions & raccordements*



Appendix 6: Programmable logic controller – CROUZET millenium III

1 **Power Supply**: 12VDC, 24VDC, 24VAC, 100-240VAC

2 **Smart Design**: Adapted for modular panels, can be DIN-rail mount or panel mount.

3 **Digital and Analog Inputs**:

- Digital up to 20Hz
- 0 to 10V or VCC: to control with direct voltage or potentiometers
- LDR: direct connection of LDR light sensors
- NTC: direct connection of NTC temperature probes

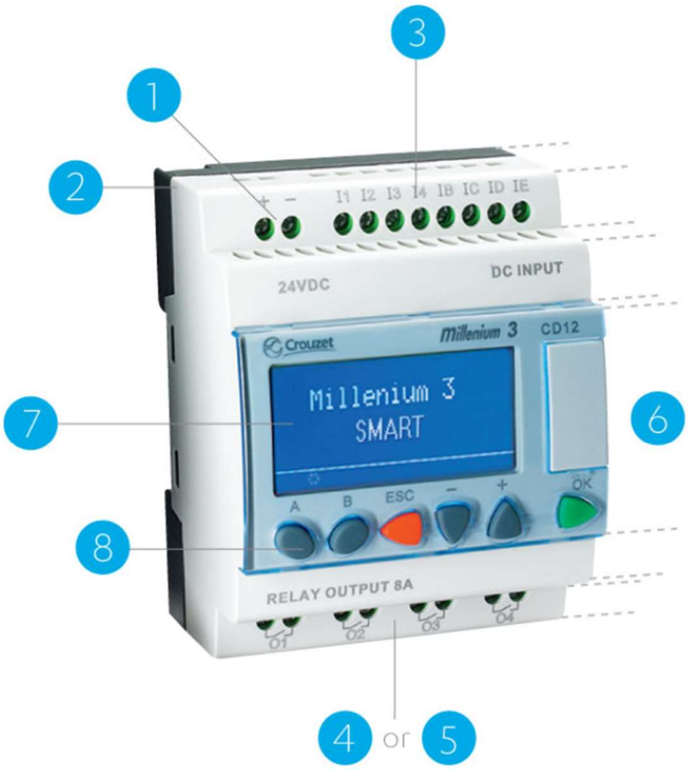
4 **Relay Outputs**: Standard 8A outputs

5 **Static PWM Outputs**: For DC motor speed control, AC drives

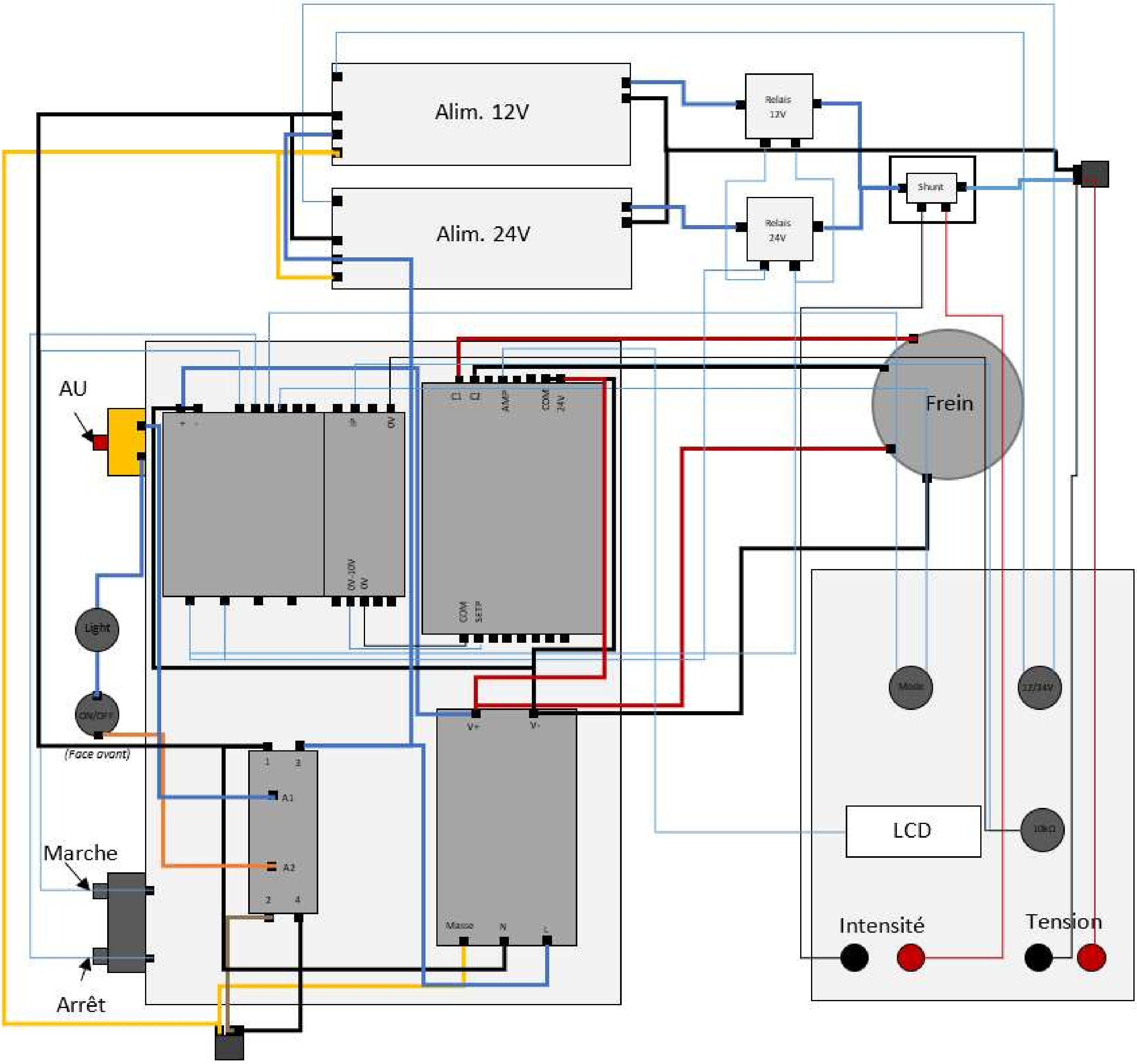
6 **Expand up to 50 I/Os**: Expand your applications

7 **Embedded Highly Visible Screen**: Good visualization - Bright blue screen or classic

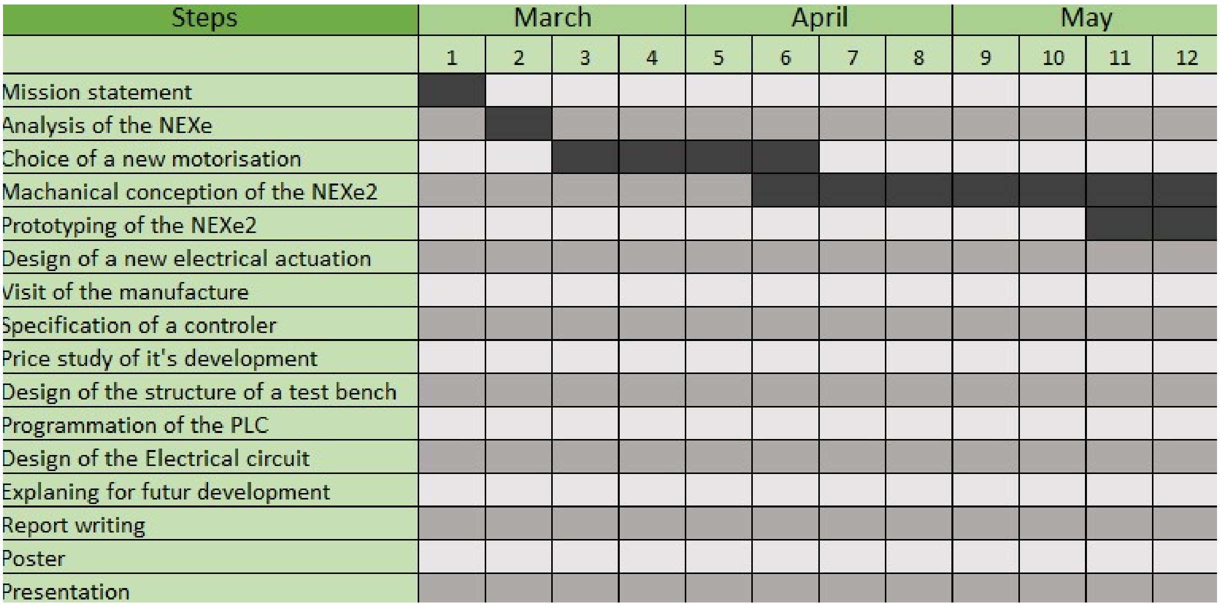
8 **Programmable Buttons**: Each button can be configured for a different function. Use front face button to execute action manually

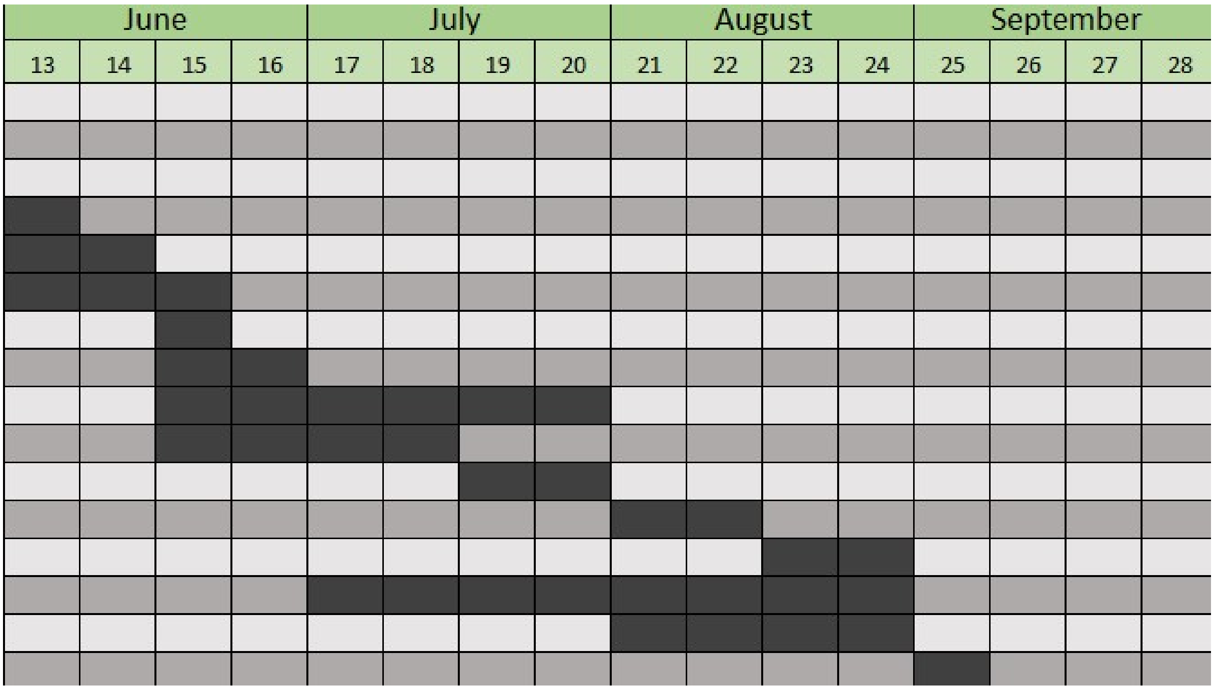


Appendix 7: Control box wiring scheme of the test bench



Appendix 8: Gantt diagram of the thesis





DESIGN OF A MOTORIZED SAIL FURLING SYSTEM:

Summury :

Ce rapport de stage décrit les différentes étapes de réalisation d'un produit industriel. Le point départ du projet a été l'analyse de la première version du système à concevoir. La motorisation a ensuite été au cœur de l'étude car il s'agit de l'élément central du système. La conception mécanique s'est ensuite articulée autour de la sélection du moteur. Après un premier prototype, j'ai pu proposer une solution pour améliorer le système du point de vue électronique. La collaboration avec plusieurs entreprises m'a permis de réaliser une étude de prix pour un contrôleur adapté à nos besoins. Finalement un banc d'essai a pu être créé pour pouvoir tester cette nouvelle gamme d'emmagasineurs ainsi que les autres modèles d'enrouleurs de la gamme. Le banc utilise un automate ainsi qu'un frein adapté à la simulation partielle de l'action du vent sur une voile.

This master's thesis describes the different steps of the conception of an industrial product. First, the project began through the analysis of the previous version of the designed system. The motorization has then been at the centre of the study as it is the main component of the system. The mechanical structure has been developed following the selection of the motor. After having done a first prototype of the system, I had the opportunity to propose an electronical solution to improve the product. Finally, a test bench has been developed, fully adapted to the range of furling system of the brand.

Key words: Voilier, CAO, Mécanique, Contrôleur, Banc d'essai