Semester Project

Laboratoire d'Automatique

Autumn 14

Babyfoot : Fast Positionning

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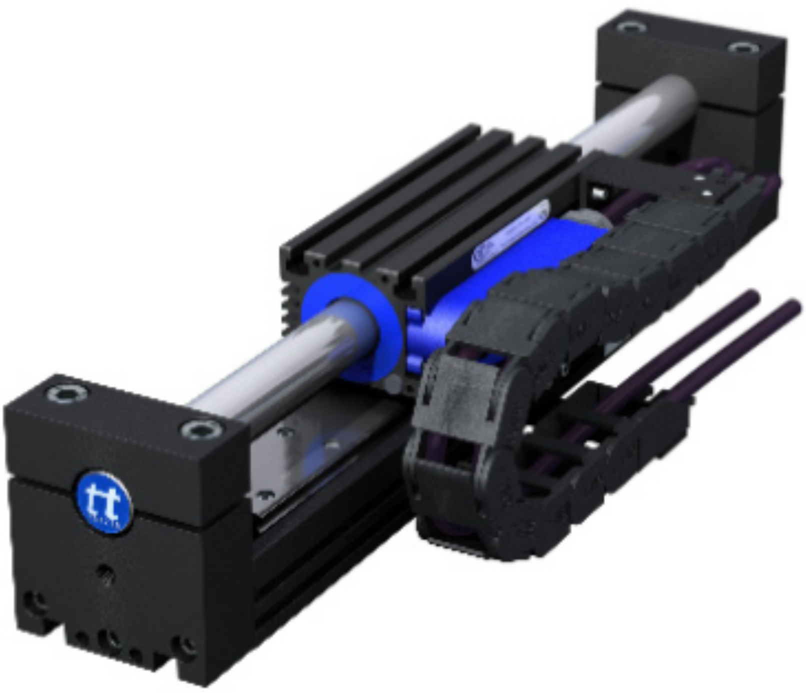

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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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Projet de semestre M1
Automne 2014

Candidat : **METRAILLER Simon**
Section de Microtechnique

Sujet : **Babyfoot : Fast Positioning**

Les buts de ce projet sont premièrement de concevoir et mettre en oeuvre un nouveau système d'actuation des barres du babyfoot à l'aide de moteurs linéaires.

La deuxième partie du projet consiste à caractériser le tir d'un joueur du babyfoot. Plus précisément, on cherche à connaître l'influence de l'angle et de la position du joueur par rapport à la balle sur la trajectoire prise par la balle une fois le tir effectué.

Le nombre de crédits réservés au plan d'études pour ce projet est de **douze**.

Prof. Colin Jones / Dr Christophe Salzmann

Assistant responsable :
KORDA Milan (tél. int. 3 10 59)

Table des matières

1 Introduction :

I became aware of the project of the automation of a babyfoot by two friends who each did a semester project on the babyfoot. I could follow a little the progress of their project and I became more and more interested in this project of automatic project. It's for this reason I decided to look for a project on the babyfoot. There have been several projects on the babyfoot that allowed to have an already efficient system. The system is able to track the ball, stop it the most of the time and to shoot it straight away. Anyway we can continue to improve the system to make it even better.

The first goal of my project is to change the actual system of the translation by linear motors. These motors are the better system of translation and are therefore perfectly suited to our new system of translation. The second goal is to be no longer limited by a straight shot. We want to be able to do a shot with an angle. We can imagine that this is the beginning of a strategy of attack. The babyfoot would become more unpredictable and therefore harder to beat. The system will probably be much better than human in a few semesters, after some new projects. There are still many possibles improvements to do for this project.

The report aims to present to the reader the improvements that have been made to the system, to continue the development of the global project of the babyfoot. We start by talking about the mechanical part of new translation system, in other words we describe the parts that make it up and his design. It continues with the automatic part. The informations for the connexions and the configuration of the motor controllers are given. The connexions for the NI board is too describe. We finish by the determination of the shot angle. In fact we would like to know the required position of the player before the shot to shoot with a desired angle. A relatively simple method for "answer" this problem is explained. This method will prove to be close to the exerimental tests of shots.

2 Improvement of the translation

2.1 Existing bar actuator :

The old system used a rotary motor with a belt for the translation, and for the rotation, a rotary motor fixed on the belt. We want to replace the system for the translation with linear motors.

2.2 New actuator :

I consulted the company website Parkem, that is the linear motors supplier in Switzerland. The linear motor can be ordered in kit or in module, that made me think of 2 solutions for the new system. The first uses a linear motor in kit on one side of the babyfoot and the rotation motor on the other side. The linear motor is fixed on a support, it is the rode that moves. The disavantage is that we have to find a new system for the rotation and this system will certainly be complicated.

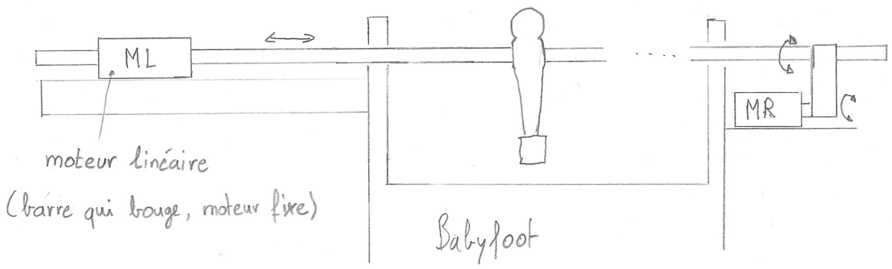

Figure 1 : Solution with ServoTube in kit

For the second solution, that uses a linear motor in module, I thought about something very simple, just to put the existing rotation motor on the linear motor. Here it's the linear motor that moves. The little disavantage is that we add some inertia for the motion of the linear motor, but the conception is so much easier. We just have to design a fixation for the rotation motor and a table to support the entire system. This solution will also take less place than the first. So, we decided to choose this solution.

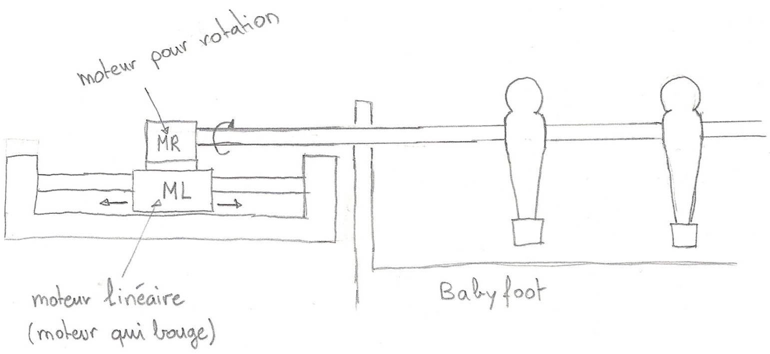

Figure 2 : Solution with a ServoTube in module

3 Mechanical part

3.1 Linear motor and motor controller :

For the selection of the motors and the controllers, I was in relation with the Parkem company's engineer. I described him our project and gave him the performance (at least as good as the previous) we would have for the new system and he told me what was best for us. The linear motors are ServoTubes Module SM2504S and the drivers are Xenus XTL. This motors have a maximum speed of 8.5 m/s and a peak acceleration of 222 m/s². These specifications are impressive, but they are of course theoretical specifications. Concerning the encoder for the postion, the motors have the option S. It's a sin/cos encoder. The output signal period is 51.2 mm and have 4096 counts per period. So, the resolution for the position of this encoder is 0.0125 mm. We can see the main specifications in the Appendix 6.1.

The engineer of Parkem did a test of the characteristic of the motor in open loop, with a mass of 1.12 kg on the motor. This mass represents the mass of the rotation motor that will be fixed on the linear motor and the mass of the babyfoot bar. The linear motor reaches 200 mm in 125 ms. This performance is better than the one of the old system.

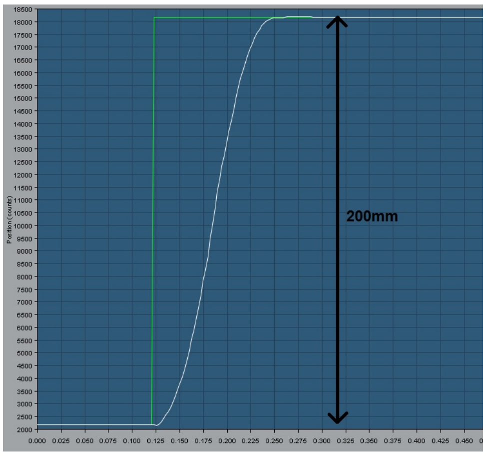

Figure 3 : Characteristic of the linear motor

3.2 Design of the fixation of the rotation motor on the linear motor :

The aim is to make the less changes on the previous system, to be as simple as possible. A main part of the old system is the carriage. « *The carriage plays a central role. It links the translation and rotation systems together* » [4]. The rotation motor is fixed to the carriage that is itself fixed to the belt and on the skate for the translation. So we keep the old carriages but we must adapt them a little to be fixed on the linear motors. First, we must milling their bottom to make them plane. Then, we machine them to have the same dimensions and the same mounting hole locations, because the two old carriages were a bit different. According to the dimensions of the forcer (in datasheet) of the linear motor, we can't fix directly the carriage on it. I have to design a plate that will be between the forcer and the carriage. The plate is in aluminium and has 2 holes to fix it on the forcer and 4 threaded holes to fix the carriage on the plate. The drawings of the parts can be found in Appendix 8.5.

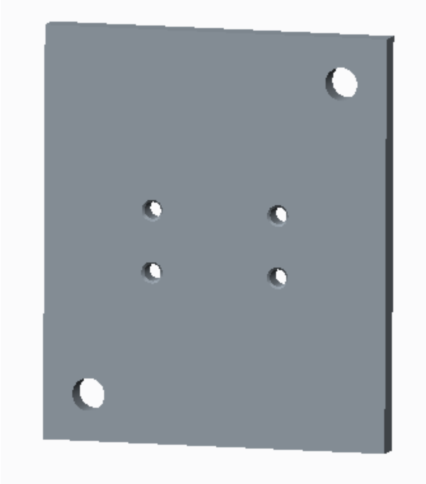

Figure 4 : Aluminium Plate

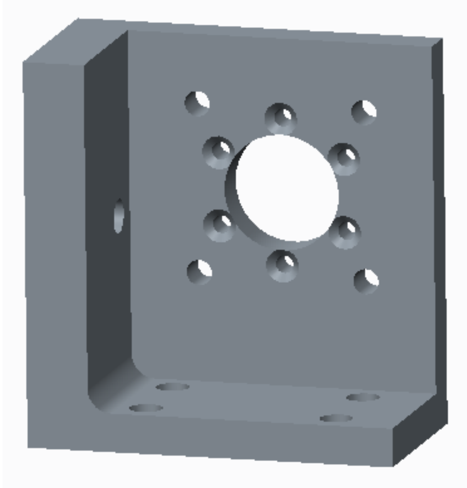

Figure 5 : Carriage

3.3 Design of the table :

The table is made using components of the company Item. The linear motors have a very high speed and acceleration, they will cause significant vibrations. So we need a good rigidity for our table. We use Item bars of profile "8" (section of 40 mm x 40 mm). The table has 2 levels, one to fix the motors and one with a wood plate, to put a weight and the motor controllers. The weight can be a good help for reducing vibrations. To assembly the bars together, we use 16 aluminium squares of 80mm x 80mm (in red in the figure 6) and 8 aluminium squares of 40mm x 40mm (in green in the figure 6). The large squares are needed to support the weight of the motors and the additional weight on the wood plate. They also guarantee a better rigidity. We take smaller squares to fix the two horizontal bars on which the linear motors are raised, because they cannot slip due to the weight of the motors. The small squares have mainly to fix the horizontal movement of the bars. The squares have guides that fit into the slot of the bars when tightening. These are the guides that secure the vertical movement and it's why we choose smaller squares. The feets of the table are threaded feets, so we can adjust the height and the angle of the table. We decided to not attach the table to the babyfoot to transmit as little as possible the vibrations of the motors. Another reason is that we haven't security on the motors, so if something goes wrong, the risk of damage is higher if the table and the babyfoot are fixed. We must anyway avoid that the table slides during the use of the motors. So, to ensure good adhesion of the table on the floor, we add rubber pads on the threaded feets. These pads have a surprising adhesion, and with the additional weight on the wood plate, the table will not slips without a big force is applied on it . The list of all the material required for the table is in the Appendix 8.2.

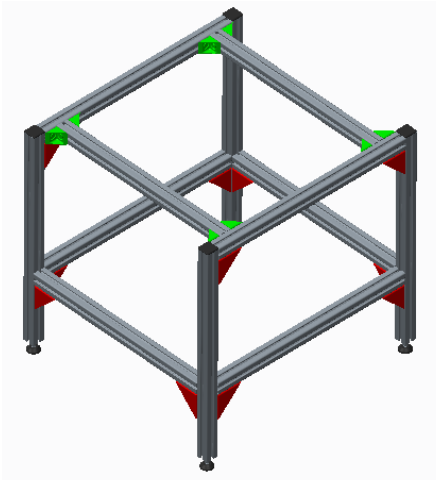

Figure 6 : CAD view of the table

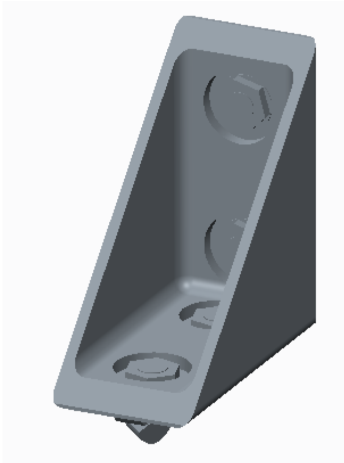

Figure 7 : Big square

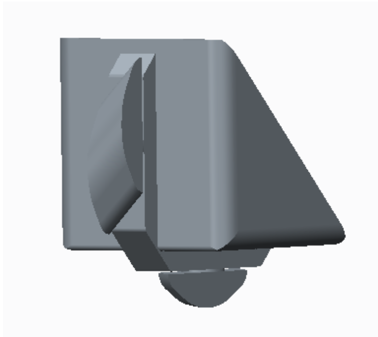

Figure 8 : Small square

4 Automatic Part

4.1 Motors controllers

4.1.1 Linear motor controller Xenus

The Xenus has 8 inputs/outputs connections, J1 to J8. The connections for the motors, J2 and J8, are already done by the company Parkem. We have to do the connection for the main power supply of the Xenus (J1), the control power supply (J4) and the communication with the acquisition card DAQ from National Instruments (J7). The Xenus has a RS232 connection (J5) to communicate directly from the computer with the CME 2 software developped by the company Copley Controls. We have to configure the Xenus before the first use, and we do it with the RS232 connection.

4.1.1.1 Connections :

Main power supply connection, J1 :

This is the main voltage, it's not a tree-phase voltage. We have to do the connexion only with one line of 240 V. The J7-4 is not used, the 3 is the earth, the 2 is the neutral and the 1 is the line.

Control power supply connection, J4 :

A +24 Vdc power with 500 mA maximum is required for drive operations. We connect only the J4-1 and J4-3 because we don't use a brake.

Communication connection, J7 :

It's not necessary to wire all the pins, it depends of what we need. We want to command the motors with a ±10 analog voltage, so we have to connect the pins 2 and 3. The position feedback is made by the multi-mode encoder port. We want to use the A/B signals to know the position of the motors, we connect the J7-26 and the J7-24 to do this. The Xenus has 12 digital inputs we can use for several operations. The first input, IN1, is used to enable and disable the Xenus. We need 3 digital inputs, IN2, IN3, IN4, that will allow us to choose different tasks for the Xenus. We wire the pins 4 to 7. A better explanation of the use of this control pins will be made in the Configuration chapter. The last connections to do concern the frame ground and the signal ground, that are the J7-1, J7-15 and J7-19. There is a description of all the wire connections in Appendix 6.3.1

4.1.1.2 Configuration :

The configuration is done with the CME 2 software that can be downloaded on the company Copley Controls website. The software runs on Windows and is easy to use. The first step is to open the basic setup of the amplifier and click on « ServoTube Setup ». We have to indicate which motor we use, the type of command we want, and to set the multi-mode port as emulated buffered feedback. Then we configure the digital input IN1 as active high, in the Input/Output screen of the CME 2.

After this, we use the CVM control program screen that lets us access the Indexer 2 Program. It is a powerful, easy to use indexer that runs on the Copley Virtual Machine (CVM), an embedded virtual machine available on most Copley Controls drives. Up to 32 sequences can be created with one or more steps which contain moves dwell times, I/O control, parameter changes, and conditional logic. Upon receiving a Go command, the program executes the sequence that has been selected. I choose the digital input IN4 in active high to activate the Go command. The sequence selection is also done by digital inputs. I choose 2 digital inputs, IN2 and IN3, for the sequence selection, so I can program 4 different sequences.

Sequences	Inputs	
	IN3	IN2
3	1	1
2	1	0
1	0	1
0	0	0

Tableau 1 : Sequence selection

The four sequences are :

- Homing : it sets the zero position for the motors.
- Analog position : this function is used to change the operating mode of the drive to analog position mode and configure the mode.
- Analog velocity : like the previous sequence, this function is used to change the operating mode of the drive to analog velocity mode and configure the mode.
- Disable drive : this function is used to software disable the drive.

The full configuration can be seen in the Appendix 8.4.

4.1.2 Rotation motor controller ESCON :

The connections and configuration of the ESCONs was already done in the previous projects. The encoder of the rotation motor of the defenders was broken, so I just fix the rotation motor on the linear motor, without connecting the cables. For the rotation motor of the goalkeeper, I just lengthen the wires to lay the ESCONs on the wood plate of the table.

4.2 Electronic design :

This part concerns the connection between the motor controllers, Xenus and ESCON, and the SCB-68 board from National Instruments we use to communicate with the computer. Two boards are required for all the connections. On the first, we connect the position feedback of the goalkeeper. The feedback of the Xenus is connected to the counter 0 and the one of the ESCON to the counter 1. We use the 2 analog outputs to command the motors of the goalkeeper. As explained in the previous chapter « linear motor controller », to select the sequences and the Go command, we chose three digital inputs of the Xenus. These three inputs are connected to the port 0 (P0.0, P0.1, P0.2).

The connections of the second board are the same but for the motor controllers of the defenders. But there is a difference in the use of the port 0 of the second board. Here it serves to enable/disable all the motor controllers (goalkeeper and defenders). So, we connect the command selection of the Xenus of the defenders also to the port 0 of the first board. There is a description of all the wire connections in Appendix 8.3.2

4.3 LabView – Controller design :

In my project, I will not use the LabView program created in the previous projects. My goal is to install the motors and to make them work. It will probably be not difficult to integrate the new motors in the Labview program, it's a work to do in the future. I create 3 VIs to control and test the system. One to read the counters of the motors, one to control the motors with an analog voltage and a last to command the motor controllers. For the last, the principle is to write on the port 0 of the first board to select the sequences of the Xenus and on the port 0 of the second board to enable or disable each controller. To write on a digital port of the board, I use a VI of the DAQmx base and unfortunately with this VI, we can only write one channel for all lines. It meens we can not seperate the control for only one line of the port. The port has 8 line, P0.0 to P0.7. So for exemple, we want to set the P0.1 and the P0.3 to 1, we must write in the VI the command 1010. Concerning the sequence selection of the Xenus, the Go command is connected to the P0.0. As long as we are not writing a 1 to the end of command , there will be no sequence executed even if a sequence has been selected. For exemple, the command 100 select the sequence 2 but the Go command is at 0.

5 Angle determination

The goal of this part is to give angles to the ball after the shot and try to determine the position of the player that corresponds to a certain angle. In other words, what should be the player's position in relation to the position of the ball to make a shot with an angle selected by the user. The results of this part are quite approximate for several reasons. First, the main reason is the change in the initial shooting conditions. It is not possible to guarantee precisely the same initial position of the ball for each shot. Even a small difference in positioning can lead to a significant difference in the angle. Second, the player's foot is not a rectangular parallelepiped. It is thinner at the bottom than the top, and the face that strikes the ball is a little concave. To be able to calculate the angle of the ball, we have to measure where the ball goes to the other side of the babyfoot. There are also inaccuracies in these measurements. Finally, we make approximations in the method that gives the player's position in relation to the position of the ball to get the desired angle.

5.1 Explication of the experiment :

My idea for the experiment is to place the ball at a well-defined position and hit it with different positions of the player and observe the angle of the ball after the shot. In fact, I defined 6 areas I want to reach with the ball, 3 on the left of the initial position of the ball and 3 on the right. All the areas are equispaced. I fixed a ruler just behind the areas and I filmed the passage of the ball for each shot to be able to measure where the ball passes. I made a little stop in cardboard that can put the ball in the same position most of the time, to have the maximum of same initial conditions for each shot. I use the goalkeeper to do the experiment and I control it in position by analog voltage of ±10 V. For a better understanding, we can look at the figures 9 and 10, that are pictures of the experiment.

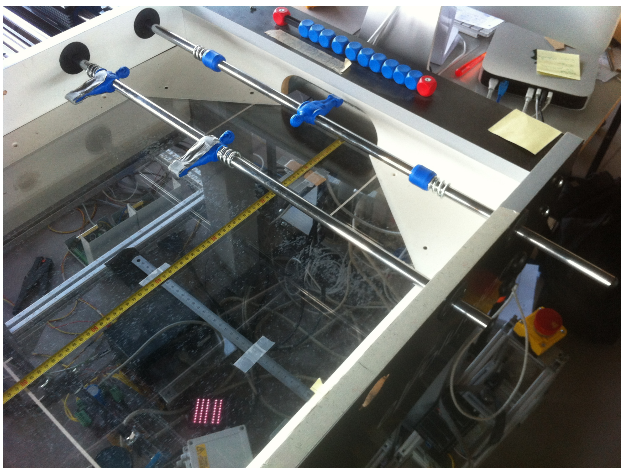

Figure 10 : View of the initial position

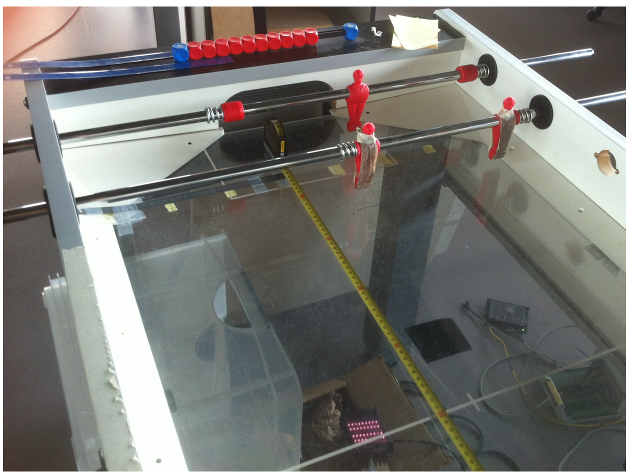

Figure 9 : View of the areas

The progress of the experiment is simple. I put the ball to its initial position. I move the goalkeeper to the initial position of the ball, in other words, the middle of the player's foot hits the middle of the ball. Then I choose the area I want to reach and I move a little bit the goalkeeper to the left to reach a right area or to the right to reach a left area. When I find the position of the goalkeeper that achieves to reach as close as possible the desired target, I note the motor control voltage for this position. It's important to have a repeatability in the shots and not note the voltage at the first shot that reached the desired area. I then do a series of shots that are filmed and that will give enough measurements to calculate the average angle and the gap. I did 15 shots by areas and analyse the movie on the computer to determine where the ball passes on the other corner of the babyfoot. I just have to repeat the operation for all the areas. I will also try to change the vertical distance between the ball and the player to see if that distance influences the angle of the shot.

5.2 Technical data of the experiment :

The goalkeeper is controlled by a analog tension of ±10 V. The 10 V is the maximum position to the left and the -10 V the maximum position to the right. The goalkeeper has a stroke of 203 mm. So, 10 V correspond to 101.5 mm. I choose the initial position of the ball at 5 V. The ball is at a distance of 30 mm from the player in vertical position. The areas are equispaced of 85 mm. I measured the diameter of the ball and the width of the player's foot to know where is the impact of the foot on the ball. I also measured the distance between the initial position of the ball and the line of areas. This distance is needed to calculate the angles by trigonometry. Summary and schema of the technical data :

- 1 V = 10.15 mm
- Initial position at 5 V
- ∅ ball = 33.6 mm
- Width of player's foot = 21.2 mm
- Distance between 2 areas = 85 mm
- Distance between initial position and areas = 945.5 mm

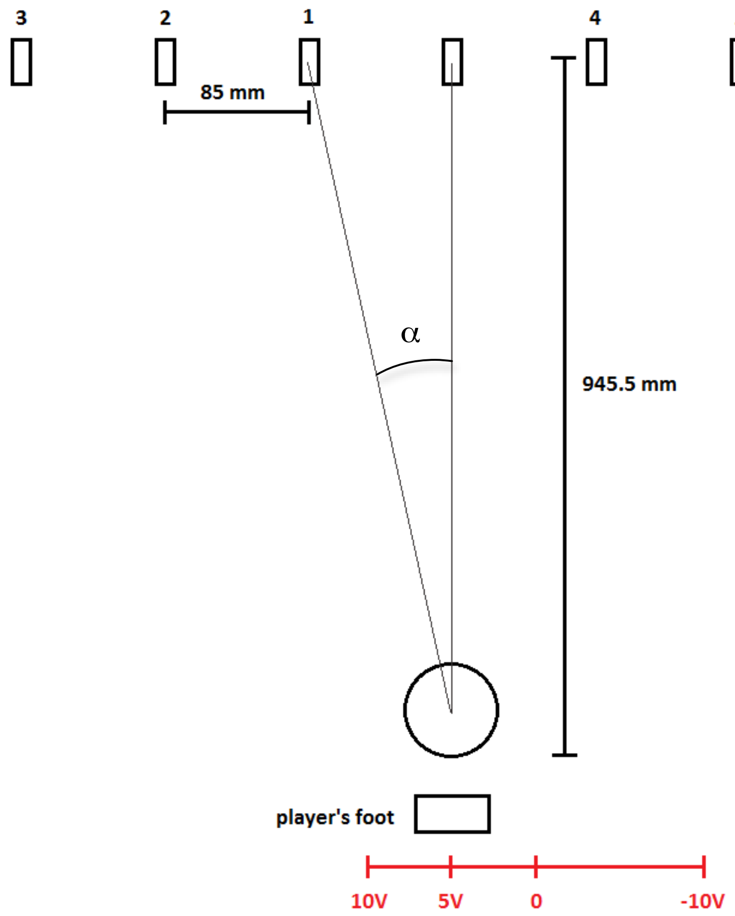

Figure 11 : Schema of the experiment

5.3 Equations to calculate the angle and results :

The equations to calculate the angle of the ball is a simple trigonometry relation. We know the distance between the center of the ball and the line of areas and we mesure the distance between where the ball passes after the shot and the vertical trajectory. We name this distance d. We have a right-angled triangle and we can use the tangent to find the angle.

Distance between the center of the ball and the line of areas :

$$D = 945.5 - \frac{33.6}{2} = 928.7\,mm$$

Equation of the angle :

$$\alpha = \tan^{-1}\left(\frac{d}{D}\right)$$

With this equation we can now calculate the angle of the ball that corresponds to a control voltage, thus a position of the goalkeeper. Here are the results I find, the areas are defined by a number and correspond to those of figure 11.

Areas	Position of areas [mm]	Theoretical angle [°]	Analog voltage [V]	Move of the goalkeeper [mm]	Average position reached [mm]	Average angle [°]	Gap max [°]
1	85	5.23	3.85	-11.67	93.32	5.74	±0.995
2	170	10.37	3.65	-13.70	176.32	10.75	±2.38
3	255	15.35	3.50	-15.22	258.50	15.55	±2.04
4	-85	-5.23	6.15	11.67	-95.23	-5.85	±1.22
5	-170	-10.37	6.35	13.70	-166.20	-10.15	±1.055
6	-255	-15.35	6.5	15.22	-223.80	-13.54	±1.69

Tableau 2 : Results of the experiment

I also measured the average max angle to the right and to the left. I find 43.88° ± 1.68° for the right and 40.89° ± 1.74° for the left. To reach these angles, the player's foot is the farthest as possible of the middle of the ball but ensuring a correct shot. It does not just brush the ball. I calculate the maximal gap by taking the difference between the farthest angle among all measures from the mean angle and the mean angle. In this way, we consider the worst repeatability we can have. We can see that the repeatability changes between each area. This variation is caused mainly by the imprecision of the initial conditions. I tried to do shots by putting the ball closer to the player's foot. In the first series of shots, the ball was at a distance of 30 mm from the player's foot. For the second series, I putted the ball only at a distance of 10 mm from the player's foot. This 2 distances are about the maximum that can be taken. Less than 10 mm would be too close to the player's foot and more than 30 mm would be too far from the player's foot to effectuate a correct shot. By comparing the measurements, I only found small differences between the 2 series of shots, of maximal order of 0.5V.

5.4 Method to determine the player's position :

The method I'm going to propose is based on a geometry principle that may seem simple but it can determine the position of the goalkeeper consistently with experimental results found earlier. As I said in the last chapter, I have not seen a great influence of the distance between the ball and the player's foot. So, I chose to neglect the influence of this distance and to say that only the impact point on the ball affects the angle of the shot. To understand the method, we can look at the figure12. The principle is to identify the impact point of the player's foot on the ball. Then we have to draw a line through the impact point and the center of the ball. This line will be the trajectory of the ball after the shot and the angle will be between this line trajectory and the vertical trajectory. If we draw the move of the goalkeeper, we have a right-angled triangle. We know the radius of the ball. By the principle of the vertically opposite angles and as we choose the angle we want to give to the ball, we can calculate the move to do for the player with a trigonometric relation.

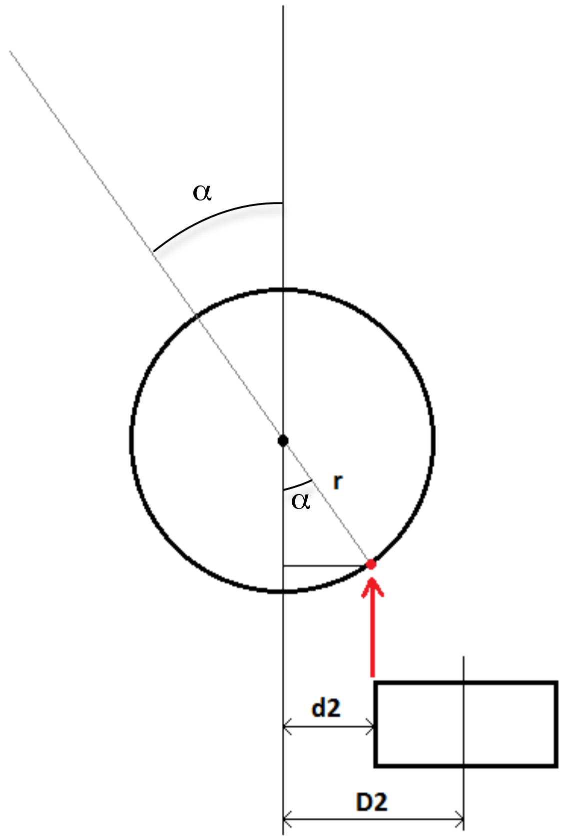

Figure 12 : Schema of the method

We want to calculate the distance d_2 for a selected angle α :

$$d_2 = r \times \sin(\alpha) = 16.8 \times \sin(\alpha)$$

To know the distance D_2 that is the move of the player, we must add the half of the width of the player's foot :

$$D_2 = -\mathrm{sgn}(\alpha) \times (10.6 + d_2)$$

If we want, we can calculate the control voltage for this move :

$$V = 5 + \frac{D_2}{10.15}$$

We can verify the validity of the method by using the angles of the areas of the experiment. We can see if the position of the player indicated by the method is near the position find by the experiment to make the same angle. As the values of the move of the goalkeeper for the left areas are the same as those for the right areas, we do the calculations for 3 areas :

angle α [°]	D_2 method [mm]	D_2 experiment [mm]	Voltage control method [V]	Voltage contol experiment [V]
5.23	-12.13	-11.67	3.80	3.85
10.37	-13.62	-13.70	3.66	3.65
15.35	-15.05	-15.35	3.52	3.50

Tableau 3 : Comparison experiment/method

We constat that the method give results close to the results of experiment. I made other shots of the method with other angles and the results were satisfactory. The test was to put a plastic bottle cap at the other end of the babyfoot to a place that give us the desired angle, to calculate the required move of the goalkeeper and the control voltage, to entry the value of the control voltage, to do the shot and to observe if the ball hits the cap. Despite a simplistic appearance, the results are surprising good, and I think this method is a good base to start making strategies with shooting angles.

6 Conclusion

The 2 main goals of the the project have been achived in my opinion. The new actuator is installed and ready to drive and it works well. We can control it in position by analog voltage and in velocity always by analog voltage. Unfortunately, this control is in open loop, I don't have to develop the Labview program. So the babyfoot is « blind » again, while the new system isn't integrate to the main VI. We want to command the babyfoot in velocity and in closed loop. This is an important point that will certainly take part in a future semester project. It is important because this is the central reason of why know the babyfoot is blind again. The closed-loop gives to the Labview program the information of the position of the player. It's the only way to have a control in velocity, without this, the system can not know when the motors must stop to be at the a required position. With the second part of this project, we are able to give a position of the player to shoot the ball with a predefined angle. The closen-loop is also important here, because the interset to shoot with angle is to define player strategies and try to find the better strategy, one that will stop almost of all the shots and will often score. With the simple method I described at the end, we can have a good start in this direction. I described two important possible improvements but many more can be still done in the future.

I enjoyed working on this project. I was really satisfied to discover the linear motors, that are really good and impressive motors. The only little trouble I encountered was to must wait on the delivery of the linear motors to finally really start most of the project.

Thanks :

I would like to thanks Dr. Christophe Salzmann for his disponibility and his help during the semester, as Mr.Milan Kordnd Mr Colin Jones for their advices. I really appreciate to thanks Mr. Norbert Crot for his precious help concerning the mechanical design. As well as M. Giangcarlo Gangi, Parkem company's engineer, for all the explanations on the linear motors he gives me.

7 Reference/Bibliography

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5) Report « Control System for Babyfoot », autumn 2013

8 Appendix

8.1 Linear motors datasheet :

The linear motors are SM 2504S.

MODELS Sx2504-2510 and Xx3804-3810
SERVOTUBE MODULE

dunkermotoren
linear systems

ELECTRICAL SPECIFICATIONS

FORCER TYPE	2504		2506		2508		2510		units
	S[1]	P[1]	S[1]	P[1]	S[1]	P[1]	S[1]	P[1]	
Peak force @ 25°C ambient for 1 sec	312	156	468	234	624	312	780	390	N
Peak current @ 25°C ambient for 1 sec	20								Apk
With 25 x 25 x2.5cm heatsink plate									
Continuous stall force @ 25°C ambient [2]	51.2		69.5		86.4		102.4		N
Continuous stall current @ 25°C ambient	2.31	4.62	2.10	4.20	1.96	3.92	1.86	3.72	Arms
	3.27	6.54	2.97	5.94	2.77	5.54	2.62	5.24	Apk
Without heatsink plate									
Continuous stall force @ 25°C ambient [2]	42.5		59.5		75.1		90.0		N
Continuous stall current @ 25°C ambient	1.92	3.84	1.80	3.60	1.70	3.40	1.63	3.26	Arms
	2.72	5.44	2.54	5.08	2.41	4.82	2.31	4.62	Apk
Force constant (sine commutation)	22.1	11.0	33.1	16.5	44.1	22.0	55.2	27.6	N/Arms
	15.6	7.8	23.4	11.7	31.2	15.6	39.0	19.5	N/Apk
Back EMF constant (phase to phase)	18.0	9.0	27.0	13.5	36.0	18.0	45.0	22.5	Vpk/m/s
Fundamental forcer constant	6.47		7.92		9.13		10.24		N/√W
Eddy current loss	9.51		12.55		15.58		18.61		N/m/s
Resistance @ 25°C (phase to phase)	6.02	1.50	9.02	2.25	12.03	3.01	15.04	3.76	Ohm
Resistance @ 100°C (phase to phase)	7.75	1.94	11.63	2.91	15.51	3.88	19.39	4.85	Ohm
Inductance @ 1kHz (phase to phase)	3.90	0.97	5.85	1.46	7.80	1.95	9.75	2.44	mH
Electrical time constant	0.65								ms
Maximum working voltage	380								V d.c.
Pole pitch (one electrical cycle)	51.2								mm
Peak acceleration [3]	222	111	222	111	235	117	255	127	m/s^2
Maximum speed [4]	8.5	7.3	6.4	7.1	5.3	7.3	4.5	6.7	m/s

FORCER TYPE	3804		3806		3808		3810		units
	S[1]	P[1]	S[1]	P[1]	S[1]	P[1]	S[1]	P[1]	
Peak force @ 25°C ambient for 1 sec	744	372	1116	558	1488	744	1860	930	N
Peak current @ 25°C ambient for 1 sec	20								Apk
With 25 x 25 x2.5cm heatsink plate									
Continuous stall force @ 25°C ambient [2]	137.3		186.9		232.1		276.2		N
Continuous stall current @ 25°C ambient	2.61	5.23	2.37	4.74	2.20	4.41	2.10	4.20	Arms
	3.69	7.39	3.35	6.71	3.12	6.23	2.97	5.94	Apk
Without heatsink plate									
Continuous stall force @ 25°C ambient [2]	120.1		168.2		212.7		255.0		N
Continuous stall current @ 25°C ambient	2.28	4.57	2.13	4.27	2.02	4.04	1.94	3.88	Arms
	3.23	6.46	3.01	6.03	2.86	5.72	2.74	5.49	Apk
Force constant (sine commutation)	52.6	26.3	78.9	39.4	105.2	52.6	131.5	65.7	N/Arms
	37.2	18.6	55.8	27.9	74.4	37.2	93.0	46.5	N/Apk
Back EMF constant (phase to phase)	43.0	21.5	64.4	32.2	85.9	42.9	107.4	53.7	Vpk/m/s
Fundamental forcer constant	14.54		17.80		20.56		22.99		N/√W
Eddy current loss	3.7		3.7		3.7		3.7		N/m/s
Sleeve cogging force	7.3		4.2		8.3		5.6		+/-N
Resistance @ 25°C (phase to phase)	6.77	1.69	10.16	2.54	13.54	3.38	16.93	4.23	Ohm
Resistance @ 100°C (phase to phase)	8.73	2.18	13.10	3.27	17.45	4.36	21.82	5.45	Ohm
Inductance @ 1kHz (phase to phase)	8.52	2.13	12.78	3.19	17.04	4.26	21.30	5.32	mH
Electrical time constant	1.26								ms
Maximum working voltage	380								V d.c.
Pole pitch (one electrical cycle)	71.2								mm
Peak acceleration [3]	243	121	275	137	294	147	307	153	m/s^2
Maximum speed [4]	5.9	8.7	4.2	7.1	3.3	5.8	2.6	4.9	m/s

DS01100/C

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Page 2

Notes: -
(1) S=series forcer phases, P=parallel forcer phases
(2) Reduce continuous stall force to 89% at 40°C ambient
(3) Based on a moving forcer with no payload
(4) Based on a moving forcer with triangular move over maximum stroke and no payload

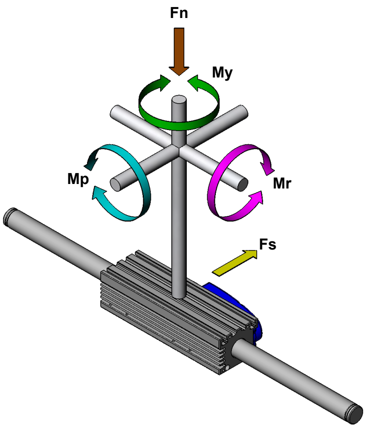
THERMAL SPECIFICATIONS

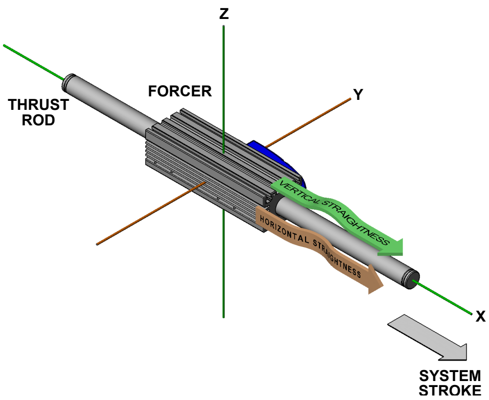
FORCER TYPE	2504	2506	2508	2510	3804	3806	3808	3810	units
Maximum phase temperature	100								°C
Thermal resistance $Rth_{phase\text{-}housing}$	0.41	0.27	0.20	0.16	0.23	0.16	0.13	0.11	°C/Watt
With 25 x 25 x2.5cm heatsink plate									
Power dissipation @ 25°C ambient	62.3	77.0	89.2	100.2	89.3	110.3	127.1	144.2	Watt
Thermal resistance $Rth_{housing\text{-}ambient}$	0.79	0.69	0.64	0.59	0.61	0.52	0.46	0.41	°C/Watt
Without heatsink plate									
Power dissipation @ 25°C ambient	43.1	56.4	67.6	77.3	68.2	89.3	107.0	123.0	Watt
Thermal resistance $Rth_{housing\text{-}ambient}$	1.33	1.06	0.91	0.81	0.87	0.68	0.57	0.50	°C/Watt
Thermal time constant	1188	1276	1377	1486	1677	1798	1924	2056	s

MECHANICAL SPECIFICATIONS

FORCER TYPE	2504	2506	2508	2510	3804	3806	3808	3810	units
Maximum stroke	1151	1100	1049	998	1323	1252	1181	1110	mm
Moving mass	1.40	2.10	2.65	3.05	3.05	4.05	5.05	6.05	kg
Maximum normal force, Fn (1) (3)	1.05	2.11							kN
Maximum side force, Fs (1)									
Maximum roll moment, Mr (1)	17.8	35.6							Nm
Maximum pitch moment, Mp (1)	6.4	112	158	212	103	172	238	313	Nm
Maximum yaw moment, My (1)									
Maximum normal force, Fn (2) (3)	0.49	0.98							kN
Maximum side force, Fs (2)									
Maximum roll moment, Mr (2)	8.2	16.4							Nm
Maximum pitch moment, Mp (2)	2.9	52	73	98	48	79	110	145	Nm
Maximum yaw moment, My (2)									
Constrained vertical straightness (flatness)	60								µm/m
Constrained horizontal straightness	80								µm/m
Unconstrained vertical straightness (flatness)	100								µm/m
Unconstrained horizontal straightness	80								µm/m

Notes: -
(1) For a bearing life expectancy of 10000 km with no other forces or moments
(2) For a bearing life expectancy of 100000 km with no other forces or moments
(3) Load in kg = force/9.81





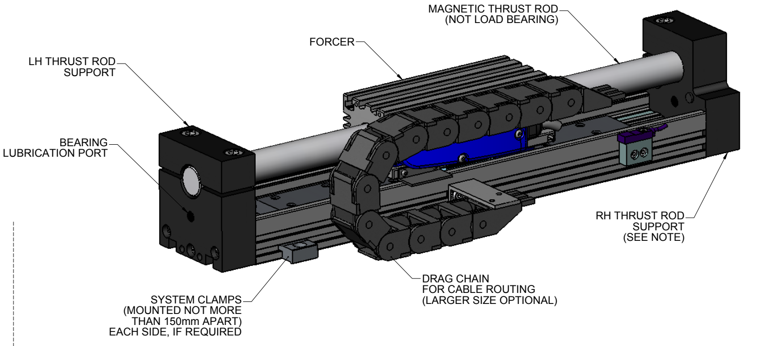
OUTLINE DRAWINGS

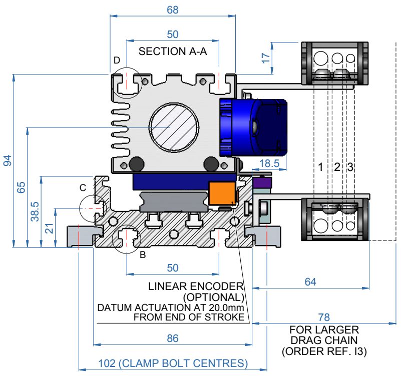
SM25

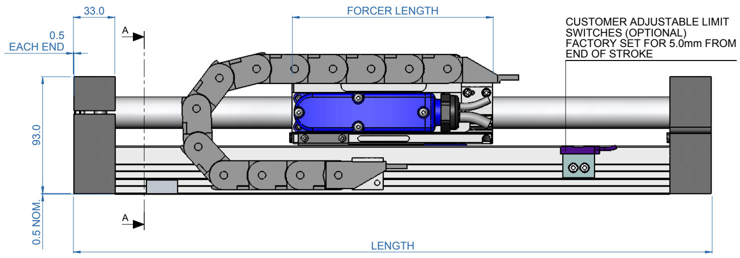
FORCER	FORCER LENGTH (mm)	WITH BUFFERS (mm)
2504	160	164
2506	211	215
2508	262	266
2510	313	317

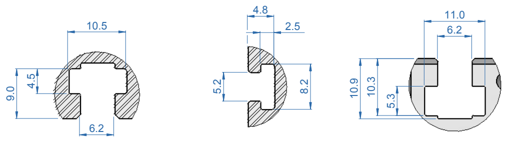
CABLES:

1. Ø7.6 POWER CABLE
2. Ø5.8 SENSOR CABLE
3. Ø4.5 ENCODER CABLE (OPTIONAL)









DETAIL B
SLOTS FOR M5 T-NUTS & M6 SQUARE / HEX. NUTS

DETAIL C
SLOTS FOR M4 SQUARE NUTS

DETAIL D
SLOTS FOR M5 T-NUTS & M6 SQUARE / HEX. NUTS

NOTE:
RH THRUST ROD SUPPORT SHOWN IS FOR 2504 MODULES ONLY, FOR ALL OTHER SIZES THIS SUPPORT WILL BE AS LH THRUST ROD SUPPORT.

Length	Stroke			
	2504	2506	2508	2510
253	23	-	-	-
278	48	-	-	-
304	74	23	-	-
330	100	49	-	-
355	125	74	23	-
381	151	100	49	-
406	176	125	74	23
432	202	151	100	49
458	228	177	126	75
483	253	202	151	100
509	279	228	177	126
535	305	254	203	152
560	330	279	228	177
586	356	305	254	203
612	382	331	280	229
637	407	356	305	254
663	433	382	331	280

Length	Stroke			
	2504	2506	2508	2510
689	459	408	357	306
714	484	433	382	331
740	510	459	408	357
766	536	485	434	383
791	561	510	459	408
817	587	536	485	434
868	638	587	536	485
919	689	638	587	536
971	741	690	639	588
1022	792	741	690	639
1073	843	792	741	690
1125	895	844	793	742
1176	946	895	844	793
1227	997	946	895	844
1279	1049	998	947	896
1330	1100	1049	998	947
1381	1151	1100	1049	998

Approximate module mass (kg)			
2504	2506	2508	2510
(0.0108 x L)+2.35	(0.0108 x L)+3.04	(0.0108 x L)+3.58	(0.0108 x L)+3.96
where L = Length in mm			

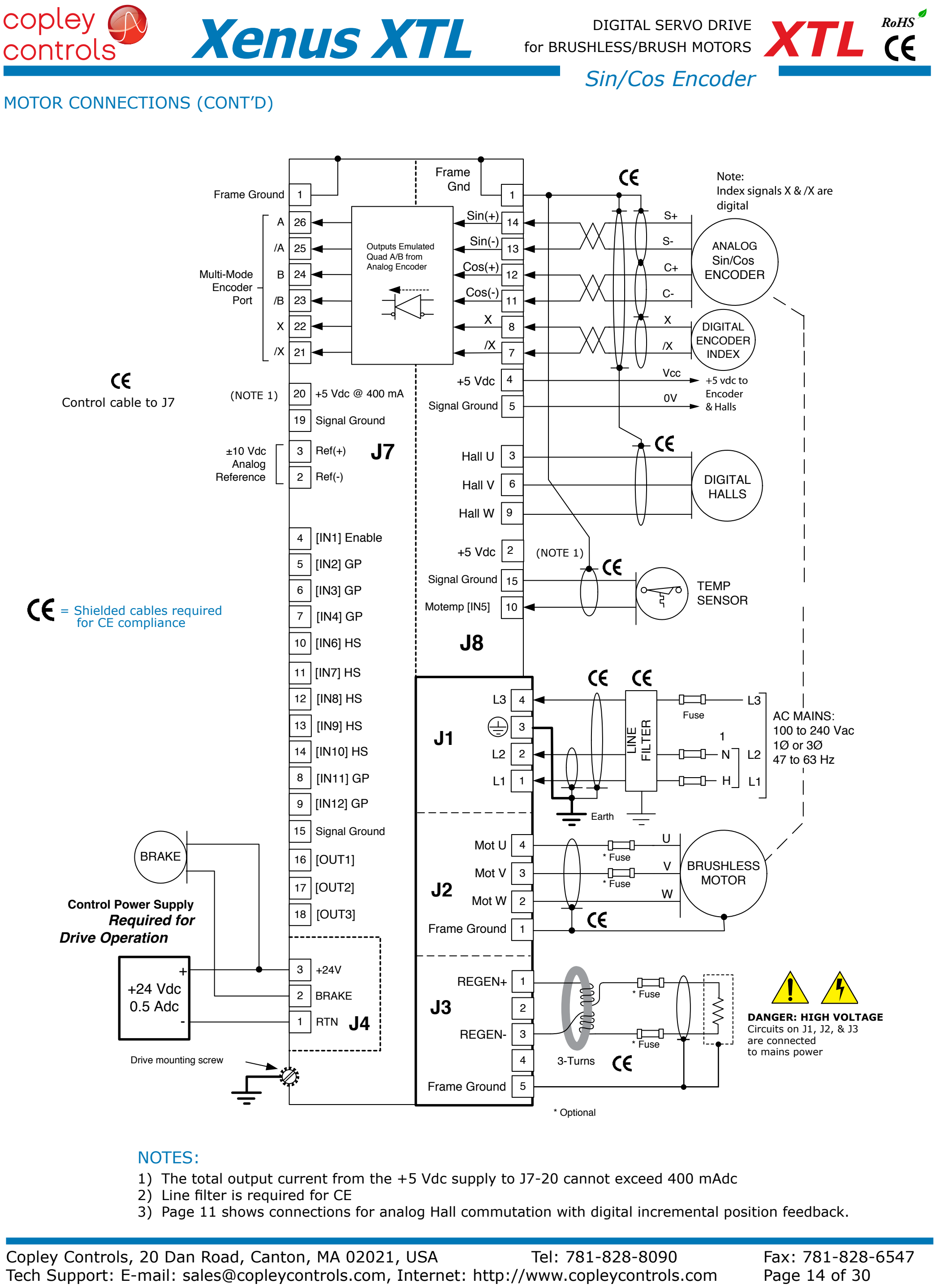
8.2 Material for the table :

All the parts were ordered from Item, on their website.

Quantity	Designation	Length	Specification
4	Profilé 8 40x40 léger, naturel (perpendicular)	660 mm	
4	Profilé 8 40x40 léger, naturel (parallel)	610 mm	
4	Profilé 8 40x40 léger, naturel (vertical)	685 mm	Taraudage M8x60mm au centre
4	Embout 8 40x40, noir		
12	Equerre automatique 8 80x80 Al		
8	Equerre automatique 8 40x40 Al		
4	Pied D40, M8x60, noir		
4	Patin D40, noir		
8	Ecrou V8 St M6, zingué		

8.3 Wire connections :

8.3.1 Linear motor controllers Xenus :

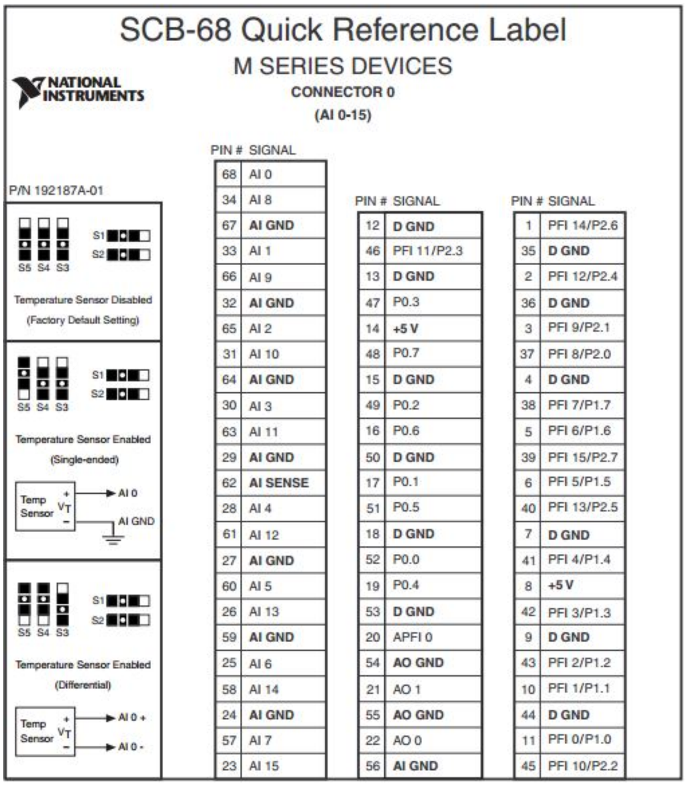


I used 2 shielded cables for the J7. A big with 8 wires and a small with 3 wires. Following, there is the colour code for the J7 :

Big shielded cable		
Wire colour	J7 pin n°	Signal
yellow	1	Frame ground
red	3	±10 Vdc Ref(+)
white	2	±10 Vdc Ref(-)
green	26	A signal
blue	24	B signal
grey	5	[IN2]
brown	15	Signal ground
pink	19	Signal ground

Small shielded cable		
Wire colour	J7 pin n°	Signal
red	7	[IN4]
white	6	[IN3]
blue	4	[IN1] Enable

8.3.2 SCB-68 boards :



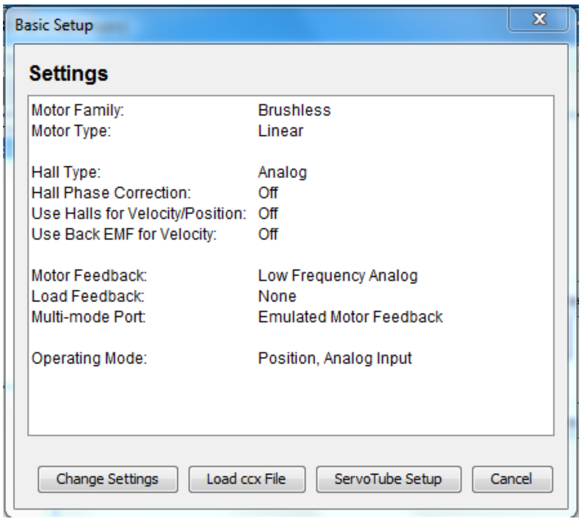
As said in the chapter « Electronic design » we required 2 boards for all the connections. The abbreviation « GK » is for goalkeeper and « D » for defenders. I detail here, for each board, which pin is used and by which signal. The frame ground of the Xenus is not connected to a pin but to the shield of the board.

Board 1				
Pin n°	Controller signal	Fonction	Controller	Colour
37	A signal	Position feedback (CTR0)	Xenus GK	green
45	B signal			blue
22	±10 Vdc Ref(+)	Analog command (AO 0)		red
55	±10 Vdc Ref(-)			white
42	A signal	Position feedback (CTR1)	ESCON GK	grey
46	B signal			purple
41	Z signal			blue
21	±10 Vdc Ref(+)	Analog command (AO 1)		white
12	±10 Vdc Ref(-)			green
52	[IN4]	Sequences selection (Port 0)	Xenus GK +D	red
17	[IN2]			grey
49	[IN3]			white
13	Signal ground		ESCON GK	white
54	Signals ground		Xenus GK	pink + brown

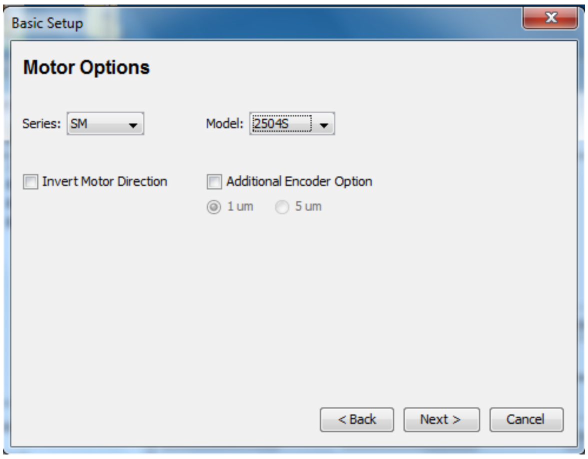
For the second board, the connections of the position feedback and the analog command of the Xenus D are the same as those of the Xenus GK on the first board. The difference, like I said, is in the use of the port 0. The ESCON D is not connected as the encoder of the rotation motor of the defenders is defective.

Board 2				
Pin n°	Controller signal	Fonction	Controller	Colour
37	A signal	Position feedback (CTR0)	Xenus D	green
45	B signal			blue
22	±10 Vdc Ref(+)	Analog command (AO 0)		red
55	±10 Vdc Ref(-)			white
52	[IN1]	Drive enable (Port 0)	Xenus GK	blue
17	Enable		ESCON GK	brown
49	[IN1]		Xenus D	blue
54	Signals ground		Xenus GK	pink + brown

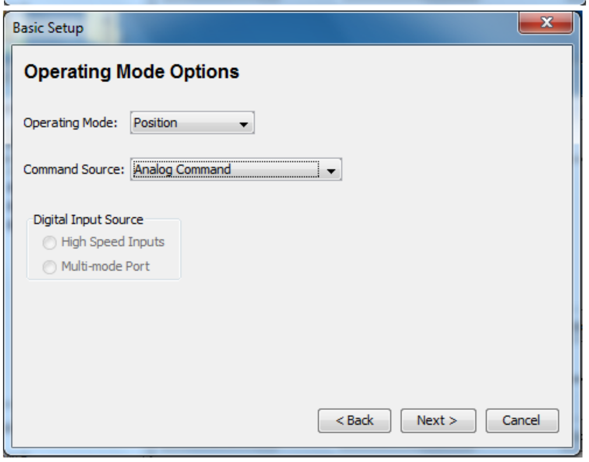
8.4 Xenus configuration :



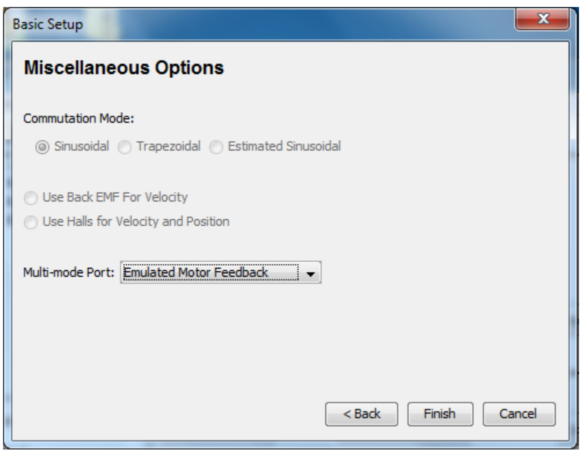
This is the screen of the basic setup of the amplifier. We can see a resume of the settings. It's on this screen we have to click on « Servotube Setup ».



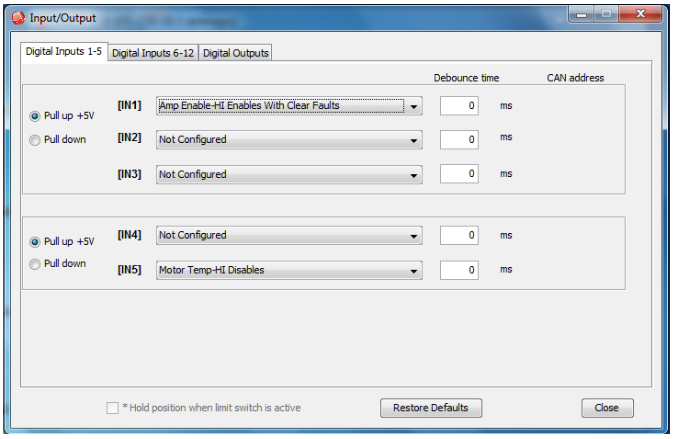
Linear motors selection



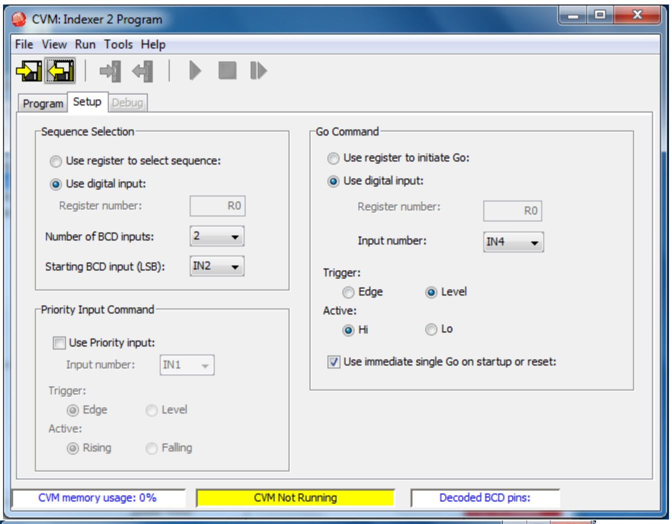
Command selection



Use of the Multi-mode Port



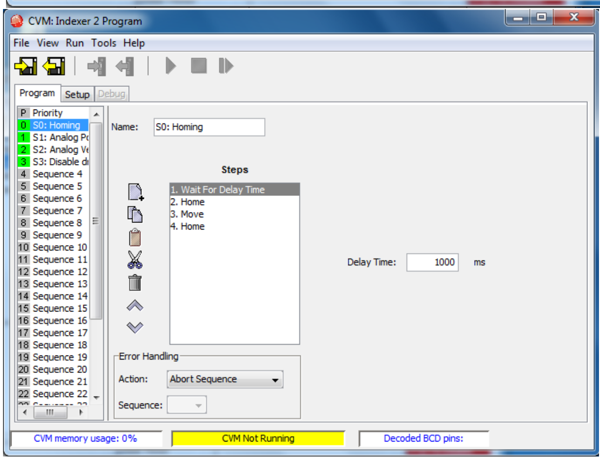
Set the digital input [IN1] as active high



CVM : Indexer 2 Program screen

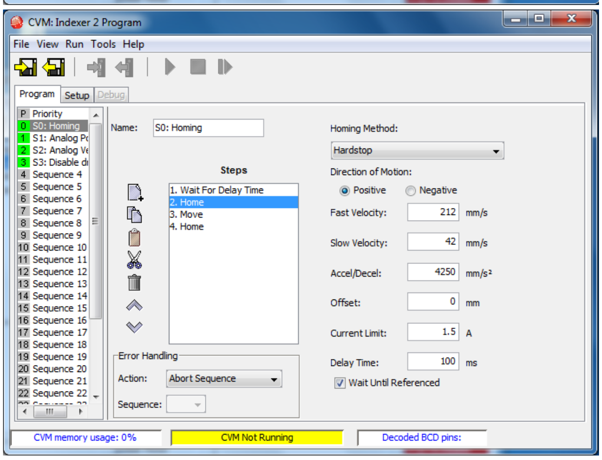
For the Sequence selection, set the number of digital inputs as 2 and the starting input is [IN2]

For the Go Command, the digital input to use is [IN4] in active high.



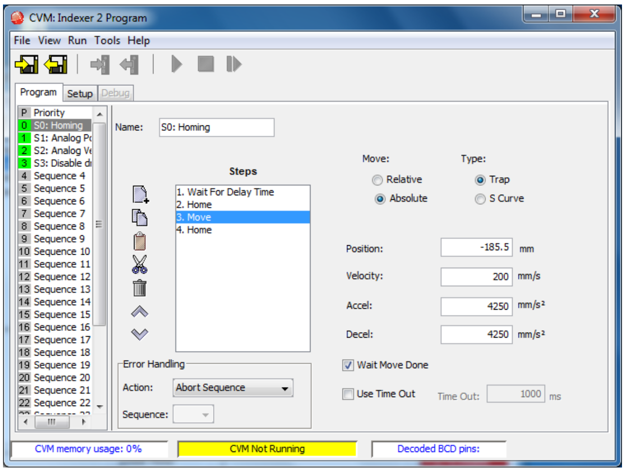
Step 1 of sequence Homing

Wait for a time of 1000 ms



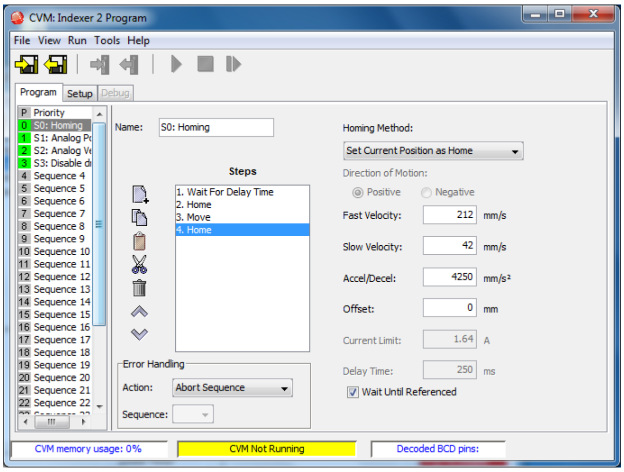
Step 2, Home : Hardstop

The motors move until they are stopped by the end of the displacement of the babyfoot bar. When the motors see a current higher as 1.5 A during a time of 100 ms, the movement is stopped and the current position is the 0 position

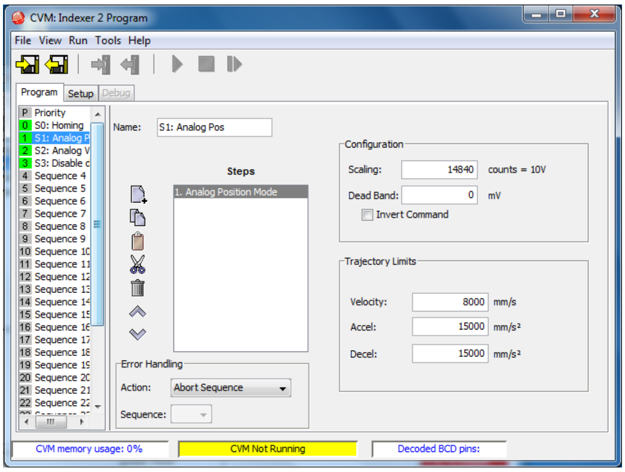


Step 3, Move

The motors moves to a absolute postion that represents the middle of the displacement of the bar. For the defenders, it's -185.5 mm and for the goalkeeper it's -101.5 mm

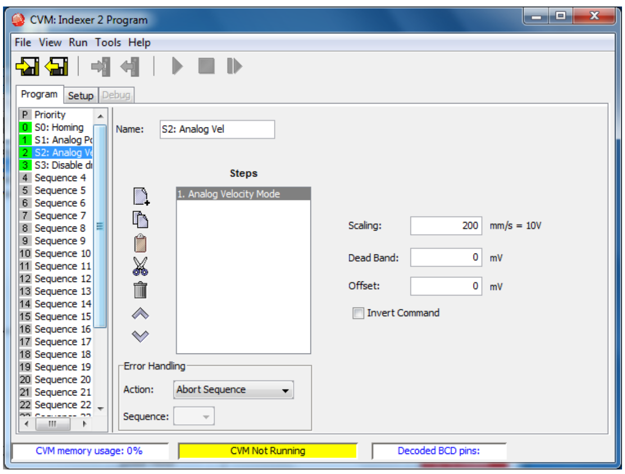


Step 4, Set Current Position as Home



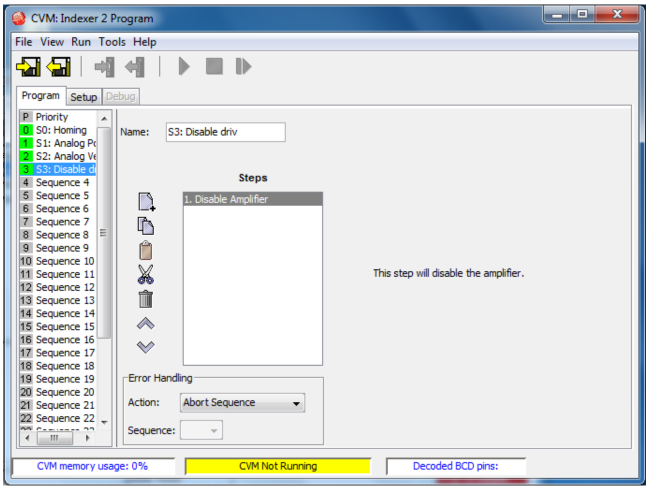
Sequence Analog Position

We choose how many counts represent 10 V. This number corresponds to the half of the movement of the bars. For the defenders it's 14840 counts, for the goalkeeper it's 8120.



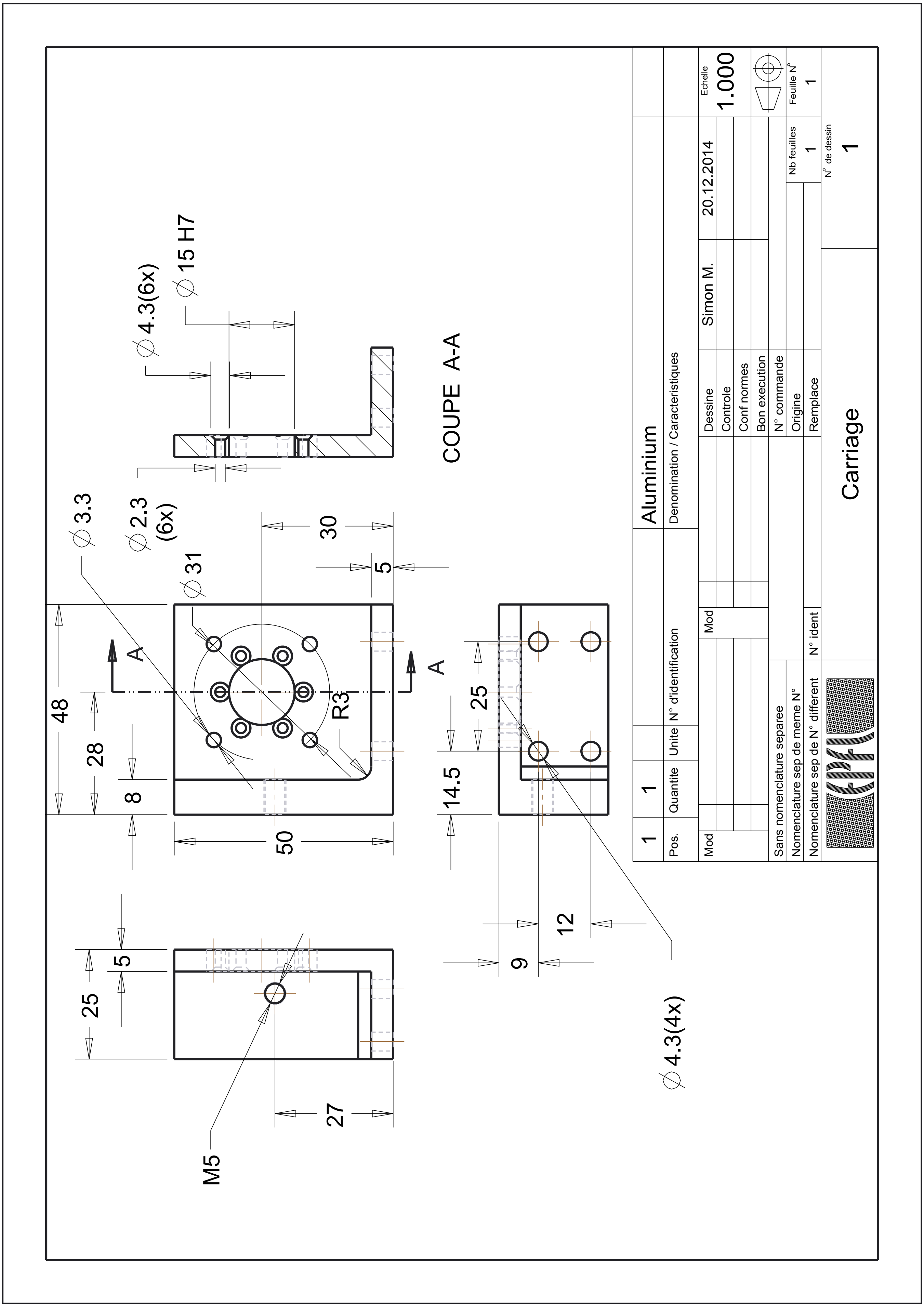
Sequence Analog Velocity

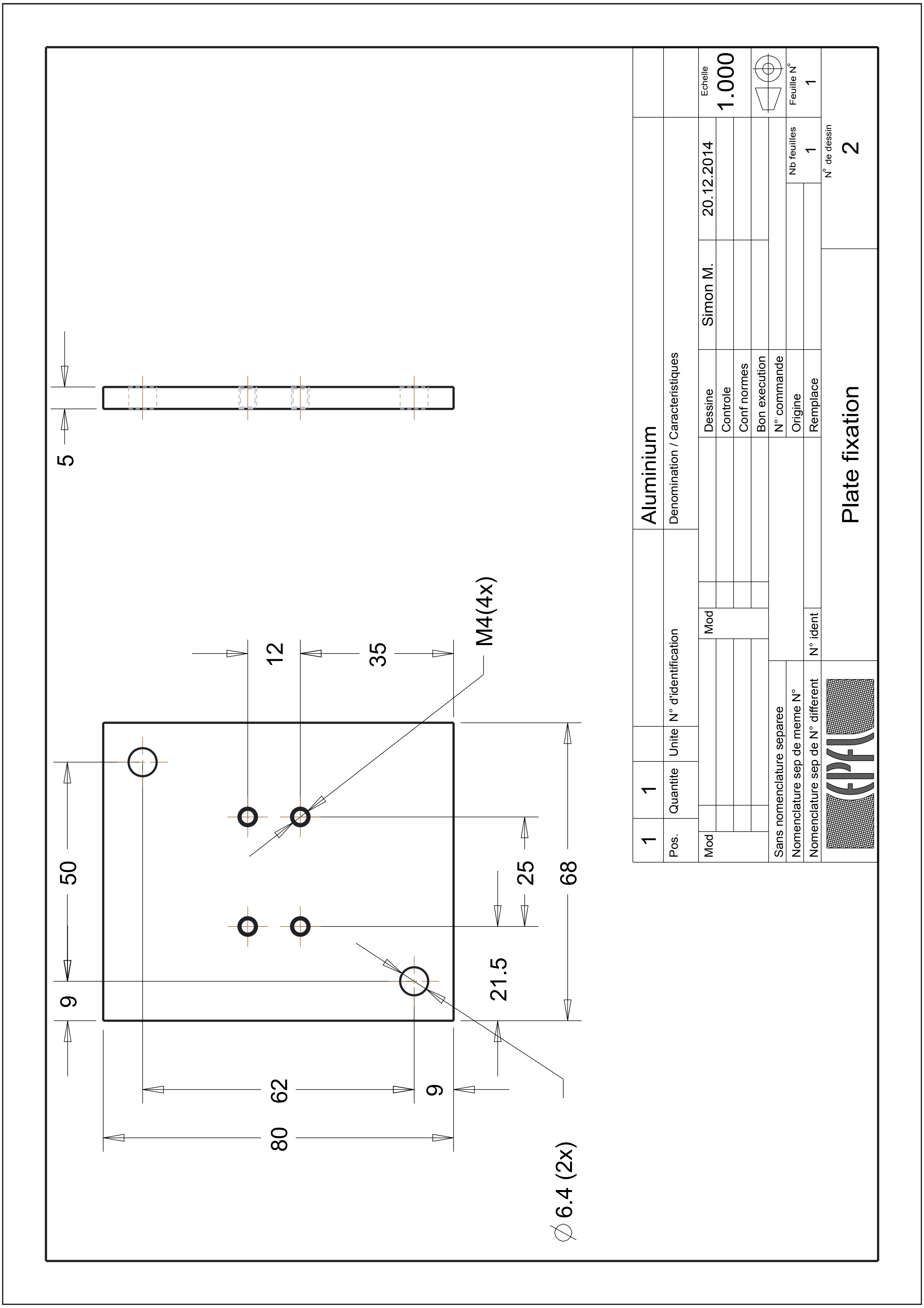
We choose how many mm/s represent 10 V.



Sequence Disable Drive

8.5 Drawings :


COUPE A-A
A
A
⌀ 4.3(6x)
⌀ 15 H7
⌀ 3.3
⌀ 2.3 (6x)
⌀ 31
⌀ 4.3(4x)
R3
M5
48
28
8
50
30
5
25
14.5
12
9
27
Aluminium
Denomination / Caracteristiques
Pos.
Quantite
Unite
N° d'identification
1
1
Mod
Dessine
Controle
Conf normes
Bon execution
N° commande
Origine
Remplace
Simon M.
20.12.2014
Echelle
1.000
Feuille N°
1
Nb feuilles
1
N° de dessin
1
Sans nomenclature separee
Nomenclature sep de meme N°
Nomenclature sep de N° different
N° ident
Carriage



5
50
9
12
35
M4(4x)
25
68
21.5
62
9
80
⌀6.4 (2x)
1
1
1
Pos.
Quantite
Unite
N° d'identification
Aluminium
Denomination / Caracteristiques
Mod
Mod
Dessine
Controle
Conf normes
Bon execution
N° commande
Origine
Remplace
Simon M.
20.12.2014
Echelle
1.000
Feuille N°
1
Nb feuilles
1
N° de dessin
2
Sans nomenclature separee
Nomenclature sep de meme N°
Nomenclature sep de N° different
N° ident
Plate fixation