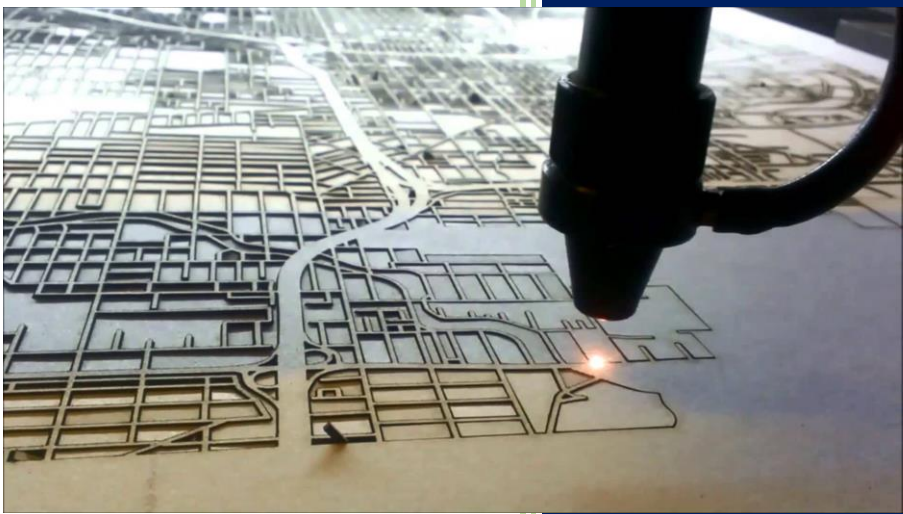
Final report

EXPO 22



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Foreword

This report is the third report of the EXPO22-project Laser Cutter. The EXPO-team consists of 6 second-year mechatronics students of Fontys Hogeschool Engineering Eindhoven, the Netherlands.

This report was made for everyone who would like to know about the progress of the project group building the laser cutter. It is also written for people who like to know how the laser cutter is made This report is based on university of applied science knowledge, but is also very well readable for people with general technological knowledge.

To get a small overview of this project, you can read the summary at the next page. You can find the table of contents after the summary, if you wish to read more specific information.

We, as a team, would like to thank our tutor Chris Remmers and Pavel Samalík, for there technical and group process support throughout the project. We also would like to thank all of the people who supported the project, both inside and outside of Fontys. With special thanks to our sponsors:

- Stichting STHO
  For trusting in this project and financially supporting the team
- TechQ s.r.o.
  For trusting in this project and supply parts to implement the laser cutter
- www.openbuilds.org
  for sponsoring a huge amount of materials to create the entire frame for this project frame.

Eindhoven, march 30, 2016, team Laser Cutter.

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Summary

In the expo projects during the second year of engineering students. the project group who made this rapport made a laser cutter for the students of Fontys Hogeschool Engineering to use this machine for creating parts for their projects.

The goal of Project Laser Cutter is to build a laser cutter, which is safe and can be used within the school. Also it has to be able to cut through 10 millimetres thick acrylic material or 10 millimetres thick plywood.

This project will follow the V-model. This model is a way for systematically engineering which contains of the following phases:

- Initiation phase
- User requirement phase
- System requirement phase
- System design phase
- Implementation phase
- Testing phase
- Product delivery phase.

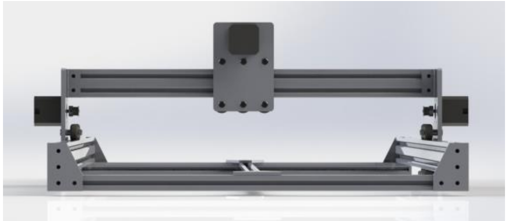
The rapport is build up in this same manner. Because the size of this project all the projects will cover subsystems of the laser cutter and go through this model for every subsystems.

All of the subsystems for this project will be:

- Movement mechanism Z-AXIS
- Movement mechanism X&Y-AXIS
- Electrical supply for the complete system
- Laser source/water-cooling
- Laser direction
- Controller board
- Interface
- Suction system
- Air knife
- Optical measuring instrument

These themes will be covered during all of the projects. The project groups had the possibility to fill this in for every project. And every start of a new period the project group gets 100 euros from the school to create this laser cutter. Also the project group is free to look for sponsors investing in this project.

Conclusions and recommendations period 1
In period one a project group started creating a system for the movement in the X-axis and Y-axis. To move the laser head for the cutting. They have been able to implement this XY-table but it still had to be optimized.



Conclusions and recommendations Period 2
the project group started to sort out the laser electrical supply, controller board and optical measurement probe.

designing laser electrical supply failed this forced the project group to buy one in another period.

Creating the controller board also failed because of the level of programming was too high for the members of the project group with a critical member resigning from the group. In a next period the project group had to come up with a solution for this problem.

Het optical measurement probe was completely designed and tested but had to be optimized during a next period.

Conclusions and recommendations Period 3

Het optical measurement probe was finished but a shell has to be made during a next period to make it possible to mount it on to the laser head.

A construction for the Z-axis were designed and mechanical drawings for the construction were made. Also the parts were ordered but were not delivered in time to finish the complete construction.

The complete electrical wiring system was designed with wiring scheme's but there was no time to fully implement this. A 230v AC to 24V converter was ordered with fuses for the junction box. Which still has to be ordered in a next period. With parts for the emergency stop and laser electrical supply.

A controller board was made by the project group and implemented.

Conclusions and recommendations Period 4
has not been started yet

Introduction

At Fontys Hogeschool Engineering every period students participate in projects. In these projects students will design technical machines/robots within a project group made of students and supervised by a tutor. If possible the students can implement their ideas to create a prototype of the machine/robot they have designed. To increase the quality and possibilities to create these prototype the school provides the students with some areas to create parts like
an etching room to create Printed circuit boards, 3d printers to create hard to make parts from plastics. A milling, lading and wood shop to create parts made of harder materials like wood and aluminium. Something what is missing from these rooms is a place where it's possible to laser cut sheet material. This is a very fast way to create small parts to construct a design or make it look more professional.

Because of this Oscar Fokker got the idea to build a laser cutter with his fellow students. He subjected this idea to Pavel Samalík to build a laser cutter during the EXPO projects these are the projects in the second year of every engineering student. Together they made it possible to realize this project. This project is a great opportunity for students to make a large leap in their ability to design a functioning product, especially laser cutters.

Unfortunately, there is not a lot of knowledge within Fontys about laser cutters. A lot of research has been done by the project group about security measures, requirements, wishes, possibilities of construction of the frame, and so forth. For example, the laser must not accidentally beam out of the housing, blinding or injuring someone. This will all be mentioned in this report.

The goal of Project Laser Cutter is to build a laser cutter, which is safe and can be used within the school. Also it has to be able to cut through 10 millimetres thick acrylic material or 10 millimetres thick plywood. Also to for the students to learn how to create a machine for parts making. This rapport is written to inform people who are interested how to make a laser cutter and students joining in on the project because the project group will be changed during the 4 periods of the EXPO projects.

The structure of this will be as following. Chapter 1 will explain how the project group started the project of the laser cutter. Chapter 2 will show the user requirements and what requirements fit to which subsystem. Chapter 3 system requirements will show all the requirements the project group set up to be able to create the laser cutter. Chapter 4 in system design will contain all the specifications and calculations. Chapter 5 will give global view of how the project group created the subsystems. Chapter 6 in the testing phase all of the subsystems will be tested and results of these tests will be shown in this chapter. Chapter 7 contains of the conclusions that all of the project groups had during these projects.

1. Initiation phase

At the start of the project Q3 the project group decided to create the report like this. Because of the lost information of previous project groups because of this not all the information about the projects of Q1 and Q2 are available. Because of the size of this report only the last information for the imitation phase will be mentioned. Information about previous projects can be found in older versions of this report.

1.1 Project organization

In the project organisation the project groups divide their roles within their project groups. Because of text saving only the names of the last project group working on this project will be mentioned.

At the start of Q3 the project group divided 2 kinds of roles to all of the 6 members of the team. The table below gives an overview to see who covered what role.

Group member	Project role	Design role
Oscar Fokker	Reporter	Mechanical engineer
Max Sijbers	Researcher	Mechanical engineer
Yves Elmensdorp	Reporter	Electrical engineer
Ken Van de Weerdt	Author	Electrical engineer
Eljakim Burger	Project leader	Software engineer
Rick Jansen	Administrator	Software engineer

Table 1. Project organization

1.2 Defining the objective

Objective of Project Laser Cutter is to build a laser cutter, which is safe and can be used within the school. Also it has to be able to cut through 10 millimetres thick acrylic material or 10 millimetres thick plywood. Also the project group has to Fulfil the customer requirements discussed in chapter 2.

To create a working laser cutter several subsystems are needed to make this possible. These subsystems are linked to each other or trough each other. The diagram below shows how these systems are connected in the legend you can see how all the subsystems are connected with each other.

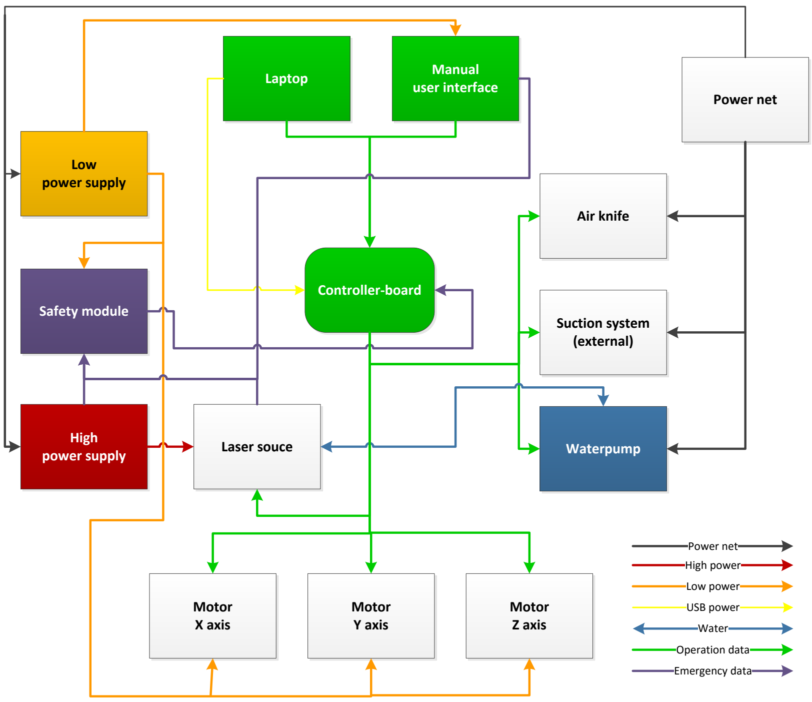


Figure 1. System overview

1.3 Project borders.

To make sure the project group would know what to cover and what not in Q3 the project group made a width depth table. This table shows what subject will be covered during this project and how far these subjects will be worked out. Below you can find this table. At the top you can find the subsystems. And in the left you can see how far the project group will go with this subject.

	Afscherming	Bewegingsmechanisme Voor Z ass	Elektrische voeding voor hele systeem	Interface bedienings paneel	Informatie verwerking/ elektrische aansturing	Afzuiging	Air Knife	Lasersource/ Water koeling	Spiegels	Optisch Meetinstrument
Voorinderzoek	Optioneel	Essentieel	Essentieel	N.V.T	Compleet	Optioneel	N.V.T	Essentieel	I.P.D proj	Compleet
Proof of concept	Optioneel	Essentieel	N.V.T	N.V.T	N.V.T	Optioneel	N.V.T	Essentieel	I.P.D proj	Compleet
Design	Optioneel	Essentieel	N.V.T	N.V.T	N.V.T	Optioneel	N.V.T	Optioneel	I.P.D proj	Compleet
Prototype	Optioneel	Optioneel	N.V.T	N.V.T	N.V.Y	Optioneel	N.V.T	Optioneel	I.P.D proj	Essentieel
Productie model	Optioneel	Essentieel	Bestellen	N.V.T	Bestellen	Optioneel	N.V.T	Optioneel	I.P.D proj	Essentieel

Figure 2 Width depth table

1.4 Costs and concerns

Because this project works over multiple quarters it's very important a good balance is made to check how much money the project group has left to spend to implement the laser cutter. The balance at the beginning of the project in Q3 can be found below.

beschrijving	bedrag	gesponserd	sponsor	werkelijk uitgegeven	Budget p. periode	Budget over
kennis voucher	€ 500,00	jep	STHO			€ 500,00
Periode 1 EXPO 51					€ 100,00	
Openbuilds parts,	€ 191,95	€ 191,74	openbuilds.org			
import belasting	€ 40,74	€ -				
Stepper motors + drivers	€ 88,25	€ 88,25	TechQ s.r.o.			
totaal	€ 320,94	€ 279,99		€ 40,95		€ 59,05
Periode 2 EXPO 22					€ 100,00	
USB Interface, Transceiver, USB 2.0, 2.97 V, 5.5 V, SSOP, 16	€ 2,12	€ -				
CRYSTAL, 20MHZ, 18PF, HC49/4H	€ 0,30	€ -				
8 Bit Microcontroller, 20 MHz, 64 KB, 4 KB, 40, DIP	€ 5,46	€ -				
SRAM, SERIAL, 1MBIT, 2.5V, 8SOIC	€ 2,37	€ -				
totaal	€ 10,25	€ -		€ 10,25		€ 89,75
Periode 3 EXPO 22					€ 100,00	
totaal	€ -	€ -		€ -		€ 100,00
Periode 4 EXPO 22					€ 100,00	
totaal	€ -	€ -		€ -		€ 100,00

Totaal balans	
Periode Geld	€ 400,00
Kennis voucher	€ 500,00
uitgaven	€ 51,20
balans	€ 848,80

Figure 3. Project balance at the start of the project

1.5 Project planning

A project can only run smoothly if a project planning is made. In the initiation phase the project group made a planning for Q3. This planning can be found in *Appendix I.*

2. User requirements

This chapter will cover the User requirements. The user requirements are wishes and demands the costumer has and have to be implemented in the end result or be discussed with the costumer. The costumer for the laser cutter provided a list of requirements that need to be implemented in the laser cutter these requirements can be found in table 2.

The given table can be overwhelming to find the right requirement for the right subsystem. Because of this the project group divided al of the user requirements in table 2 and matched these to the right subsystems.

The subsystems were made in different periods. Below you can find a sum up of all the subsystems and in what period the requirements were setup:

- **Movement mechanism Z-AXIS [Q3]**
- **Movement mechanism X&Y-AXIS [Q1]**
- **Electrical supply for the complete system [Q3]**
- **Laser source/water-cooling [Q4]**
- **Laser direction [Q7]**
- **Controller board [Q3]**
- **Interface [Q4]**
- **Suction system [Q4]**
- **Air knife [Q4]**
- **Optical measuring instrument [Q2]**

at the left of the table you can find the requirement number and on the right of the table you can find the requirement description.

Machine Requirements	Description
R01	Cutting/engraving machine, using water cooled laser source (CO_2) with power 100W.
R02	Machine is equipped with a suction system for gas exhaustion and with the filter to keep the air clean when leaving the machine
R03	Machine can cut through the following materials: • 10mm acrylate • 5mm wood
R04	Working area of the machine is square 600 by 300 mm.
R05	Precision of movements is 100 µm or better.
R06	The focal point spot size is 1/3 mm or better.
R07	The machine has an emergency stop.
R08	The machine has glass covers, at the location where the laser radiations may cause damage the glass cover must be sheltered by a protective layer blocking the radiation.
R09	The machine is equipped with an air jet (air knife) to keep the focus point of the laser clean.
R10	The machine is equipped with infrared detection of heat. The heat detection is closely-coupled with control loop of the machine in order to detect a potentially dangerous situation: laser ON and no heat generated at the focus point, meaning broken optical path and hence possible laser radiation of the machine's inside cover.
R11	Automatic shut-down of the laser source within 500ms: • after the upper cover gets opened, • if the suction stops working, • if the water cycling system stops working, or • if according to S10 heat should be measured but it is not.
R12	The machine size (width/length/height) is 1000mm/2000mm/400mm
R13	The laser beam is directed to the cutting head using system of mirrors.
R14	The machine can engrave materials with a height of 250mm.
R15	The laser cutter has to be NEN-CE certified to make it safe enough to be used within the school

Table 2 user requirements

	Movement mechanism Z-AXIS
Requirements	**Description**
R03	Machine can cut through the following materials: • 10mm acrylic • 5mm wood
R04	Working area of the machine is square 600 by 300 mm.
R14	The machine can engrave materials with height of 250mm.

Table 3. Subsystem user requirements movement mechanism Z-AXIS

Movement mechanism X&Y-AXIS

requirements for the X&Y-Axis were not set during Q1 and will be filled in in a next period Q4.

	Electrical supply for the complete system
Requirements	**Description**
R01	Cutting/engraving machine, using water cooled laser source (CO_2) with power 100W.
R02	Machine is equipped with a suction system for gas exhaustion and with the filter to keep the air clean when leaving the machine
R07	The machine has an emergency stop.
R09	The machine is equipped with an air jet (air knife) to keep the focus clean.
R10	The machine is equipped with infrared detection of heat. The heat detection is closely-coupled with control loop of the machine in order to detect a potentially dangerous situation: laser ON and no heat generated at the focus point, meaning broken optical path and hence possible laser radiation of the machine's inside cover.
R11	Automatic shut-down of the laser source within 500ms: • after the upper cover gets opened, • if the suction stops working, • if the water cycling system stops working, or • if according to S10 heat should be measured but it is not.

Table 4. Subsystem user requirements electrical supply for the complete system

	Laser source/water-cooling
Requirements	**Description**
R01	Cutting/engraving machine, using water cooled laser source (CO_2) with power 100W.
R06	The spot size is 1/3 mm or better.
R10	The machine is equipped with infrared detection of heat. The heat detection is closely-coupled with control loop of the machine in order to detect a potentially dangerous situation: laser ON and no heat generated at the focus point, meaning broken optical path and hence possible laser radiation of the machine's inside cover.
R11	Automatic shut-down of the laser source within 500ms: • When the upper cover gets opened, • If the suction stops working, • If the water cycling system stops working, • If according to S10 heat should be measured but it is not.
R12	The machine can engrave materials with a height of 250mm.
R13	The laser beam is directed to the cutting head by using a system of mirrors.

Table 5. Subsystem user requirements laser source/water-cooling

	Controller board
Requirements	**Description**
R05	Precision of movements is 100 µm or better.
R09	The machine is equipped with an air jet (air knife) to keep the focus point of the laser clean.
R10	The machine is equipped with infrared detection of heat. The heat detection is closely-coupled with control loop of the machine in order to detect a potentially dangerous situation: laser ON and no heat generated at the focus point, meaning broken optical path and hence possible laser radiation of the machine's inside cover.
R11	Automatic shut-down of the laser source within 500ms: • after the upper cover gets opened, • if the suction stops working, • if the water cycling system stops working, or • if according to S10 heat should be measured but it is not.

Table 6. Subsystem user requirements Controller board

3. System requirements

System requirements are requirements the project group set up to be able to create the laser cutter. These requirements are more defined with measurable information. This chapter will show all the tables of every system requirement of all of the subsystems covered in every project that have passed. Below is a sum up of all of the subsystems and what period these were covered.

- **Movement mechanism Z-AXIS [Q3]**
- **Movement mechanism X&Y-AXIS [Q1]**
- **Electrical supply for the complete system [Q3]**
- **Laser source/water-cooling [Q4]**
- **Laser direction [Q7]**
- **Controller board [Q3]**
- **Interface [Q4]**
- **Suction system [Q4]**
- **Air knife [Q4]**
- **Optical measuring instrument [Q2]**

Note: the controller board is not mentioned in the user requirements but it is essential for realizing the laser cutter

		Movement mechanism Z-AXIS
Specification	**Requirement**	**Description**
S01	**R03** **R14**	System needs a platform which can move up and down to adjust the focus when objects of different sizes are being engraved or laser cut. the distance the platform needs to travel is 250 mm.
S03	**R04**	The surface of the platform needs to be at least 300 mm deep and 600 mm wide
S04	**R15**	The surface of the platform must have a grid sort of raster to prevent the laser from cutting true the table.
S05	**-**	The table needs to be parallel (level) to the path of the laser at all times to prevent the laser of becoming out of focus (maximum deviation from 1 side of the platform to another is 1mm).
S06	**-**	The platform needs to be a sub-system so it can be built as an independent part.

Table 7. System requirements movement mechanism Z-AXIS

Movement mechanism X&Y-AXIS

requirements for the X&Y-Axis were not set during Q1 and will be filled in in a next period Q4.

		Electrical supply for the complete system
Specification	**Requirement**	**Description**
S07	**R01**	The laser source must be equipped with the matched power supply to provide 100W continuous power in a way that keeps the lifespan of the source optimal.
S09	**R07**	There will be a kill switch placed on top of the laser cutter this switch has to make sure the laser source is turned off immediately And stop all of the motors
S10	**R10, R11**	The power supply of the laser source is switched off by the software or by the electronics after an emergency stop or after a dangerous situation has been detected within 500ms.
S11	**-**	A fuse box will be made to protect the separate power systems and the wiring.
S12	**-**	Because of the water cooling the electronics will be covered to protect it from getting a short circuit
S13	**R09**	A transformer has to be made to supply voltage and current for the air Jet (air knife).
S14	**R02**	A transformer has to be made to supply voltage and current for the suction system for gas exhaustion.
S15		A transformer has to be made to supply voltage and current for the controller-board.
S16		A transformer has to be made to supply voltage and current for the stepper motors.
S17		A transformer has to be made to supply voltage and current for the pump for the cooling system.
S18		A transformer has to be made to supply voltage and current for the interface

Table 8. System requirements electrical supply for the complete system

		Laser source/water-cooling
Specification	**Requirement**	**Description**
S19	**R01**	The laser power is 100W (continuous)
S20	**R01**	Area characteristics (beam divergence) of the laser may not exceed 20% deviation.
S21	**R01**	Laser beam diameter may not be larger than 8,0mm. According to manufacturer's specifications.
S22	**R01**	The laser source must be equipped with the water cooling mechanism has to be able to cool a power system of 100W output power.
S23	**R01**	The laser tube temperature must be monitored to prevent overheating.
S24	**R01**	The laser source must be equipped with the matched power supply to provide 100W continuous power in a way that keeps the lifespan of the source optimal.
S25	**R06**	The laser source must be aligned with the mirror system to allow the optical path to deliver the power to the focus point.
S26	**R10, R11**	The power supply of the laser source is switched off by the software or by the electronics after an emergency stop or after a dangerous situation has been detected within 500ms.
S27	**R12**	The laser tube is at most 1750mm length to fit with the machine size.
S28	**R12**	The diameter of the tube is at most 90mm to fit with the machine size.
S29	**R12**	The laser is mounted behind the cutting area, shielded from interaction with the user.
S30	**R13**	The laser source must be aligned with the mirror system to allow the optical path to deliver the power to the focus point.
S31	**R13**	The construction and mirror alignment can be tested by a laser pen using a bracket.
S32	**-**	The laser tube must be mounted horizontally
S33	**-**	The water cooling outlet tube must be facing up.

Table 9. System requirements laser source/water-cooling

		Controller-board
Specification	**Requirement**	**Description**
S34	**-**	The controller board needs to be able to drive 4 different stepper drivers at least
S35	**-**	The software of the controller board needs to be adjustable to our needs
S36	**R10,R11**	The power supply of the laser source is switched off by the software or by the electronics after an emergency stop or after a dangerous situation has been detected within 500ms.

Table 10. System requirements controller board

		Optical measuring instrument
Specification	**Requirement**	**Description**
S37	**-**	The measuring instrument has to be able to measure a precision from a micro meter.
S38	**-**	The measuring instrument has to give a visual preview of the measured data.

Table 11. System requirements optical measuring instrument

4. System design

In the system design phase the project group is going to design all of the sub systems for to create the laser cutter. All of the subsystems created over all of the periods will be mentioned in this chapter. Below is a sum up of all of the subsystems and periods the subsystems were made.

- **Movement mechanism Z-AXIS [Q3]**
- **Movement mechanism X&Y-AXIS [Q1]**
- **Electrical supply for the complete system [Q3]**
- **Laser source/water-cooling [Q4]**
- **Laser direction [Q7]**
- **Controller board [Q3]**
- **Interface [Q4]**
- **Suction system [Q4]**
- **Air knife [Q4]**
- **Optical measuring instrument [Q2]**

Note: the design information for the movement mechanism X&Y-Axis are not mentioned in this version of the rapport because it did not fit the report and has to be changed to make it fit.

4.1 Movement mechanism Z-AXIS

To focus the laser beam the z-axis has to be moveable. The precision of moving the z-axis had to be very exactly, otherwise to laser beam achievements will not be perfect. The precision from each movement must have a precision of 100 micro meter
The platform have to cover a y movement from 25 cm. This is because the height of the object has a maximum from 25 cm. There is also specified that the total mass to lift, this is included the platform from 15kg

4.1.1 Morphological Overview

From these requirements there is made a morphological overview to choose the best construction

Moving part	**Directions z-axis** **By means of**	**Driving**	**Transmission from motor to movement direction**
Laser head	Spindle	1 Stepper motor	Spindle
Platform	Rack	1 DC motor	Rack
	Belt	1 Servo full rotation	Belt
	chain		chain

Laser head	Advantage: No advantage but first we thought that we only can move the laser head , but later we know that the laser head and laser tube always has to stay on the same height.
	Disadvantage: If you chose to move the laser head, you also have to move the laser tube.. And this is very complicated , because if the laser light is skewed within the laser head. The precision is not reliable.
Platform	Advantage: The mechanical construction is not very complicated, and the laser tube and laser head stay always on the same position. You have to move 1 part instead of 2(laser head)
	Disadvantage: The mass and volume from each design is different. So the design we had to make, we had to assume the worst situation. And that is heavy and big design.

Driving

Stepper motor	Advantage: It is very precisely. A lot of different stepper with other torque. There is enough choice.
	Disadvantage:

DC motor	Advantage: A lot of different motors with high torque
	Disadvantage: The precision is not so good as a stepper.

Servo	Advantage: The servo is smaller and lighter than the other driving's. The height torque .
	Disadvantage: The precision is not so good as a stepper.

Directions z-axis/ Transmission from motor to movement direction;

Spindle	Advantage: It is very precisely. Through the spindle the required torque will be low.
	Disadvantage: The movement is in z direction very slow

Rack	Advantage: The movement can be fast. Through the rack the required torque will be high.
	Disadvantage: The mechanical construction in transmission with 1 stepper motor is very difficult. And if you chose for motor steppers, the price will be to height.

Belt	Advantage: It is precisely and light.
	Disadvantage: The force from the table is too high for the belts. And if you will use belts, you still have to design a construction for stabilize the platform movement.

chain	Advantage: It is strong
	Disadvantage: It is to heavy and the precision is not good enough for a laser cutter.

There is chosen for moving the platform with spindles ,1 stepper motor and a belt.

Z axis Choices
from the morphologic overview we thought up 2 different methods of moving the platform up and down.
the items from which choices can be made are the amount of engines, the amount of threaded rods, the amount of belts to drive the threaded rods depending on the amount of motors and the method of keeping the platform from moving sideways.

Choice 1
The first method consists of a system of 4 threaded rods in each corner of the platform that lift the platform up and down.
these rods are connected together by a belt which is driven by a single stepper motor.
to keep the platform from moving sideways, the same kind of aluminium profile that was used in the X-Y frame is used. the profiles used as a rail in combination with a wheel that fits the profile.
this was used instead of the linear bearing system often seen in 3D printers and Laser Cutters.

advantages:
- 4 threaded rods lift the platform simultaneously so when the weight is in 1 corner of the platform, that corner doesn't drop in height.
- only 1 motor is used to drive the whole system. this is cheaper and al the 4 threaded rods are driven at the same time
- the advantage of keeping the platform from moving sideways by using wheels and profiles is that you can make an integral construction out of the profiles. this means the profiles are used to build the frame around the platform and at the same time it functions as a guidance system like linear bearings would.

Disadvantages:
-4 threaded rods at each corner span a long distance to be overcome by the belt that connects them to each other, so the belt has a considerable length.
- When u use 1 motor to drive the platform u need a strong engine to make sure it can lift the platform
- when u use profiles and wheels to ensure the platforms position and u integrate them in the frame, every deviation in the frame has its effect on the position of the platform.

Choice 2
The second method which is derived from the morphologic overview, consist of two threaded rods centred on each side of the platform, connected to each other by a single belt driven by one motor. the table is kept in position by 4 linear bearings which travel along 4 steel rods.

Advantages:
- only 2 threaded rods are needed so that reduces the costs and the friction the motor has to overcome
- the belt in this case can be shorter because it only passes along 2 threaded rods instead of 4
- only one motor is used so costs are saved here.

Disadvantages:
- because the platform is not supported in each corner but only in the middle the platform can bend when much weight is placed on a corner therefore the laser can become out of focus.
- the system is less stable, meaning that its only supported on two points instead of 4.
- When u use 1 motor to drive the platform u need a strong engine to make sure it can lift the platform

We choose for:
We choose for Choice 1.
This is because in our opinion Choice 1 is more stable and we think the integral solution for locking the platform in to position using the profile with the wheels is the best solution for our platform.

4.1.2 Motor torque needed and pulley choice

The movement in the z-axis direction is caused by 1 steppermoter. The stepper has to lift a mass of 15 kg. This is the total mass of the construction and the material that is used during laser cutting.

For these calculation we used the book “Roloff/Matex machineonderdelen version 5 and accesorry table book”

Chapter 8 is used to calculate the required torque to lift the platform with a stepper motor.

In figure4 is a picture to understand the situation

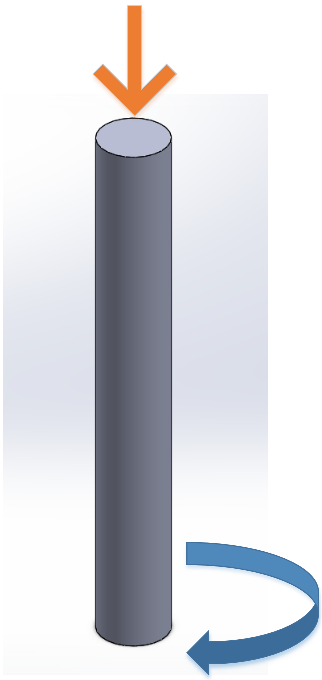


Figure 4. Situation sketch

The orange arrow is the force of the platform. This force is a quarter of the total mass, because there are in total 4 spindles. The blue arrow shows a rotation, this rotation is the required torque that is driven by a stepper motor.

The spindle is connected to a pulley, the ratio between the stepper pulley and the pulley on the spindle is very important to calculate the required torque of the stepper motor. So there is calculated the best ratio between these two.

In figure 4 is a picture of the situation

Figure 5. Pulley and motor ratio sketch

The yellow circle is the pulley of the motor.
The blue circle Is the pulley of the spindle
The red wire represent the belt.

The calculation are made in Matlab in figure 6,is the calculation of the required torque to move the spindle.
In figure7, is the calculation between the ratio of motor torque and diameter of the spindle pulley.
And in figure8, is the motor torque as a function of the diameter from the spindle pulley.

```
clc
clear all
close all hidden

m=15;                       %Mass to lift[kg]
a=9.81;                     %[m/s^2]
n=4;                        %amount of spindles
d2=9;                       %Effective diameter[mm]
Spoed=2;                    %Pitch[mm]
q=12;                       %screw-thread friction angle[degree]

F=(m*a)/n;                          %Force for each spindle[N]
phi=atand(Spoed/(d2*pi));          %Pitch angle[degree]
T=F*(d2/2)*tand(phi+q);            %Required Torque 1 spindle[N*mm]
T2=T/1000;                         %Required Torque 1 spindle[N*mm]

Required_Torque =T2*4              %Required Torque 4 spindle[N*m]
```

Command Window

```
Required_Torque =

    0.1905
```

Figure 6. Calculation required torque in Matlab

```
clc
clear ALL
close ALL HIDDEN
%determine pulley spindle and motor

R1=0.0225;                      %m
M1=[0.05:0.01:0.4];             %Torque motor variable[N*m]
M2= 0.1905;                     %required torque[N*m]

F=M1/R1;                        %force[N]
R2= M2*(F.^-1);                 %[m]
Diameter_Pulley = (R2*2)*1000;  %[mm]

plot(Diameter_Pulley,M1 );
title('Required torque');
xlabel('Diameter pulley spindle[mm]');
ylabel('Torque motor[Nm]');
```

Figure 7. Calculation between motor torque and pulley

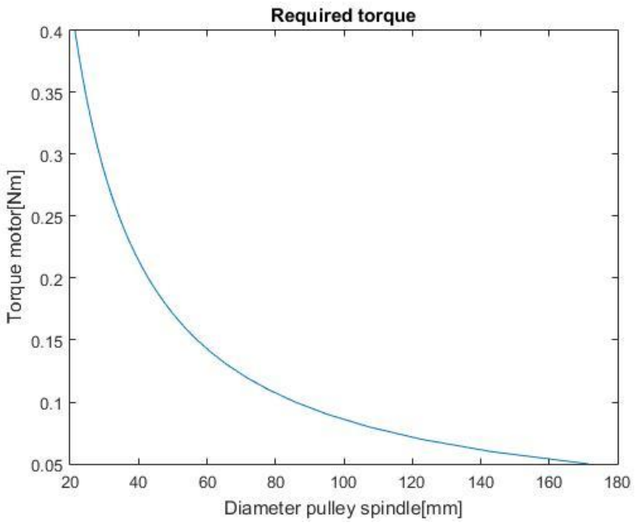


Figure 8. Characteristic between motor torque and pulley in graph

The conclusion:

There is chosen for a pulley of 66.21. Out of the graph the stepper needs at least a torque of 0.1295[Nm]

4.1.3Precision z-axis

To focus the laser beam the z-axis has to be moveable. The precision of moving the z-axis had to be very exactly, otherwise to laser beam achievements will not be perfect.

There is calculated the precision of the z-axis movement. This is calculated with a 1.8 degree/step stepper motor and a stepper driver with 6 different modes.
These 6 modes are full step, half stepp,1/4 step, 1/8 step, 1/16 step, 1/32 step.
And because there are two different pulley diameter, there is calculated the ration between these two, because 1 full cycle by a small pulley is a half cycle by a bigger pulley as an example.
See for the calculation figure 9

```
% stepper: 1.8 graden per stap
% driver : 1,5,4,8,16,32
x=[1 1/2 1/4 1/8 1/16 1/32]; % Stepper motor modes


D1=45.84;                          %diameter pulley stepper motor[mm]
D2=66.21;                          %diamter pulley spindle[mm]
Pitch=2;
Ratio=D2/D1;                       %Ratio between the two diameters

Amount_of_steps_Motor_Full_Circle=(360/1.8)*((x).^-1);
Amount_of_steps_Spindle_Full_Circle=Ratio*Amount_of_steps_Motor_Full_Circle;
Precison=2*(Amount_of_steps_Spindle_Full_Circle.^-1)*1000;


bar(Precison);
step={'1', '1/2', '1/4' ,'1/8', '1/16', '1/32'};
set(gca, 'XTick', 1:6)
set(gca, 'XTickLabel', step)
xlabel('Step mode');
ylabel('Precision[Mirco meter]')
```

Figuur 9. Precision Z-axis calculation

The results of these calculation are plotted in a bar graph, see figure 10

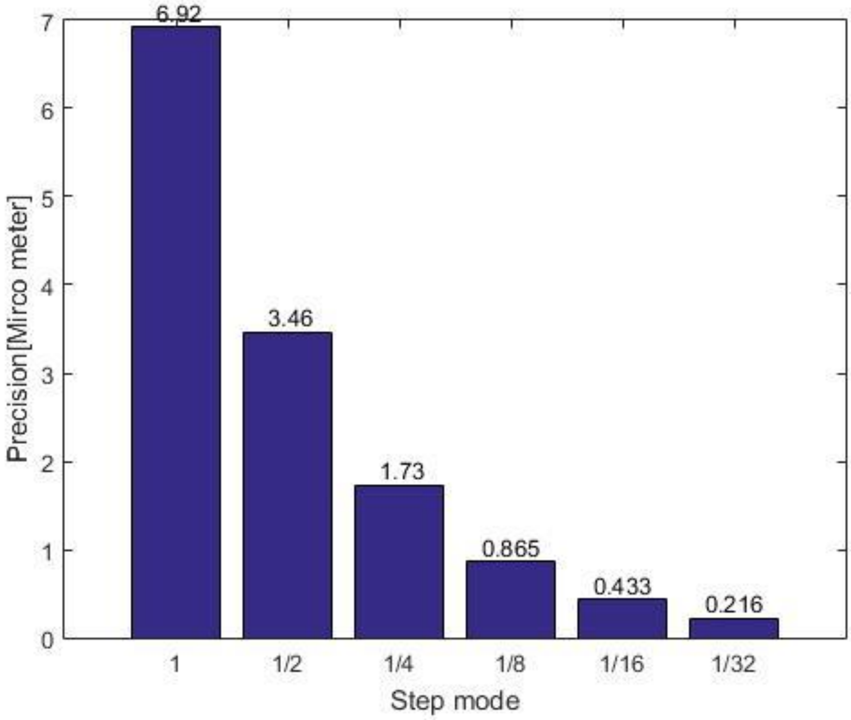
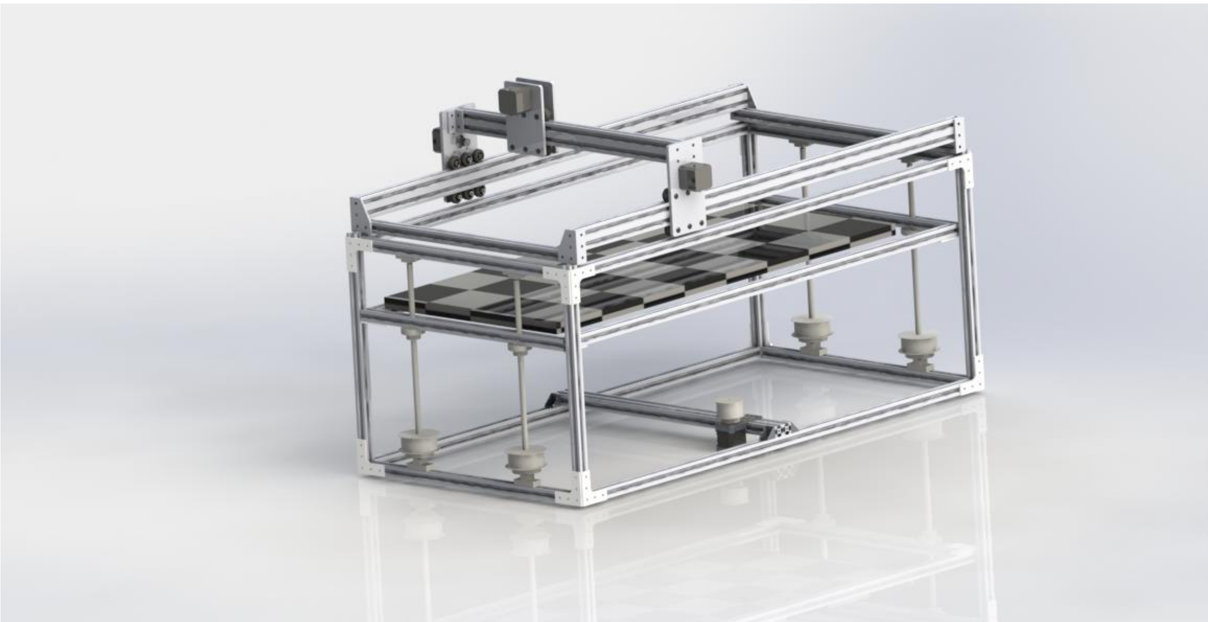


Figure 10. Precision Z-axis plotted in bar graph

The required precision was 100 micro meter, so the mechanical requirement is achieved.

4.1.3 Design

Our design is made in SOLIDWORKS . In the picture below you can see it.



4.2 Power distribution

The laser cutter will be connected to the power net 230v AC. Some of the sub-systems need a different voltage source. because of this a solution has to be made for the power distribution to the sub systems. the values have to be known to make sure that the systems get the power they need. The following systems need a power supply:

- Laser source
- Cooling system
- Interface
- Controller-board
- Stepper motors
- Suction system
- Air jet
- Optical probe

4.2.1 Power supply laser source

One of the requirement for the laser source was that it had a power of 100W. Research showed that it was very hard to make our own power supply for the laser due to its “extreme ” needs. Most of the 100w laser power sources need a input between 35-50KV and 25-38mA. Due to these extreme voltages it is hard to create our own power supply and due to safety measures it needs and to keep the machine safe within the EMC rulings there was chosen to buy this supply. This ensures that the power supply for the laser is safe and within EMC rulings.

4.2.2 Power supply stepper motors/drivers

The stepper motors for this project were provided by the costumer at the start of the project. These are from the type NEMA 17HM15-0406S specifications for these motors can be found in the datasheet *appendix II*. The motors are used to realize the movement in X,Y,Z directions.

The supply voltage for the motor may vary between (12V to 24V)
The phase resistance is 30Ohms

The stepper motors need to be driven by stepper drivers. The stepper drivers mounted on the Tiny-G controller-board are stepper drivers DRV8825 Specifications for these drivers can be found in the datasheet *appendix III*. The task for these drivers is to turn on and of the coils in the stepper motors to create a rotating motion.

The supply voltage for the driver may vary between (3.3V to 5V)
The supply voltage for the motors may vary between (8.1V to 45V)
The maximum current the DRV8825 can take is 3 amps.

The motors draw a maximum current that has to be calculated with Ohm's law. The datasheet provides us with the resistance for the phases of the motor.

Ohm's law : $U = I*R$

Known values: $U = 24V$
$R = 30\Omega$

Answer: $I = U/R$
$I = 24/30$
$I = 0.8A$

The maximum current draw per motor is 0.8 amperes there are 4 motors placed in the machine with the possibility to turn all at ones. That makes the current draw 4 times 0.8

Total current draw: $I_{motors} = I*n$
$I_{motors} = 0.8*4$
$I_{motors} = 3.2A$

So the worst case scenario of the motors lies at 3.2A, To a have bigger margin of security there was chosen to set up the maximum amps to 1A. Because of this decision there will be a smaller chance of a power supply failure. This failure can occurred if the motors start jamming during movement, this will draw a lot of current. The sum for the new maximum current will be 4 times 1A. This means that the power supply needs to deliver a minimum of 4A.

4.2.3 Power supply Controller-board

The controller-board is a PCB that receives the information from the laptop and controls the drivers for the movement of the laser head. The design for the PCB can be found in the *appendix IV*.

The brain of the controller board is connected to the USB which voltage and current is converted by the FT230X Serial chip from 5v 500mA to 3.3V/50mA. This is the voltage source for the ATXMEGA-192D3-AU, the brain of the controller board and the DRV8825 the drivers for the stepper motors. Because of this the 12V power supply will not be affected by the power use of the brain from the controller-board or the drivers.

The power supply for the stepper drivers will be connected to the controller-board because these are integrated in the board.

4.2.4 Optical probe

The Optical probe gets it power from a mounted Arduino Nano that's connected to USB. The power of this connection is 5V 0.5A DC.

4.2.5 Suction system

The suction system will be externally mounted to save space within the laser cutter and therefore will be connected to the power net 230v AC

4.2.6 Cooling system

The cooling system consists an electric pump. The pump needs to transport the water through the laser source and a radiator to cool the laser source. De pump works on the net power 230v AC.

4.2.7 Interface

The interface works on a 5V DC power supply. This is optional and will not be covered this project

4.2.8 Air jet

The power source for the air jet is currently unknown because it's there is no plan or information within the project group. This system will be designed in Q4

4.2.9 Overview

A diagram and a table were made to create a clear view for the power supply of the separate systems.

System	Voltage	Amperes	External Supply
Laser source	35-50KV	25-35mA	Yes
Cooling system	230V AC	Still to be examine	-
Interface	5V DC	Still to be examine	-
Controller-board/ drivers	USB -> 3.3V	50mA	No
Stepper motors/drivers	12 DC	1A	Yes
Suction system	230V AC	Still to be examine	-
Air jet	Q4	Q4	Q4
Optical probe	5V DC	0.5/2A	No

Table 12 Overview electrical power system

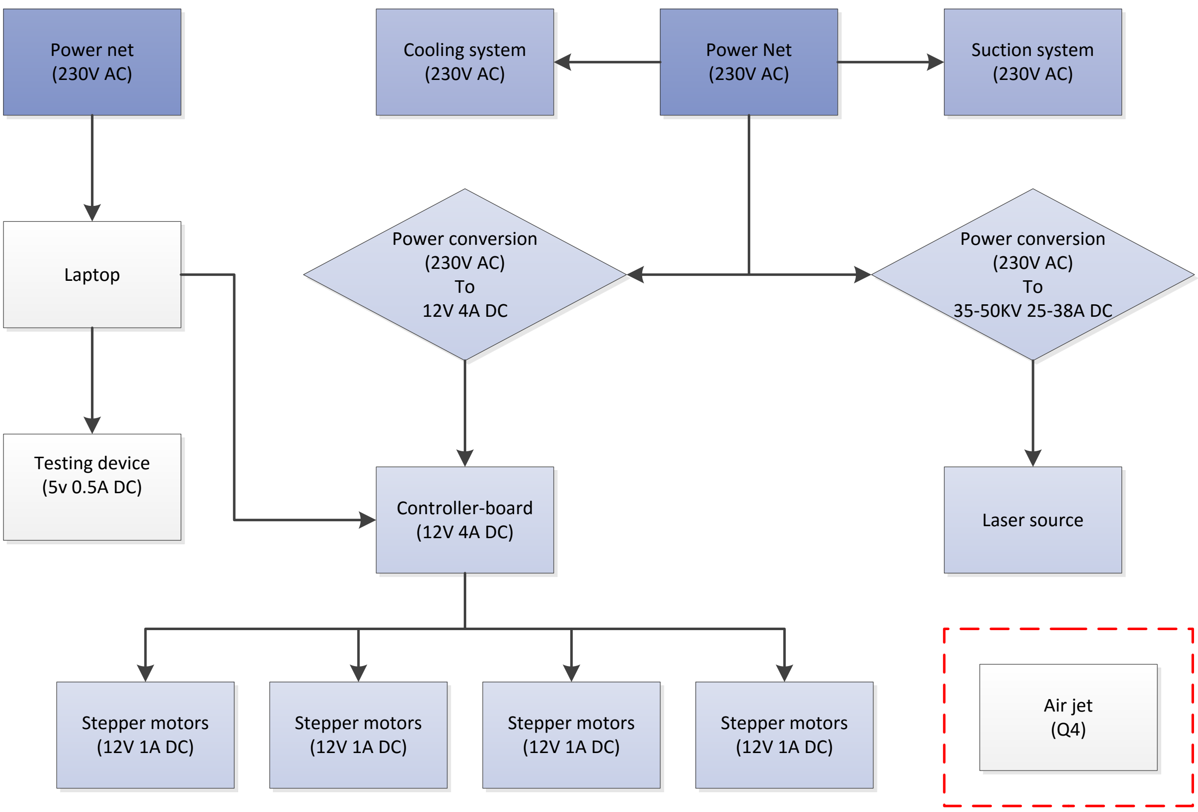


Figure 11. Diagram power supply

4.2.10 Controller-board power supply

Conclusion

Because almost all devices are power by 230V AC or by the 5V USB input. The only devices that need to be supplied externally are the 4 stepper motors and the 100W laser tube. Because there is a very small amount of information about the 100W laser tube, there is chosen to not buy this supply yet. To keep the machine safe and pas the NEN-CE-norms the power supply for the controller board will also be bought. This power supply is NEN-CE certified so this will give no trouble when integrated in the laser cutter.

Restrictions:

- Minimal current supply of 4A
- voltage supply of 12V

4.2.11 Power consumption

the power consumption in Watt for the machine is determent for all the objects inside the laser cuter. To give a clear overview a diagram is made to point out the systems that are connected where.

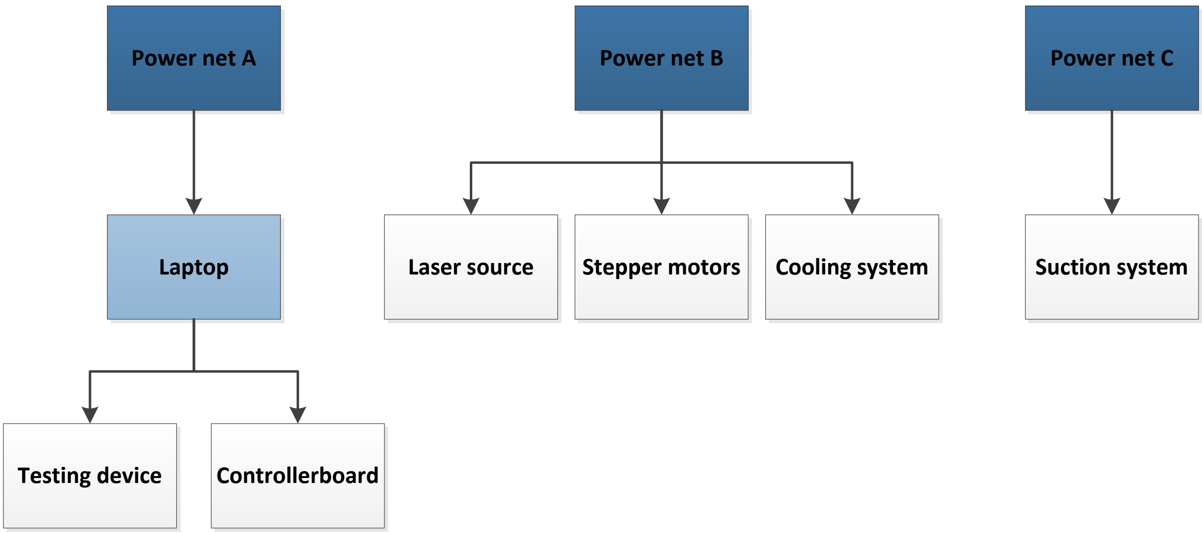


Figure 12. Diagram power consumption

power net A

the laptop is connected to power net A. the Optical probe and controller board are connected to the laptop. Theoretically it's possible to run these on the laptop battery. The conclusion we take from this is that there are no fuses needed for the Optical probe and the controller board.

Power net B

Power net B supplies the laser source stepper motors and cooling system. For these systems we will calculate the power consumption and the fuses needed.

Laser source

the power consumption for the laser source is determined by the costumer:

$$P_{laser} = 100W$$

Stepper motors

the stepper motors power consumption can be calculated. The current and voltage are already known.

Known values: $U_{stepper} = 12v$

$I_{stepper} = 5A$

Answer: $P_{stepper} = U_{stepper} * I_{stepper}$

$P_{stepper} = 12*5$

$P_{stepper} = 60Watt$

The laser cutter consists of four steppers so the total motor power consumption will be

$$P_{motors} = P_{stepper}*4$$
$$P_{motors} = 60*4$$
$$P_{motors} = 240 \text{ watt}$$

Cooling system

the cooling system has a pump that is driven by an electric motor. After some research we concluded that a pump is needed has a power consumption of 30 watt

Power net C

Power net C is used for the suction system. This system will be a separate module and because of this no fuses are needed for this system.

4.2.12 Total power consumption

The total power consumption can be determined by adding up all the calculated values for power net B. power net A and B are neglected because these are separate systems which have jet to be chosen.

$$P_{total} = P_{laser}+P_{motors}+P_{cooling}$$
$$P_{total} = 100+240+30$$
$$P_{total} = 370W$$

4.2.13 Emergency stop

To make the machine safe an emergency button has to be implemented into the power system. This system has to stop the motors from moving and cut off the power supply to the laser source without damaging any of the electric components. There are 4 components that need to be shutdown of electricity, the air suction, water pump, laser power supply and the power supply of the stepper motors. The decision was made to cut off the 230V supply that runs to the power supplies of the components. To do this a relay is added so that there is no high voltage on the button and all the devices are switch off at the same time. The emergency button needs to have 2 NC contacts, one for the low voltage signal to the relay and one for the low voltage signal to the controller board. The signal that goes to the controller board is an emergency line so that the controller board can monitor if the button is pressed so that the program stops executing.

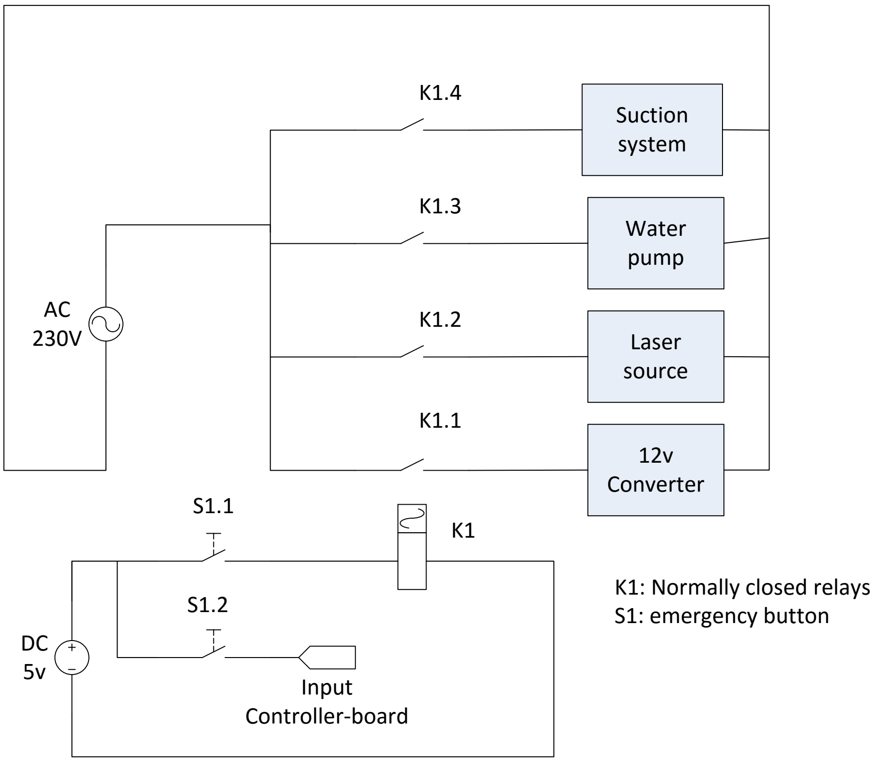


Figure 93. Electrical scheme emergency stop

4.2.14 Junction Box

The junction box is a watertight steel box that will protect all of the electronics from cooling water and moving parts within the later cutter. The size of this box will be determined by the components that will be placed in the box:

- Controller-board
- Power converter 12V
- Emergency stop system
- Fuses
- Wiring

4.3 Controller-board

The controller board is the “brain” of the laser cutter, it determines every action taken by the machine, that is why it is crucial to choose the controller board wisely. It needs enough computational power and speed to keep up with the flow of information, although can’t make any error during the cutting.

4.3.1 Controller-board choice

Creating the controller-board is very difficult, it has been tried in Q2 but this failed. Because of this a controller-board has to be bought. Listed below are the different controller boards suitable for our project:

Item	Mach3 CNC breakout	TinyG	Linux CNC	CNC Xpro2	Laser interface PCB
3de order system	no	yes	no	no	no
Software costs	225$	free	free	free	free
Driver costs	excluded	included	excluded	included	Included / excluded
cost van PCB + components	22,49.-	50.-	109$	120$	20.-
Raspberry Pi connection	no	yes	yes	yes	possible
Open source library [yes/no]	no	Yes	Yes	Yes (GRBL)	yes
In house knowledge	yes	yes	no	no	no
On the shelf product / make	Buy	make	make	Buy	make
Power supply	USB	USB	USB	USB	Parallel Port
data	USB	USB	USB	USB	Parallel Port
Amount of axis	4	6	4	3	3

Table 13. Controller-board choice

Definitive choice

There is chosen for the device TinyG.

Mach3 is a software that you can download for free or a paid version. The difference between these 2 versions is the amount G-Code lines. The free version has a limit of 500 lines off G-Code. This is enough for the smaller projects. The full version costs 225$, but that is for single user use only, a license for a company will be significantly more expensive. At first this option looks cheap, but the added non open source software makes it the most expensive.

Then the power supply for the board and the communication is through 1 cable, an USB cable. It is not a must have but it is more convenient. Because now we don’t have to pay for a new cable when purchasing the board and you only have to plug one cable in your pc instead of two.

Because our experience only applies to 2 of the 5 options, these will be our most promising products, otherwise without the proper knowledge of the system the product has a greater chance of failing

The TinyG’s software is open source, which makes adjusting the program to our needs relatively easy. Mach3 is a closed software package, which initially might be easier to use, but does not give the adaptability of an adjustable program. Mach3 looked perfect for our utilities initially, but after some research it was found out that it would be unusable for our purposes, that is why, in the end the TinyG was chosen.

4.3.2 TinyG controller-board

The TinyG board is a multi-axis motion control system. It is designed for CNC applications and other applications that require highly precise motion control. Here are some of the main features of the hardware.

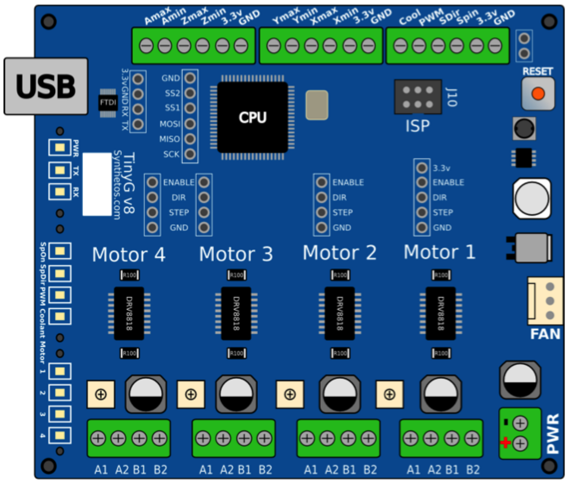


Figure 14. Controller-board layout

Features.

- Integrated motion control system with embedded microcontroller; Atmel ATxmega192A3.
- 4 stepper motor drivers (TI DRV8818) integrated on the board
- Stepper drivers handle 2.5 amps per winding which will handle NEMA17 motors and most NEMA23s
- 12v-30v motor voltage supported
- Accepts Gcode from USB port and interprets it locally on the board
- 6-axis control (XYZ + ABC rotary axes) maps to any 4 motors
- Constant jerk acceleration planning (3rd order S curves) for smooth and fast motion transitions
- Very smooth step pulse generation using phase-optimized fractional-step DDA running at 50 KHz with very low noise
- Micro stepping up to 1/8 (optimized DDA makes this smoother than many 1/16 implementations)
- 3 pin fan header, which can be used to cool the stepper motor drivers.
- status LED's.
- Chilipeppr; a server based control program, including a 3d real-time model of the project.

Additional CNC features.

- Homing cycle
- Probing
- Jogging support
- Feedhold and Feedstart (pause and resume the cutting)
- Various stepper motor power management modes
- Real-time status reports for a digital readout system.
- Independent, per-axis control of jerk, maximum seek and feed rate and other parameters to enable fine tuning a wide variety of machine types

Technical specifications.

- Atmel ATxmega192A3 running at 32 MHz (192K flash and 16K ram) Increased performance compared to a 328P (Arduino Uno) 16MHz, 32K flash and 2K ram.
- USB via FT230xs - runs 115,200 baud by default
- GPIO ports provide 8 inputs for limit / homing switches, plus 4 output ports for spindle, coolant or other uses
- SPI programming connector, requires Atmel AVRISP MKII programmer.

Connecting TinyG.

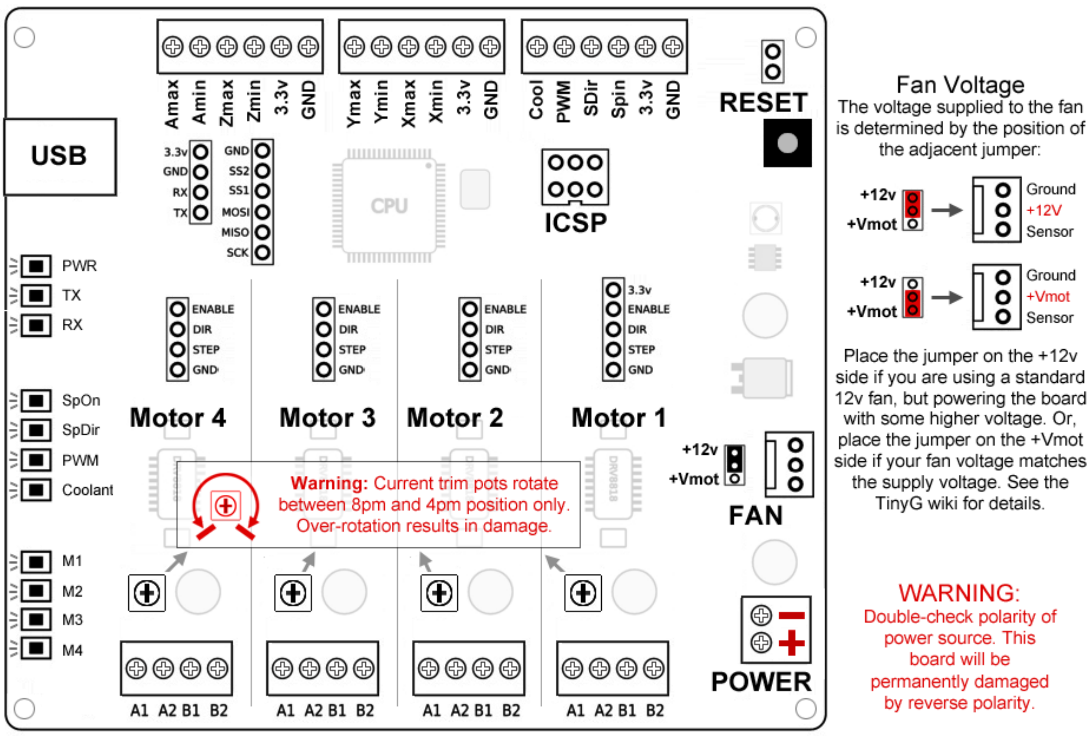


Figure 15. controller-board connection

Information processing.

1. FT230XS:
   Data enters the TinyG from a computer trough the USB port, in the form of G-codes created in the Chilipeppr program. The FT230XS converts the data from Universal Serial Bus to Serial UART, Which the microcontroller can process. It is capable of operating up to 3MBaud.

2. Atmel ATxmega192A3:
   The Central Processing Unit of the TinyG, the Atmel ATxmega192A3 translates the incoming G-code lines to machine instructions (PWM pulses for each stepper motor), which are passed onto the Stepper drivers. It uses 3rd order S curves, an advanced graphics algorithm to calculate the most optimal machine path, what results in precise movement.

   The CPU also controls the limit / homing switches, to ensure the position of the laser on the project's surface. spindle controls; which won't be used and reprogrammed for additional features. coolant flow and operation, checks and controls the temperatures of the system. Added status LED's for ease of use.

3. DRV8818
   These stepper drivers are directly controlling the individual windings of the stepper motors, using information coming from the CPU.

   The device has two H-bridge drivers, as well as micro stepping indexer logic to control a stepper motor. A simple step/direction interface allows easy interfacing to controller circuits. Pins allow configuration of the motor in full-step, half-step, quarter-step, or eighth-step modes.

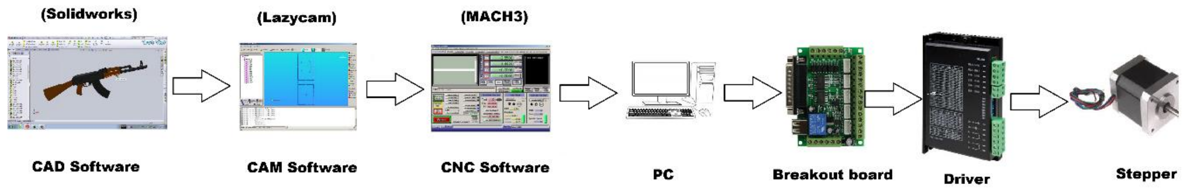


Figure 16. Schematic scheme

4.3.3 TinyG assembly

Since the TinyG can only be bought from the USA, it will be faster to produce the PCB ourselves, then to ship it overseas. The eagle schematics of the TinyG were supplied to us by Fontys, which are included in *appendix IV*.

The board was made at an external company, because of the complexity we were unable to create it ourselves. Because of this option, it was also possible for us to get a stencil, which greatly increases ease of soldering the board. The board is going to be assembled at the Fontys, with the help of a teacher with access to a reflow oven. The solder paste is applied to the copper connections on the board, were the components will be placed on. The oven bakes the paste to around 300C, were it solidifies and creates a good electrical connection between the board and the component. A reflow oven is perfect for our application, because of the size of the components. which are much smaller than the tip of a soldering iron.

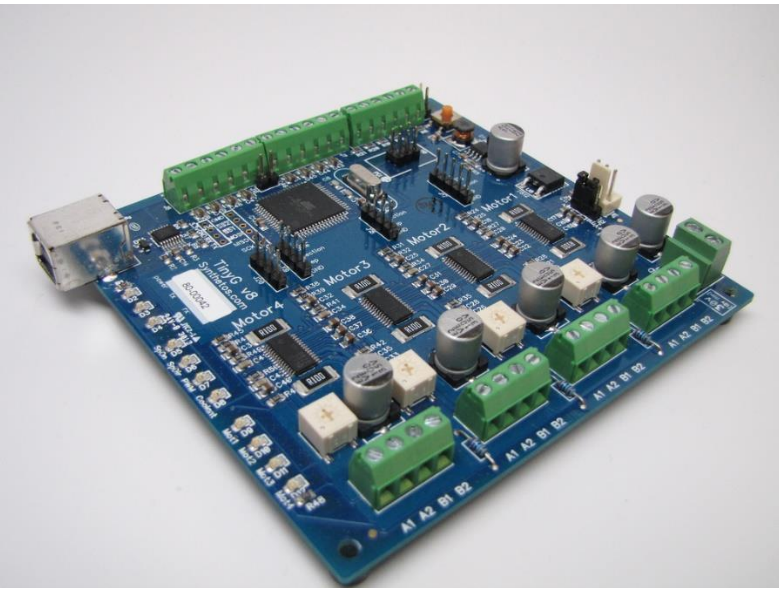


Figure 17. Assembled PCB

4.4. Position/accuracy measurement

Since it is desirable to cut the design as accurately as possible, there for a new assignment was made to make a tool to measure this accuracy. A requirement was that it needed to be measured on a micron and display the result in a digital form. In addition, the clickable probe will be mounted next to the laser head so that after the cutting is done it can scan the slot. Therefor there was chosen to do this with the aid of an optical mouse. Because there are a plurality of optical mice with each a different optical chip, so therefor there needed to be a research carried out on the principle of an optical mouse. By opening an obtained mouse and reading the type of the chip, the research begun for the question what the optical chip does. The chip type that is used in this project and report is the ADNS5020EN from Avago Technologies.

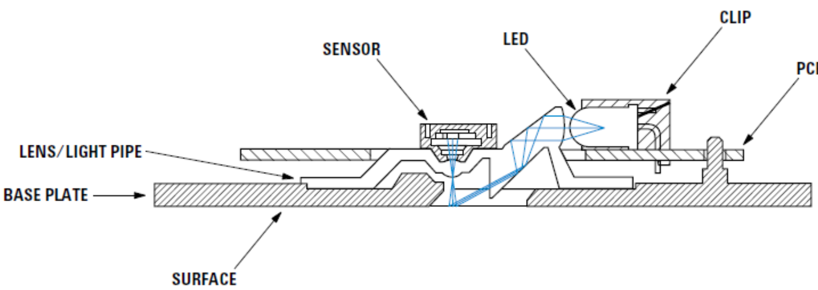


Figure 18. Light reflection

4.4.1 Reading the Surface

The optical chip has a input for the reflecting light at the bottom of the chip. The light source is coming from a red led and travels through 2 mirrors to the surface and is being reflected into the lens of the chip. There is a red led because the colour red has a long wavelength and a high relative responsively. Internally this response is converted to a digital value and transmitted via the data channels from the CPU. The light input from the chip divides the image into a pixel matrix of 15x15. The pixels have a value from 0 to 100 whereby 0 is black and 100 is white. Internally there are standard functions designed which can do a pixels "grab", but also are capable of detecting motion in the y-axis and x-axis. In the case of the measurement probe we will use the pixel grab function to make an image.

LAST PIXEL

14	29	44	59	74	89	104	119	134	149	164	179	194	209	224
13	28	43	58	73	88	103	118	133	148	163	178	193	208	223
12	27	42	57	72	87	102	117	132	147	162	177	192	207	222
11	26	41	56	71	86	101	116	131	146	161	176	191	206	221
10	25	40	55	70	85	100	115	130	145	160	175	190	205	220
9	24	39	54	69	84	99	114	129	144	159	174	189	204	219
8	23	38	53	68	83	98	113	128	143	158	173	188	203	218
7	22	37	52	67	82	97	112	127	142	157	172	187	202	217
6	21	36	51	66	81	96	111	126	141	156	171	186	201	216
5	20	35	50	65	80	95	110	125	140	155	170	185	200	215
4	19	34	49	64	79	94	109	124	139	154	169	184	199	214
3	18	33	48	63	78	93	108	123	138	153	168	183	198	213
2	17	32	47	62	77	92	107	122	137	152	167	182	197	212
1	16	31	46	61	76	91	106	121	136	151	166	181	196	211
0	15	30	45	60	75	90	105	120	135	150	165	180	195	210

FIRST PIXEL

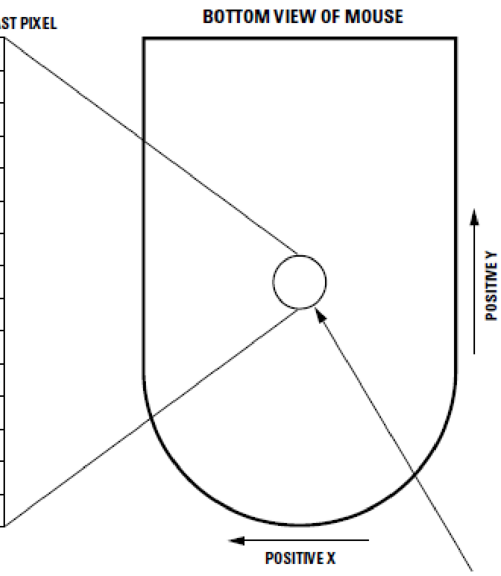


Figure 19. Overview pixel matrix

4.4.2 3Data connection

To make this data useful, there is made a data connection with the SDIO and the SCLK from the chip and with some data inputs from an Arduino Uno. The SCLK line is for the clock pulse, this pulse will ensures that the process is synchronized. This will reduce chances for errors. The SDIO (Serial Digital Input Output) line will be used for all the data busses. The Arduino ensures that the optical chip follows the pixel grab protocol and then retrieves the data from it. This data will be transferred from the Arduino to a computer that will visualize the image. This will be written in java with the programming software processing, The program sends a data bit to the Arduino so that a new grab event will activate. After that, the program retrieves the values of the pixels and put them into an array from 15x15 values. If all values are retrieved and saved into the array, the program will visualize the image. By a benchmark in addition to the picture, you can notice measure how accurate the cut is.

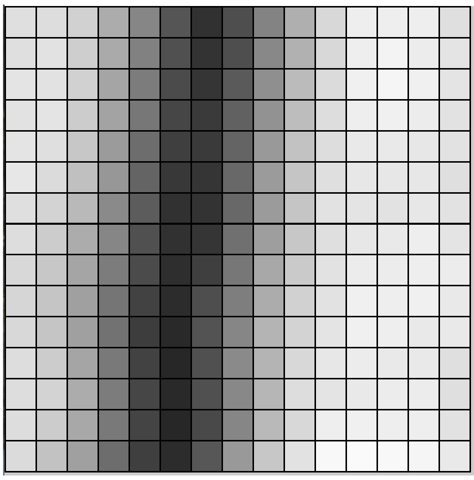


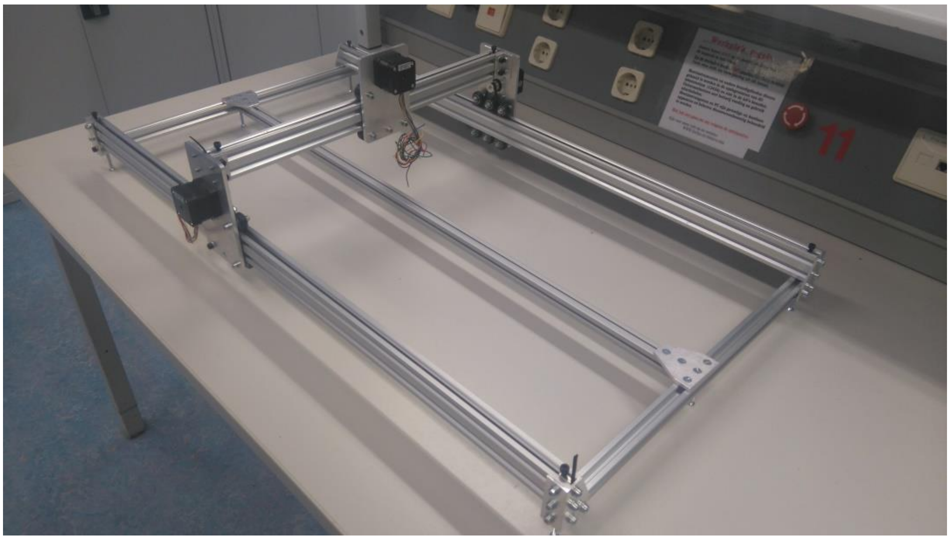
Figure 20. Pixel grab visual

5. Realization phase

In the realization phase the project group started implementing ordering and creating their designs. In this period the project group made the following things:

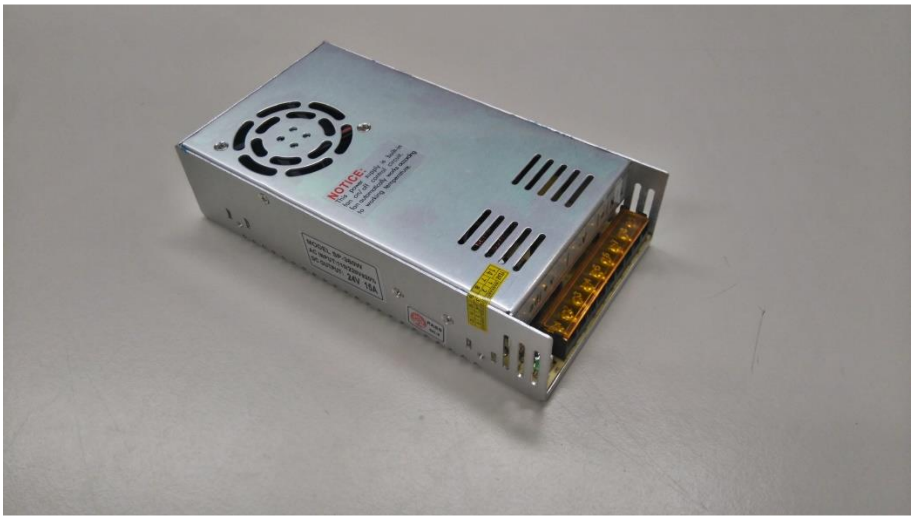
- Power supply case
- Tiny-G PCB
- A construction for moving in the Z-AXIS
- Measurement probe

At the start of the project in Q3 the had a complete XY system that was made in Q1 and some drivers for the stepper motors.



Power supply case

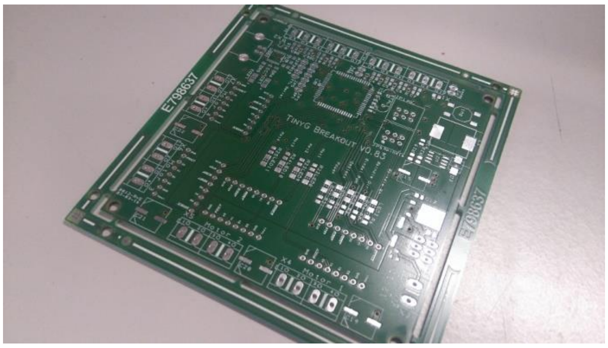
The stepper motors need a 24V dc power supply the project group ordered some this transformer. This transformer will be placed in the junction box to protect it from moving parts and water possibly leaking from the cooling system.



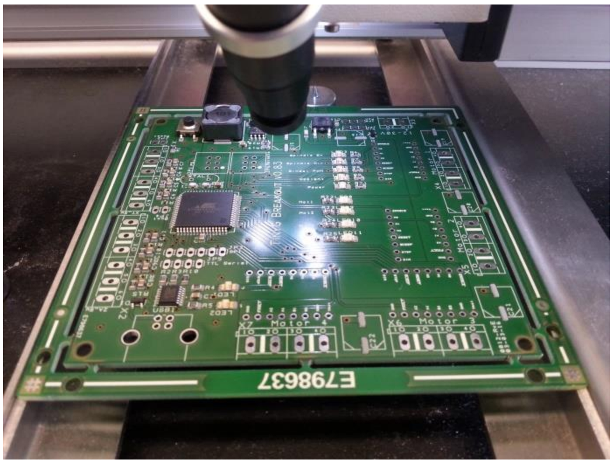
Because of lack of time the project group could not start building the junction box which has to be done in the next period.

Tiny-G PCB

It is not possible to buy a Tiny-G controller board in Europe. To evade import costs the project group decided to create one ourselves. This mend that all of the SMD parts had to be ordered and a PCB had to be made externally.



The SMD parts had to be placed with a pic and place machine and soldered on to the board using a special oven.



The end result was a Tiny-G board ready to be tested. But first a boot loader had to be installed on to the board to run the software with.

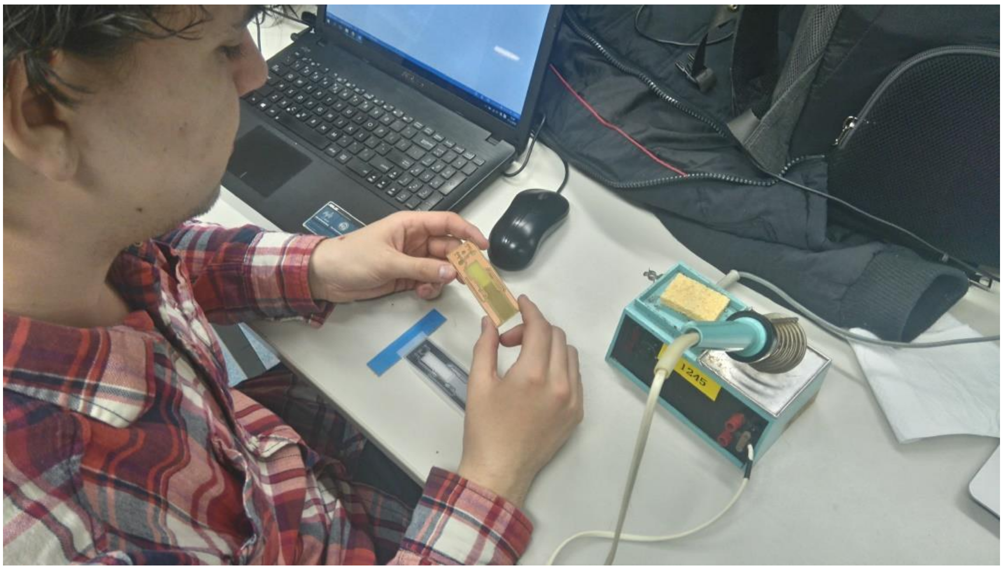
Construction for moving in the Z-AXIS

To create the movement in the Z-AXIS the project group needed some mechanical parts these pars could not be made in the machine shop or were too expensive to make ourselves. Because of this the mechanical parts were ordered.

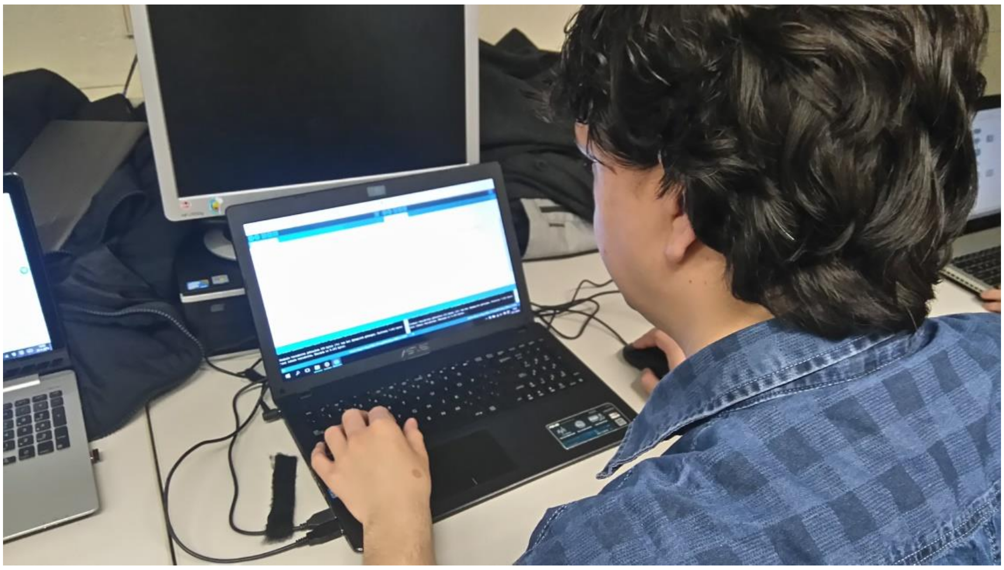
The materials for the frame were ordered from America and sponsored by Openbuilds. Sadly the parts were not in time to arrive for the project in Q3.

Optical probe

Yves made a PCB design for the measuring system. He etched the board himself and soldered on the parts to create a functioning PCB.



Also a program had to be made to visualize and measure the data on to the computer. He did this programming in Arduino and Processing. The processing program was complicated and new for him so he had some help from Pavel Samalík to write down the code.



6. Testing Phase

To see if the final product is functioning properly we need a test phase. In this phase, the product is tested and adjusted if necessary, some small mistakes are removed and subsequently improved. Testing of the product follows a specific test plan. This is shown in table 14.

Table 14: Test plan

		Parameter			
Specification	**How**	**Critical**	**Minor**	**No error**	**Test result**
Supply					
Voltage TinyG USB	Multimeter + calculation	<4V - >6V DC	<4.8V - >5.2V DC	5V DC	
Voltage laser cutter	Multimeter + calculation	<35KV - >50KV	Voltage range	35KV - 50KV	
Voltage stepper motors	Multimeter + calculation	<11V - >13V DC	>12.2V - <11.8V DC	12V DC	
Voltage cooling system	Multimeter + calculation	>250V AC	< 8% deviation	230V AC	
Voltage testing device	Multimeter + calculation	<4V - >6V DC	4.8V-5.2V DC	5V DC	
Voltage suction system	Multimeter + calculation	>250V AC	< 8% deviation	230V AC	
Fuse box	Calculation + datasheet	>250V AC	< 8% deviation	<4% deviation	
TinyG					
Copper traces	Multimeter	No connection	No connection	connection	
Solder bridges	Multimeter	connection	connection	No connection	
Pin connections	Datasheet + observation	Wrong connections	Wrong connections	Connections according to datasheet	
Emergency situation reaction time	Datasheet + observation	Q4	Q4	Q4	
Stepper motor					
Step angle (0.9°)	Tachometer	>6% deviation	<6% deviation	±5%	
Holding torque	Calculation	<2.5 - >2.7 Kg.cm	<2.58 - >2.62 Kg.cm	2.6 Kg.cm	
Rated current / phase	Multimeter + calculation	<0.3 - >0.5A A	<0.38 - >0.42 A	0.4 A	
Phase resistance	Multimeter + calculation	<25 - >35 Ohm	<27 - >33 Ohm	30Ohm	

Table 14: Test plan

Specification	How	Parameter			Test result
		Critical	Minor	No error	
Frame					
Frame alignment	Calculation + observation	>1%	>0.3%	±0.1%	
Bolt / belt connections	observation	bad	average	good	
Rail strength	Calculation + observation	Q4	Q4	Q4	
Cooling system					
Pump flow rate	Flow sensor	Q4	Q4	Q4	
Water temperature	Temperature probe	>90	<90 - >80	<80	
Heat dissipation	Temperature probe	Q4	Q4	Q4	
Tube connections	observation	leaks	Loose fittings	Tight connection	
Optical probe					
Sensor accuracy	Measurement + observation	>1um	±1um	<1 um	V
Data connection	Data transfer	incompatible	errors	good	V
Sensor alignment	Measurement + observation	>1mm	±1mm	<1 mm	V
Laser source					
Output power	Multimeter + calculation	Q4	Q4	100W	
Beam divergence	Measurement + observation	>25%	>20%	<20%	
Laser temperature	Temperature probe	>110	>100	<100 degrees	
Laser efficiency (W)	Measurement + calculation	<20%	<30%	±35%	
Beam diameter	Measurement + observation	>10mm	>9mm	<8mm	
Suction system					
Air flow rate	Flow sensor	Q4	Q4	Q4	
Flame creation	observation	constant	few	none	
Laser Glass					
reflectance	Q4	Q4	Q4	Q4	
Direct laser contact time	Q4	Q4	Q4	Q4	

Table 14: Test plan

		Parameter			
Specification	**How**	**Critical**	**Minor**	**No error**	**Test result**
Microcontroller for user interface					
voltage	Multimeter + calculation	Q4	Q4	Q4	
Data connection	Observation + data transfer	Q4	Q4	Q4	
User interface					
Emergency button	Q4	Q4	Q4	Q4	
Display	Q4	Q4	Q4	Q4	
buttons	Q4	Q4	Q4	Q4	
	Q4	Q4	Q4	Q4	
Indicator					
LED indicator	Multimeter + observation				
Voltage		<2V	2V-3V	3V-4V	
Current		<20mA	20mA-30mA	>30mA	

7. Conclusions and recommendations For the next period

During this period the project group made great progress but not everything was finished. In this chapter the conclusions and recommendations are discussed to make it clear for the next period what still has to be done. Below is a sum up of all the modules that had to be worked on and in what period the project group started working on to the module.

- **Movement mechanism Z-AXIS [Q3]**
- **Movement mechanism X&Y-AXIS [Q1]**
- **Electrical supply for the complete system [Q3]**
- **Laser source/water-cooling [Q4]**
- **Laser direction [Q7]**
- **Controller board [Q3]**
- **Interface [Q4]**
- **Suction system [Q4]**
- **Air knife [Q4]**
- **Optical measuring instrument [Q2]**

7.1 Movement mechanism Z-AXIS

Because of the late delivery from America all of the assembling of the Z-AXIS has to be done in Q4. De documentation work drawings and design were completed during Q3. The project group was aware of this risk but took it because of financial reasons.

7.2 Movement mechanism X&Y-AXIS

The still has to be optimized to make it as straight as possible. The documentation has to be adjusted to fit this report. This has to be done in Q4

7.3 Electrical supply for the complete system

Almost all of the designing for the electrical system was finished during Q3 except for the air-knife. In Q4 the project group must discuss with the costumer if an air knife is necessary for this project. In Q4 the project group has to finish making the electrical scheme's and order the fuses, laser source, emergency stop and the junction box and put all of these parts in.

7.4 Controller board

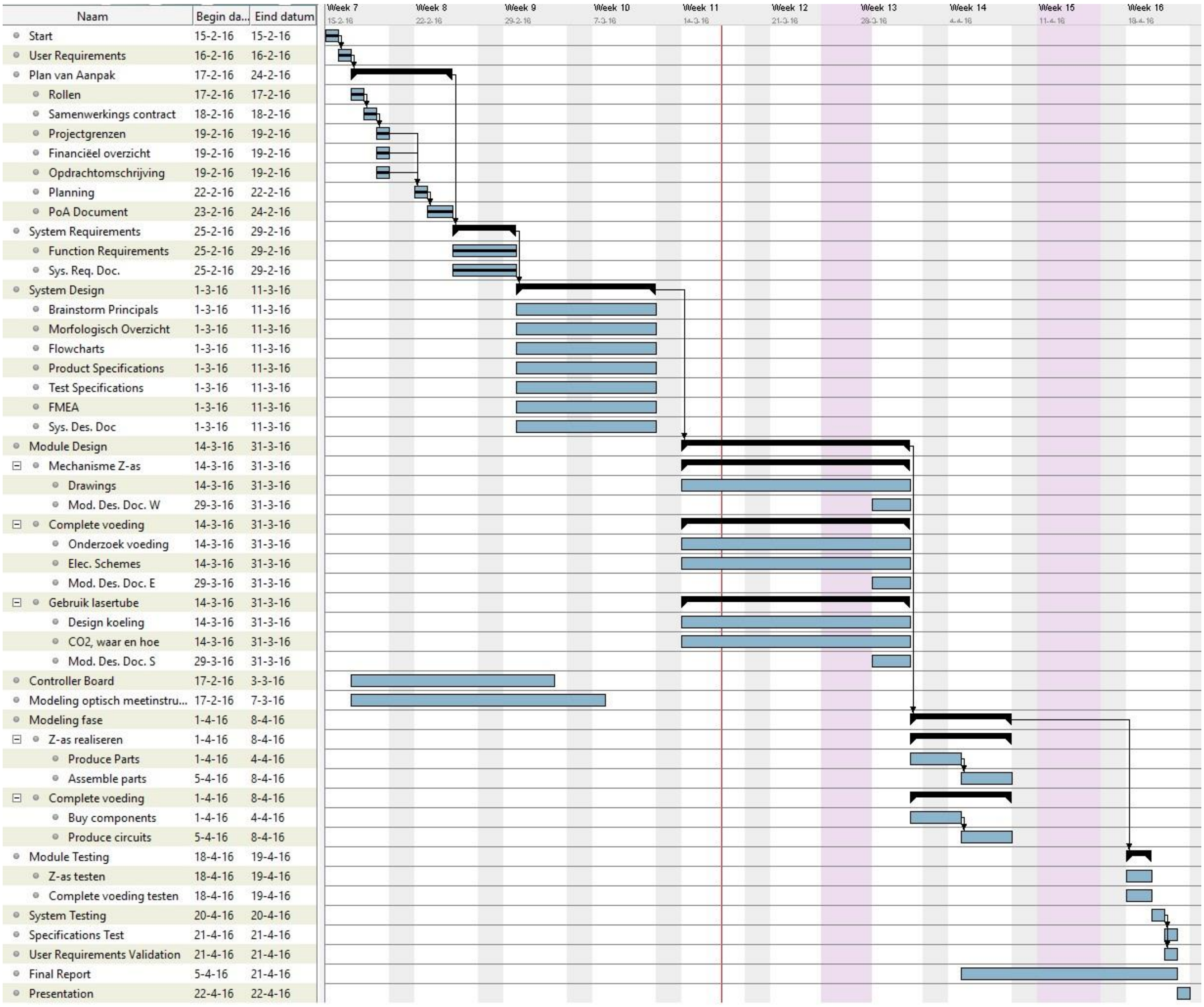
The physical controller board is completely finished along with the documentation. But because of trouble with the software the project group was unable to test it in the school. This has to be done in Q4.

7.5 Optical measuring instrument

The optical measuring instrument was completely finished and tested during Q3.

Appendix

Appendix I. the project planning



Naam	Begin da...	Eind datum
Start	15-2-16	15-2-16
User Requirements	16-2-16	16-2-16
Plan van Aanpak	17-2-16	24-2-16
Rollen	17-2-16	17-2-16
Samenwerkings contract	18-2-16	18-2-16
Projectgrenzen	19-2-16	19-2-16
Financiëel overzicht	19-2-16	19-2-16
Opdrachtomschrijving	19-2-16	19-2-16
Planning	22-2-16	22-2-16
PoA Document	23-2-16	24-2-16
System Requirements	25-2-16	29-2-16
Function Requirements	25-2-16	29-2-16
Sys. Req. Doc.	25-2-16	29-2-16
System Design	1-3-16	11-3-16
Brainstorm Principals	1-3-16	11-3-16
Morfologisch Overzicht	1-3-16	11-3-16
Flowcharts	1-3-16	11-3-16
Product Specifications	1-3-16	11-3-16
Test Specifications	1-3-16	11-3-16
FMEA	1-3-16	11-3-16
Sys. Des. Doc	1-3-16	11-3-16
Module Design	14-3-16	31-3-16
Mechanisme Z-as	14-3-16	31-3-16
Drawings	14-3-16	31-3-16
Mod. Des. Doc. W	29-3-16	31-3-16
Complete voeding	14-3-16	31-3-16
Onderzoek voeding	14-3-16	31-3-16
Elec. Schemes	14-3-16	31-3-16
Mod. Des. Doc. E	29-3-16	31-3-16
Gebruik lasertube	14-3-16	31-3-16
Design koeling	14-3-16	31-3-16
CO2, waar en hoe	14-3-16	31-3-16
Mod. Des. Doc. S	29-3-16	31-3-16
Controller Board	17-2-16	3-3-16
Modeling optisch meetinstru...	17-2-16	7-3-16
Modeling fase	1-4-16	8-4-16
Z-as realiseren	1-4-16	8-4-16
Produce Parts	1-4-16	4-4-16
Assemble parts	5-4-16	8-4-16
Complete voeding	1-4-16	8-4-16
Buy components	1-4-16	4-4-16
Produce circuits	5-4-16	8-4-16
Module Testing	18-4-16	19-4-16
Z-as testen	18-4-16	19-4-16
Complete voeding testen	18-4-16	19-4-16
System Testing	20-4-16	20-4-16
Specifications Test	21-4-16	21-4-16
User Requirements Validation	21-4-16	21-4-16
Final Report	5-4-16	21-4-16
Presentation	22-4-16	22-4-16

Appendix II. Nema 17 stepper

Description

Nema 17 stepper motor with 0.9° step angle (400 steps/revolution). Each phase draws current 400mA at 12V, allowing for a holding torque of 26Ncm(36.8oz.in).

Electrical Specification

Manufacturer Part Number	17HM15-0406S
Motor Type	Unipolar Stepper
Step Angle	0.9°
Holding Torque	26Ncm(36.8oz.in)
Rated Current/phase	0.4A
Phase Resistance	30ohms
Recommended Voltage	12-24V
Inductance	30mH±20%(1KHz)

Physical Specification

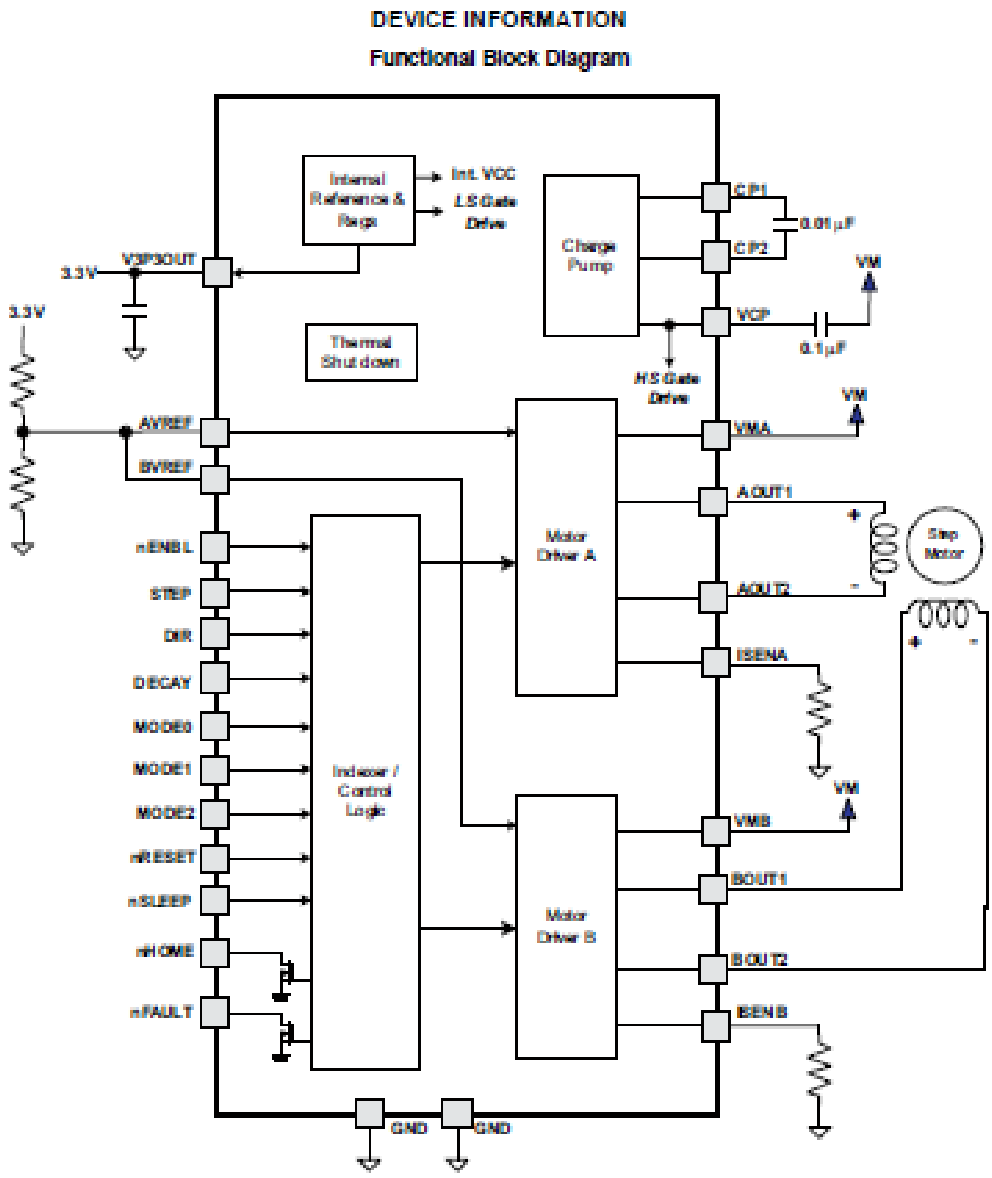
Frame Size	42 x 42mm
Body Length	39mm
Shaft Diameter	Φ5mm
Shaft Length	24mm
D-cut Length	15mm
Number of Leads	6
Lead Length	500mm
Weight	300g

Connection

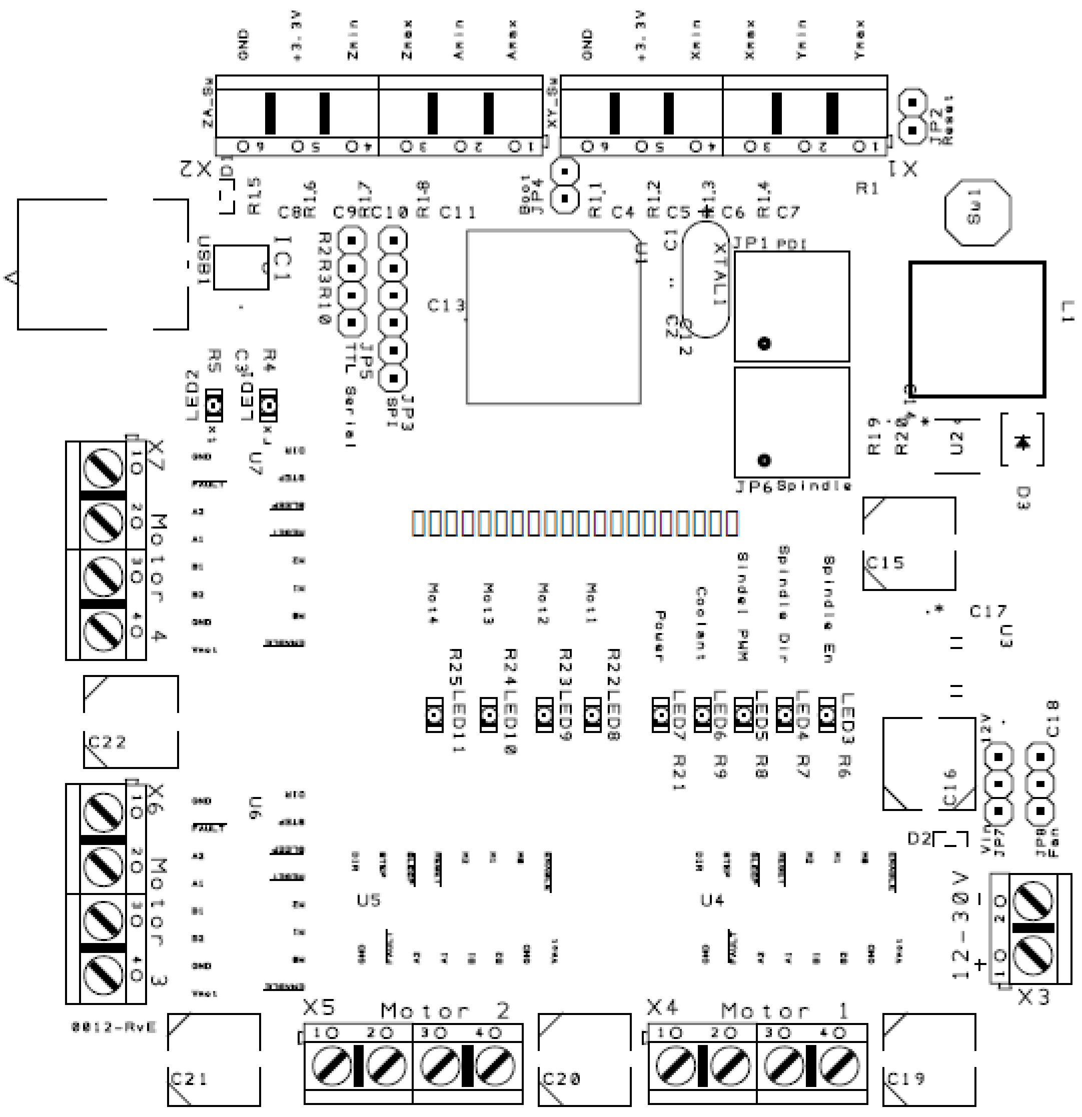
Wire Color	Black	Yellow	Green	Red	White	Blue
Board Connector	A	A C	C	B	B D	D

Appendix III. DRV8825

DRV8825



Appendix IV. Eagle layout



Glossary

Chapter 1. Initiation phase

Q1,2,3,4:
a quarter of a study year in which the project group worked to make the laser cutter.

Chapter 2. User requirements

Air knife:
a stream of high pressured air that will blow away any debris of a project.

Chapter 3. System requirements

Chapter 4 System design

AC:
alternating current

DC:
Direct current

NC:
Normally closed

G-code:

G-code is a language in which the machine knows how to make something. The g-code tells the machine how fast to move, and to which position it has to move. Every line of g-code gives machine a new position and another speed.

Baud rate:

The serial communication speed measured in bits per second.

CNC:

Numerical control (NC) is the automation of machine tools that are operated by precisely programmed commands encoded on a storage medium, as opposed to controlled manually by hand wheels or levers, or mechanically automated by cams alone. Most NC today is computer (or computerized) numerical control (CNC),[1] in which computers play an integral part of the control.

DDA:

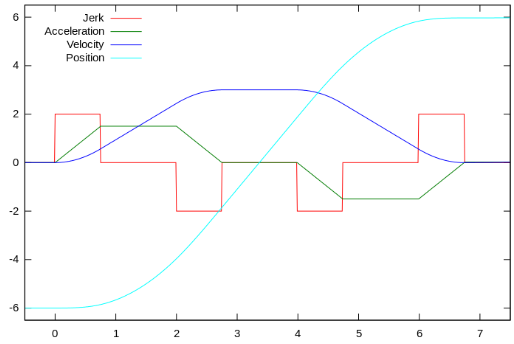
Digital differential analyser (DDA). The primary advantages of a DDA over the conventional analog differential analyser are greater precision of the results and the lack of drift/noise/slip/lash in the calculations. The precision is only limited by register size and the resulting accumulated rounding/truncation errors of repeated addition. For problems that can be expressed as differential equations, a DDA can solve them much faster than a general purpose computer (using similar technology).

SMD
Surface mounted device. Very tiny electrical components to place on to a printed circuit board.

Jerk:

In physics, jerk is the rate of change of acceleration; that is, the derivative of acceleration with respect to time, and as such the second derivative of velocity, or the third derivative of position.

According to the result of dimensional analysis of jerk, [length/time^3], the SI units are m/s^3 (or m·s^{-3}). There is no universal agreement on the symbol for jerk, but $\vec{j}$ is commonly used.



Jogging:

The user is able to manually adjust the position of the machine's head.

Chapter 5. Realization Phase

Chapter 6. Testing phase

Chapter 7. Conclusions for the next period