ENSI 3 PROJECT REPORT

Subject: Design of an autonomous sailboat for long range missions

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Summary

1) Presentation of the context

Over the last years autonomous sailboats have known a growing interest. Theoretically it gives us the possibility to design systems fully autonomous in terms of energy since the wind is used for propulsion. Several projects have been launched. I will give a short presentation of two of them: the Vaimos and the Improbable.

The Vaimos was designed by the Ifremer for oceanic measures campaigns. During its design it was thought to be reliable, upgradable but not to achieve long range missions. Therefore a lot of sensors are used and the energy consumption is not optimum. This ship is capable to sail for four days, after that the batteries will be depleted. The embedded systems are drawing a lot of power and the energy production systems such as solar panels or the wind turbine are not capable of producing enough energy to sustain the system.

The Improbable was developed for another purpose. It was thought for a low consumption, a high reliability and the use of sensors is kept to a minimum. This sailboat was designed for long range missions. The idea was to make an Atlantic crossing in full autonomy. Even if solar panels were not implemented at the end of project it would have been enough to meet the energy needs of this ship since the embedded systems are low power consumption systems.

As we can see these projects are complementary. The Ifremer decided to make a new sailboat for long range missions. The idea is to make a new version of the Vaimos thought to address the issues of energy consumption. How can we solve the problem? Basically we should lower the energy consumption and higher the energy production. By designing this new ship with the same philosophy we should be able to obtain a system capable of long range missions and featured with the necessary sensors so that it will be able to perform its oceanic missions.

As you have probably guessed, my job in this project is to deal with energy issues. This report explains what can be done to improve the energy balance of the ship. In a first part I will make an analysis of the Vaimos embedded systems to find out what can be improved and then I will develop more in details the solutions I believe the more appropriate.

2) Power consumption of the Vaimos

Before trying to improve the energy balance of the sailboat, I decided to evaluate the power consumption of the ship in order to know what amount of energy we should product or save to insure the full autonomy. These calculations have been made using data saved by the Vaimos during the Brest – Douarnenez mission. To find the average power consumption, I have first calculated the total energy consumption. For the autonomy estimation it is supposed that the energy available is equivalent to the full loaded batteries of the Vaimos (24 V / 120 Ah). The results can be found in the table below.

Calculations with Brest - Douanenez data	
Total energy consumption (in J)	1966356,10
Total time (in s)	69406,06
Average power (in W)	28,33
Battery energy (in W.h)	2880,00
Current autonomy (in days)	4,24

As we can see the current average power consumption of the Vaimos is about 30 W, it allows 4 days of autonomy to the Vaimos. We know from previous experiments conducted at ENSTA – Bretagne and at Ifremer that the average power we can expect from solar panels and from the wind turbine will not exceed 2 W for both systems. In the end we draw about ten times what we produce, we are far from having an autonomous system. We must decrease the power consumption as much as possible but as there is a big gap between consumption and production the key of the problem will be in finding a way to produce more energy. Indeed even if we manage to reduce the power consumption we must keep in mind that this kind of system will be upgraded in time and the customer will always need more sensors, communication systems and other power consuming systems therefore it is important for the credibility of the ship to be featured with a serious power generation system. Because of these reasons I will quickly deal with what can done to reduce the waste of energy aboard the sailboat and I will then focus on how to produce enough energy.

3) How to reduce the energy consumption

There are a few ways of saving power. The different possibilities that came to my mind are:

-Using different actuators with a lower power consumption

-Lower the consumption of secondary systems

-Lower the consumption of embedded electronics

-Using energy saving algorithms

I have analyzed each possibility. When possible I tried to predict the amount of energy we could save. My conclusion for each possibility is based on the impact on the energy balance of the ship, how complex it is to make the solution work, what the Ifremer is ready to change or not and the impact on reliability.

The Ifremer is not favorable to use other actuators because the ones used at the moment (for the sail and the rudder) have already been used in other projects and have proved their reliability. Anyway the actuator of the sail is not used all the time but only sometimes to adjust the position of the sail. That is why a change in this system would not result in a big modification on the average energy consumption. The actuator of the rudder is however used all the time. A solution to improve it would be to use a wind vane steering system. In this case the rudder is steered using the energy of the wind. However this solution will imply complications in laws of command (we can only change the angle between the wind and the rudder and this angle will change with the torque on the rudder) and take a lot of time to implement. Moreover the reliability will necessarily decrease with this device. All these reasons made me think that changes on actuators are not useful at the moment and we should do it only if the other solutions are not efficient enough.

After having taken a look to the secondary systems of the Vaimos I concluded that it is not really possible to improve their energy balance. These systems are all made systems such as communication devices or other devices with a correct consumption. However some of these systems are working all the time. I recommend the use of a relay board to switch off all unnecessary systems and wake them up only when necessary.

A look into the embedded electronics of the Vaimos showed that it is possible to gain a lot of power by applying a few changes.

It is possible to remove the board which is converting RS232 to a PWM signal for the control of the brushless engine of the rudder. Indeed the Armadeus board is capable of generating directly a PWM signal. By removing this board we will save 0.4 W. This solution is easy to implement only a few changes in the code are necessary.

It is also possible to remove the serial server board (MOXA) since the Armadeus board is featured with enough UARTs. The issue is that this board allows the use of the TCP/IP protocol with serial ports. As everything has been programmed using this protocol and as it allows an easy debugging the Ifremer wants to keep the use of this protocol on the serial ports. With the help of Mr. REYNET and Mr. LE BARS we managed to prove that by using the command "ser2net" we can use directly the serial ports of the Armadeus board with the TCP/IP protocol therefore this board is no longer necessary. By removing this board we save 7.5 W. I have not found other possibilities to decrease the consumption of embedded electronics. By applying these changes on the new version of the Vaimos we can save 8 W (almost one third of the total consumption). Since these changes are simple to implement and are even helping to improve the reliability by diminishing the number of components, I strongly recommend their implementation.

It is more difficult to predict what amount of energy could be saved by using energy saving algorithms since I cannot run any test at the moment but I will try to give some estimations and ideas of improvement. As I said before some secondary systems are always activated, they should be turned on only when necessary. We can do it by using a relay board and as a consequence changes must be implemented in the code to take into account this new way of functioning. The frequency of adjustment of the sail should be lowered if possible because this system is power consuming. Taking into account the consumption of the Wi-Fi board that was always switched on during the mission, and the energy we could gain by using the relay board and by improving the frequency of use of each secondary system I believe that we could save about 5W. There is no proof concerning this number it is only a guess.

The table below shows the amount of energy that can be saved by applying the previous changes and gives an estimation of the new average power consumption and autonomy without any system to product energy onboard.

Estimations with "low power consumption electronics"	
MOXA consumption (in W)	7,5
Brushless engine control board (in W)	0,4
Estimated saved power by using properly the relay board (in W)	5
Estimated average power (in W)	15,43
Estimated autonomy (in days)	7,78

4) How to higher the energy production

As explained before, tests run by the Ifremer and ENSTA – Bretagne proved that solar panels and a wind turbine are not producing enough energy to power the ship. We can expect about 4 W by combining these systems. Even if it can be interesting to implement them aboard the sailboat we need another source of energy to insure the autonomy.

Here is my reasoning: First we need to use renewable energies, indeed another type of energy would imply a refueling and then we could not have a full autonomy. If we cannot use solar panels or a wind turbine what can we use? The main source of energy aboard the ship is the wind, it allows the ship to move thanks to its sail. Could we take a part of this energy for power generation? How? The energy of the sail is mechanical energy, to take a part of it we need to have a movement. The only movement created by the sail is movement of the hull compared with the sea. I know two ways of converting this energy into electricity:

-using a propeller and a generator

-using a paddle wheel and a generator.

The propeller is a well known solution. However it has some drawbacks. First it will generate a streak when not used and slower the sailboat. Secondly a hole is needed to allow the shaft to pass through the hull and will generate waterproofing issues. Last but not least algae will be collected into the propeller and it will diminish the yield of the system and generate an additional streak.

The paddle wheel can be disengaged easily so then the streak when not used would be minimal, the shaft can pass above the level of the sea so the waterproofing will be easier. It is hoped (but not tested) that algae will not be collected with a paddle wheel properly designed as the mechanical parts in contact with water would be strait.

This quick analysis of these solutions made me think that the paddle wheel is the best solution. It would be good however to know what we can expect in terms of energy production. As explained in the next section, according to the theory on paddle wheels, we can expect a generation of 107 W of mechanical energy (about 53 W after conversion into electrical power) for a speed of 8 km/h. However the available power is quickly decreasing with speed, for a speed of 4 km/h we can expect 13 W (about 7 W after conversion into electrical power). Based on the Vaimos navigation data record the average speed is often superior to 5 km/h, that is why the paddle wheel seems to be a viable solution to produce power.

5) Design of the paddle wheel

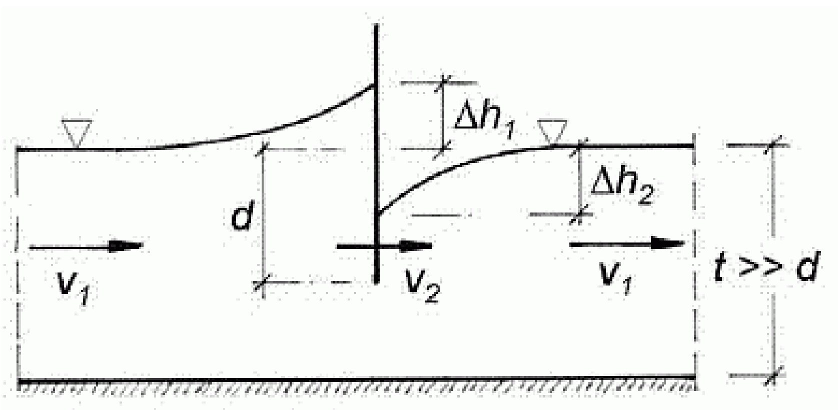
The design of the paddle wheel was organized in several steps. First I calculated the theoretical power production of the paddle wheel. Knowing the amount of mechanical energy we should expect I selected the more appropriate generator with its mechanics and electronics. When all the components were chosen I designed the system with CATIA and realized it for real. At this moment the system was ready for tests.

5.1) Calculation of the theoretical power production

After some research on paddle wheel theory, I found an interesting web page published by the ENSEEIHT. My calculations are based on their article about paddle wheels available here:

http://hmf.enseeiht.fr/travaux/CD0708/beiere/3/html/bi/3/ch2.html

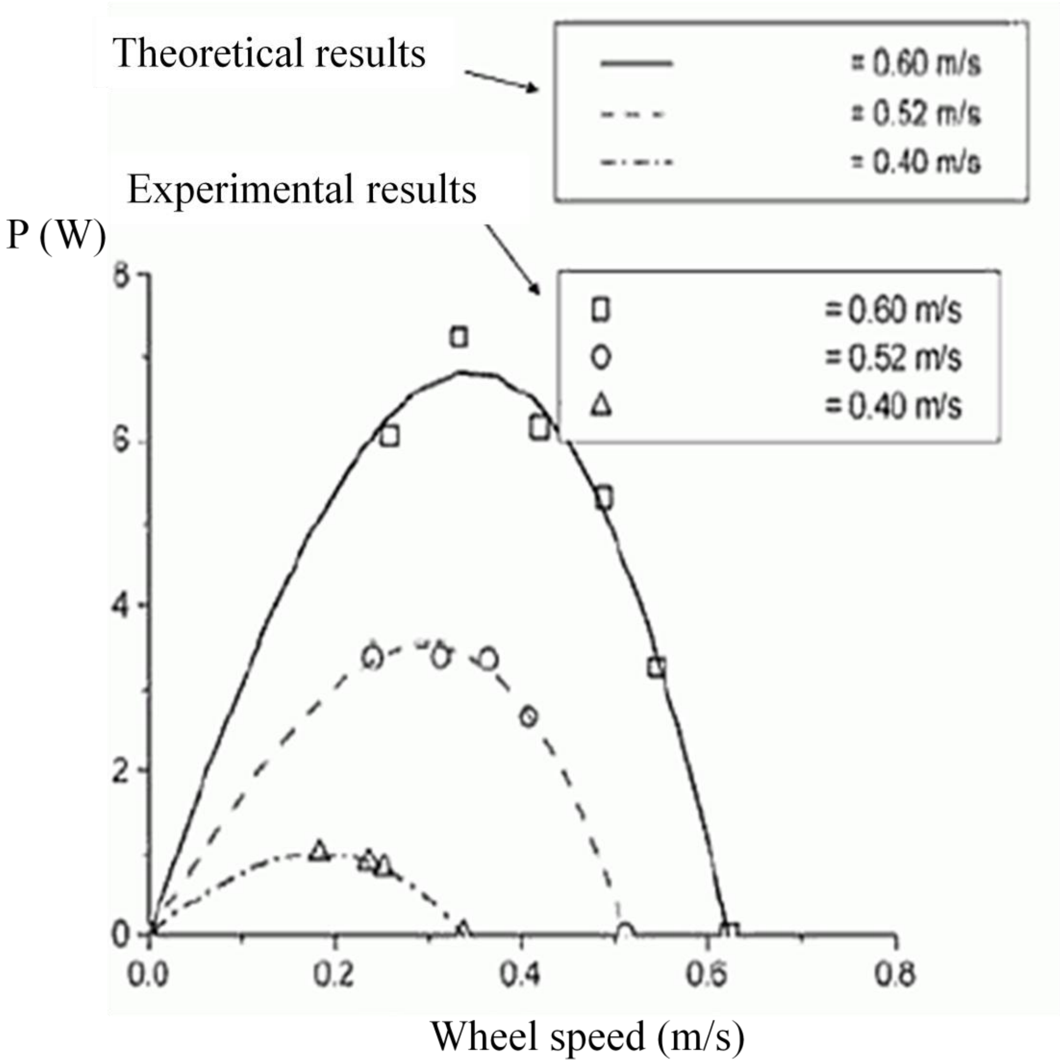
Just for information the interesting part of theory for this project is the about flows in deep water. Calculations developed by Müller are leading to the following formula which predicts the power available on one blade:



$$P = \rho_w g \frac{b}{2} \left[(d + \Delta h_1)^2 - (d - \Delta h_2)^2 \right] v_2 + \rho_w b \left(d + \Delta h_1 \right) (v_1 - v_2)^2 \, v_2$$

Where b is the width of the blade.

Beyond this formula calculations and experiments were already done for a paddle wheel of 0.5 m of diameter, 1m width and 55 mm of immersion. As this paddle wheel is quite close to what we need I decided to use the results and apply the necessary corrections to calculate the power we should expect from our paddle wheel. The results of their experiment are available in the graph below.



It can be inferred from this graph that the optimum speed for the paddle wheel must be half of the flow speed. Adjustments regarding the flow speed will also be needed so that our calculations are adapted to our situation. For this we should remember that the power we can expect is not proportional to the flow speed but to its cubic speed.

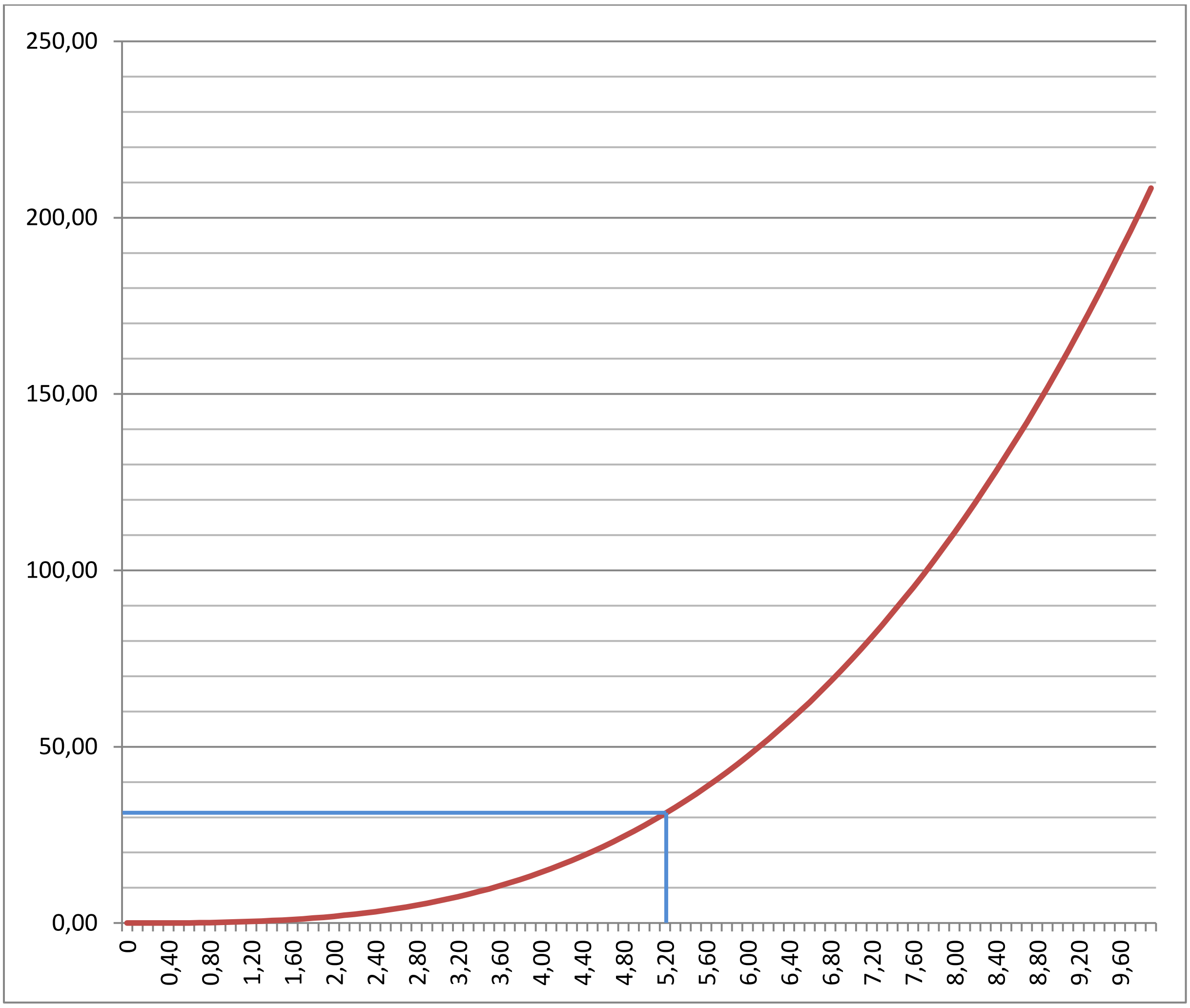
Knowing these properties we can do the power calculations for our paddle wheel. Our hypotheses are the following ones: because of mechanical constraints on the sailboat we will have a diameter of 300 mm and a width of 300 mm. In the purpose of making the calculations as simple as possible I kept the same immersion as in the experiment: 55 mm. It allows us to say that the change in diameter will not result in a difference in terms of power but only in terms of speed – torque ratio. Calculations will be done for 2 different speeds, 4 and 8 km/h. We know from navigation data of the Vaimos that it reached the average speed of 8 km/h during a mission. During the Brest - Douarnenez mission its average speed was 5 km/h. Therefore we assume that the Vaimos speed in usual conditions is always superior to 4 km/h, it explains the choices for calculation speeds. A graph will show the results for our paddle wheel for speeds between 0 to 10 km/h.

On the previous graph we can see that for a speed of 0.6 m/s we have a power production of 7 W. We will use this point for our calculations.

Calculation for 4 km/h (1.1 m/s):

Calculation for 8 km/h (2.2 m/s):

Graph showing expected mechanical power in regards with flow speed:



These calculations are showing the mechanical power we should expect however a yield should be taken into account for conversion into electrical power. At this moment of the study we will take a yield of 0.5 as the power generation chain is not known yet and 0.5 seems to be a reasonable value. Taking into account this yield and the expected power consumption of the Vaimos after the changes recommended before, we need a production of about 30 W to be autonomous with the energy coming from the paddle wheel. The blue line on the graph shows the corresponding speed of the sailboat to produce enough power. The conclusion of this section is that theoretically the paddle wheel should insure the autonomy of the sailboat when it reaches an average speed of 5.2 km/h. This speed is corresponding to its average speed during the Brest – Douarnenez mission. These calculations are then validating the concept and showing that the system will be much more efficient at high speed. It may be disengaged at low speed as its production will be very low.

5.2) Choice of the power generation chain

The idea here is to select a generator and its gearbox adapted to the speed and torque coming from the paddle wheel with a yield as best as possible. The maximum speed we decided to take into account is 8 km/h for the boat; at this speed we should be able to retrieve about 100 W of mechanical power. As explained before, the speed of the paddle wheel should be half of the flow speed, here we should have 4 km/h.

A basic calculation gives us the following results in terms of rotating speed and torque for the shaft of the paddle wheel:

N = 70.7 rpm

C = 14.4 N.m

Basically the problem is to find a motoreductor capable of retrieving 100 W at 70 rpm with a gearbox capable of sustaining a torque of 15 n.m. Because the system is used as a generator and not as a motor the gearbox ratio should be as little as possible to allow reversibility. Moreover a little gear ratio is synonymous to a good yield for the gearbox. This led me to select a motor with a rotating speed as slow as possible. After a lot of comparisons between different products my choice was the following one:

Motor: Maxon F2260.885-51.216-200 (24 V, 80 W @ 1810 rpm, max. yield: 77.4 %)

Gearbox: Maxon GP 62 A 110502 (50 N.m, ratio: 27:1, max. yield: 75 %)

In order to be able control the motor’s parameters and to retrieve energy, a 4 quadrants electronic board is needed. Because of the fact that the paddle wheel must operate with a speed half of the sailboat speed we will also need an encoder to know the rotating speed of the paddle wheel. This way and thanks to the loch or GPS speed of the sailboat we will be able to send the right orders to the electronic board so that the paddle wheel will be as efficient as possible in regards with the sailboat speed. My choice for these devices was directed by the constructor’s recommendations

Electronic control board: ADS 50/5 145391 (50 V, 5 A, 250 W, max. yield: 95 %)

Encoder: HEDS 5540 110517 (500 pulses/rotation, max. freq: 100 kHz)

The theoretical yield of this power generation chain is 0.55. We can see that we are close to our first guess.

I asked the school to order these parts; the expected delivery delay was one week. Three weeks later I was told that these parts were not available at the moment and that they would be delivered two months later… I could not wait anymore so I decided to try to make something with what we have in the school even if the design will not be optimum. Here are the features of the new engine and its gearbox:

Motor: Maxon RE 40 148867 (24 V, 150 W @ 6930 rpm, max. yield: 91 %)

Gearbox: Dunkermotoren PLG 42 S (6 N.m, ratio: 32:1, max. yield: 81 %)

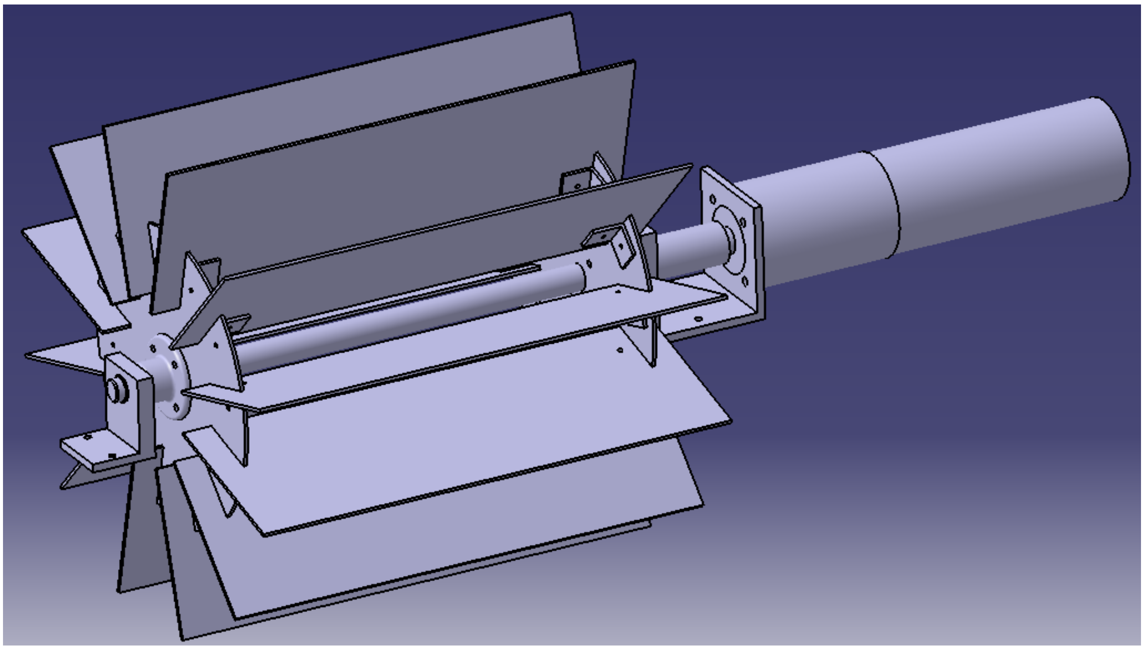
Similar electronic board and encoder were found. The issue here is that the motor is able to produce a lot of power but only when running at a high speed. When running at 8 km/h the motor will reach the speed of 2262 rpm (one third of nominal speed) therefore it will be able to retrieve one third of its nominal power: 50 W (against 80 W for the first one). Another issue is that the maximum torque on the gearbox is 6 N.m and we will exceed this value.

The theoretical yield of this power generation chain is 0.79. However the engine and the gearbox are not working as supposed to and then will never reach the maximum yield that is why we should not expect a yield superior to 0.5.

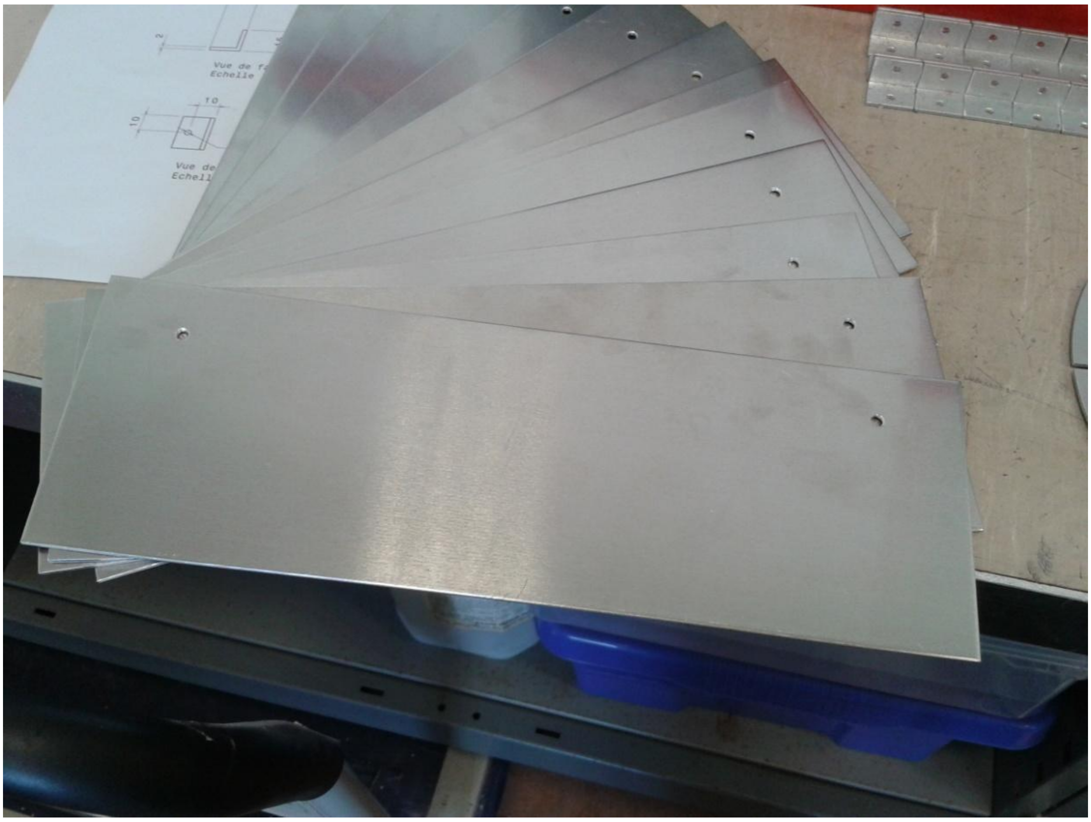
It is definitely clear that these conditions are not optimum for testing the paddle wheel and it will probably damage both the engine and the gearbox but it is the lesser evil at the moment. So I will run tests with this configuration.

5.3) Mechanical design

The guideline for the mechanical construction is simplicity. Because this version is only a prototype we can make it without taking into account mechanical constraints such as waterproofing and size except for the paddle wheel itself which respects the maximum possible size for the sailboat. In order to be as close as possible to the theoretical study made by the ENSEEIHT I decided to use the same number of paddle (12). One constraint of my design is that the paddle wheel must have a shape which is preventing it from taking algae, this way we can also test it on this aspect. This is the reason why paddles are strait and are the only part to be submerged. To make it as simple as possible the rest of the paddle wheel is only an assembly of aluminium sheets. Every part is in aluminium. Two parts in aluminium are keeping the paddle wheel onto the shaft. Two bearings are guiding it. These bearings are attached onto aluminium holders which are maintaining the whole paddle wheel onto a plywood sheet. One of these holders is also holding the gearbox. Initially rotational locking was supposed to be done thanks to a key but because of changes on the design due to the use of the new gearbox it was simpler to use screws.

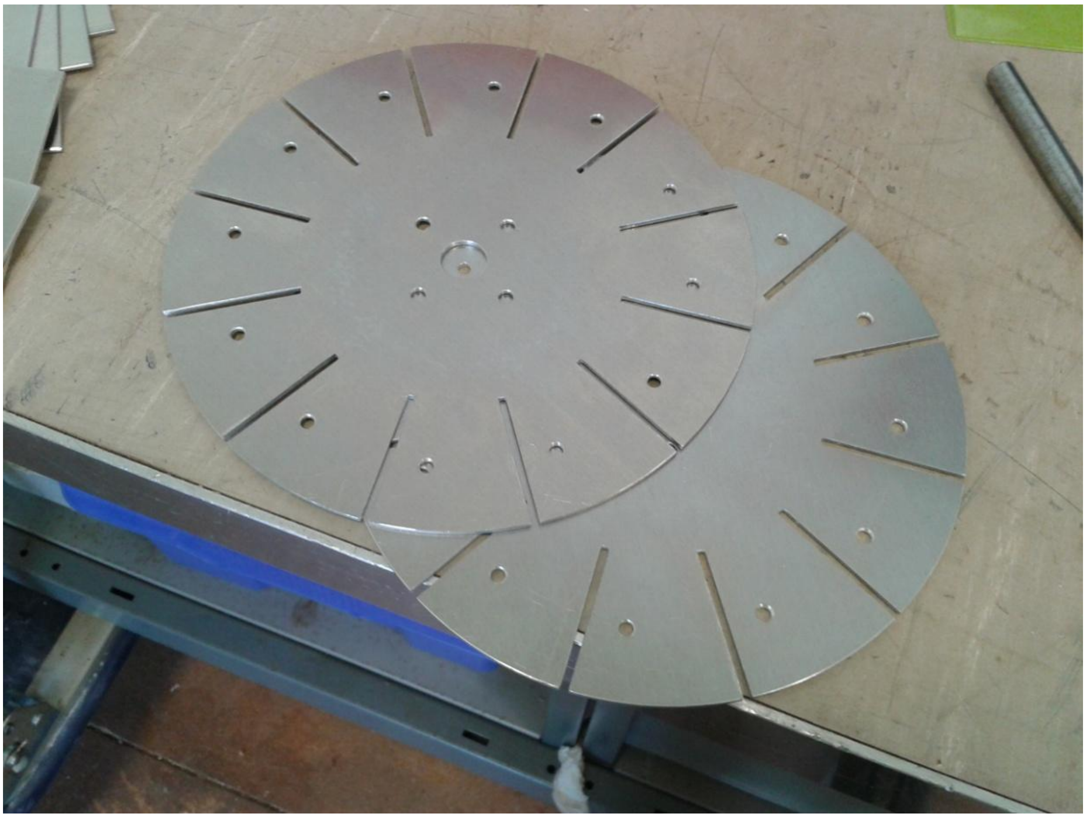


The paddle wheel designed using CATIA



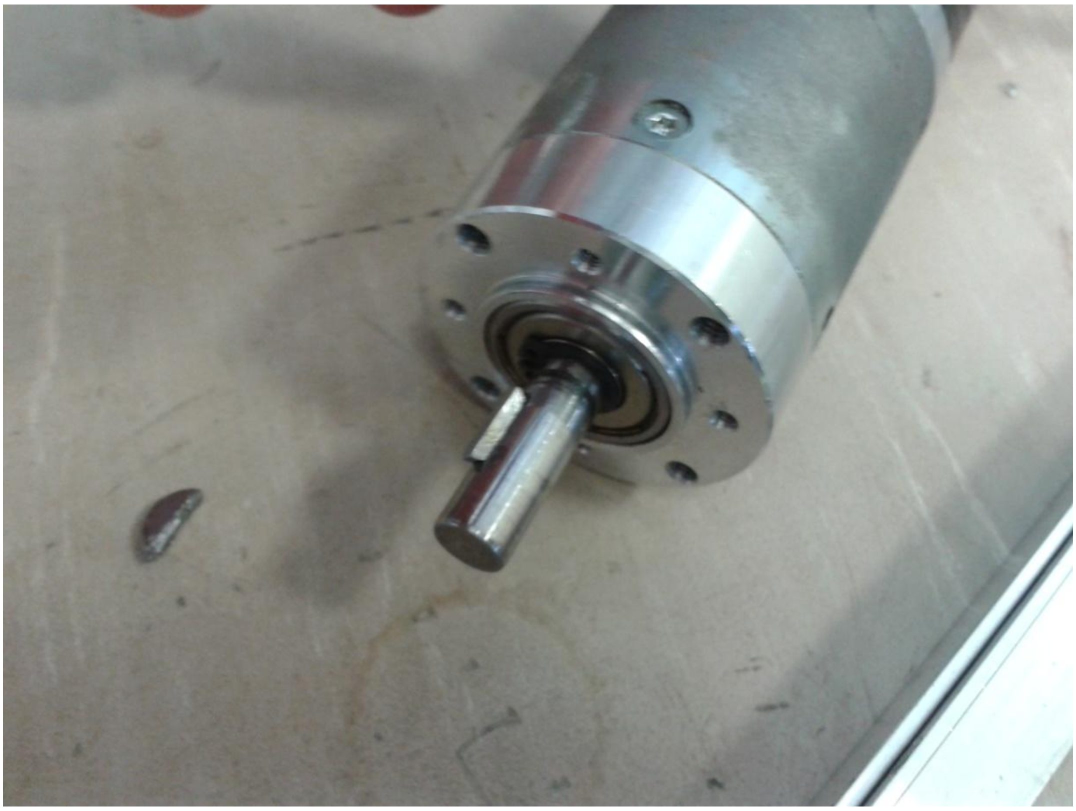
The paddles are made

The brackets used to keep each paddle onto the disks

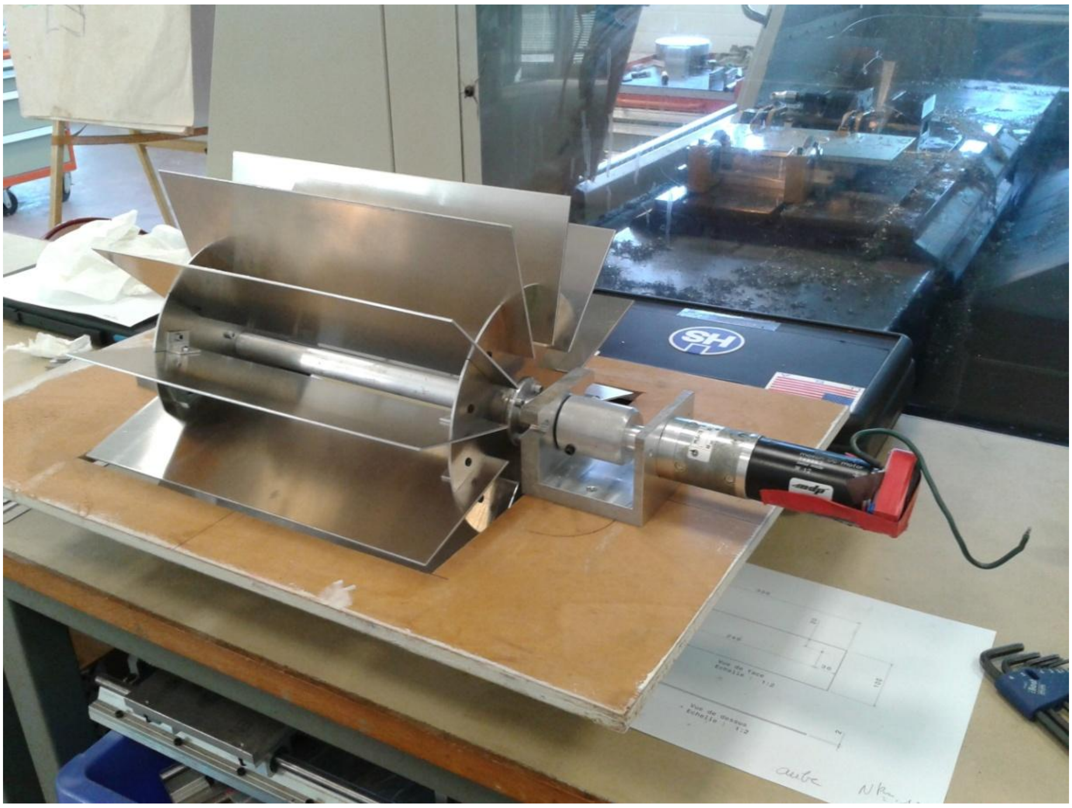


The disks

The shaft, the bearings and the parts maintaining the wheel onto the shaft



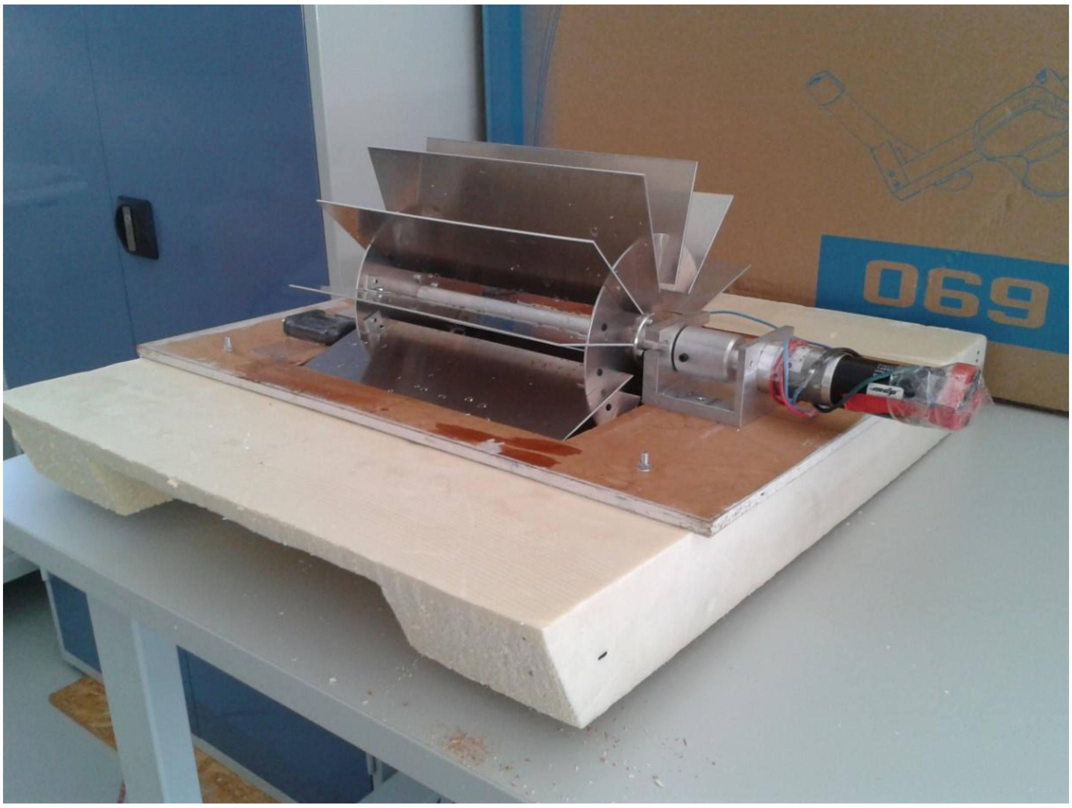
The gearbox and its new key



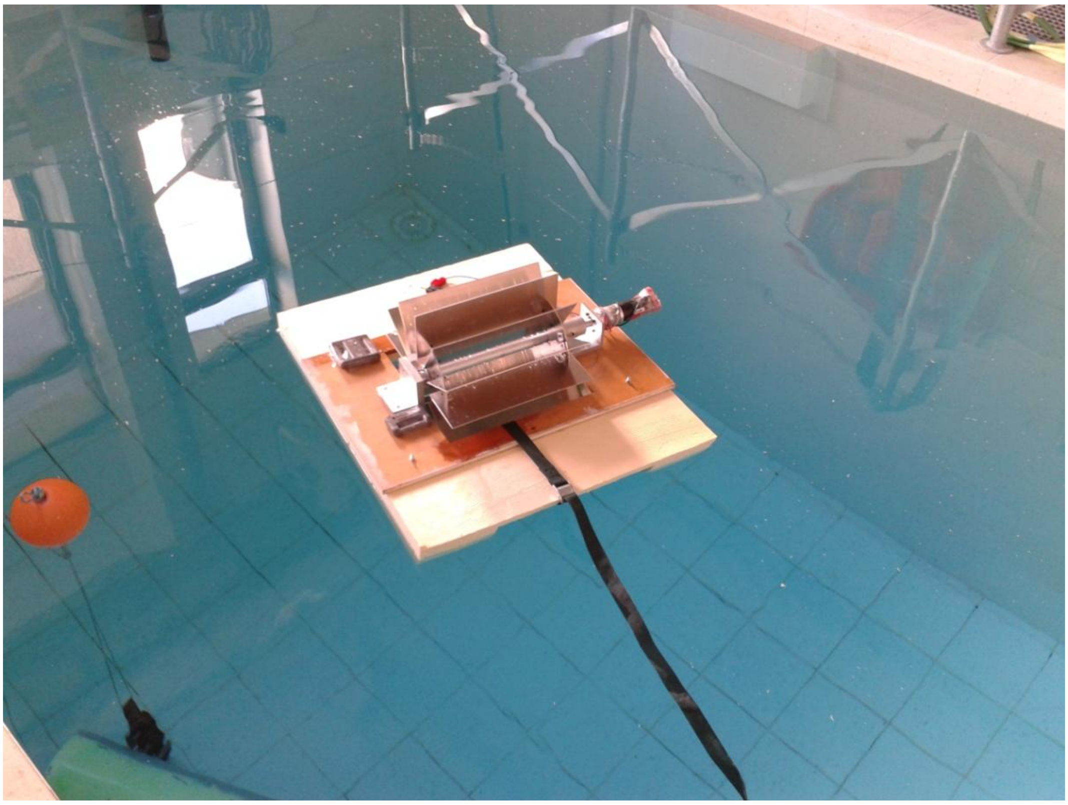
The paddle wheel assembled on the plywood sheet

Once the paddle was assembled on the plywood sheet I decided to make a little catamaran in foam in order to put the system on it. This way it is easy to tug it at a known speed and to monitor the different parameters. The plywood sheet is linked to the foam by four threaded rods.

I conducted a first test on the swimming pool of the school in order to adjust the weight of the catamaran so that the submerged part of the paddle wheel is indeed 55 mm. Once this step was achieved I could not resist the desire to give it a shot on the swimming pool, just to see if something happens. In fact I tugged the paddle wheel on a few meters and it was rotating even with when the motor was short circuited. Even if this not a proof of good functioning it is still a good new: it appears that the dimensioning is credible.



The paddle wheel assembled on the catamaran



The catamaran in the swimming pool of the school

5.4) Power measurement system

Initially I decided to use a four quadrant board to supply a 24 V battery. An ammeter connected in series would have given data concerning the power production. This configuration would allow speed servitude in order that the paddle wheel has a speed half of the flow speed. First tests in the workshop showed that the four quadrant board I had was not compliant with the motor despite what I thought at the beginning.

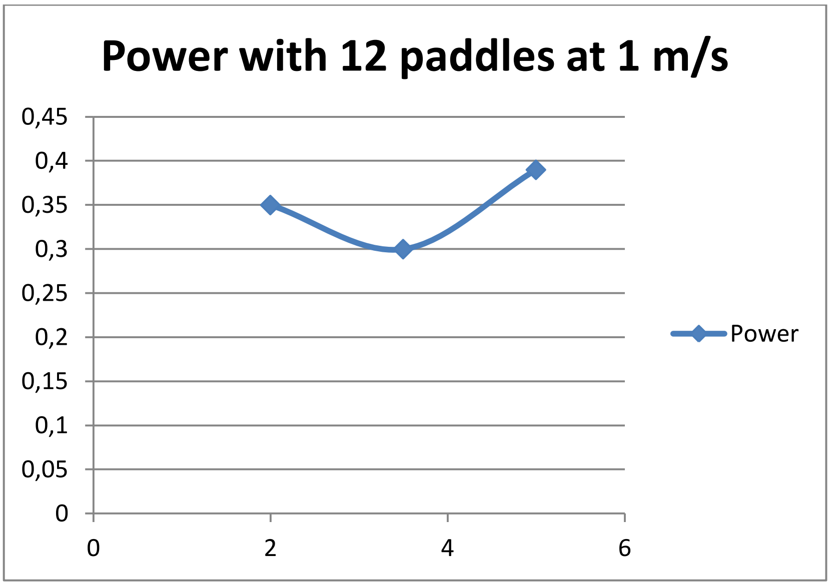
Once again I had to continue with the means at my disposal. Eventually I decided to use a variable resistor a voltmeter and an ammeter to monitor the voltage and current. Knowing the value of the resistor for each measure it is therefore easy to know the amount of power produced, it is given by the following formula:

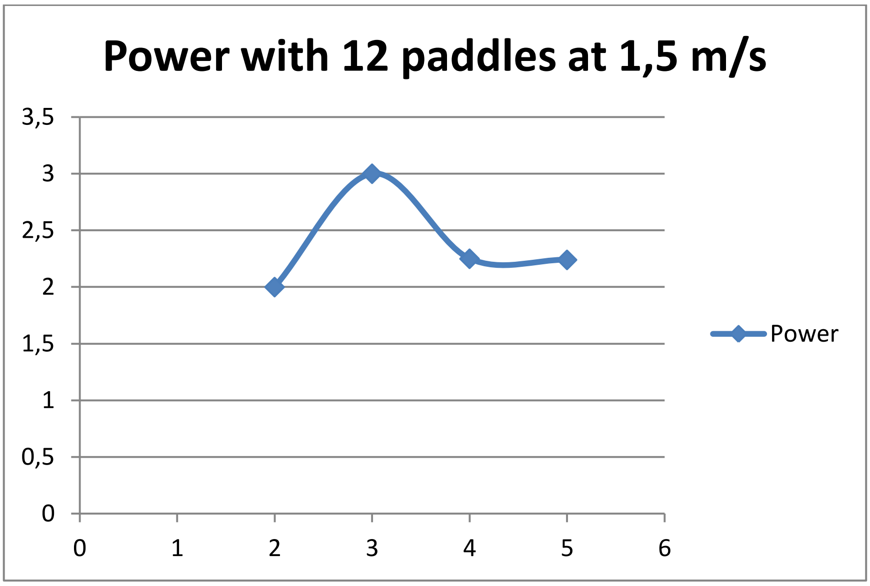
Eventually it is a good thing that the board was not working because this system is more simple, reliable and independent of any electronics. The servitude can be done easily by adjusting the value of the resistor.

5.5) Tests and future improvements

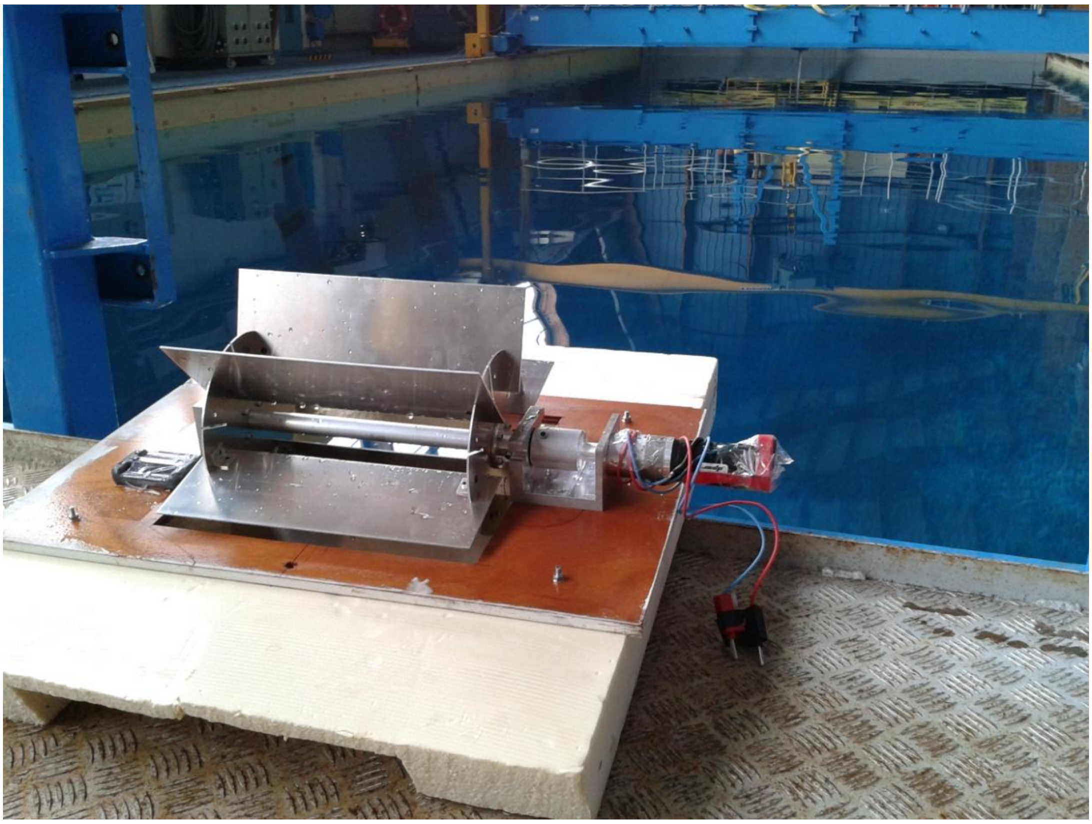
The tests were conducted at the Ifremer on the water vein with the help of Mr. MENAGE. Thanks to a movable bridge over the vein we were able to tug the catamaran at several speeds and to monitor the parameters. We had several issues: First the platform was not able to reach the speed of 2.2 m/s. The maximum speed was 1.5 m/s. We decided to try with a speed of 1 m/s. The results were really bad, the best value was 0.4 W. Initially we were expecting about 5 W for this speed (12 times more). We decided to try with the maximum speed available (1.5 m/s), the best power we were able to retrieve was 3 W. For this speed we were expecting about 16 W (5 times more). After these tests we saw that the front paddle was generating an elevation of water therefore we thought good to try after having removed half of the paddles, however the results were not better and even a bit worst. Below can be found the table and graphs concerning measured data.

12 paddles			
Speed	1 m/s		
Resistance	Voltage	Current	Power
5	1,3	0,3	0,39
3,5	1	0,3	0,3
2	0,7	0,5	0,35
12 paddles			
Speed	1,5 m/s		
Resistance	Voltage	Current	Power
5	3,2	0,7	2,24
4	3	0,75	2,25
3	3	1	3
2	2	1	2
6 paddles			
Speed	1,5 m/s		
Resistance	Voltage	Current	Power
3	2,6	0,8	2,08





The movable platform



The paddle wheel on the movable platform

How can we explain these results and improve the system? You can see below the list of all the points that I believe responsible for the big gap between theory and practice:

-During my theoretical study I considered that the difference of diameter between a paddle wheel of 500 mm and a paddle wheel of 300 mm was only changing the torque – speed ratio and not the power. This is not exact however I thought it was a good approximation, I might been wrong

-As I said before I was not able to use the right generator as it was not arrived on time. The fact that we had not this part is of course influencing the results. However knowing the results of the experiment I would say that my first choice is not the right one because even if we manage to improve the system we are far from what was we expected. I believe that we should use an engine with a lower maximum power (for instance 20 W instead of 80 W) this way we could retrieve power with a better yield adapted to the real power.

-The catamaran was clearly not an adapted platform for the tests. Indeed when tugged it, depending how high we were attaching the rope it was diving below the water or hovering over the water. Therefore we cannot know if the blades were deep enough in the water or not. If the system was completely hovering then the blades were only 20 mm deep instead of 55 mm. As suggested Mr. MENAGE it would be good to make a system directly attached onto the bridge, this way we could adjust the depth of blades and it would be a fixed value. I strongly believe that this problem has really changed the values as the wheel was rolling onto the water.

6) Conclusion

As a conclusion this project was interesting as it allowed me to deal with energy issues. It showed clearly the differences between theory and practice and how issues during development and tests can jeopardize the results of a project. Even the results we obtained were far from our first expectations I still believe that this way of creating energy is viable. The analysis of the results and of what could be done allows us to believe that we should be able to improve the system in order to reach more interesting values. However I believe that we will never be able to obtain what we expected at first.

7) Acknowledgements

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Olivier MENAGE
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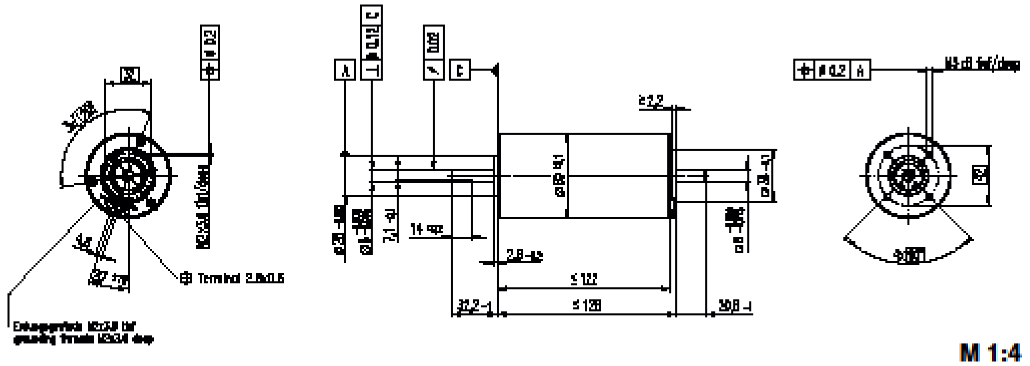
Hervé TREBAOL
Jean François GUILLEMETTE

I would like to thanks these persons for their help and kindness during this project.

8) Appendix

F 2260 ∅60 mm, Graphite Brushes, 80 Watt

maxon DC motor



M 1:4

- Stock program (red)
- Standard program (white)
- Special program (on request!) (grey)

Order Number

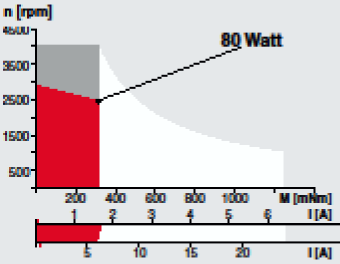
2260.[...]-51.216-200 (Insert winding number)

		Winding number	880	881	882	883	884	885	886	887	888	889	890
Motor Data													
1	Assigned power rating	W	80	80	80	80	80	80	80	80	80	80	80
2	Nominal voltage	Volt	15.0	15.0	18.0	24.0	24.0	24.0	36.0	36.0	48.0	48.0	48.0
3	No load speed	rpm	3980	2740	2650	2850	2640	2230	2690	2200	2670	2360	1800
4	Stall torque	Nm	2.88	1.97	1.91	2.06	1.87	1.67	2.01	1.59	1.94	1.69	1.35
5	Speed / torque gradient	rpm / mNm	1.44	1.45	1.43	1.42	1.45	1.37	1.36	1.41	1.40	1.42	1.35
6	No load current	mA	563	351	278	226	206	168	140	109	103	89	65
7	Starting current	A	83.8	39.4	30.6	26.3	22.2	16.7	16.1	10.4	11.5	8.87	5.41
8	Terminal resistance	Ohm	0.179	0.381	0.589	0.911	1.08	1.44	2.24	3.47	4.18	5.41	8.88
9	Max. permissible speed	rpm	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000
10	Max. continuous current	A	7.50	5.87	4.84	3.95	3.66	3.21	2.59	2.10	1.91	1.69	1.33
11	Max. continuous torque	mNm	258	294	303	309	309	321	324	322	324	323	332
12	Max. power output at nominal voltage	W	283	135	128	149	126	94.8	139	89.7	133	103	62.6
13	Max. efficiency	%	79	78	79	80	79	79	81	79	81	80	79
14	Torque constant	mNm / A	34.4	50.1	62.6	78.3	84.5	100.0	125	153	169	191	250
15	Speed constant	rpm / V	277	191	153	122	113	95.3	76.3	62.3	56.5	50.0	38.1
16	Mechanical time constant	ms	20	20	19	19	19	19	18	18	18	18	18
17	Rotor inertia	gcm²	1330	1290	1270	1250	1230	1290	1270	1230	1230	1210	1260
18	Terminal inductance	mH	0.07	0.14	0.22	0.34	0.40	0.56	0.88	1.31	1.59	2.03	3.50
19	Thermal resistance housing-ambient	K / W	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
20	Thermal resistance rotor-housing	K / W	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
21	Thermal time constant winding	s	72	70	69	68	67	70	69	67	67	66	69

Specifications

- Axial play at axial load < 15 N: ≤ 0.1 mm; > 15 N: 0.1 - 0.5 mm
  Axial play for motor combinations with encoder is limited to max. 0.15 mm
- Preloaded ball bearing
  Preload strength min. 15 N
- Max. ball bearing loads
  axial (dynamic) 15 N
  radial (5 mm from flange) 100 N
  Force for press fits (static) 400 N
  (static, shaft supported) 10 000 N
- Radial play ball bearing 0.05 mm
- Ambient temperature range -20 ... +100°C
- Max. rotor temperature +125°C
- Number of commutator segments 26
- Weight of motor 1300 g
- Values listed in the table are nominal.
  For applicable tolerances see page 43.
  For additional details please use the maxon selection program on the enclosed CD-Rom.

Operating Range | Comments | Details on page 49



Recommended operating range

Continuous operation
In observation of above listed thermal resistances (lines 19 and 20) the maximum permissible rotor temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit

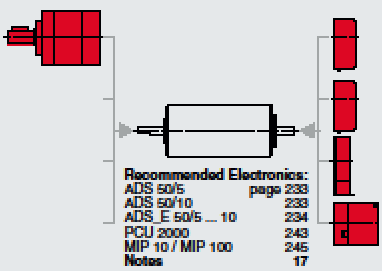
Short term operation
The motor may be briefly overloaded (recurring).

889 Motor with high resistance winding

881 Motor with low resistance winding

maxon Modular System Overview on page 17 - 21

Planetary Gearhead
∅62 mm
8 - 50 Nm
Details page 203



Recommended Electronics:
ADS 50/5 page 233
ADS 50/10 233
ADS_E 50/5 ... 10 234
PCU 2000 243
MIP 10 / MIP 100 245
Notes 17

Digital Encoder
HP HEDS 5540
500 CPT, 3 channels
Details page 217

Digital Encoder
HP HEDL 5540
500 CPT, 3 channels
Details page 219

Digital Encoder
HP HEDS 6540
1000 CPT, 3 channels
Details page 221

Brake
∅40 mm
24 VDC, 0.4 Nm
Details page 248

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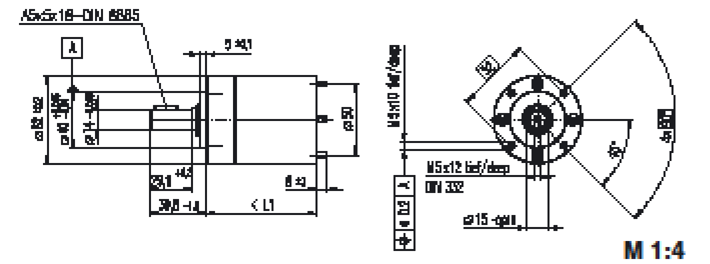
maxon DC motor 95

Planetary Gearhead GP 62 ∅62 mm, 8 - 50 Nm



Technical Data

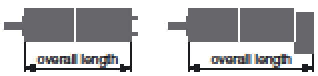
Planetary Gearhead	straight teeth
Output shaft	stainless steel, hardened
Bearing at output	ball bearing
Radial play, 7 mm from flange	max. 0.08 mm
Axial play	max. 1 mm
Max. permissible axial load	120 N
Max. permissible force for press fits	1000 N
Sense of rotation, drive to output	=
Recommended input speed	< 3000 rpm
Recommended temperature range	-30 ... +140°C

Number of stages	1	2	3
Max. radial load, 24 mm from flange	240 N	360 N	570 N
Average backlash no load	≤ 1.0°	≤ 1.5°	≤ 2.0°

maxon gear

Stock program
Standard program
Special program (on request!)

Gearhead Data			Order Number								
			110499	110501	110502	110503	110504	110505	110506	110507	110508
1	Reduction		5.2 : 1	19 : 1	27 : 1	35 : 1	71 : 1	100 : 1	139 : 1	181 : 1	236 : 1
2	Reduction absolute		57/11	3591/187	3249/121	1539/44	226223/3179	204687/2057	185193/1331	87723/484	41553/176
3	Max. motor shaft diameter	mm	8	8	8	8	8	8	8	8	8
4	Number of stages		1	2	2	2	3	3	3	3	3
5	Max. continuous torque	Nm	8	25	25	25	50	50	50	50	50
6	Intermittently permissible torque at gear output	Nm	12	37	37	37	75	75	75	75	75
7	Max. efficiency	%	80	75	75	75	70	70	70	70	70
8	Weight	g	950	1250	1250	1250	1540	1540	1540	1540	1540
9	Gearhead length L1	mm	72.5	88.3	88.3	88.3	104.2	104.2	104.2	104.2	104.2



Combination

+ Motor	Page	+ Tacho / Encoder	Page	+ Brake	Page	Overall length [mm] = Motor length + gearhead length + (tacho / encoder / brake) + assembly parts								
F 2260, 40 W	95					163.1	178.9	178.9	178.9	194.8	194.8	194.8	194.8	194.8
F 2260, 40 W	95	HED_ 5540	243/245			184.5	200.3	200.3	200.3	216.2	216.2	216.2	216.2	216.2
F 2260, 40 W	95	HEDS 6540	248			186.3	202.1	202.1	202.1	218.0	218.0	218.0	218.0	218.0
F 2260, 40 W	95			AB 40	279	192.2	208.0	208.0	208.0	223.9	223.9	223.9	223.9	223.9
F 2260, 80 W	96					198.6	214.4	214.4	214.4	230.3	230.3	230.3	230.3	230.3
F 2260, 80 W	96	HED_ 5540	243/245			220.0	235.8	235.8	235.8	251.7	251.7	251.7	251.7	251.7
F 2260, 80 W	96	HEDS 6540	248			221.8	237.6	237.6	237.6	253.5	253.5	253.5	253.5	253.5
F 2260, 80 W	96			AB 40	279	227.7	243.5	243.5	243.5	259.4	259.4	259.4	259.4	259.4
EC 45, 250 W	162					216.6	232.4	232.4	232.4	248.3	248.3	248.3	248.3	248.3
EC 45, 250 W	162	HEDL 9140	247			232.2	248.0	248.0	248.0	263.9	263.9	263.9	263.9	263.9
EC 45, 250 W	162	Res 26	253			216.6	232.4	232.4	232.4	248.3	248.3	248.3	248.3	248.3
EC 45, 250 W	162			AB 28	280	224.0	239.8	239.8	239.8	255.7	255.7	255.7	255.7	255.7
EC 45, 250 W	162	HEDL 9140	247	AB 28	280	241.0	256.8	256.8	256.8	272.7	272.7	272.7	272.7	272.7

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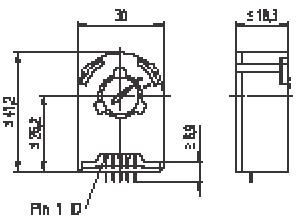
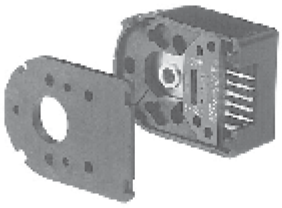
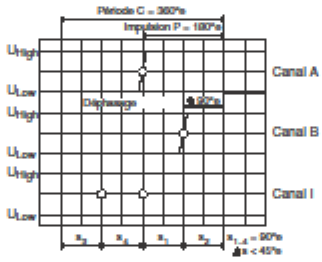
maxon gear 229

Codeur HEDS 5540 500 impulsions, 3 canaux

maxon sensor







Programme Stock
Programme Standard
Programme Spécial (sur demande)

Numéros de commande

Type	110511	110513	110515
Numéros de commande	500	500	500
Nombre de canaux	3	3	3
Fréquence impulsionnelle max. (kHz)	100	100	100
Vitesse max. (tr / min)	12000	12000	12000
Diamètre de l'arbre (mm)	3	4	6

Construction modulaire maxon

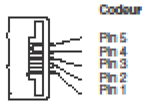
+ Moteur	Page	+ Réducteur	Page	+ Frein	Page	Longueur totale [mm] / ● voir réducteur	
RE 25	77/79					75.3	
RE 25	77/79	GP 26, 0.5 - 2.0 Nm	227			●	
RE 25	77/79	GP 32, 0.75 - 4.5 Nm	229			●	
RE 25	77/79	GP 32, 0.75 - 6.0 Nm	230/232			●	
RE 25	77/79	KD 32, 1.0 - 4.5 Nm	235			●	
RE 25	77/79	GP 32 S	249-251			●	
RE 25, 20 W	79			AB 28	318	105.7	
RE 25, 20 W	79	GP 26, 0.5 - 2.0 Nm	227	AB 28	318	●	
RE 25, 20 W	79	GP 32, 0.75 - 4.5 Nm	231	AB 28	318	●	
RE 25, 20 W	79	GP 32, 0.75 - 6.0 Nm	230/232	AB 28	318	●	
RE 25, 20 W	79	KD 32, 1.0 - 4.5 Nm	235	AB 28	318	●	
RE 25, 20 W	79	GP 32 S	249-251	AB 28	318	●	
RE 35, 90 W	81						91.7
RE 35, 90 W	81	GP 32, 0.75 - 4.5 Nm	229				●
RE 35, 90 W	81	GP 32, 0.75 - 6.0 Nm	231/232				●
RE 35, 90 W	81	GP 32, 4.0 - 8.0 Nm	234				●
RE 35, 90 W	81	GP 42, 3.0 - 15 Nm	237				●
RE 35, 90 W	81	GP 32 S	249-251				●
RE 35, 90 W	81			AB 28	318	124.1	
RE 35, 90 W	81	GP 32, 0.75 - 4.5 Nm	229	AB 28	318	●	
RE 35, 90 W	81	GP 32, 0.75 - 6.0 Nm	231/232	AB 28	318	●	
RE 35, 90 W	81	GP 32, 4.0 - 8.0 Nm	234	AB 28	318	●	
RE 35, 90 W	81	GP 42, 3.0 - 15 Nm	237	AB 28	318	●	
RE 35, 90 W	81	GP 32 S	249-251	AB 28	318	●	
RE 40, 150 W	82						91.7
RE 40, 150 W	82	GP 42, 3.0 - 15 Nm	237				●
RE 40, 150 W	82	GP 52, 4.0 - 30 Nm	240				●
RE 40, 150 W	82			AB 28	318	124.2	
RE 40, 150 W	82	GP 42, 3.0 - 15 Nm	237	AB 28	318	●	
RE 40, 150 W	82	GP 52, 4.0 - 30 Nm	240	AB 28	318	●	

Données techniques

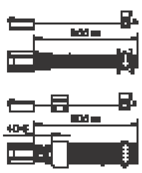
Tension d'alimentation V_{CC}	5 V ± 10%
Signal de sortie	TTL compatible
Déphasage Φ	90°e ± 45°e
Temps de montée du signal (typique avec C_L = 25 pF, R_L = 2.7 kΩ, 25°C)	180 ns
Temps de descente du signal (typique avec C_L = 25 pF, R_L = 2.7 kΩ, 25°C)	40 ns
Largeur (nominale) d'impulsion d'index	90°e
Plage de températures	-40 ... +100°C
Moment d'inertie du disque	≤ 0.6 gcm²
Tension d'alimentation	250000 rad s⁻²
Courant par canal	min. -1 mA, max. 5 mA

Le signal d'index I est synchronisé avec le canal A ou B.

Connectique



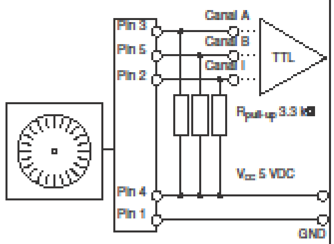
Codeur	Signification	Pin no. à 3409.506
Pin 5	Canal B	1
Pin 4	V_{CC}	2
Pin 3	Canal A	3
Pin 2	Canal I	4
Pin 1	GND	5



Câble avec connecteur:
maxon Art. No. 3409.506
Le connecteur (Harting 918.906.6803) peut être fixé à la longueur désiré par simple sertissage.

Câble avec connecteur:
(compatible avec codeur HEDS5010)
maxon Art. No. 3409.504
Le connecteur (3M 89110-0101) peut être fixé à la longueur désiré par simple sertissage.

Exemple de connexion



Température ambiante ϑ_U = 25°C

266 maxon sensor Edition Juin 2011 / Modifications réservées

maxon motor control

4-Q-DC Servoamplificateur Données

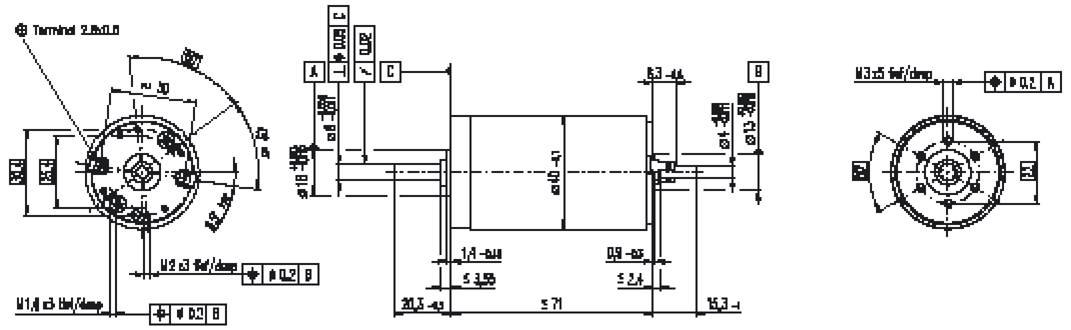
LSC 30/2 4-Q-DC Servoamplificateur
Servoamplificateur linéaire 4 quadrants pour moteurs DC à activation magnétique permanente jusqu'à 50 Watt.

ADS 50/5 4-Q-DC Servoamplificateur
Servoamplificateur PWM puissant pour moteurs DC à activation magnétique permanente de 10 à env. 250 Watt de puissance de sortie. Disponible en Version Standard en boîtier modulaire.

	LSC 30/2	ADS 50/5
Modes de fonctionnement		
	Compensation IxR, régulateur de tension, codeur de réglage, génératrice tachymétrique DC, régulateur de courant	**Compensation IxR, codeur de réglage, génératrice tachymétrique DC, régulateur de courant**
Données électriques		
Tension de service V_{CC}	12 - 30 VDC	12 - 50 VDC
Tension de sortie max.	V_{CC} -5 V	0.9 x V_{CC}
Courant de sortie max. I_{max}	2 A	10 A
Courant permanent I_{cont}	2 A	5 A
Cadence de l'étage final		50 kHz
Rendement max.		95 %
Self interne du moteur		150 µH / 5 A
Entrées		
Valeur de consigne «Set value»	configurable, -10 ... +10 V, -3.9 ... +3.9 V	-10 ... +10 V
Circuit libre	«Disable» Disable min. V_{CC} - 1 V, Enable max. GND + 1 V	«Enable» +4 ... 50 V
Génératrice tachymétrique DC	min. 2 VDC, max. 50 VDC	min. 2 VDC, max. 50 VDC
Signaux d'encodage	Canaux A et B, max. 100 kHz, TTL	Canaux A, A\, B, B\, max. 100 kHz, TTL
Sorties		
Message de surveillance «Ready»	Open Collector, max. 30 VDC (I_L < 20 mA)	Open Collector max. 30 VDC (I_L < 20 mA)
Moniteur courant «Monitor I»		-10 ... +10 VDC (prot. contre les courts-circuits)
Moniteur vitesse «Monitor n»		-10 ... +10 VDC (prot. contre les courts-circuits)
Sorties de tension		
Tensions auxiliaires	+3.9 VDC, -3.9 VDC, max. 2 mA	+/- 12 VDC, max. 12 mA (prot. contre courts-circuits)
Alimentation codeur	+5 VDC, max. 80 mA	+5 VDC, max. 80 mA
Potentiomètre de reglage	Compensation IxR, Offset, n_{max}, I_{max}, gain	Compensation IxR, Offset, n_{max}, I_{max}, gain
Fonctions de protection	Surveillance thermique de l'étage final	Contre les surintensités, les surtempératures et les courts-circuits du câble du moteur
Affichage	LED vert = READY, LED rouge = ERROR	LED 2 couleurs, vert = READY, rouge = ERROR
Domaine de température / d'humidité		
Fonctionnement	0 ... +45°C	-10 ... +45°C
Stockage	-40 ... +85°C	-40 ... +85°C
Non condensé	20 ... 80 %	20 ... 80 %
Données mécaniques		
Poids	environ 330 g	environ 400 g
Dimensions (L x l x h)	103 x 100 x 34 mm (voir page 284)	180 x 103 x 26 mm (voir page 284)
Fixation	Flanc pour vis M4	Flanc pour vis M4
Connexions	voir page 284	voir page 284
Numéro de commande		
	250521 LSC 30/2, 4-Q-DC Servoamplificateur en boîtier modulaire	145391 ADS 50/5, 4-Q-DC Servoamplificateur Version Standard en boîtier modulaire
Accessoires		
		235811 DSR 70/30 Chopper de frein

RE 40 ∅40 mm, Graphite Brushes, 150 Watt

maxon DC motor



M 1:2

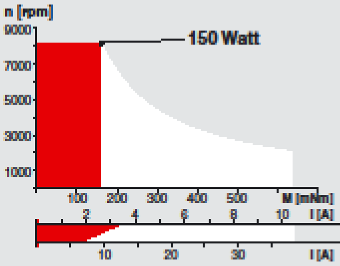
- Stock program
- Standard program
- Special program (on request!)

Order Number			148866	148867	148877	218008	218009	218010	218011	218012	218013	218014	218015
Industrial version			263065	263066	263067	263068	263069	263070	263071	263072	263073	263074	263075
Motor Data													
1	Assigned power rating	W	150	150	150	150	150	150	150	150	150	150	150
2	Nominal voltage	Volt	12.0	24.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0
3	No load speed	rpm	6920	7580	7580	6420	5560	3330	2690	2130	1710	1420	987
4	Stall torque	mNm	1690	2290	2500	1990	1580	996	796	641	512	415	289
5	Speed / torque gradient	rpm / mNm	4.11	3.32	3.04	3.23	3.53	3.36	3.39	3.35	3.37	3.44	3.45
6	No load current	mA	241	137	69	54	44	22	17	13	10	8	5
7	Starting current	A	103	75.9	41.4	28.0	19.2	7.26	4.69	3.00	1.92	1.29	0.627
8	Terminal resistance	Ohm	0.117	0.316	1.16	1.72	2.50	6.61	10.2	16.0	24.9	37.1	76.6
9	Max. permissible speed	rpm	8200	8200	8200	8200	8200	8200	8200	8200	8200	8200	8200
10	Max. continuous current	A	6.00	6.00	3.33	2.75	2.41	1.41	1.13	0.904	0.725	0.594	0.414
11	Max. continuous torque	mNm	98.7	181	201	196	198	193	192	193	193	191	190
12	Max. power output at nominal voltage	W	285	440	491	332	255	86.5	55.7	35.6	22.9	15.3	7.40
13	Max. efficiency	%	88	91	92	91	91	89	88	87	86	85	83
14	Torque constant	mNm / A	16.4	30.2	60.3	71.3	82.2	137	170	214	266	321	461
15	Speed constant	rpm / V	581	317	158	134	116	69.7	56.2	44.7	35.9	29.8	20.7
16	Mechanical time constant	ms	6	5	4	4	4	4	4	4	4	4	4
17	Rotor inertia	gcm²	135	134	134	125	127	118	117	118	117	114	114
18	Terminal inductance	mH	0.02	0.08	0.33	0.46	0.61	1.70	2.62	4.14	6.40	9.31	19.20
19	Thermal resistance housing-ambient	K / W	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
20	Thermal resistance rotor-housing	K / W	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
21	Thermal time constant winding	s	41	40	40	38	38	36	35	35	35	34	34

Specifications

- Axial play 0.05 - 0.15 mm
- Max. ball bearing loads
  axial (dynamic)
  not preloaded 5.6 N
  preloaded 2.4 N
  radial (5 mm from flange) 28 N
  Force for press fits (static) 110 N
  (static, shaft supported) 1200 N
- Radial play ball bearing 0.025 mm
- Ambient temperature range -20 ... +100°C
- Max. rotor temperature +155°C
- Number of commutator segments 13
- Weight of motor 480 g
- 2 pole permanent magnet
- Values listed in the table are nominal.
  For applicable tolerances see page 43.
  For additional details please use the maxon selection program on the enclosed CD-ROM.

Operating Range



Comments Details on page 49

Recommended operating range

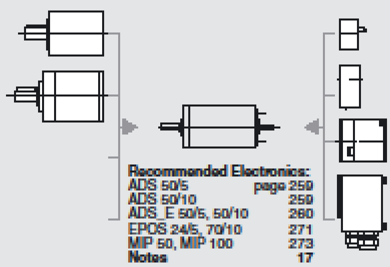
Continuous operation
In observation of above listed thermal resistances (lines 19 and 20) the maximum permissible rotor temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

Short term operation
The motor may be briefly overloaded (recurring).

148877 Motor with high resistance winding
148866 Motor with low resistance winding

maxon Modular System

Overview on page 17 - 21



Planetary Gearhead
Ø42 mm
3 - 15 Nm
Details page 224

Planetary Gearhead
Ø52 mm
4 - 30 Nm
Details page 227

Recommended Electronics:

ADS 50/5	page 259
ADS 50/10	259
ADS_E 50/5, 50/10	260
EPOS 24/5, 70/10	271
MIP 50, MIP 100	273
Notes	17

Encoder MR
256 - 1024 CPT,
3 channels
Details page 239

Encoder HED_ 5540
500 CPT, 3 channels
Details page 242 / 244

Brake AB
Ø40 mm,
24 VDC, 0.4 Nm
Details page 279

Industrial version
Encoder HEDL 9140
Details page 247
Brake AB
Details page 280

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maxon DC motor 83

PLG 42 S

Planetary Gearbox PLG 42 S

Planetengetriebe PLG 42 S

- *Compact, industry compatible planetary gearbox*
- *High efficiency*
- *Ring gear, planetary carriers and sun wheels made of steel*
- *Output shaft with dual ball bearings*
- *All stages have straight toothing*

- Kompaktes, industrietaugliches Planetengetriebe
- Hoher Wirkungsgrad
- Hohlrad, Planetenträger und Sonnenritzel aus Stahl
- Ausgangswelle doppelt kugelgelagert
- Alle Getriebestufen geradverzahnt ausgeführt

Data

Leistungsdaten

PLG 42 S - Ring gear made of steel/ Hohlrad Stahl																	
Reduction ratio/ Untersetzungsverhältnis	BG31*	4	6.25	8	16	25	32	50	64	100	128	156.25	200	256	312.5	400	512
Reduction ratio/ Untersetzungsverhältnis	BG42*/ BG45*	4	6.25	8	16	25	32	50	64	100	128	156.25	200	256	312.5	400	512
Reduction ratio/ Untersetzungsverhältnis	GR42*	4	6.25	8	16	25	32	50	64	100	128	156.25	200	256	312.5	400	512
Reduction ratio/ Untersetzungsverhältnis	G30*		6.25	8			32	50	64						312.5	400	512
Efficiency/ Wirkungsgrad		0.9			0.81					0.73							
Number of stages/ Stufenzahl		1			2					3							
Continuous torque/ Dauerdrehmoment	Ncm	90 (plastic planet gears, Kunststoff-Planetenräder)/ 350			600					1400							
Weight of gearbox/ Getriebegewicht	kg	0.27			0.37					0.88							
Axial load/radial load/ Axiallast/Radiallast	N	150/ 250			150/ 250					150/ 250							

* Ratios depending on combined motor
* Untersetzungen abhängig vom kombinierten Motor

Standard / Standard — On request / auf Anfrage

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