Deliverable 4 : Jumper cutting/stripping machine

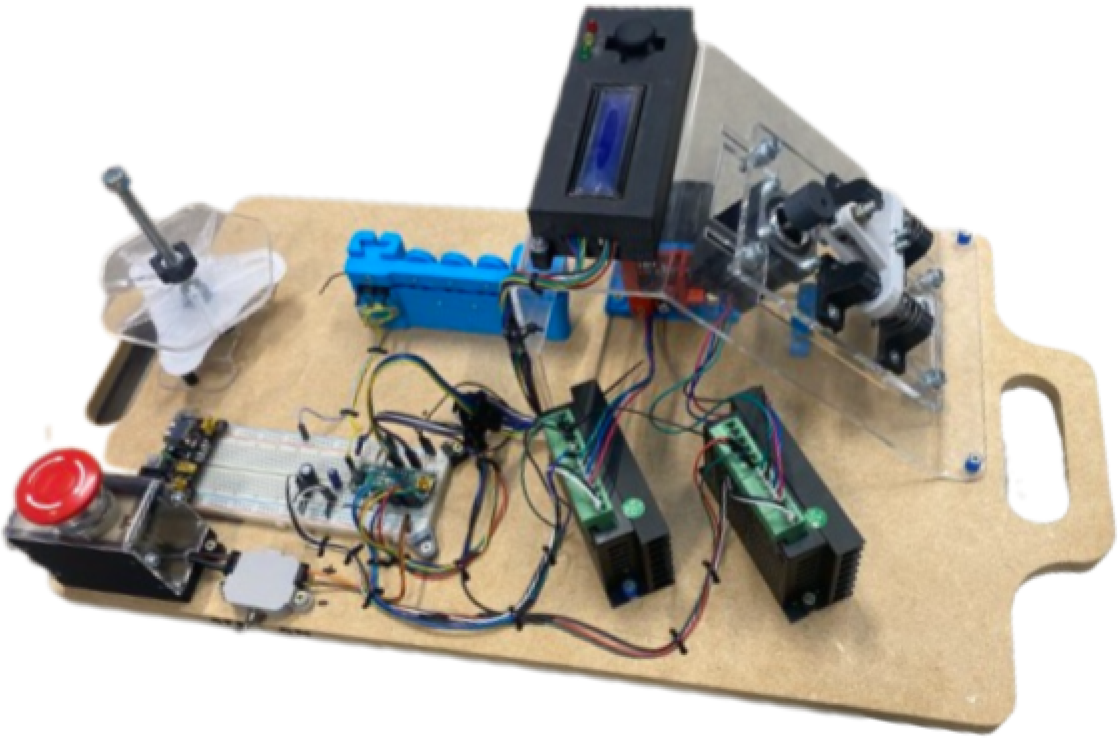

Figure 1: Final prototype

Date: 16/05/2023

Group N°12

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Contents

1. Context of the study

Our goal is to create a jumper cutting and stripping machine for Frédéric Mantegazza, to be used in schools, particularly Ense3, for educational and research purposes. Our client specifically requested that our project be open-source, which means we have to put all our research and documentation on GitHub. This project has a cost limit of 300€.

This machine will primarily cut and strip wires to create jumpers for electrical devices like breadboards. To complete this project, our group opted to utilize the AGILE methodology, as it can accommodate the evolving needs of our non-professional client and allows us to separate the project into four sub-projects that align with the AGILE method's cycles. Additionally, focusing on two sub-systems in each cycle enables efficient organization and effective collaboration.

Throughout the year, we have continuously enhanced the functionality of the jumper machine and introduced new features. It is essential to remember that our final product is a prototype, which will be continuously improved by the next IdP promotions.

The aim of this report is to present the design process of the jumper machine, the obstacles we encountered, and the solutions we developed.

2. Final expression of the need negotiated with the client

Throughout the project, the requirements changed. At the very beginning of the project, we had a meeting with the client to set the first requirements. However, during the development of the product, we realized that some requirements were too specific for what we could deliver. We therefore organized several meetings with the client throughout the year to negotiate new requirements. Here are our final requirements.

Functions	Sub-functions	Criteria	Description
Distribution of rigid wire	Feed with wire	Practical	It must be possible to integrate a coil of rigid wire to feed the system
	Tighten the thread in the system	Straightness	The wire axis must not deviate from the wire feed axis
	Carry the wire through the system	Practical	The wire must be able to be transported to each relevant part of the system
	suited for specific wire	practical	The system must work with the specific wire ordered by the client
	Warn the user about lake of wire	security	It must stop the system if there is no more wire at the entry of the distribution and alert the user
	Carry the wire with strength	Practical	It must be capable of stripping a 5 cm wire

Cutting the wires	Cut the wires to the right length	Length	The distance between the edges must be compatible with the length of the laboratory breadboard
	Cutting the wire into a bizot	Angular	The section of the cut wire must have a slope to facilitate the insertion of the edges in the breadbord
	Cut the wire	Visual	The wire must be separated from the coil of wire after the operation
	suited for specific wire	practical	The system must work with the specific wire ordered by the client
Stripping	Remove the sleeve from the wires' edges	Visual	There is no more sleeve on the area to be stripped
	Have the right size of edge	Length	The stripped edges must have a given length
	Do not damage the conductor	Quality	Check that there are no significant marks on the conductor in the stripped area
	Control the waste	Practical	The 2 sleeves must be taken by the system and not become harmful elements for the good functioning of the rest of the process
Bend the wire	Bend the edges at the right angle	Angular	The 2 edges must be bent at the right angle
	Do not distort the body	Straightness	After the operation, the straightness of the body must not have shifted from the initial axis of the wire
	Do not damage the jumpers	Quality	There should be no visible damage to the jumper after the edges are bent
	Do not dealign the edges	Alignment	The edges must be aligned when looking at the profile of the jumper
	Do not distort the edges	Straightness	After the operation, the straightness of the edges must be kept
Sort	Separate the sleeves from the jumpers	Practical	At the end of the manufacturing process of a jumper, the 2 pieces of sleeveing and the jumper must be separated in their respective areas
Function	Supply electricity	Practical	Can be powered by various sources (nomadic mode...)
	Resist to the environment	Temperature	The system works without anomaly for 10 jumpers in the given temperature range
	Maintenance	Simplicity	The system must be dismountable/remountable according to the main components after a certain time with basic tools
	Be consistent in the process	Fiability	On a given volume of jumper production, the system must have a maximum percentage of defective jumpers (which do not respect the specifications)
	Rate	Speed	The manufacturing process of a functional jumper, from the moment it is ordered to the moment it is finalized, must be less than a given time
Secure	Have an emergency stop	Temporal	The system must be able to be completely shut down in less than a certain time with a simple manipulation
	Do not allow access to moving parts during the operation	Practical	Have a safety device that prevents the system from starting up if the instructions are not followed
Spatial clutter	Do not exceed the maximum volume	Volume	The system must not exceed the maximum dimensioning
	Do not exceed the maximum weight	Weight	The entire system (excluding coil of wire, holder and user) must not exceed the maximum weight
Utility	Respect the budget	Financial	The entire system performing the process (excluding coil of wire and labor) should not exceed the maximum cost
	Be in open source	Practical	At the end of the project, it must be made available in open source
	Be accessible	Accessibility	The project must be able to be carried out in FabLab type infrastructures for individuals
	Documentation	Accessibility	The system must have a user manual and a maintenance manual

Figure 2 : Final requirements

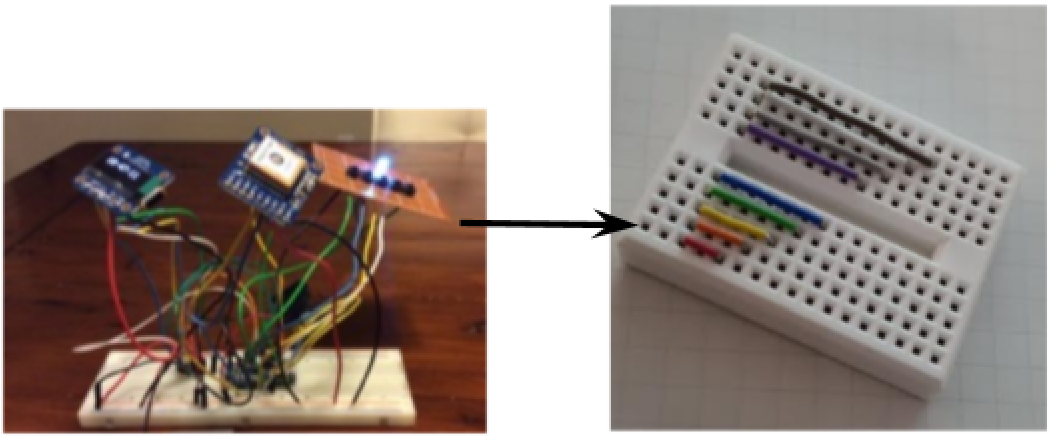

Figure 3 : Presentation of the problem and the expectations of the machine

3. Final product

We chose to put the prototype on a board that has handles in order to make it easily transportable. We fixed the electrical cables with tie clips in order to have a clean machine. The whole organization of the machine was rethought in order to limit the clutter and to facilitate the use of the machine. That's why we put the man-machine interface on the inclined plate.

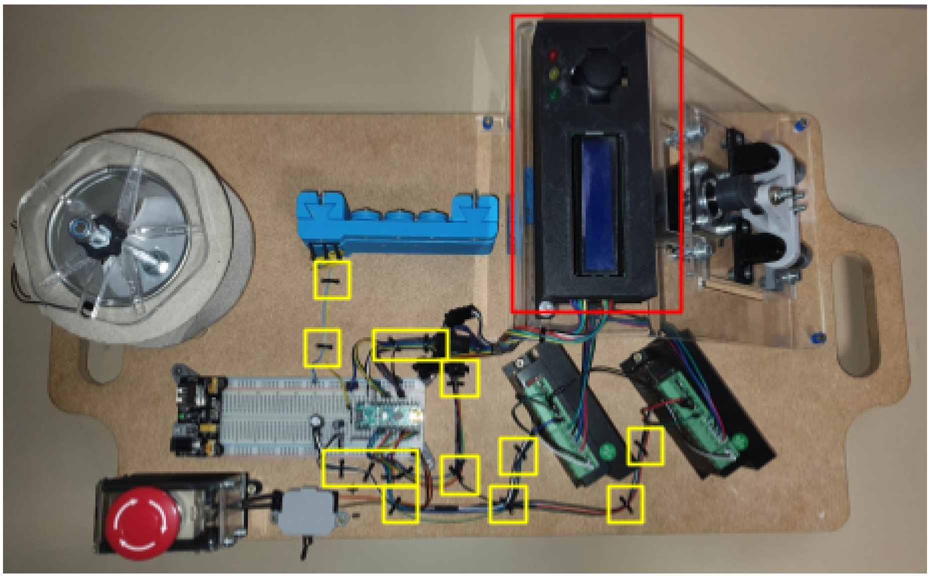

Figure 4 : Final prototype, Tie clips in yellow and HMI in red

A. General functioning

The machine is very simple to use, as the user only needs to switch on the start button, choose the number of jumpers they want to make and the desired length, and then start the process.

Once the user has initiated the process, the machine unwinds the wire from a coil and guides it through a rigid tube via a 3D printing extruder. The inclined blades on the machine bite the sheath of the wire, while the extruder pulls the wire back to strip off the insulation. The wire then advances, and the process is repeated to strip off the insulation once again.

Finally, the wire is cut at a 45-degree angle by the blades, and the waste drops off the machine via a small slope.

B. Distribution part

The wire used for the jumpers is always the same (single core wire AWG 23). It must remain straight according to the specifications, and the wire reel must rotate freely without getting stuck. To achieve this, a height-adjustable cone system is used to secure the wire reel. The wire passes through a first guiding system made of rollers, which can be adjusted in height to tighten or loosen the wire as needed.

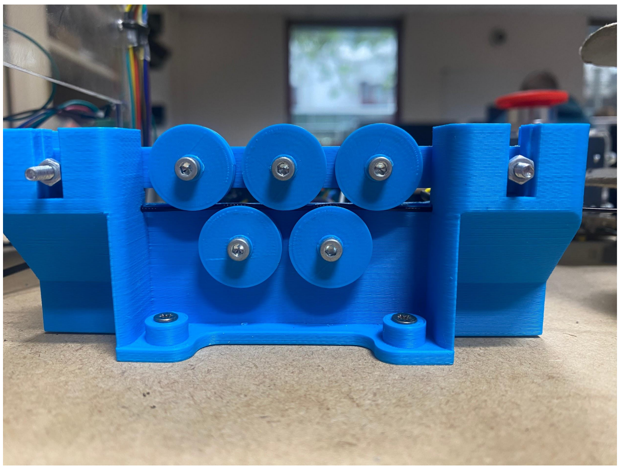

Figure 5 : Tightening system with 5 rollers

Next, the wire is directed into an extruder for 3D printing, which can be manually opened to guide the wire by hand if necessary. Finally, the wire is guided from the extruder's output to the blades through rigid tubes (LEGRIS*2x4 POLYAMIDE CALIBRE).

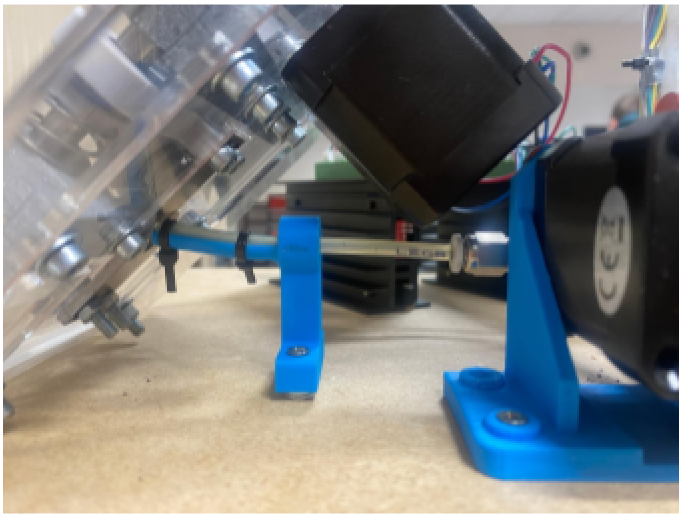

Figure 6 : Guiding pipe from extruder to the blades and the extruder.

C. Cutting and stripping part

The system must transform AWG 23 reel wire into jumpers which are bent wires with stripped ends. For this, we complete the process imagined in the first AGILE cycle as follows:

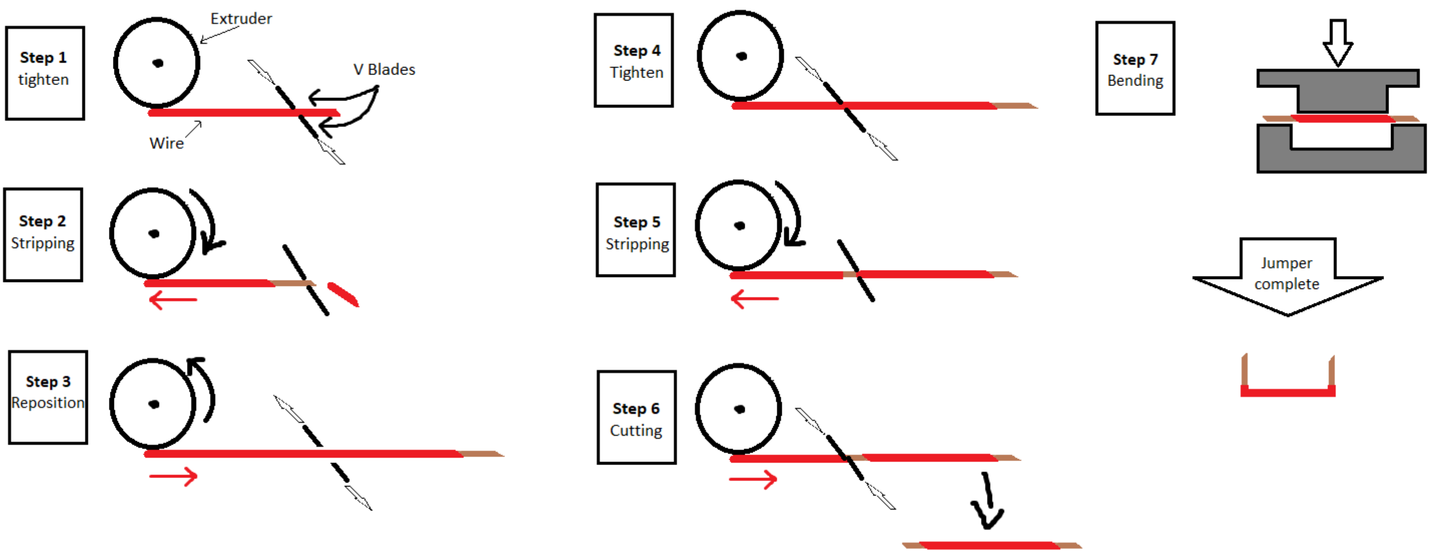

Figure 7 : Cutting and stripping

The system will first cut the sheath the double the length of the leg of a jumper, then this sheath is pulled off with the blades retaining it and falls off. After, the wire is fed until the machine can cut the sheath so that the bit left will be of the desired length. This sheath is centered and the machine can then cut the wire at its tip.

The program will start again, as much as needed to cut the number of jumpers as the user asked.

The machine we made is constituted of a moving V blade closing on the same type of blade. A support is pushed in the way to cut and strip with a cam controlled by a stepper motor (Nema 17; 59 Ncm and 2A) and to ensure this system goes back to its original position, two springs were added. This whole system is fixed on a plate we can move up and down (to allow a height adjustment). This on a fixed inclined support to get a cut around 45°, to facilitate the entry of the jumpers in breadboards.

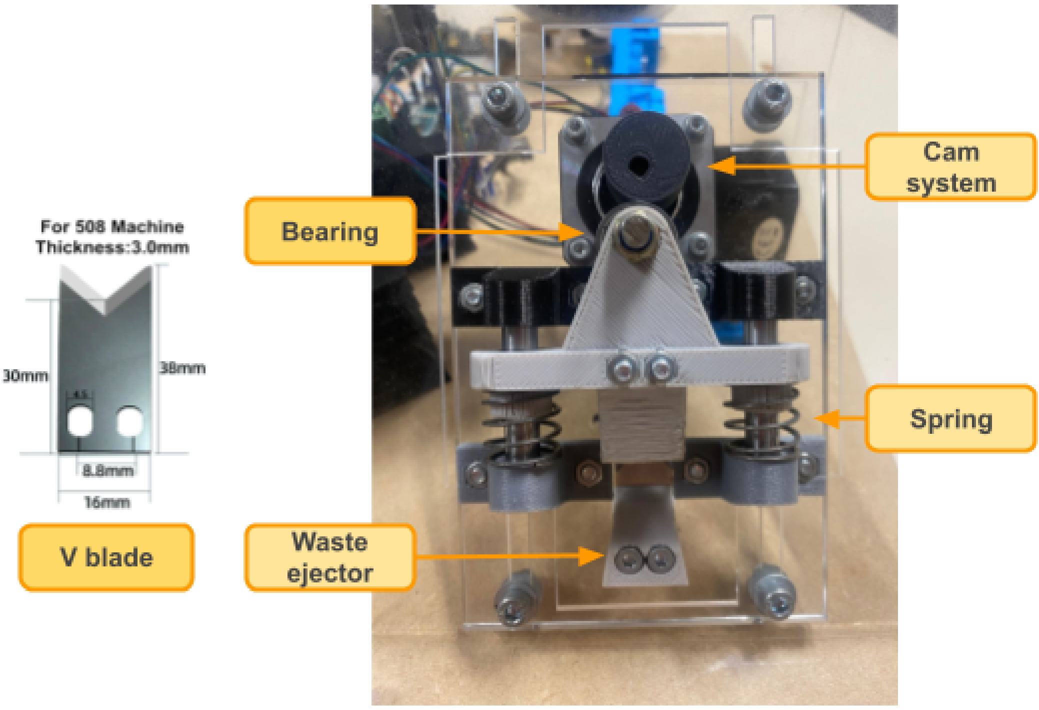

Figure 8 : Cutting and stripping system

The first main issue with this is to ensure we pull the sheath without too much effort, but it won't happen if the blades bite in the core of the wire. The simplest and best solution is just to turn back the cam a few steps after cutting the sheath so that it retains it with enough room so that the core won't be stuck in the blades.

D. Bending the wire

Bending is a crucial step in the process of making jumpers. It is important to bend them accurately so that the wire remains straight as per the specifications. Precision is of utmost importance because even the slightest deviation can cause the wire to not fit properly into the breadboard.
During our first revision of the bending process, we had an issue with the elastic return, it didn't allow us to have the right angle at the edges and the jumper couldn't fit properly in the breadboard. In order to fix it we designed a die that counters the elastic return issue using an undercut and a flexible part to push the edges against the undercut. In order to make the flexible part, we used semiflex since it is an accessible flexible material for fused filament fabrication.

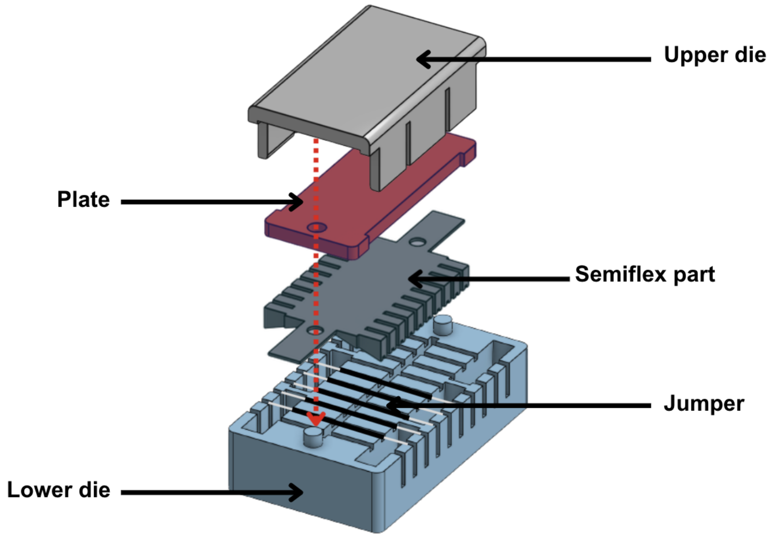

Figure 9 : Bending parts for the largest jumper size (25.4)

There are three main steps to the bending mechanism : First, the jumper is placed in the grooves of the lower die. Then, when applying pressure on top of the upper die, the semiflex part and the plate are pressed against the jumper. The spring contracts when the upper die and the semiflex part force the jumper edges against the lower die undercut. When hand pressure is released from the upper die, the wire is no longer pushed against the die and the edges are bent to a 90° angle.

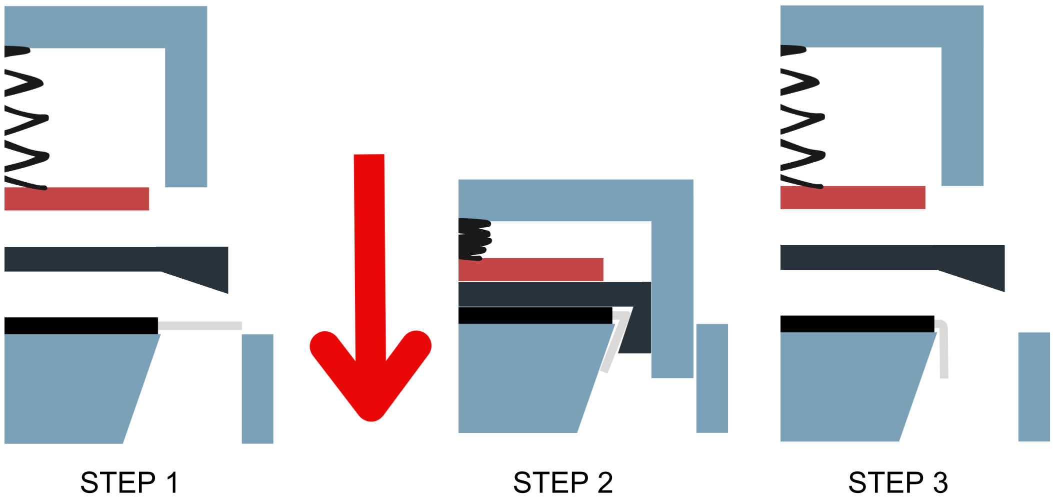

Figure 10 : 3 steps of bending mechanism

Since we need to make various lengths of jumpers, we designed dies for each jumper size, from three to ten steps (7.62 to 25.4 mm).

In order to facilitate the removal of the jumpers from the lower die, we designed a jumper remover that slides in a slot in the lower die and lifts the jumpers a bit so they can be easily removed.

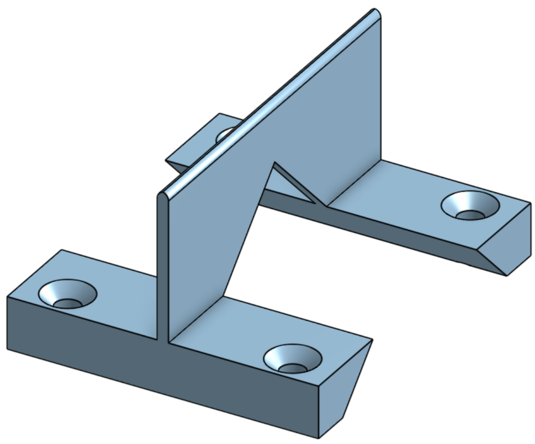

Figure 11 : Jumper remover

E. Human machine interface

I. Emergency stop button

The emergency stop button is a crucial safety feature of the system, as it stops the entire machine when activated. The button is housed in a casing made of laser-cut and 3D-printed materials, which help to simplify the human-machine interactions and make the button easily accessible to users. In case of any emergency, the user can quickly and easily press the button to halt the machine's operations and prevent any potential hazards.

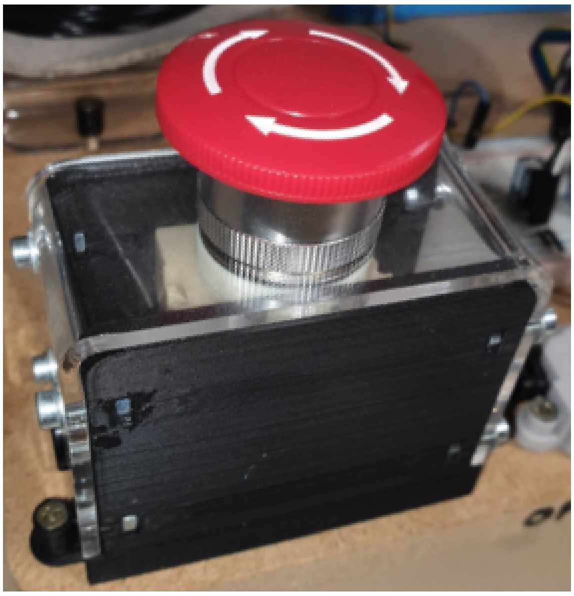

Figure 12 : Emergency stop button

II. Control interface

Creating a HMI was an important step to ensure the machine is usable. It allows the user to change the parameters of the machine without changing the code. Different menus were set up to change those values: for the number of jumpers to cut, for their length and for the positioning of the blade to strip the wire. Also two more menus were added: one to feed the wire once it's in the extruder (avoiding a tedious task by hand) and the menu to start the program to make jumpers.

A joystick can change menus vertically and change the values of the menus concerned horizontally, once entered with the button of this joystick. To see that information, a simple 16x2 screen was added for the precise information, and three LEDs were added: green when everything is functioning and it's fine to manipulate the machine, orange when everything is functioning but one or both motors are functioning, and red when wire is missing.

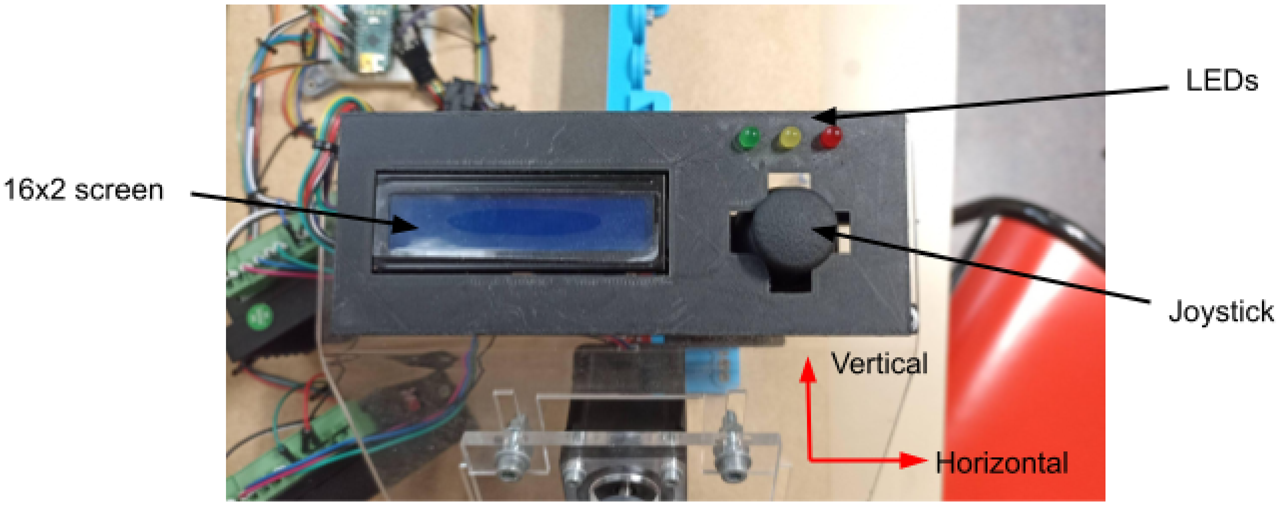

Figure 13 : HMI organisation

4. Technical and scientific work

A. Cut stress

To justify our experimental choices and determine the appropriate dimensioning of the stepper motors, we conducted experiments to investigate the forces involved in cutting and stripping wires. Our client required a cutting angle of 45° to facilitate jumper insertion into breadboards, but we wanted to assess how the cutting force changes with varying insertion angles. To accomplish this, we developed an experimental apparatus (Figure 14) that uses a dynamometer to measure the force (in Newtons) applied to the wire during cutting. The wire is guided through a tube and the insertion angle is manually adjusted using a protractor. We took five force measurements for each angle value and calculated the average.

Figure 14 : Experimental device

Our results (Figure 15) revealed that the lowest cutting force value was 52.2 N, which corresponded to an insertion angle of 90°. However, this contradicts the required oblique cut. The most relevant value was 61 N, corresponding to an insertion angle of 50°, which validated our observations that the guide system reduced the angle by about 10°. We still need to consult with our client to determine if the cutting angle can be reduced.

Regarding stripping, we found that a 4 cm sheath could be stripped with a force of approximately 1 N, but this depended on whether the sheath had been pre-cut. In cases where the stripping was poor, the stepper motor could pull with the extruder up to 17 N, but this was inadequate. Therefore, we assumed that the sheath would always be cut correctly.

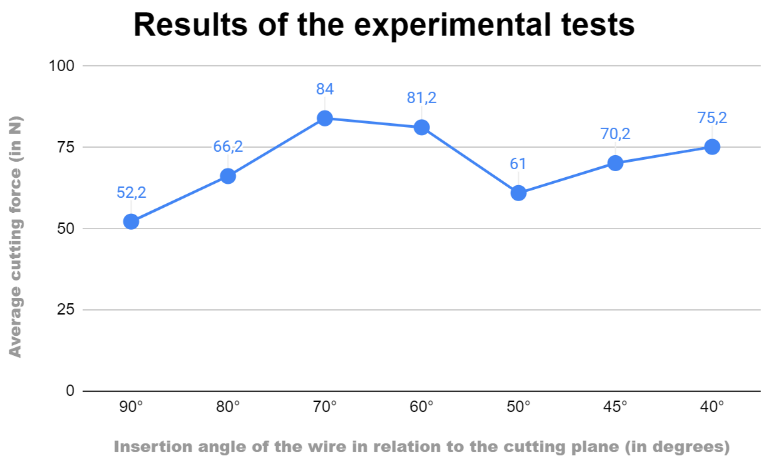

Figure 15 : Results obtained with the experimental device

B. Bending tests

When testing the first revision of our bending system, we noticed we couldn't validate requirement 4.1 - Bend the edges at the right angle. In order to compensate for the wire springback we designed a die with an undercut.

Objective of the test: determine which undercut angle is ideal to compensate for springback when bending jumpers.

Process: After having designed and printed a bending die with five different undercut angles, it is necessary to carry out five bending tests to determine the best angle. In order to determine whether the jumper obtained after bending is considered as "good", the same visual validation criteria defined in the requirements will be used. In addition, the jumper must fit correctly and easily into the breadboard.

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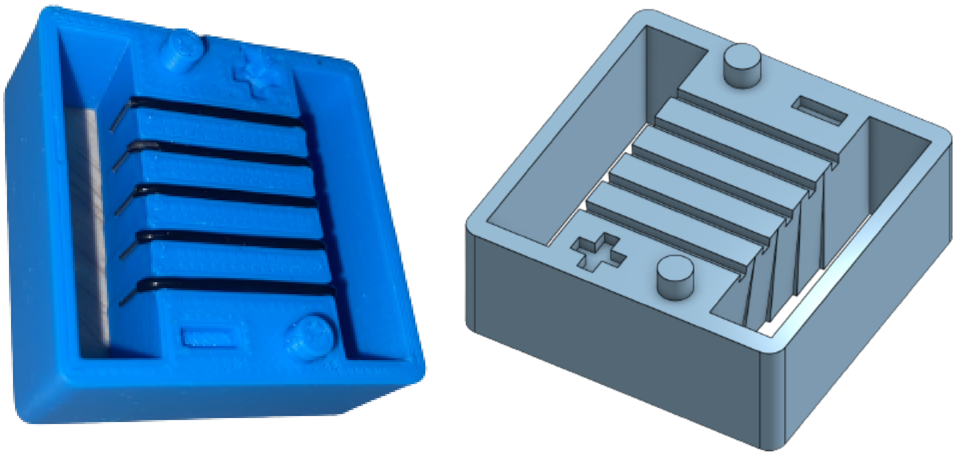


Figure 16 : Die for testing various undercut angles

Equipment:

- 3D printed die with five different undercut angles
- semiflex piece allowing to bend the jumpers' edges until the elastic return is compensated
- holding plate to prevent the body of the jumpers from rising up during bending
- u-shaped piece that rests on the ends of the semiflex piece to bend the jumpers' edges
- ocular measuring device called eyes
- breadboard

Test 1: we carried out five tests (angles: 8°, 6°, 4°, 2, 0°) and noted the quality of the jumpers according to the visual criterion and good fit in the breadboard. The scoring system is explained below:

- ➔ **"NO":** angle of the jumper's edges doesn't look good and the jumper doesn't fit in the breadboard
- ➔ **"OK-":** angle of the jumper's edges looks good and the jumper doesn't fit in the breadboard without a slight adjustment
- ➔ **"OK":** angle of the jumper's edges looks good and the jumper fits perfectly in the breadboard

The table with the results is attached to the appendix (1st test). We already knew that 0° was not at all the ideal angle, but we wanted to demonstrate that again, and we found that 8° was not suitable either. The 6° angle was visually better but did not fit in the breadboard. Finally, the 4° and 2° angles seemed to be the best angles.

Thanks to this test, it appeared that the ideal angle we are looking for is between 2° and 4°. It is for this reason that we decided to refine the angular range in order to carry out new tests.

Test 2: based on the same process and with a new 3D printed die, we carried out five more tests by refining the angular range (angles: 4°, 3.5°, 3°, 2.5, 2°). Criterions and scoring system remain the same.

The table with the results is attached to the appendix (2^{nd} test). All jumpers looked good and most of them were perfectly fitting into the breadboard. We decided to choose the 2.5° because we got the best jumpers with this angle.

Conclusion: The 0° angle is the worst angle because it is not possible to compensate for the elastic return and the angles above 6° should be avoided. Therefore, and thanks to the second test, it is highly recommended to choose an angle in the range 2° and 4° because they all allow you to get the best jumpers. For example, we have chosen a 2.5° angle based on the tests we did.

c. Distribution tests

We have conducted tests on jumpers. We launched for each size of pin a dozen jumpers and we observed if the size, the straightness were validated and if the jumper does not present any defects. To make the measurements, we put a white witness on one of the wires with Tip-ex.

There were no problems with the extruder. A wire is made to go back and forth. We mark the thread at the initial position and then we notice the thread at the end of the back and forth. The difference between the 2 marks shows the shift.
On 30 round trips, we have an offset of 0,04mm and on 100 round trips, we have an offset of 0,02mm.

D. Stripping tests

We tested the flexibility of the inclined plate under cutting and stripping forces. We used a measuring gauge that we placed on the plate while the machine was running. Our measurements proved that the plate moves very little (order of magnitude of a hundredth of a millimeter). We concluded that the variations due to the flexibility of the plate had no impact on the quality of the jumpers.

We performed some tests to ensure the repeatability of the stripping motors. It is critical to verify repeatability because this is the part that needs the most precision.
We changed the program to perform 30 movements from the origin to a set position (in numbers of steps). The goal is to observe a displacement of the motor. For parameters, we had the resolution in **numbers of steps per revolution**. Also we added an **offset to the origin** of the stepper position every time it came back (going back to the “origin” + the number of offset steps).
To perform the test, we secured the machine in position, with a **mechanical comparator** set to measure the displacements along the axis of movement from the blade.

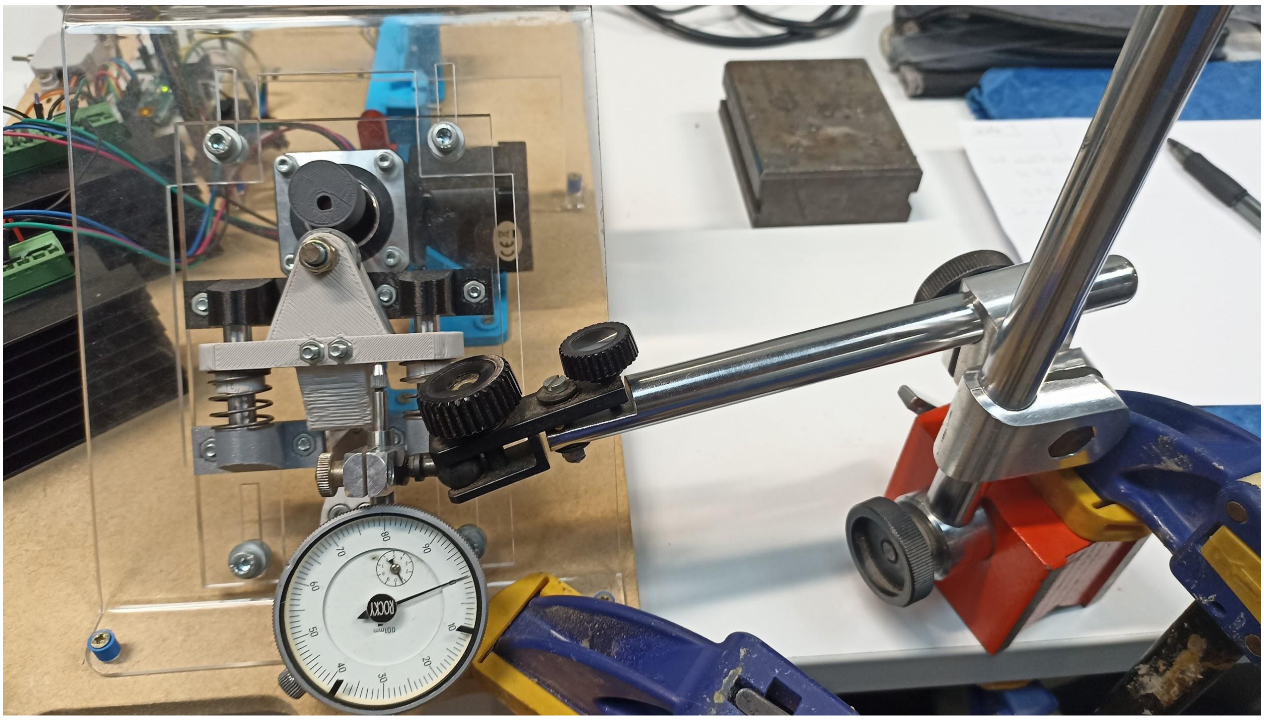
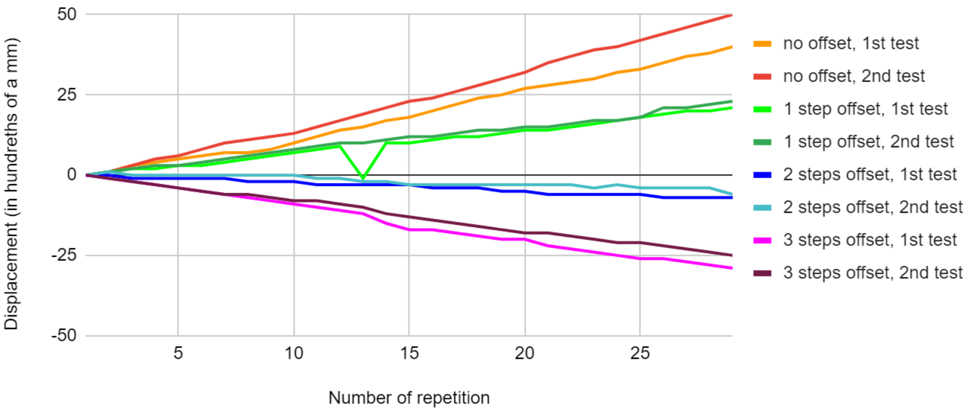
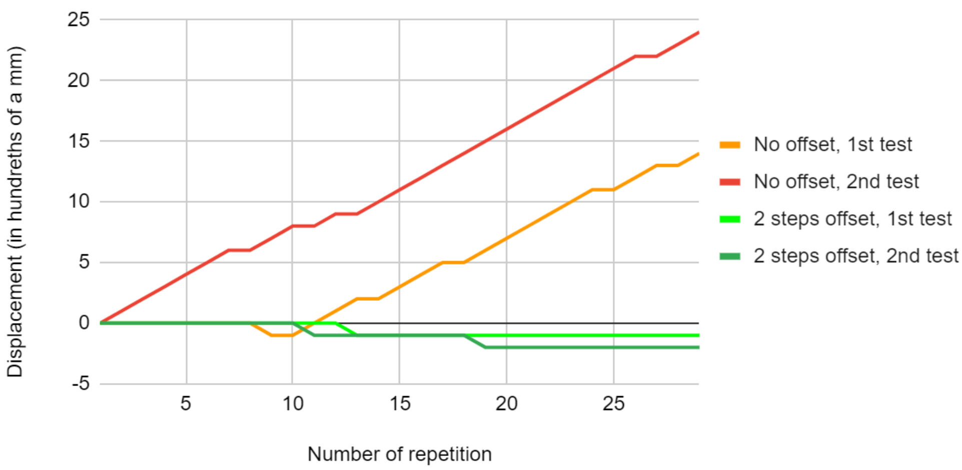


Figure 17 : Stripping repeatability experimental device



Blade support displacement (1600 steps per revolution)



Blade support displacement (3200 steps per revolution)

Conclusion: The results clearly show there is a displacement of our motor for each repetition, with a different constant tendency for each offset.
To solve that issue, we raised the number of steps per revolution from 1600 to 3200 as it cut the errors by a factor of 2. Also, we added a 2 steps offset every time the cam turns back to the origin, as for each resolution this offset results in the least error in time, even though there is still a tendency to drop for this offset. It will be recommended to redo the stripping position every hundredths of jumpers' cut, some longer tests are needed to check more precisely how many we can cut before there is an issue and we stay in the tolerances fixed.

5. Verification of the specifications

The client has approved the validation of various specifications for the jumper cutting machine, ensuring comprehensive and reliable performance.

The machine integrates a coil of rigid wire and maintains precise alignment with the wire feed axis. It efficiently transports the wire to relevant parts of the system and works seamlessly with the specific wire ordered by the client. The system also features a stop and alert mechanism for wire unavailability, strips wires effectively, and ensures compatibility with the length of the breadboard. It separates the wire from the coil, implements strict quality control, and produces uniformly stripped edges without significant marks. It handles sleeves properly, operates according to the specifications and is dismountable/remountable for easy maintenance. It maintains a low percentage of defective jumpers, adheres to dimensioning and weight limits, and remains cost-effective. Finally, the prototype is designed for FabLab infrastructures, ensuring accessibility for students and researchers.

Concerning the bending function, we did not have enough time to test every die size. However, thanks to the tests carried out, requirements 4.2 to 4.6 can be considered validated and requirement 4.1 is also validated if we consider that the undercut angle must be between 2° and 4° for it to be satisfied.

We discussed with the client and concluded that the "sort" and "secure" functions cannot be implemented this year. These functions will be studied by the next group of students working on this project.

The "less than 10 seconds" time function was not validated for larger jumpers only.

Regarding the open source aspect, it is currently being developed at the time of submitting this deliverable. It is nearly complete, with the exception of the user guide and maintenance guide, which are yet to be finalized.

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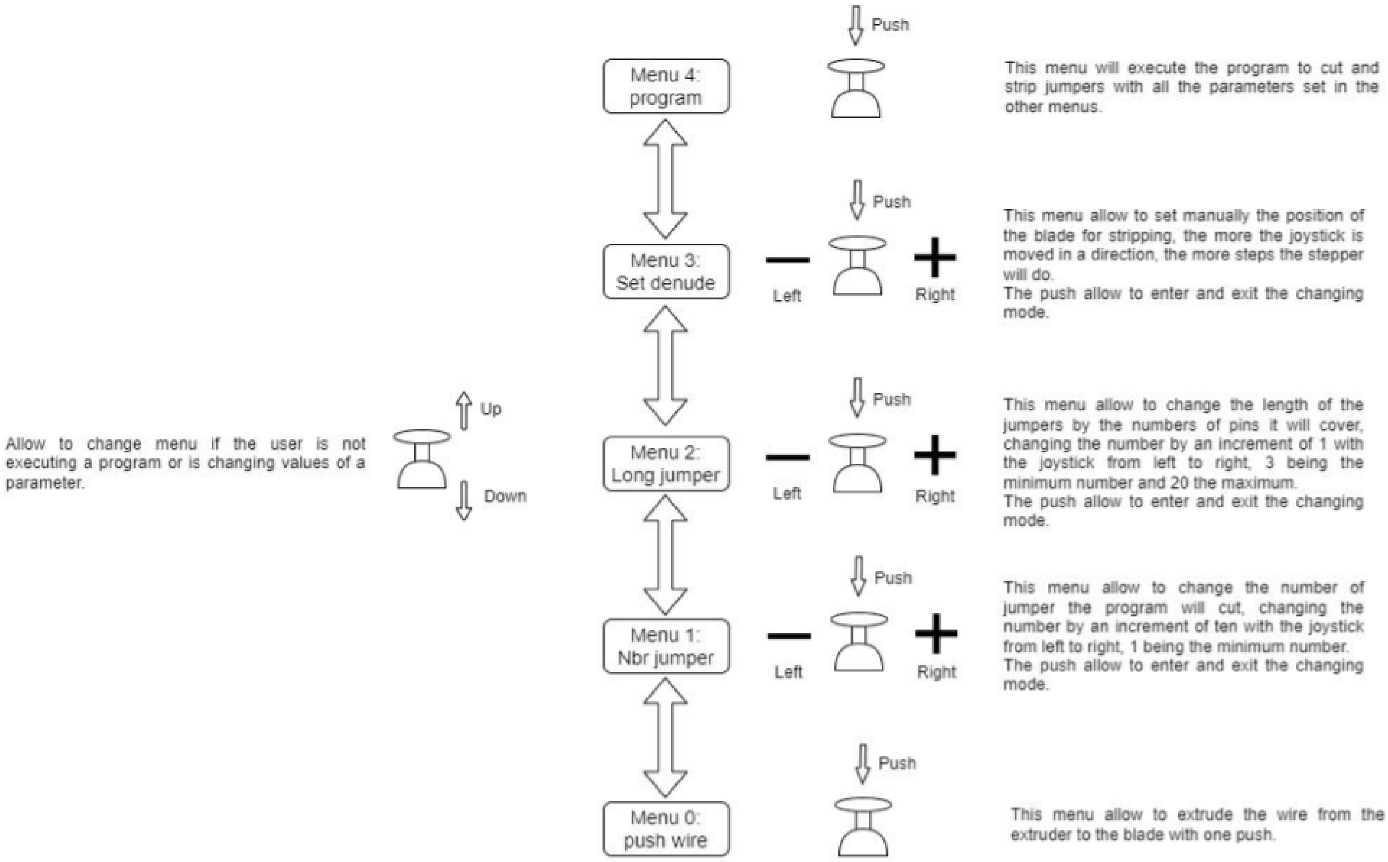
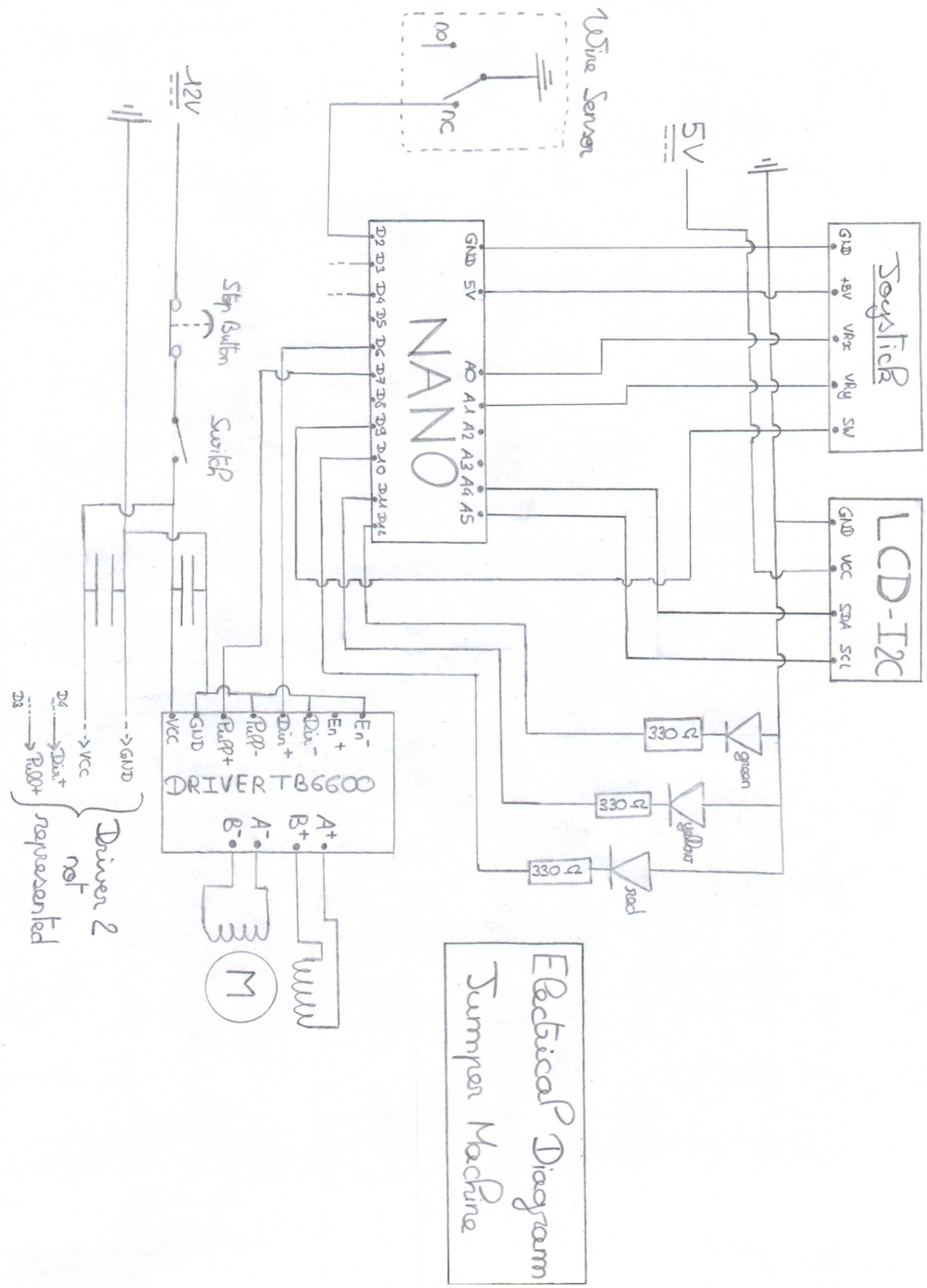
6. Appendix

Man-machine interface




Electrical Diagram
Jumper Machine
NANO
Joystick
LCD-I2C
DRIVER TB6600
Wire Sensor
Stop Button
Switch
12V
5V
330 Ω
green
yellow
red
Driver 2 not represented

Tables of bending test results

- *1st test*

	Angle (°)	8	6	4	2	0
TEST 1	**Fits in breadbord**	NO	OK-	OK-	OK	NO
TEST 2	**Fits in breadbord**	OK-	OK-	OK	OK	NO
TEST 3	**Fits in breadbord**	NO	OK	OK	OK	NO
TEST 4	**Fits in breadbord**	NO	OK-	OK	OK	NO
TEST 5	**Fits in breadbord**	NO	NO	OK	OK	NO

- *2nd test*

	Angle (°)	4	3.5	3	2.5	2
TEST 1	**Fits in breadbord**	OK	OK	OK	OK	OK-
TEST 2	**Fits in breadbord**	OK-	OK	OK	OK	OK
TEST 3	**Fits in breadbord**	OK	OK	OK	OK	OK
TEST 4	**Fits in breadbord**	OK-	OK-	OK-	OK	OK-
TEST 5	**Fits in breadbord**	OK	OK	OK	OK	OK

PICTURES OF THE MACHINE