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Título del proyecto:

DESIGN, BUILD AND PROGRAMMING A SMALL MILLING MACHINE

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ABSTRACT

Milling is the machining process of using rotary cutters to remove material from a workpiece advancing (or feeding) in a direction at an angle with the axis of the tool. It covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes in industry and machine shops today for machining parts to precise sizes and shapes.

Milling operates on the principle of rotary motion. A milling cutter is spun about an axis while a workpiece is advanced through it in such a way that the blades of the cutter are able to shave chips of material with each pass. Milling processes are designed such that the cutter makes many individual cuts on the material in a single run [1].

GRATITUDES

The accomplishment of this thesis would not have been possible without the invaluable help of many people who have supported us along this experience. It is not only our duty but a pleasure to thank all of them for their help.

In the first place, we would like to express our gratitude to the Erasmushogeschool Brussel for providing us the chance of completing our bachelor degree in mechanical industrial science with the performance of the bachelor thesis.

We want to show our gratitude to Mr.Ronald Van Ham, our promoter. We are really pleased to him for showing us how all our knowledge can be applied to the real life. And for providing us the chance of taking part in such a experimental project that would not have been possible at our home city university.

We would also like to be grateful with all the fabLAB staff, who have helped us during all the project in all the difficulties we have had to face up with, specially Lieven Standaert and Serge Kubera, for supporting us in all the hours we spent in the fabLAB in the last nine months.

Also, we would like to show all our gratitude to those people who have supported us from the distance. To our families and relatives, friends, both the ones in Spain, and all the new friends we have known in this amazing experience, and also to our promoter in the Public University of Navarra, Dr. Pablo Sanchís Gurpide for encouraging us to this experience and helping us in every step we made till the submit of this thesis.

CHAPTER 1. INTRODUCTION

1.1- OBJECTIVES

The goal of this project is to design and build a prototype of a small milling machine. What makes special this milling machine is going to be intended for milling in a vehicle registration plate. The size of our vehicle registration plate is 50x10x1,5 cm. That's why the dimensions of our milling machine must be the less as possible in order to save usable space and the most important think in engineering, save the more materials/money we can.

On the other hand, this milling machine is going to be designed for milling small letters and small drawings in within the vehicle registration plate.

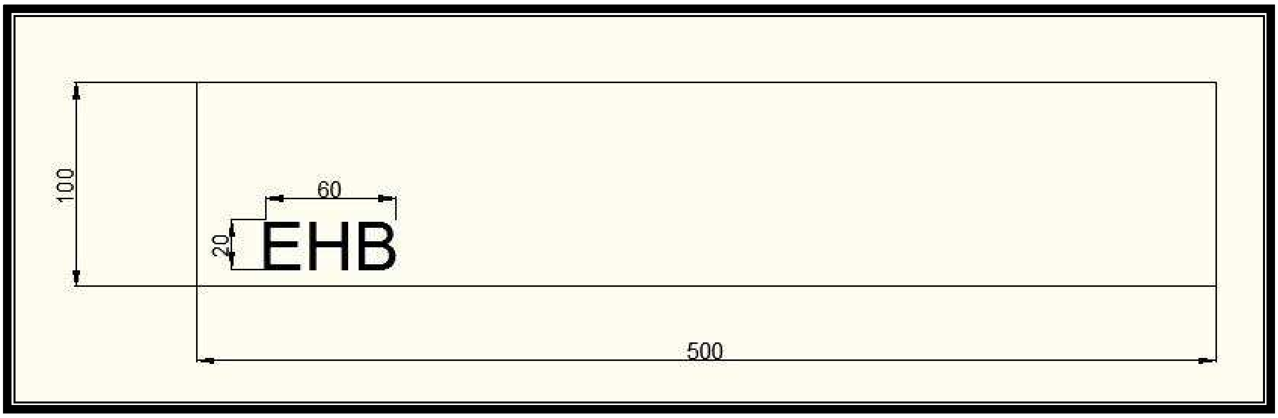


Figure 1: Example of the vehicle registration plate with the size of the milled letters in mm.

Because of that, we will need to build the milling machine with enough accuracy to achieve this goal.

The main material of the structure of our milling machine will be wood (3mm MDF). In order to get the enough precision in our milling, we will decide all the mobile parts of our milling machine will be made with two plates fitted.

To move the three mobile cars we will use three stepped motors that will make possible all the movements in the X,Y,Z axis.

The other basic aspect in our thesis is that this machine is going to be a CNC milling machine.

A machine tool that uses programs to automatically execute a series of machining operations. CNC machines offer increased productivity and flexibility[2].

For make this possible, we will use an electronic system based on Arduino UNO[3] hardware and software. Besides the Arduino UNO, we will use other hardware and software but we will explain them in the following pages.

1.2 DEVELOPMENT STAGES

To reach the objectives, we followed these steps:

- Step1: Study previous machines and designing the new one.
- Step2: Study the working of the tools in the FabLab.
- Step3: Design and build the structure with AutoCad, Inventor and the studied tools.
- Step4: Study and connect the stepper driver with Arduino UNO
- Step5: Study and work with Deskproto and ReplicatorG
- Step6: Testing and validating

CHAPTER 2. MATERIALS

In this chapter we will describe the whole set of materials that we used in the construction of the milling machine.

2.1 WOODEN PARTS

First, the structure of our machine is made with 1.8 cm thick wood that has been cut with the USB-CNC machine available in the FabLab. We have used this type of wood because the structure should be resistant and should stand firmly to set the machine so as to prevent movement and vibration that reduce the accuracy when the milling machine is operating.

Following in the same range of materials, the 3 cars that allow movement on 3 axis of the machine have been built with MDF (Medium Density Fiberboard) of 3 mm. Medium-density fiberboard, or MDF, is a manufactured wood product composed of wood fibers that are mixed with resin and wax and pressed into flat panels under high temperature and pressure[4]. Is a derived from wood that offers good conditions to work on it, has a great consistency, strength and quality, allowing cuts without chipping or cracking. As natural wood, can be screwed, glued and assembled. And most importantly the price is reduced, so that their use will reduce the construction costs of the machine.

The reason we chose the 3 mm thick MDF is because cars are made with two plates fitted.

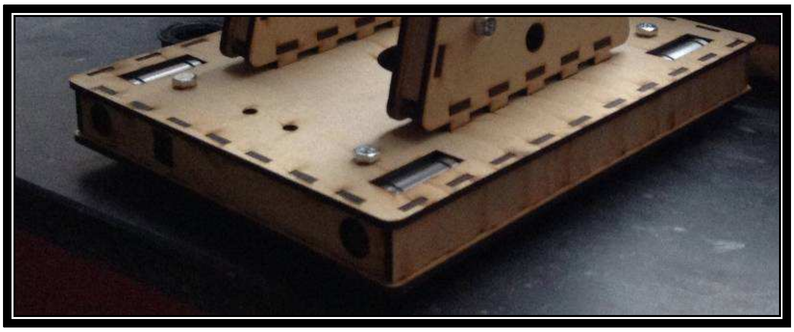


Figure 2: Two plates of MDF fitted by holes.

This design we have given to the cars, with the thickness of 3 mm each plate, gives the machine rigidity and very good consistency. This 3mm MDF also has an easy cut with the laser cutter at our disposal in the FabLab, which facilitate the construction of these mobile cars.

And to finish with the parts constructed with wood should be mentioned that both the drill holder located in the center car of our machine as the support of the belt fixed to the lateral walls of the machine structure have been constructed with 6mm thick wood. Choosing a larger thickness is because those parts will be exposed to higher efforts and vibrations caused by the operation of the drill and the friction between the knife of the Drill and the material of the vehicle registration plate.

2.2. SCREWS SECTION

Then we move on to the description of the screws section. To join this set of wooden pieces and give them more rigidity we used screws, washers and nuts of different sizes (mainly M5 and M3) depending on the space available in the different parts. M5 screws we used the most in the parts where it was essential to provide rigidity to the assembly as is the case of the double bond of the clamping plates or in the attachment of the stepper motors. However, in other smaller spaces such as the piece that holds the belt of the x axis we have decided to use metric 3 screws.

And continuing with this type of metal parts, we have also used threaded rods. In the support of the drill we have used threaded rods of metric 8, cause is there where the drill is being attached, so a strong enough rod was needed. Also for holding one of gears that transmits motion to the belt we have used a threaded rod of M3 that will provide enough strength.

To finish with this kind of metal parts to stiffen the assembly and avoid movements we have placed nuts with an inside diameter of 10 mm to fix the cars to the tubes on the y axis of our machine.

2.3. STEPPER MOTORS

To give the movement to our milling machine we use three stepper motors. The stepper motor is a device that converts a series of electrical impulses in angular displacements, which means that is capable of moving a number of degrees (steps) depending on the order that you will give. The stepper motor is a highly accurate motor as its shaft can rotate 1.8 ° per step which means that to make 360º has to make 200 steps. This gives them incredible accuracy, which transferred to the CNC will provide a great ability to make very small and delicate pieces, but you can also make large parts.

Stepper motor "step modes" include Full, Half and Microstep. The type of step mode output of any stepper motor is dependent on the design of the driver.

FULL STEP
Standard hybrid stepping motors have 200 rotor teeth, or 200 full steps per revolution of the motor shaft. Dividing the 200 steps into the 360º of rotation equals a 1.8º full step angle. Normally, full step mode is achieved by energizing both windings while reversing the current alternately. Essentially one digital pulse from the driver is equivalent to one step.

HALF STEP
Half step simply means that the step motor is rotating at 400 steps per revolution. In this mode, one winding is energized and then two windings are energized alternately, causing the rotor to rotate at half the distance, or 0.9º. Although it provides approximately 30% less torque, half-step mode produces a smoother motion than full-step mode.

MICROSTEP
Microstepping is a relatively new stepper motor technology that controls the current in the motor winding to a degree that further subdivides the number of positions between poles. Microstepping drives are capable of dividing a full step (1.8º) into 256 microsteps, resulting in 51,200 steps per revolution (.007º/step). Microstepping is typically used in applications that require accurate positioning and smoother motion over a wide range of speeds. Like the half-step mode, microstepping provides approximately 30% less torque than full-step mode[5].

The type of stepper motor used in our machine is the high torque hybrid stepper (SY57STH56-3008B) motor[6]. We are using the stepper motor in the HALF STEP mode, because we have 400 steps per revolution. We sacrifice 30% of torque to have more accuracy.

Hybrid stepper motor is characterized for having multiple teeth in the stator and the rotor, the rotor with an axially magnetized concentric magnet around its axis. This type of motor has a high precision and high torque and can be configured to deliver a pitch angle as small as 1.8 °, which is what our electric motor is going to give.

General specifications	
Step Angle (°)	1.8
Temperature Rise (℃)	80 Max (rated current, 2 phase on)
Ambient Temperature (℃)	-20 ~ +50
Number of Phase	2
Insulation Resistance (MΩ)	100 Min (500VDC)
Insulation Class	Class B
Max.radial force (N)	75 (20mm from the flange)
Max.axial force (N)	15

PHASE	STEP ANGLE	CONNECTION STYLE	CURRENT	RESISTANCE	INDUCTANCE	HOLDING TORQUE	ROTOR INERTIA	WEIGHT
	DEG/STEP		A	ohms	mH	N.m	gcm^2	Kg
4	1.8	Parallel	4.2	0.375	1.1	1.24	300	0.7
		Series	2.1	1.5	4.4			
		Unipolar	3.0	0.75	1.1	0.88		

Figure 3: General specifications of the (SY57STH56-3008B) motor [7].

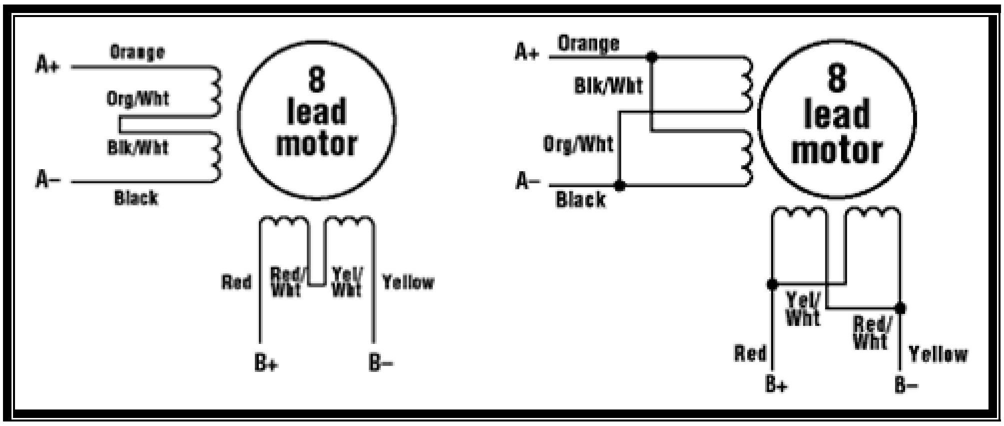
Our motor is a stepper motor of 8-wire with double winding, as unipolar motor, but with all externally terminals accessible. This allows multiple combinations of excitation, as unipolar motor uniting threes field in opposition and as the bipolar motor, windings in series or in parallel[8].

We have then, two options: to work with that stepper motors as bipolar motor and as unipolar motor:

Connection	Torque
Bipolar	1.24 Nm
Unipolar	0.88 Nm

As seen in this table, our stepper motor working as a bipolar motor gets more torque than working as a unipolar one. This is because the bipolar motor suffer a lower lost of power. That's the reason why we make the stepper motor work as a bipolar motor.

There are two ways to connect a stepper motor, in series or in parallel. A series connection provides a high inductance and therefore greater torque at low speeds. A parallel connection will lower the inductance which results in increased torque at faster speeds [9].



Series connection Parallel connection

Figure 4: Differences between a series and a parallel connection.

And as we do not want to work at high speeds, we chose a series connection for low speed and high torque.

In our case, for series connexion, we did like this.

A+ Red

A- Black

Yellow and Blue connect together and isolate

B+ White

B- Green

Orange and Brown connect together and isolate

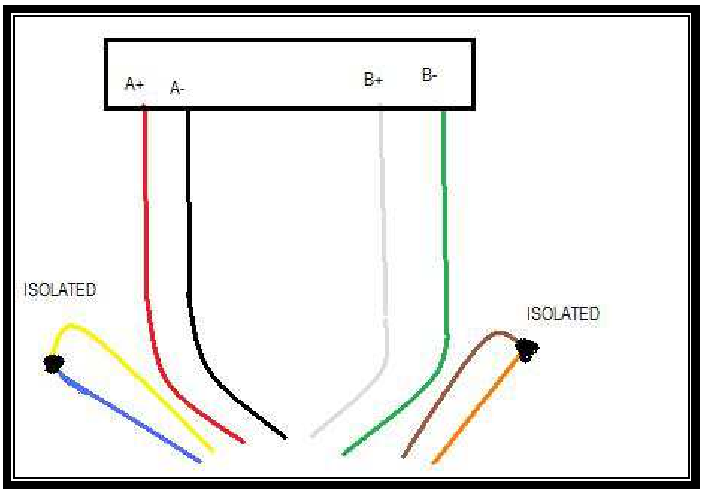


Figure 5: Example of the wires connexions.

2.4. LINEAR GUIDES OR LINEAR BEARINGS

In this section, we will describe the types of metal materials that we used in our milling machine.

To attach the three mobile cars and allow the movement on the 3 axis we used the precision ground round shaft of 10 mm of diameter in the y and z axis and of 12 mm diameter in the x axis. These pieces are bars with a very regular surface so as to facilitate the displacement over them. To make that the cars can move through these bars we have placed linear bearings with oil seal 10 and 12 mm internal diameter in respective axis. The choice of this kind of bearing is mainly because they occupy little space, so that they can be introduced inside the mobile cars, and to his good functioning when it's in contact with the precision ground round shaft reducing like this the efforts needed to be made to move all the cars.

The reason that we have chosen larger diameter bars in the x axis is to increase the bending stiffness because that axis is the axis of larger length and at the same time is the axis that supports the weight of the mobile cars and attached them to the structure.

To facilitate the movement of the cars on the timing belt we used bearings of external diameter 18 and internal diameter 6, located inside the cars. In that way the belt goes at the gear and going through these bearings will be redirected and finally fixed to the structure.

To fix the bars to the structure of the machine we used the SK-12[10] foot mounting rail support, one type of piece that will be fixed to the structure and where will be introduced and affixed the bars 12 mm of the x axis of our machine.

2.5. TIMING BELT T5

The type of belt we use to transmit the rotation of the motor to the machine and convert this circular movement in a rectilinear movement is a T5 timing belt 10 mm wide, of polyurethane reinforced with steel strings of high strength. The combination of both high quality materials form the basis of the accuracy and safety of the belts. The T5 timing belt has a 5mm metric pitch, that is to say, the distance between the teeth of the belt is 5mm; and this combined with plastic gears 8 and 10 teeth designed for this same type of belts offers the precision of movement we search for our machine.

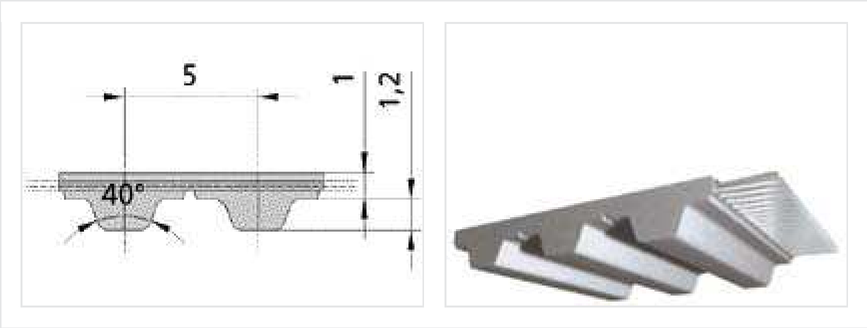


Figure 6 : Timing belt T5.

2.6. PLASTIC PARTS

In the process of building the milling machine, many times we have been in the situation that we needed specific pieces for some parts of the machine.
Normally in these cases, we didn't find the right piece for solving the problem, so we had to design and build the suitable elements in the 3D printer (explained in the following pages).

For instance:

2.6.1 GEARS

For the motors in the X and Z axis we have designed two gears of 8 teeth.
The less teeth you use, the more accuracy and the less speed you have.
Also, more force the machine will have.

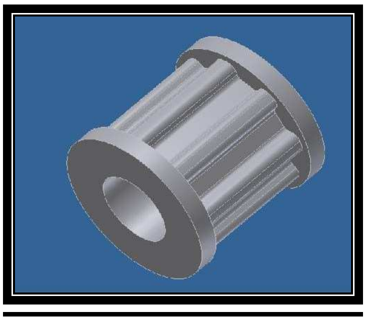


Figure 7 : 8 teeth gear.

For the motor in the Y axis we have done two gears of 10 teeth.
We have chosen 10 teeth of gear, because with less teeth it would be impossible to put the smallest bearing that exist in the fabLAB within the gear.
The bearing is 12x4x4mm. (external diameter, internal diameter, width).

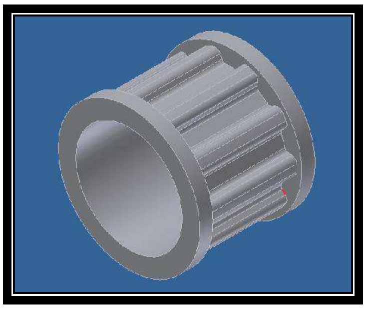
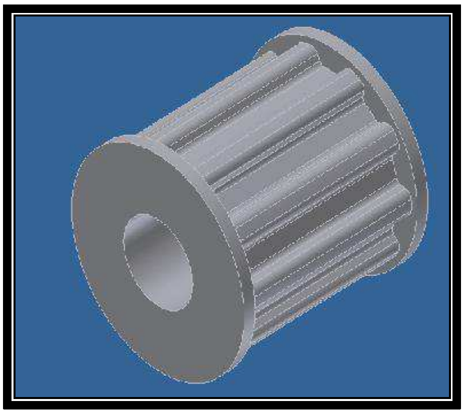


Figure 8 : Bearing within the 10 teeth gear.

Figure 9 : Bearing .
External diameter 12mm.
Internal diameter 4mm.
Widht 4mm.

In the other side of the belt, where the gear is fixed to the motor, another gear of 10 teeth.



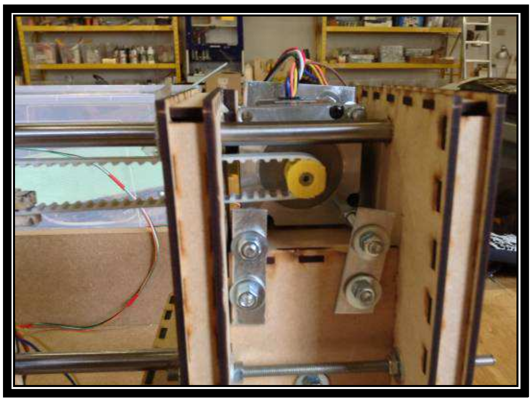


Figure 10 : 10 teeth gear.

2.6.2 BELT PIECE

To put a static belt completely tense, we designed this piece.

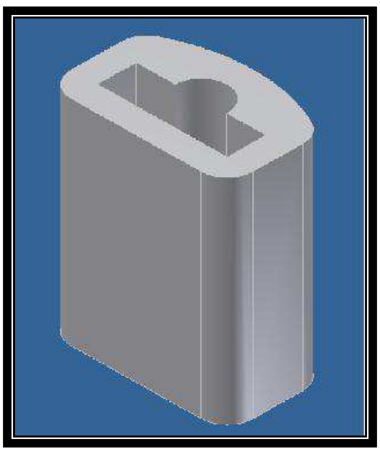


Figure 11: Belt plastic piece.

In the piece we introduce the belt and one screw, who doesn't allow the movement of the belt, and we obtain this result:

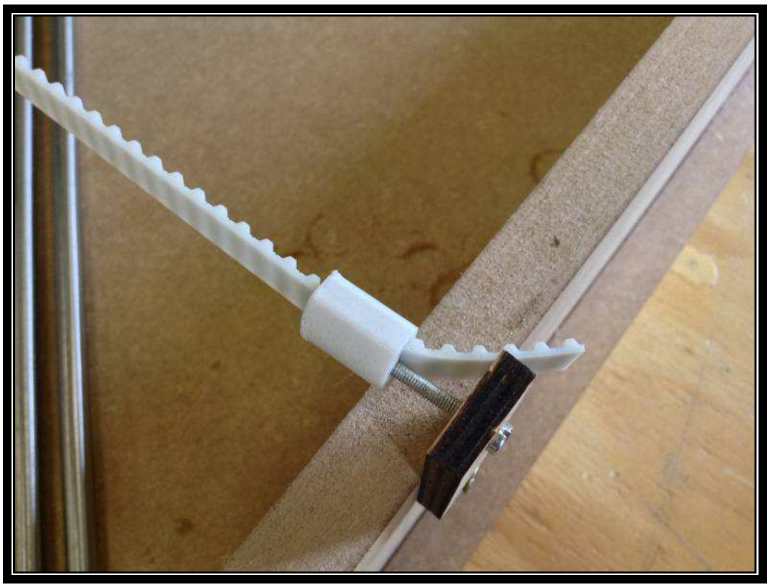


Figure 12: Real belt piece.

Figure 13: Internal block of belt piece.

2.6.3 BARS PIECE

To attach the bars to the wooden parts and don't allow the movement, first we thought about making a thread in the bar and put the nut correctly.

For sure it would be the best option, but the tools we had to make this possible were too difficult for us.

So we chose another option. We designed two pieces like this one (figure 14), and with two screws we squeeze de bar and we don't allow the displacements between the holes and the bars.

To prohibit the rotation, we added glue between the plastic piece and the wood.

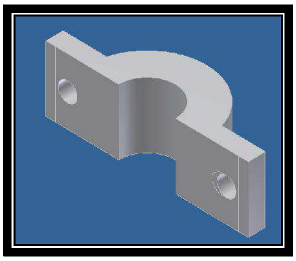


Figure 14: Bars plastic pieces.

The result of this, for instance in the base of the drill.

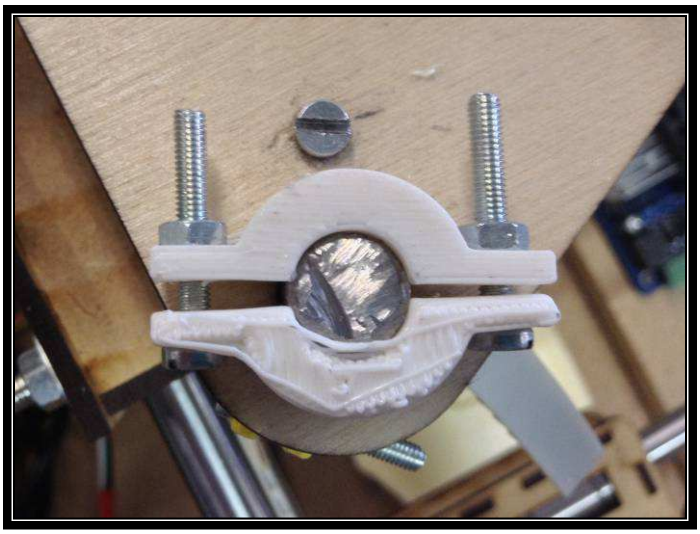


Figure 16: Plastic bars pieces in the system.

2.6.4 PULLEYS.

We designed four plastic pulleys. They are in the central car (Z axis) and in the car that allows the displacement in the X axis. They are close to the gear and where the belt is placed.

The dimensions of the pulleys are: external diameter 16 / internal diameter 14 / weidth 14.

The real bearing is inside the plastic design.
(External diameter 14 / internal diameter 5/ 5 weidth)

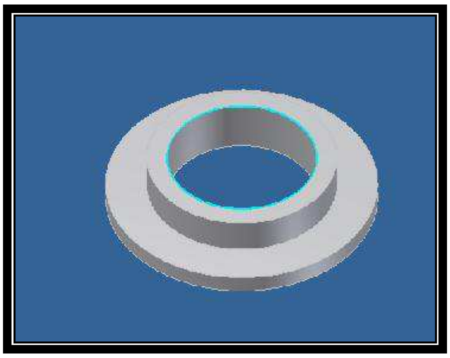


Figure 17: Bearing with the plastic support.

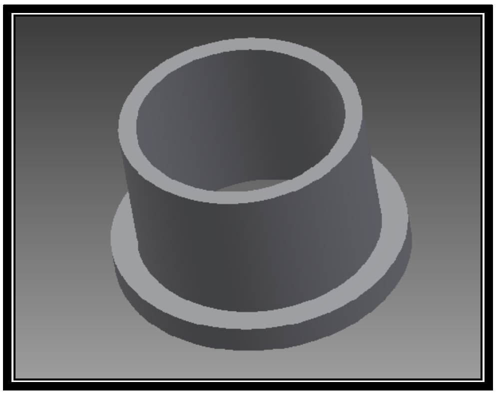


Figure 18: Bearing with the plastic support.

2.7. DRILL

The drill is an essential tool in the construction of our project. Besides being the cutting and the material removal tool when we operate with our machine, we have used it many times in the construction and installation phase of our project (for cutting or shaping metal parts or other kind of pieces ...).

The drill we use, is a rotary tool with an easy change mechanism allowing easy and fast accessory changes with a simple screwdriver. Features a variable speed high performance motor with electronic feedback circuitry that enables consistent performance at all speeds. This makes this cutter tool a very useful tool for the assembly of our project.

At the moment we have the project completed the drill becomes part of the set of our machine. The tool is placed in the wooden support we have in the center of the machine carriage and will be attached with flanges to the threaded rods that we have installed on it. From this central position is from where by putting the right accessory, operating the drill and sending the coordinates, will start cutting the material.

Figure 19: Drill.

CHAPTER 3.
TOOLS

3.1- LASER CUTTER CYBOR LS [11]

Laser cutting is a technology that uses a laser to cut materials, in this case wood of 8mm maximum. Laser cutting is a type of subtractive manufacturing that cuts a digital design file into a piece of sheet material.
A computer directs a high-power laser at the material. The material then melts, burns or vaporizes leaving an edge with a high-quality finish[12].

We have a CO2 laser cutter. CO_2 lasers are commonly "pumped" by passing a current through the gas mix (DC-excited) or using radio frequency energy (RF-excited). The RF method is newer and has become more popular. Since DC designs require electrodes inside the cavity, they can encounter electrode erosion and plating of electrode material on glassware and optics. Since RF resonators have external electrodes they are not prone to those problems[13].

Figure 20: Laser cutter.

3.2- 3D PRINTER

3D printing is a technology which makes it possible to build real objects from virtual 3D objects. This is done by "cutting" the virtual object in 2D slices and printing the real object slice by slice. Slices are printed on top of each other and since each slice has a given thickness, the real object gains volume every time a slice is added[14].

In this case, our 3D printer uses plastic as a material.

Despite there are more 3D printers in the FabLab, we have used always the MakerBot Replicator 2X[15].

Figure 21: 3D Printer Replicator 2X.

3.3- USB CNC MILLING MACHINE

The difference between USB CNC MILLING MACHINE and the laser cutter, is the first one is designed for cutting and drawing in surfaces with more thickness and stronger.

Due to we needed to cut three parts of wood of 1.8cm of thickness for the main base of our structure we were obligated on learning how to use this powerful machine.

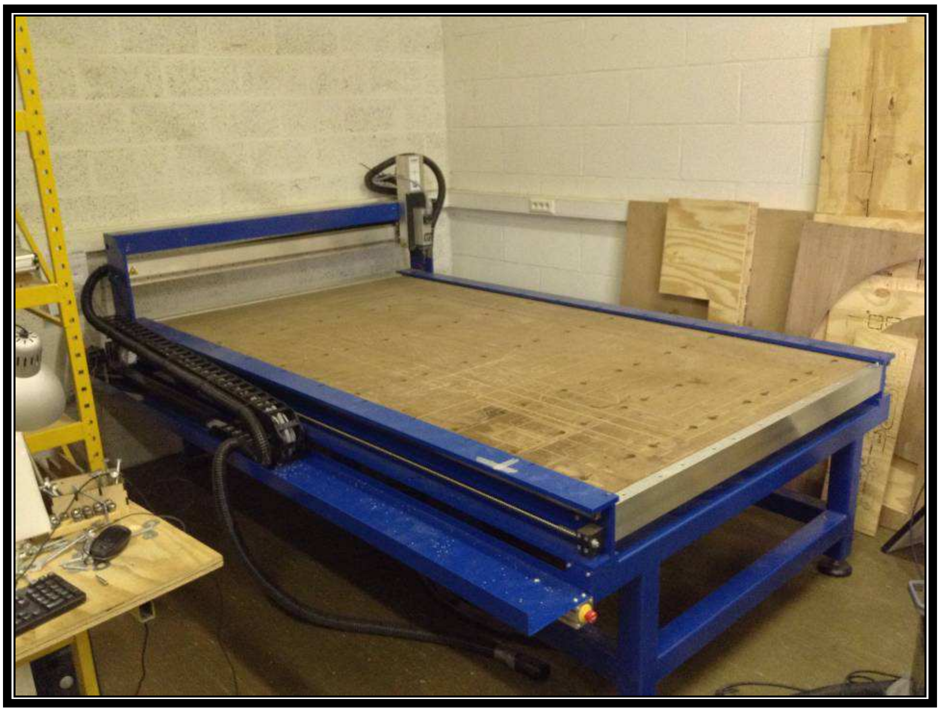


Figure 22 : USB CNC machine.

3.4- DRILL PRESS

Drill presses allow you to drill holes in metal, wood and a variety of other materials more precisely and conveniently than you could with a handheld drill. They also provide more power to drill through tough materials. The stationary bit provides accuracy and control, allowing you to drill at perfect right angles and make consistent repetitive holes. Optional accessories also make this machine quite versatile, so you can use your drill press for such diverse tasks as sanding, mortising, buffing, grinding and shaping[16].

Figure 23 : Drill press.

CHAPTER 4.
HARDWARE

4.1- ARDUINO UNO

Arduino is an open-source physical computing platform based on a simple i/o board and a development environment that implements the Processing/Wiring language. Arduino can be used to develop stand-alone interactive objects or can be connected to software on your computer[17].

Features**:**

- ATmega328 microcontroller
- Input voltage - 7-12V
- 14 Digital I/O Pins (6 PWM outputs)
- 6 Analog Inputs
- 32k Flash Memory
- 16Mhz Clock Speed

In our CNC system, Arduino Uno is going to be the responsible of translating the GCode (CNC language) and sending the correct signals of DIR and STEP to the stepper motor controller board, wich is going to control the stepped motors due to Arduino Uno signals.

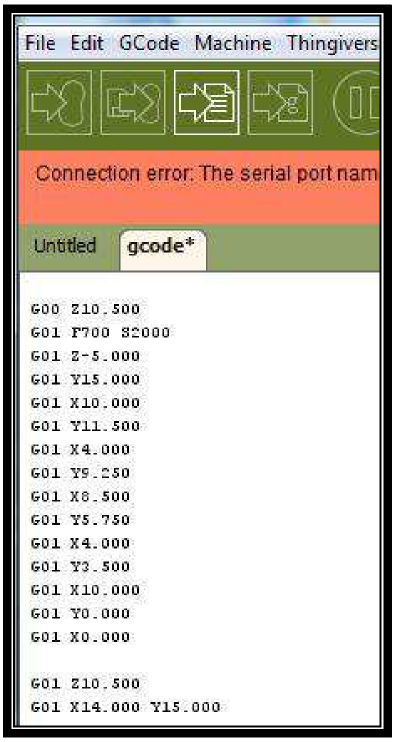


Figure 24 : Example of Gcode in ReplicatorG

In conclusion, Arduino Uno sends a pulse to STEP, a pulse to DIR, and a pulse to RESET to de board.

The pins we are going to use:

-5V: This pin outputs a regulated 5V from the regulator on the board. The board will be supplied with power of the USB connector (5V).
In that pin we will connect the Enable pin of the motor.

-GND: Ground pins.

-PWM: Write an analog value in a PWM pin. Can be used for controlling the speed of a motor. Frequency 420 Hz. In this pines we will put de DIR of the motor

-NO PWM PINS: They will be used for the STEP pins of the motor.

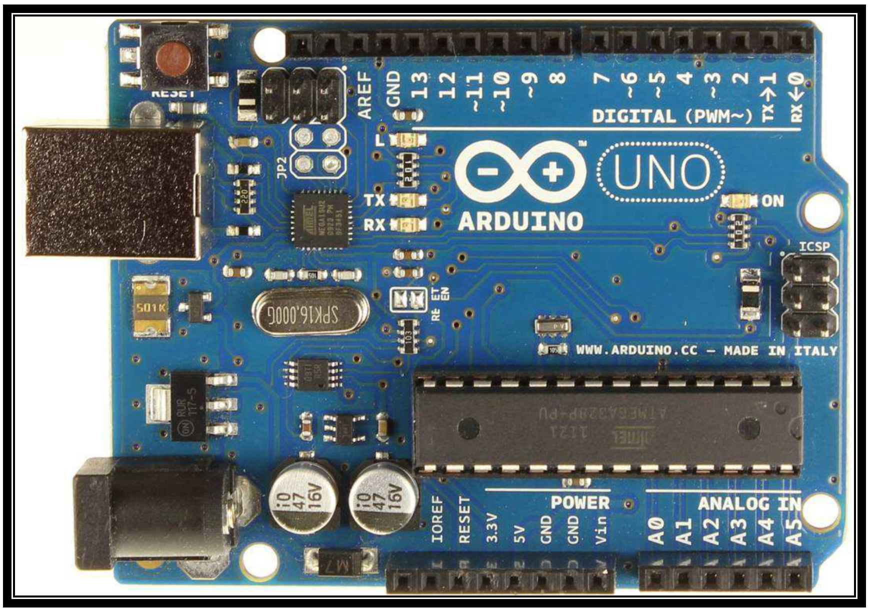


Figure 25 : Ardouino UNO Board.

4.2- STEPPER MOTOR CONTROLLER BOARD

The board's function is controlling the stepper motors.

We will connect the three stepper motors in the board, in the three axis: X,Y,Z.

In each, we have a connector with four cables inside. In our bipolar SERIES mode we have:

A+: positive of reel one
A-: negative of reel one
B+: positive of reel two
B-: negative of reel two

After that, we will connect this board to Arduino UNO with a SUBD25 pins.

When Arduino UNO sends a pulse to STEP, the motor will move forward one step. DIR receives the signal 5V, the motor will spin in the clockwise sense. If receives 0V signal, it will spin in anti clockwise sense.

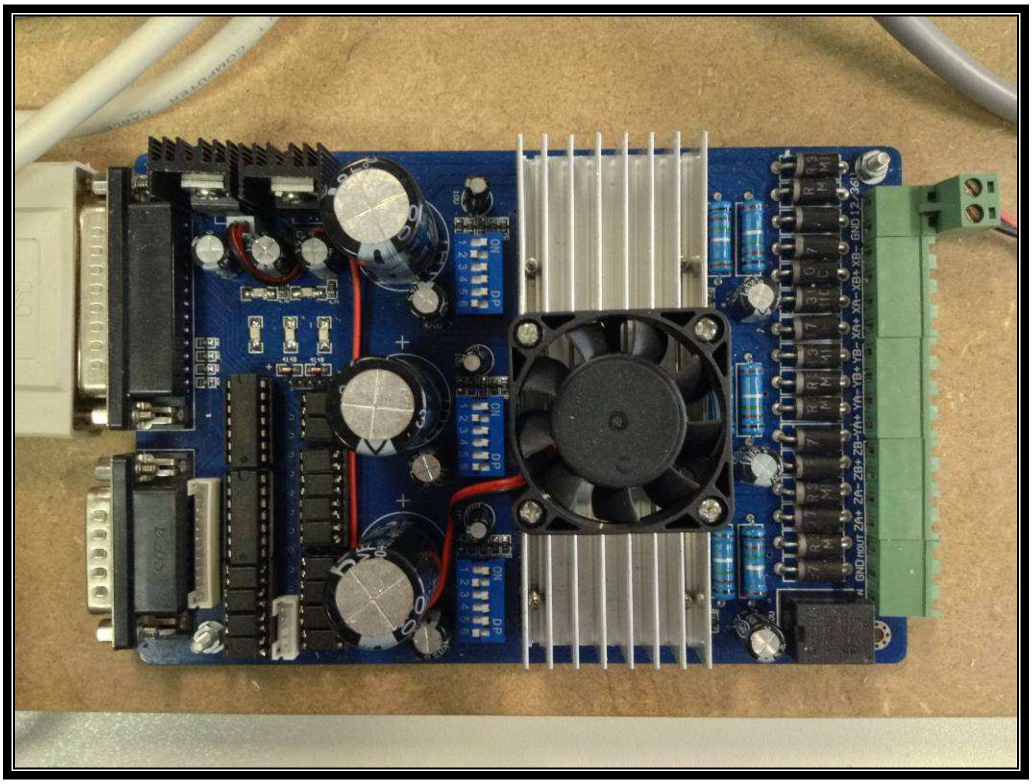


Figure 25 : Stepper motor controller board.

4.3- POWER SUPPLY

A power supply is a device that supplies electric power to an electrical load.

In our case we connect directly the power supply to the 12/36 V DC 2 pin connection of the board.

This power supply is made with voltage regulation. This property allows us to have a constant voltage level. It is very important protect the electronic devices of a power surge.

OUTPUT	12V	15A	180W

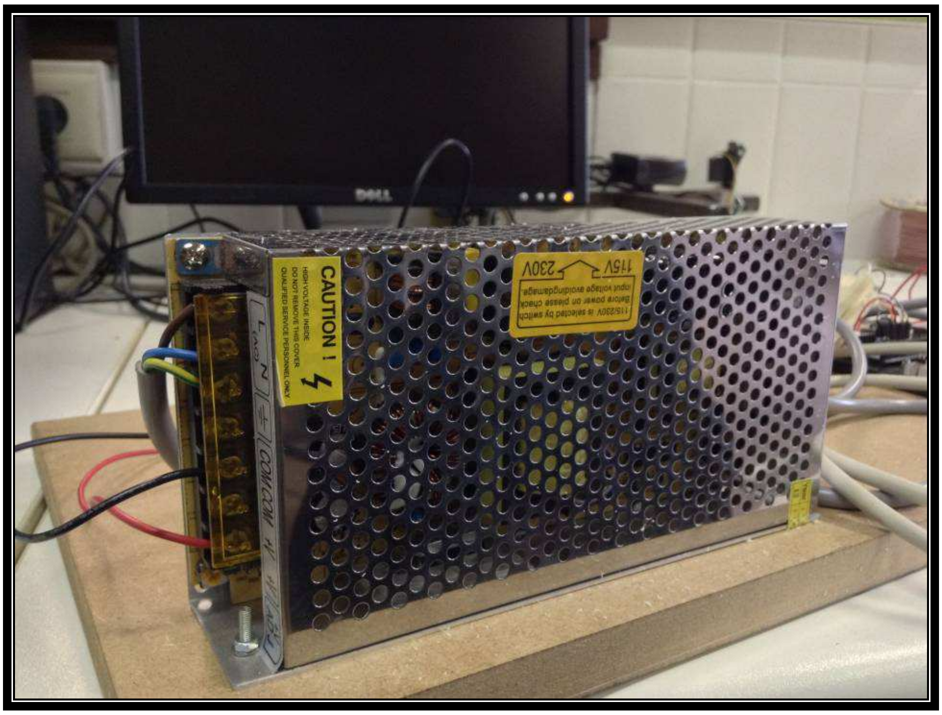


Figure 27: Power supply.

CHAPTER 5. SOFTWARE

5.1 AUTOCAD:

The Autocad is the program we have used to design all the wooden pieces (the cars, the structure, the support of the dremel and of the belt…) that after we have built with the laser cutter or the USB CNC machine.

Also with this program we have created the draw from which we calculated the g-code and that after will be engraved with the machine.

5.2 INVENTOR AUTODESK

The Inventor Professional is the 3D design program that we used for the design of all the pieces of plastic found in our machine. Also with this program we have created the model from which we calculated the g-code and that after will be engraved with the machine.

All files we have created with this program, we have saved in STL format (stereolithography). This is because in order to print a 3D printer model must be generated before the corresponding STL format. An STL file describes a raw unstructured triangulated surface by the unit normal and vertices (ordered by the right-hand rule) of the triangles using a three-dimensional Cartesian coordinate system[18].

5.3 DESKPROTO:

The DeskProto is the program that we used to get the g-code or figure drawing we want our machine later make. The procedure is to open a STL file we previously designed in Inventor Professional. Set the position and size you want it to go our piece at the base of our machine. Choosing the type of machine with which we will work (in our case we chose plain ISO G-codes mm), type of cutting tool (in our case will be 1mm diameter spherical) and the depth at which we want the tool to arrive. And finally choose the speed and precision in both, devastated and finishing operation.

In this way we will calculate the G-code of the figure that we want to create.

5.4 REPLICATOR G:

The Replicator G is the program where we introduce the G-code which we have previously calculated with DeskProto. Then we connect the program with the Teacup Firmware of Arduino UNO, so we will be connecting the machine with the Replicator G.

And finally pushing the build button the machine will start to make the model.

CHAPTER 6.
DETAILED DESCRIPTION AND ASSEMBLY

6.1 MECHANICAL PART

In essence the mechanical part of the milling machine consists in:

6.1.1 MOBILE PARTS

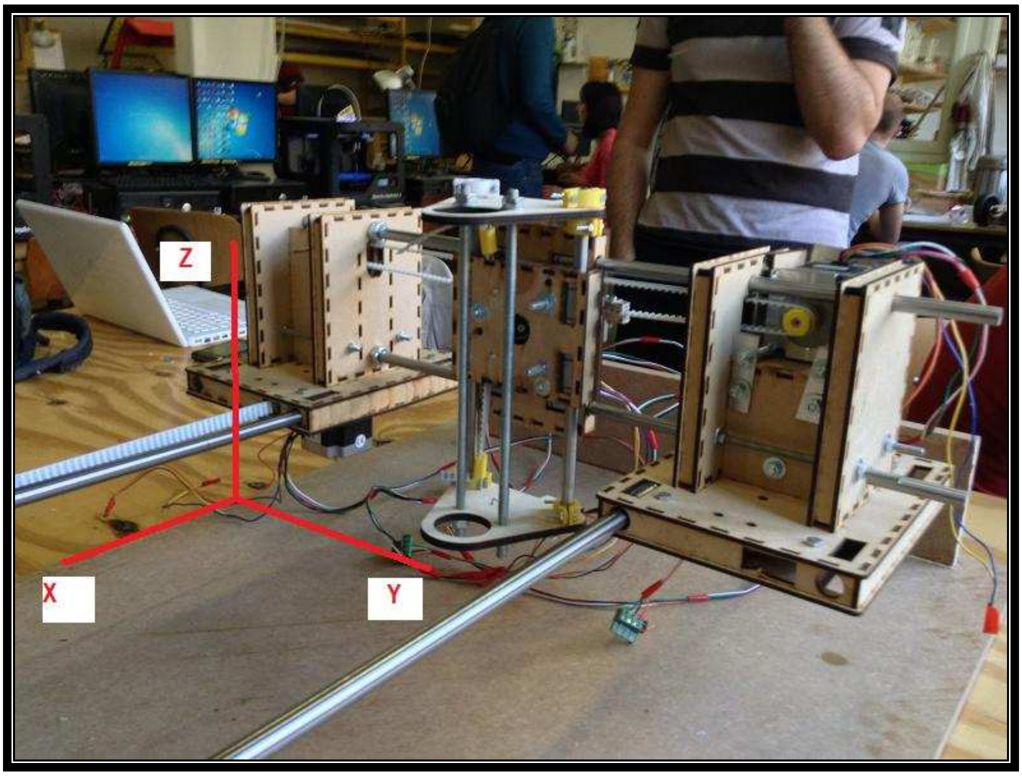


Figure 28: Axis of the small milling machine

6.1.1.1 CENTRAL CAR

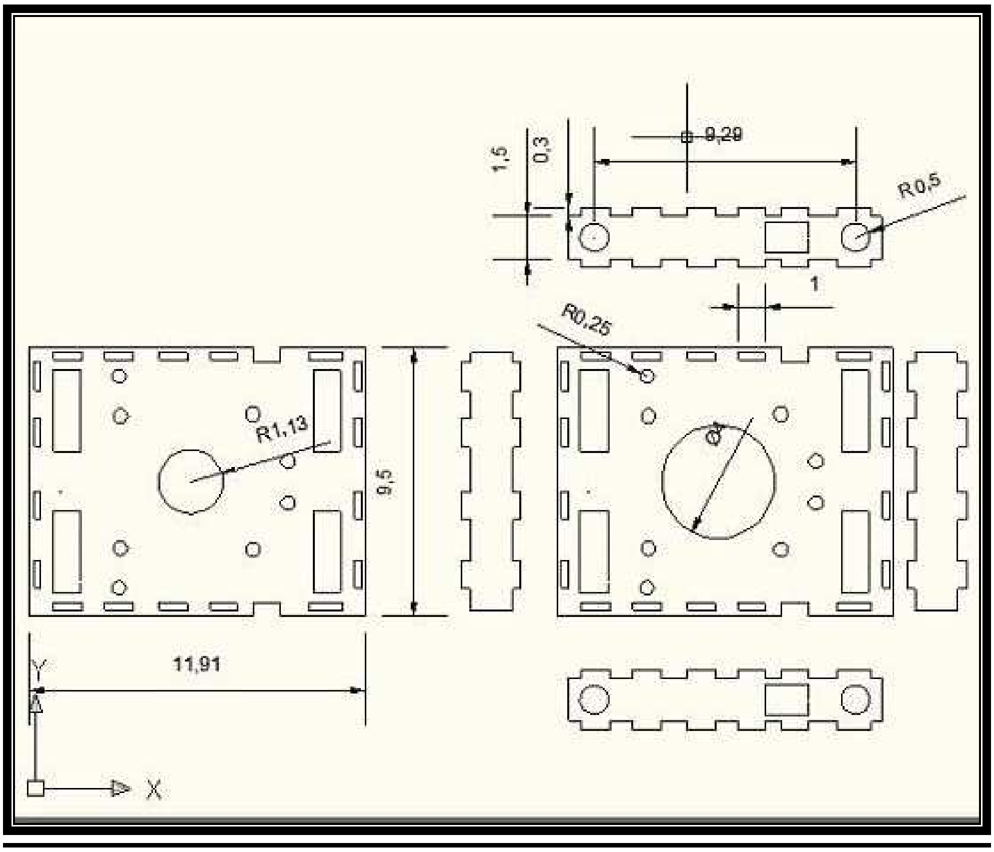
This car can move in the Z axis for the drill, and in this case the drill travel is from 0mm to 55mm. The bars of Z axis are of 10mm. The motor that makes possible de movement on the Z axis is attached by four screws.
The belt of the Z axis is attached to belt plastic pieces with an screw.

The drill is placed in the below hole and attached to the screw bars of 8mm with two bridles.

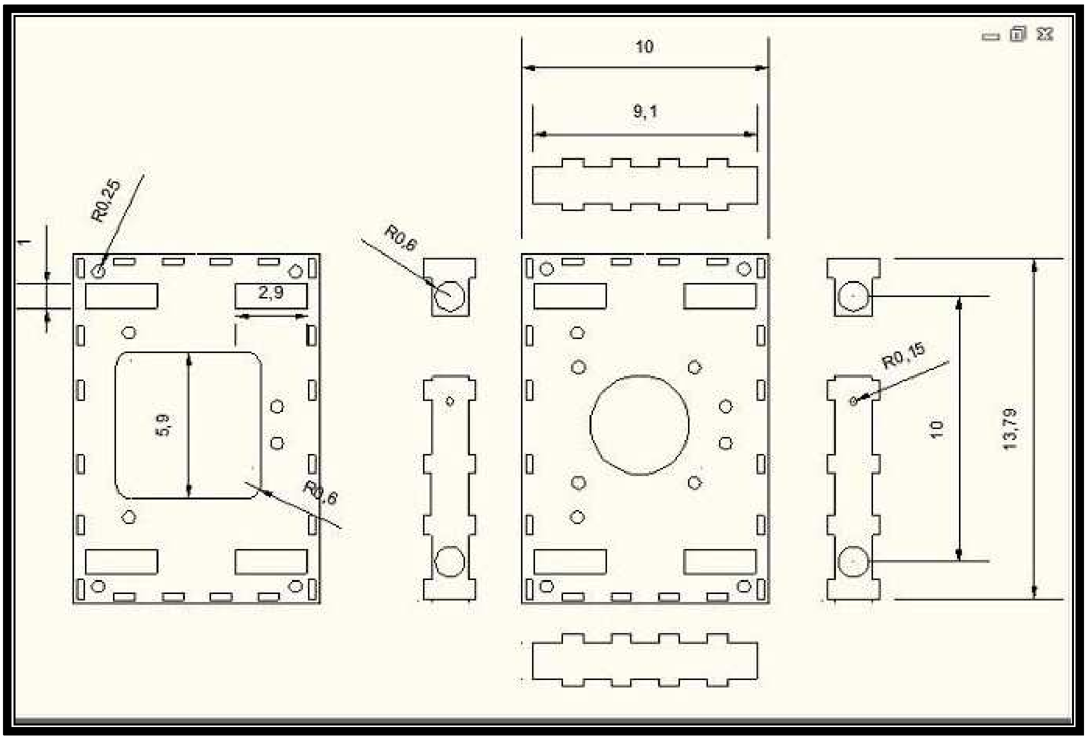
Also, the central car displace in the Y axis between the two lateral cars due to the two bars of 10 mm. In this axis the car allows 140mm of lateral displacement.

The belt that allows the Y movement is attached in the central car by a metal system where the belt is captured between two pieces of wood tighted by one screw.
The thickness of the wood is the appropriate for guarantee the parallelism of the belts.

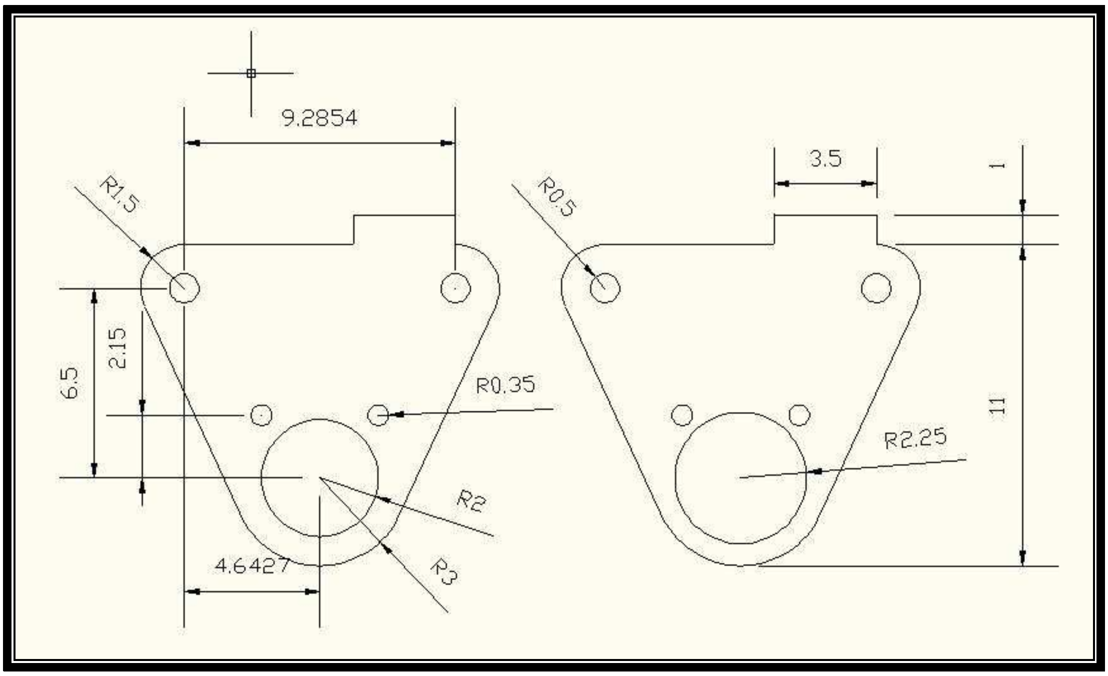
These are the plans of the central car, and also of the support of drill.



Figures 29: Central car plan.



Figures 30: Central car plan.



Figures 31: Plan of the support of the Drill.

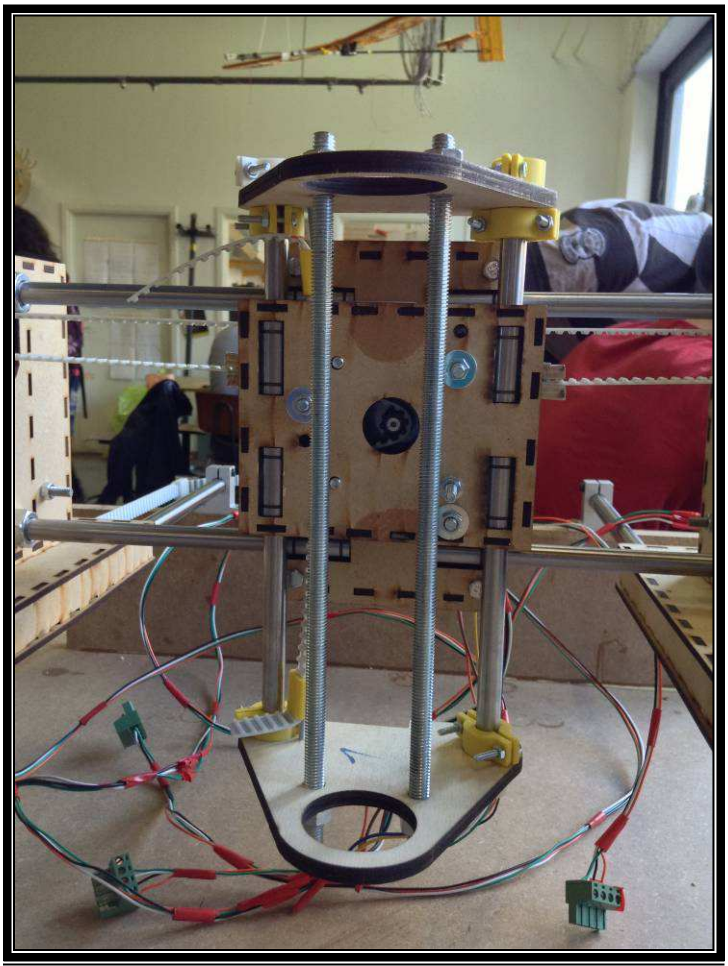


Figure 32 : Central car assembled.

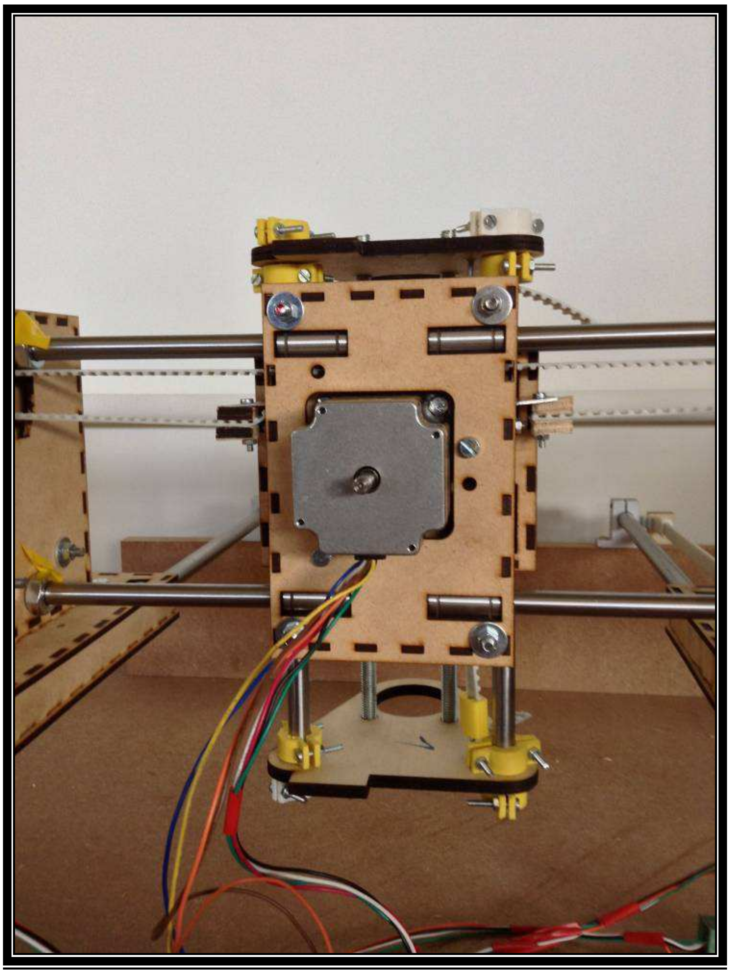


Figure 33 : Central car assembled.

6.1.1.2 LATERAL CAR ONE

In this lateral car is placed the stepped motor in the lower part of it. The function of this motor is moving the car in the X axis. It is screwed into the below wood plate.

The upper wooden supports are in charge of two functions. On the one hand they hold up the bars that allow the lateral displacement of the central car.
On the other hand, between them is placed the 10 teeth gear. Around the gear is assembled the belt of the central car that transform the circular movement into a linear movement.

The 10mm bars are attached in the wooden supports outwardly by the plastic pieces explained and showed in the “material parts” chapter.
Internally they are attached by welded nuts to the bars and in the same time to the wooden supports.

The X axis allows 500 mm of movement.

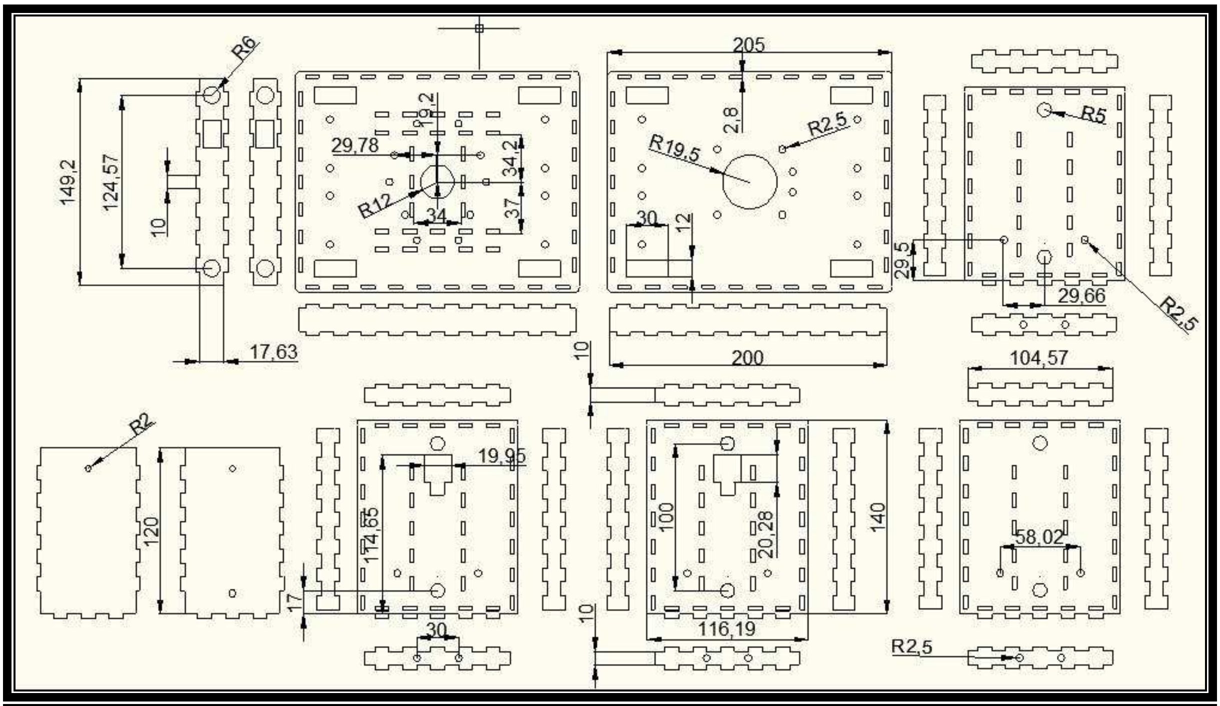


Figure 34 : Plan of lateral car one.

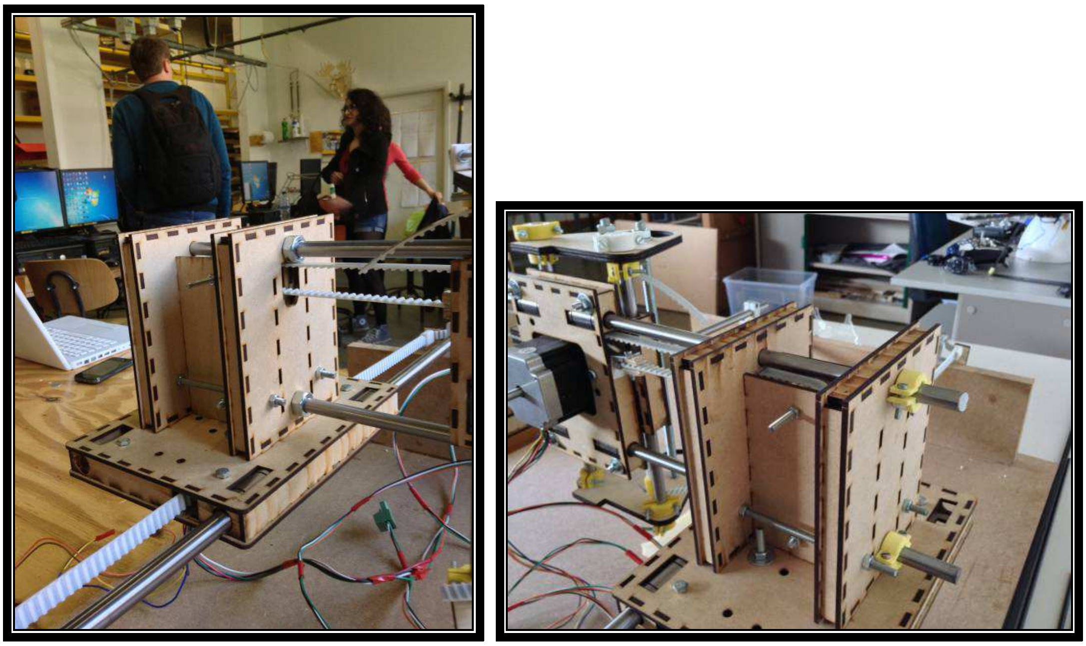


Figure 35 : Lateral car one assembled.

6.1.1.3 LATERAL CAR TWO

The design of this car is basically the same that the other lateral car.

The main difference resides in the wooden box we have created. Over this box it is located the third motor outwardly, between the two wooden supports where the bars of the central car are attached.
This wooden box allows the rotational axis of the motor stays at the same altitude than the rotational axis of the "gear-bearing" group placed in the other lateral car.

That motor is attached by some screws and some metal plates that prohibit totally the movement.

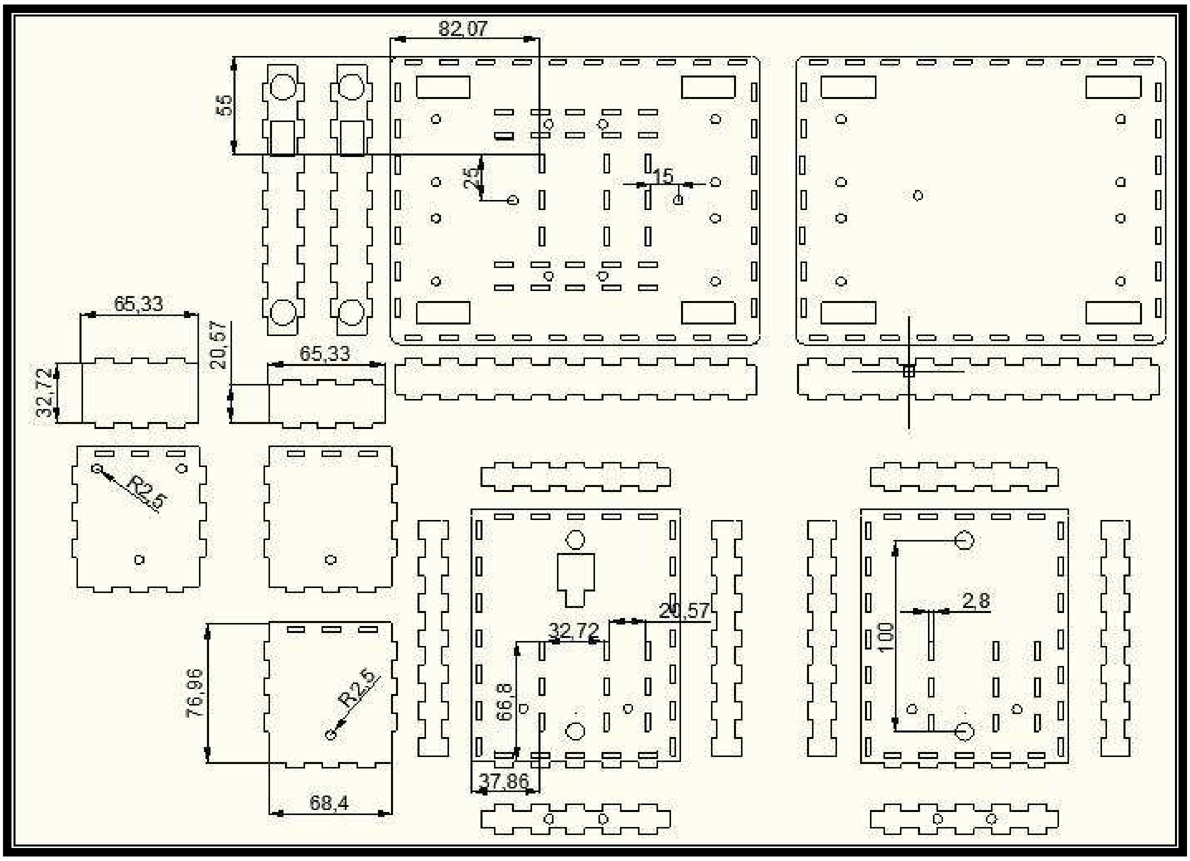


Figure 36 : Plan of lateral car two.

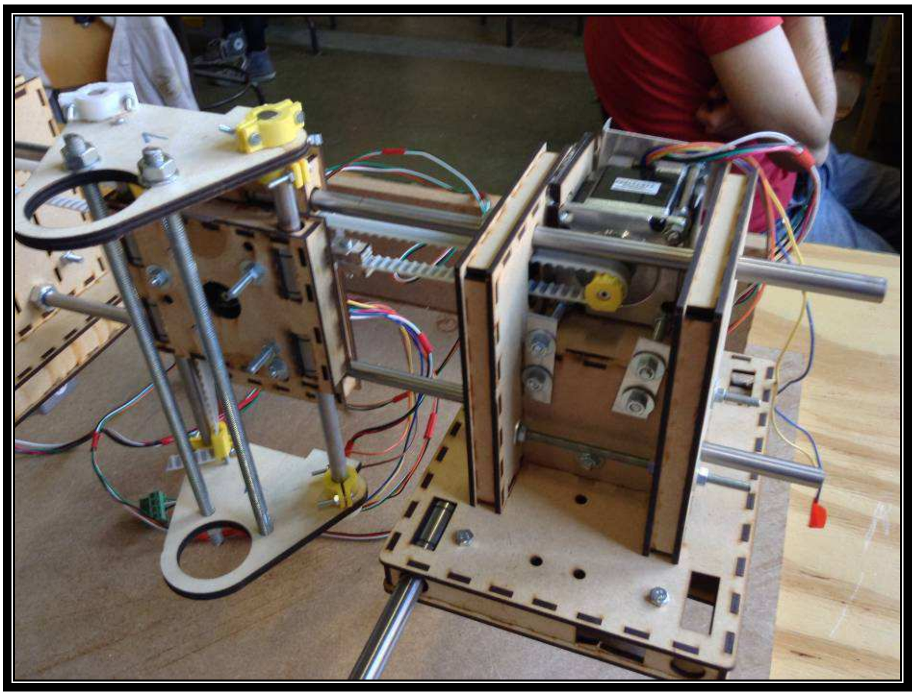


Figure 37 : Lateral car two assembled

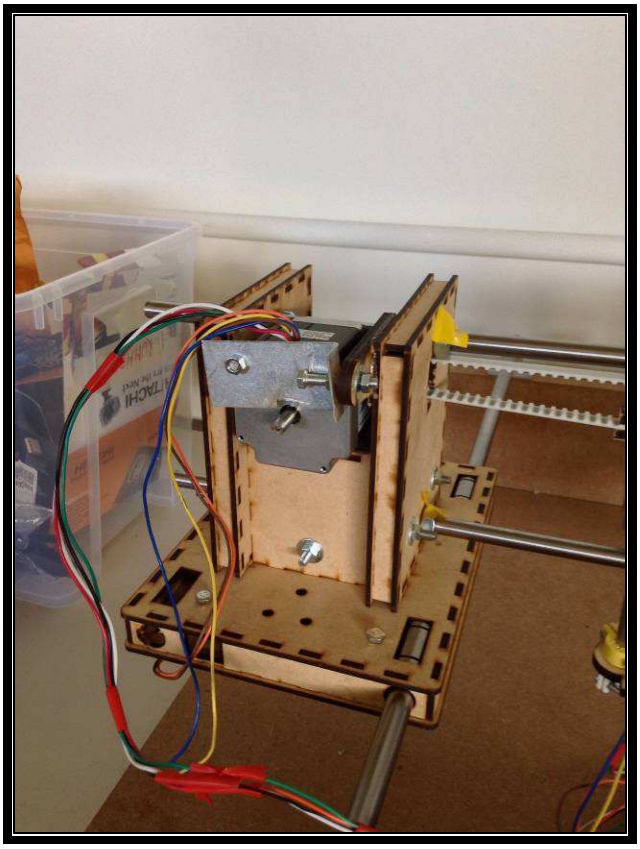


Figure 38 : Lateral car two assembled.

6.1.1 STATIC PART

We refer now to the bench of the milling machine.

The base is made by a MDF of 800mm x 650mm, with 18 mm of thickness.

Over it is placed the polyurethane (XPS) vehicle registration plate to be milled.

Also there is two pieces of the same MDF of 120mm x 550mm, with 18 mm of thickness in charge of holding weight of the milling machine with the two bars of 12mm. Over them the machine moves in the X axis.

The bars are fixed in the following metallic piece (sk-12 foot) squeezing a screw.

On the other hand the metallic piece is fixed to the wooden bench part by a lag-screw.

Just like that, the belt is stretched because of the plastic piece explained in the "material parts" chapter.

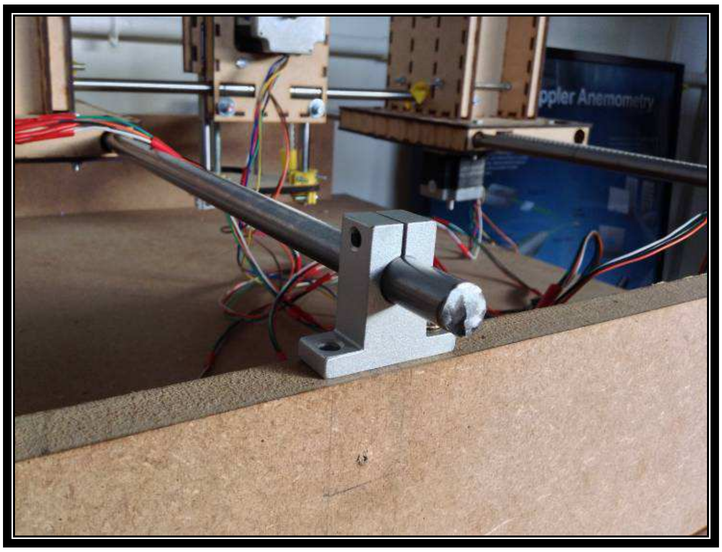


Figure 39 : Bars attached with the metallic piece Sk-12 foot.

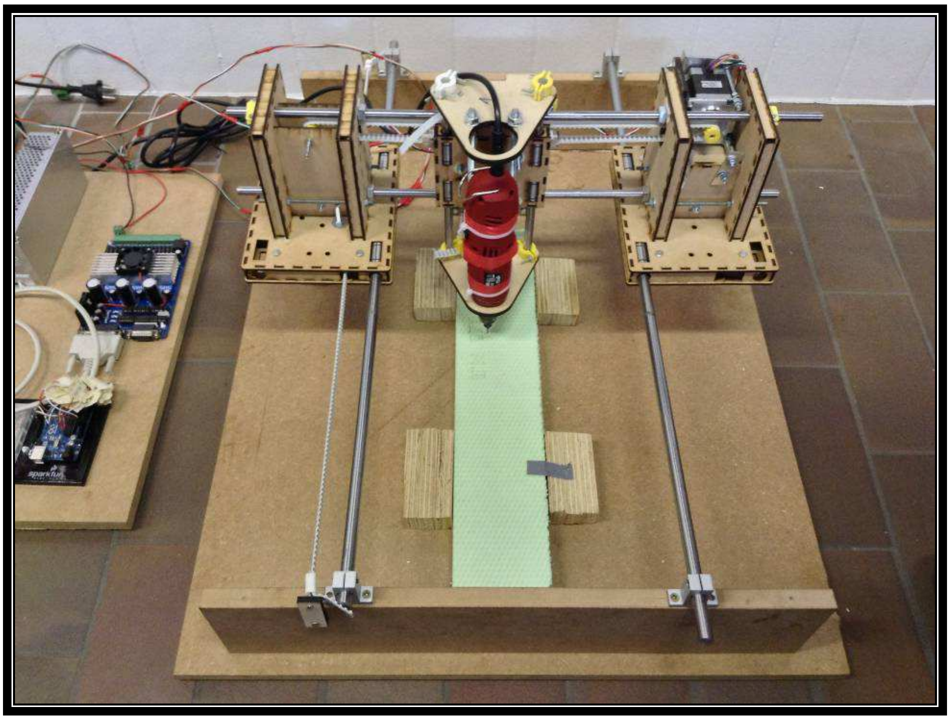


Figure 40 : General view of the bench.

The result of the small milling machine once assembled:

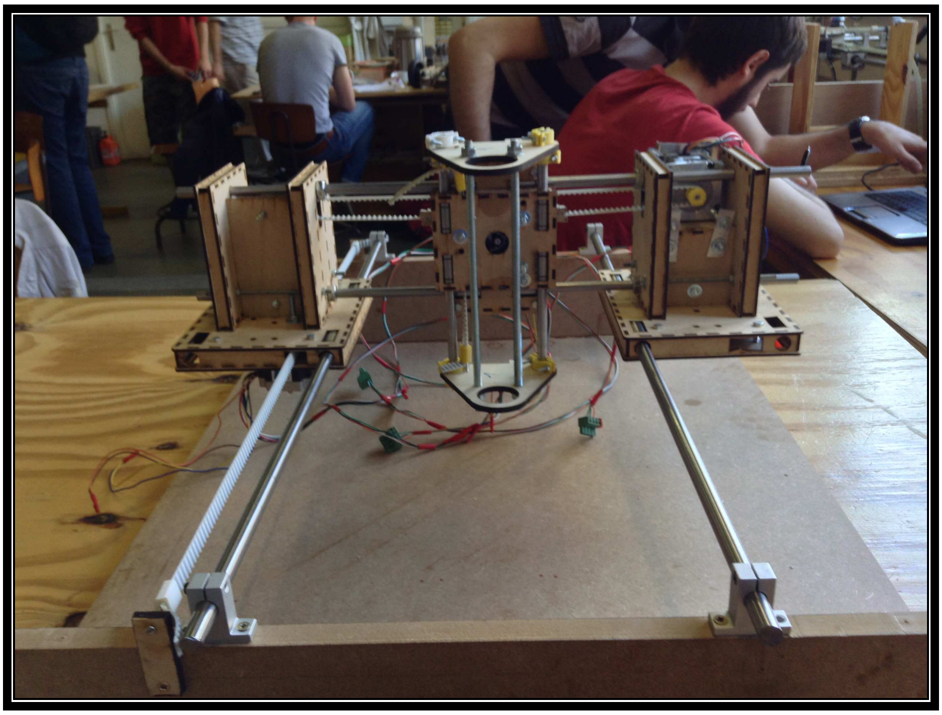


Figure 41 : General view of the SMALL MILLING MACHINE.

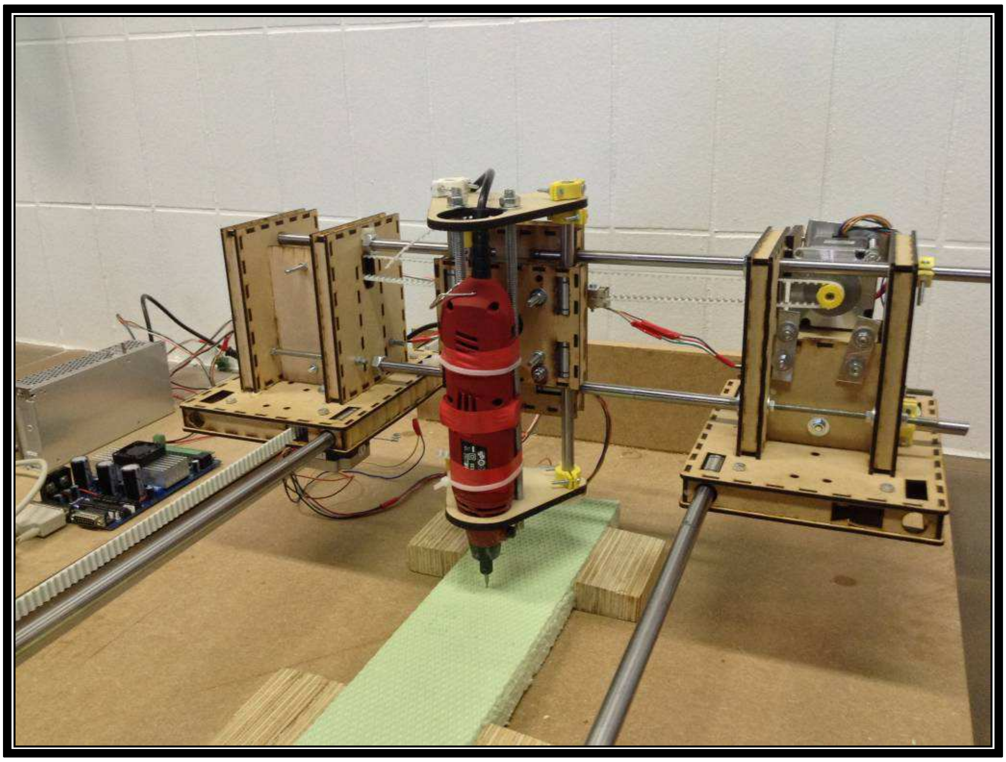


Figure 42 : General view of the SMALL MILLING MACHINE.

6.2 ELECTRONIC PART

Like we have said before, for the electronic part of the thesis, we count with the power supply, the stepper motor controller board, and the Arduino UNO.

We have decided to assembly the whole electronic system separated of the mechanic parts. In our own is more comfortable in the transportation.

The result is the next:

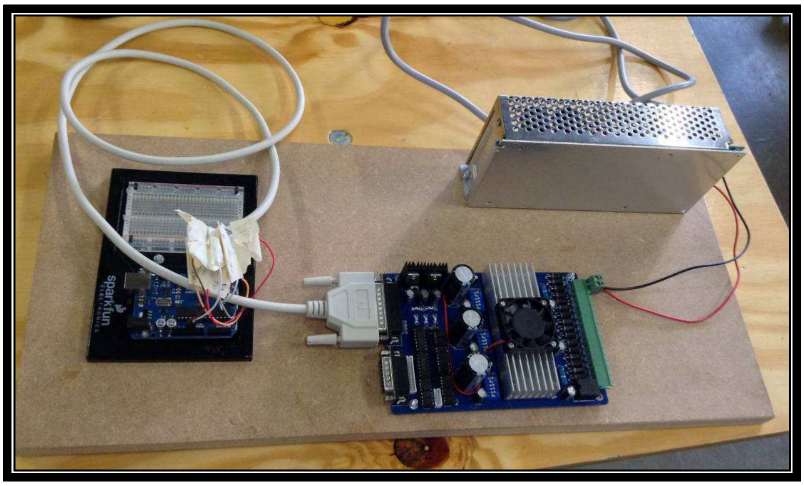


Figure 43 : General view Electronic system.

First of all, we talk about the power supply of 12/36V.
We have taken a power cable, we have peeled and we have connected to the ground, N (neutral), L (line) of the power supply.

After that, we have taken out two cables V+ and COM, and we have connected correctly to the ground of the stepper motor controller board.

In the board are connected as well the three stepper motors we have, in the appropriate way into the X,Y,Z inputs corresponding to the axis.

The connexion between the board and the Arduino UNO we have done with a 25 pin connector.

On the manual of the stepper motor controller board, we have located the necessary pins for our connexions.

These they are:

PIN 7	X DIR
PIN 1	X STEP
PIN 3	Y DIR
PIN 8	Y STEP
PIN 4	Z DIR
PIN 5	Z STEP
PIN 14	X ENABLE
PIN 2	Y ENABLE
PIN 6	Z ENABLE

After that we have located the Ground pin.

Afterwards, on the other side of the 25 pin connector we have found the previous pins with the continuity verification using a multimeter, and we have connected into the Arduino UNO as follows.

The three enables of the each axis, we have welded together, and we have introduced with a wire pin into the 5V slot of Arduino UNO.

The Ground cable we have put corresponding to the GND slot in Arduino UNO.

With the STEP and DIR pins of each axis, we have behaved as follows.

All of them we have placed in the Digital part of the Arduino UNO board.
The important thing is the DIR pins we have put in the PWM slots, whereas STEP pins we have inserted on the others digital slots.

In conclusion, this is the result of the connexions in the Digital outputs:

X Dir	Pin 3 (PWM)
X Step	Pin 2
Y Dir	Pin 5 (PWM)
Y Step	Pin 4
Z Dir	Pin 6 (PWM)
Z Step	Pin 7

Here some pictures about the connexions:

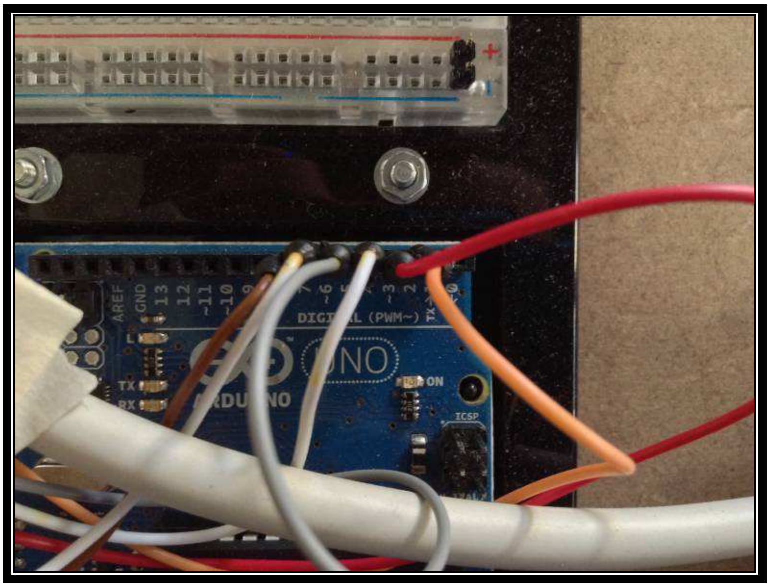


Figure 44 : DIR and STEP connexions.

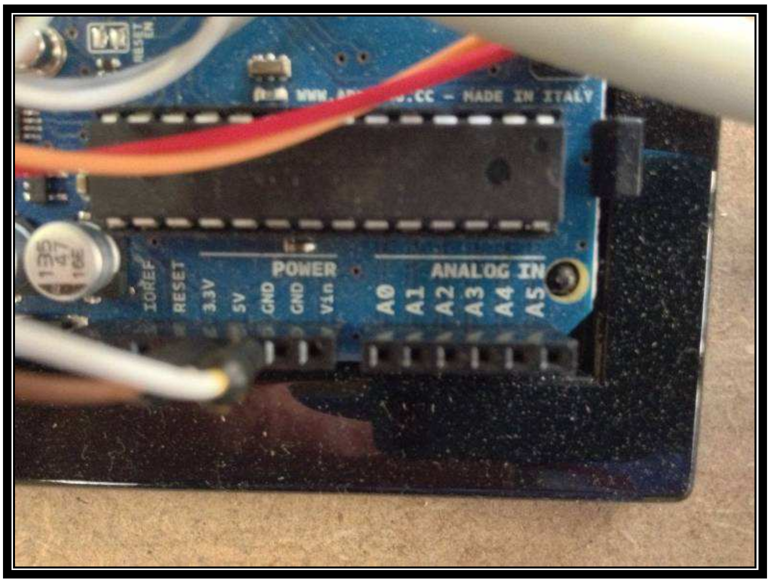


Figure 45 : GND and ENABLE connexions.

6.3 FIRMWARE

The firmware we have used is “Teacup_Firmware”.

Once opened, we open the “Config_h” tab. Here we adjust the values in order to make possible the correctly operation of our milling machine.

The most important values to change are:

- The STEPS_PER_M in all axis in order to get the values of displacements we put in our firmware, be the same than the movement we see in our cars of the milling.

In other words, they are the necessary quantity of steps that takes our stepper motor, to get a 1 metre movement of the belt.

We have calculated the values with this method:

"(steps per motor turn) / (number of gear teeth) / (belt module) * 1000 "

These are our final values:

#define STEPS_PER_M_X	10000
#define STEPS_PER_M_Y	8000
#define STEPS_PER_M_Z	10000

- The Feedrates. They are the speed with which the stepper motor controller board will feed our motors.

After some verification, we have chosen these values. The same values, because of the Motors are the same in every axis.
The units are mm/min.

#define MAXIMUM_FEEDRATE_X	800
#define MAXIMUM_FEEDRATE_Y	800
#define MAXIMUM_FEEDRATE_Z	800
#define MAXIMUM_FEEDRATE_E	800

- Assign the pins in Arduino UNO in relation with the connexions we have made.

#define X_STEP_PIN	DIO2
#define X_DIR_PIN	DIO3
#define X_MIN_PIN	AIO0
#define Y_STEP_PIN	DIO4
#define Y_DIR_PIN	DIO5
#define Y_MIN_PIN	AIO1
#define Z_STEP_PIN	DIO7
#define Z_DIR_PIN	DIO6
#define Z_MIN_PIN	AIO2

#define E_STEP_PIN AIO3

#define E_DIR_PIN AIO4

#define PS_ON_PIN AIO5

Because we are not using the extrude parts, we don’t care about these parts we find in “Teacup_firmware”

CHAPTER 7.
RESULTS.

First we designed this draw in AutoCad, with the appropriate size for the vehicle registration plate:

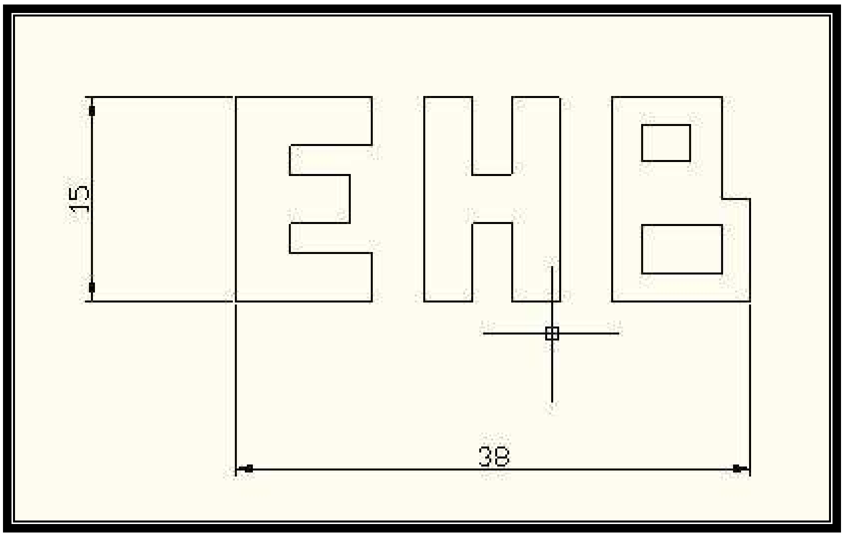


Figure 46 : AutoCad design in mm.

We have recorded two videos about the milling machine working.

The first one is a test with a 2mm knife, and with the same design that we showed before, but wit a double size.

http://www.youtube.com/watch?v=LfbALJTTrt8

The second one is the final test with the 1mm knife, with the sizes of the design we have showed before.

http://www.youtube.com/watch?v=3BVaEdNM2jY

After generating the code in Deskproto, and start milling with the ReplicatorG program, we have this result respecting the original size and with a good accuracy.

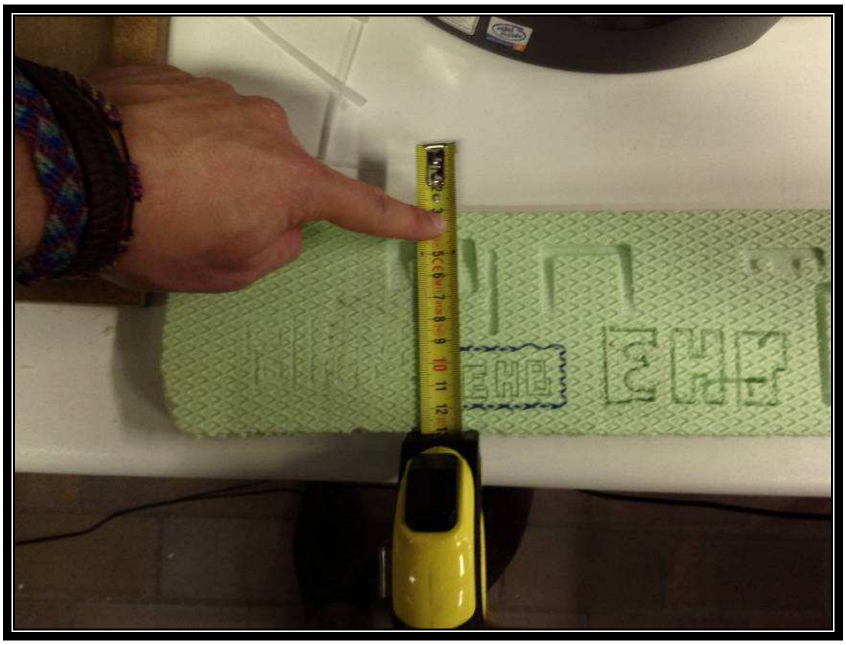


Figure 47: Final result in the vehicle registration plate.

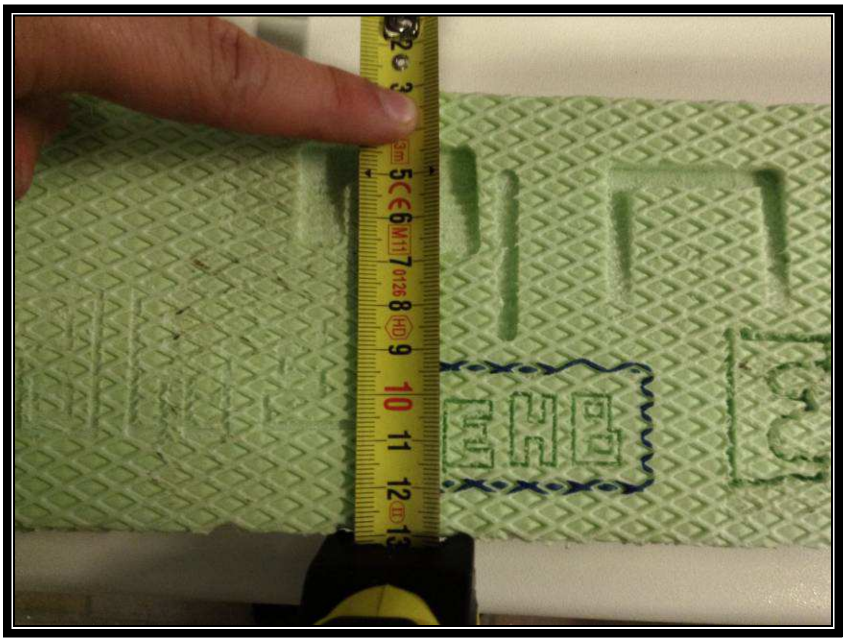


Figure 48 : Final result in the vehicle registration plate.

Finally, this is the generated CODE to mill the design:

```
G00 X-3.000 Y-3.000 Z10.500

G01 F700 S2000
G01 Z-5.000
G01 Y15.000
G01 X10.000
G01 Y11.500
G01 X4.000
G01 Y9.250
G01 X8.500
G01 Y5.750
G01 X4.000
G01 Y3.500
G01 X10.000
G01 Y0.000
G01 X0.000

G01 Z10.500
G01 X14.000 Y15.000
G01 Z-5.000
G01 Y0.000
G01 X17.500
G01 Y5.750
G01 X20.500
G01 Y0.000
G01 X24.000
G01 Y15.000
G01 X20.500
G01 Y9.250
G01 X17.500
G01 Y15.000
G01 X14.000

G01 Z10.500
G01 X27.500
G01 Z-5.000
G01 Y0.000
G01 X37.750
G01 Y7.500
G01 X35.250
G01 Y15.000
G01 X27.500

G01 Z10.500
G01 X30.000 Y13.000
G01 Z-5.000
G01 Y10.000
G01 X33.500
G01 Y13.000
G01 X30.000
```

```
G01 Z10.500
G01 Y2.000
G01 Z-5.000
G01 X35.250
G01 Y5.500
G01 X30.000
G01 Y2.000
G01 Z10.500

G01 X0.000 Y0.000
```

CHAPTER 8. CONCLUSIONS

The objective of the realization of this final project was designing and building a machine for milling in a vehicle registration plate. Following all the steps described above and in view of the results we can say that we have succeeded. Therefore, the machine can work fairly accurately in the areas of work that we were asked for.

In addition, with the attainment of this project we have seen that the realization of a homemade and economical CNC machining center is feasible from the guidelines and resources they have given us this academic year, obtaining a milling machine useful and valuable application.

At first we thought it was necessary to use two bars on the X axis but finally we realized that the stability was reasonably good with only one bar in each car, saving like this material.

After the results, it can be seen that the axis X is the one that works with less efficiently. This could be fixed by adding another bar with bearings in the car in which the motor is located to increase the friction in that car.

Another way to solve this would be to decrease the distance between the two cars of the X axis or increase the diameter of the bars on the y axis of the machine increasing like this the bending stiffness of the machine.

CHAPTER 9. REFERENCES

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