BUILDING A CNC POLYSTYRENE CUTTING MACHINE

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ABSTRACT: Cutting polystyrene shapes using a heated wire, is a method widely used in making mounds, volumetric letter cut-outs or 3D shapes. In order to reach a very good quality and precision of the cut in polystyrene, it is necessary to take into account parameters that can vary depending on the cutting speed, working environment, amperage introduced in the heated wire.
This paper shows how to build a CNC machine that cuts with nickel wire. This machine has 4 working axes (two vertical axes and two longitudinal axes). The aim of the research is to build an automatic and autonomous polystyrene cutting machine.
The machine control system uses an Arduino mega 2560 microcontroller. The cutting process is performed by sending the G code file through a serial USB or by loading the code on a SD card, the machine has the autonomy to work without the use of a computer. After sending the code by the microcontroller, it activates the stepper motors.

1. Introduction

Thermal cutting of polystyrene is the process of removing material by following a path dictated by a drawing or code, it is often used in modeling or sculpting by bringing polystyrene to desired shapes and sizes. Passing a current through a wire or a metal surface generates heat. The width of the cut and the finish of a surface are determined by the feed rate, the electrical power assigned to the heated wire, and the characteristics and properties of the material to be cut. Cutting with heated wire is aimed at making any cut to almost any length with low cutting forces and high cutting speeds. This type of cutting can also be used in 3D polystyrene carving, as the flexibility of the wire is high.

Cutting with heated wire improves the process as well as the cutting techniques, thus reducing manufacturing costs and time.

The use of heated wire can be found in a variety of fields such as construction, aerospace, medical, artistic.

The objectives of this research include:

-Constructing/calibrating/testing a CNC to put cutting into practice.

The following sections are mainly aimed at familiarizing the reader with the design processes, 3D printing using a 3D printer as well as mechanical assembly of elements.

Also, in this research will be found calculations about the current used to control the stepper motor drivers, calculations for the current in the nickel wire.

Identifying and controlling the cutting parameters are considered as the main factors affecting the product quality. The controlling should be precisely done to move the hot wire in the correct path. [1]

2. Current status

This research work has reached the stage of mechanical assembly and calibration of the axes, in the pictures below you can see the design using the specialized Solidworks software as well as the implementation of the design.

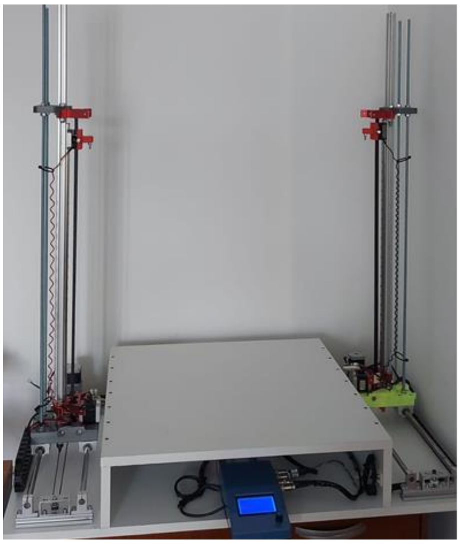

Fig.1 Current state of prototyping

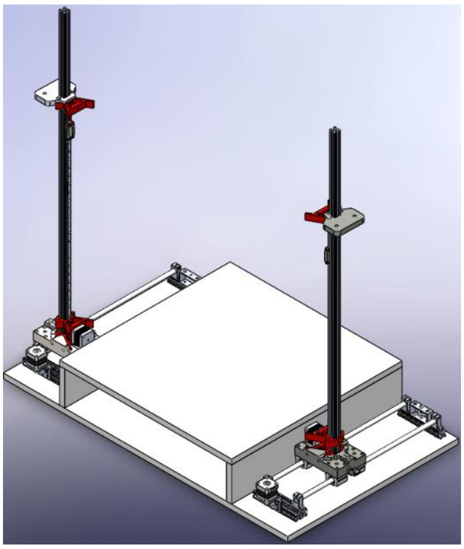

Fig.2 Current design status

The prototype is ready to move both vertically and horizontally.
In the following chapters I will detail how to design, 3D print, assemble, and program the prototype.

2.1 Design of the CNC foam

The picture below shows the cnc design, detailing of component parts is done during the research process

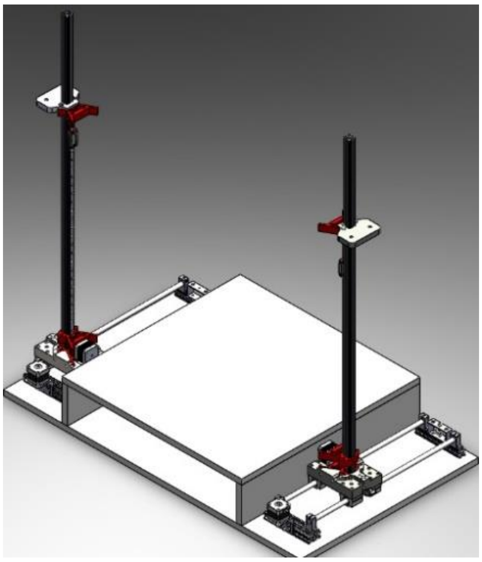

Fig.3 CNC Foam Design Assembly

2.2 Mechanical Design

The designed elements are shown in the figures below:
The parts were designed in Solidworks, their prototyping was done by 3D printing.

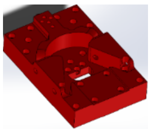

Fig.4 Movement support

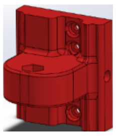

Fig.5 Nickel wire support

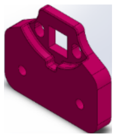

Fig.6 Structure reinforcement support

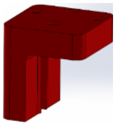

Fig.7 Belt fixing piece

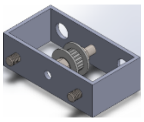

Fig.8 Flares assembly

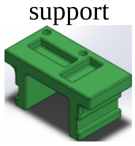

Fig.9 Stroke limiter support

2.3 3D printing and Parameterization

The figures below show the printed elements and a number of parameters used.

In table 1 you can see the parts generated in the Cura program as well as the parts printed using the Delta 3D printer, the material used is PLA.

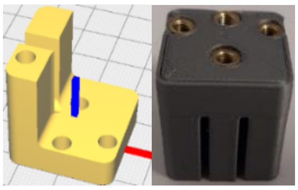

Fig.10 Belt fixing piece

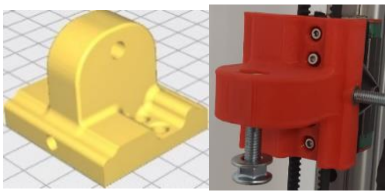

Fig. 11Wire clamp

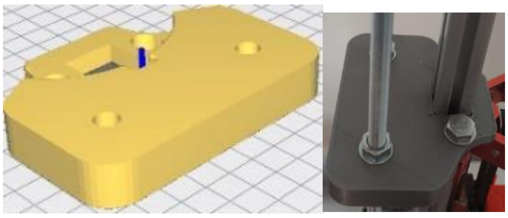

Fig.12 Reinforcement element

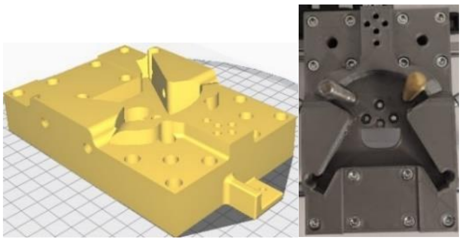

Fig.14 Elements of Cure and Print 3D

Table 1

Profile	Normal 0.2
Layer Height	0.2
Wall Thickness	2
Infill Density	80%
Infill Pattern	Octet
Printing Temperature	200
Print Speed	70
Support pattern	Triangles
Estimated print time	1h
Material usage	11g/3,68m
Profile	Normal 0.2
Layer Height	0.2
Wall Thickness	2
Infill Density	80%
Infill Pattern	Octet
Printing Temperature	200
Print Speed	70
Support pattern	Triangles
Estimated print time	2h
Material usage	21g/7m
Profile	Extra Fast 0.3
Layer Height	0.2
Wall Thickness	1
Infill Density	75%
Infill Pattern	Cross 3D
Printing Temperature	200
Print Speed	80
Support pattern	Triangles
Estimated print time	6h
Material usage	68g/23m
Profile	Extra Fast 0.3
Layer Height	0.3
Wall Thickness	1
Infill Density	75%
Infill Pattern	Cross 3D
Printing Temperature	200
Print Speed	80
Support pattern	Triangles
Estimated print time	16h
Material usage	281g/100m

3. Assembly and design optimization

In the pictures below you can see 2 sets of prototypes, below is the explanation:

Fig. 15 First prototyping

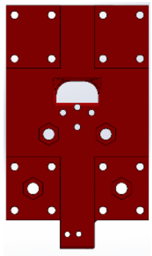

Fig.16 Optimizing design

Explanation

In fig.15 you can see the first prototyping attempt, we encountered the following problems :

-After assembly, on each longitudinal guide there was only one slide, the assembly being in translational motion, was in a constant unbalance, because the 2020 profile is high and forms the arm of the force that is applied in the 2 longitudinal bearings.

In fig. 16 you can see an improvement of the construction, I chose to mount 2 bearings on each longitudinal guide, as well as reinforcing the structure by inserting 2 M8 threaded rods which are meant to support and dampen shocks and vibrations.

For assembly we followed the following steps

Step 1: Assembly Stand

The prototyping station is made of sheet metal, its assembly is done using screws.

In the picture below you can see the designed stand as well as the necessary parts.

Fig.17 Designed stand

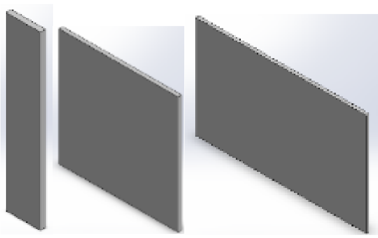

Fig.18 Elements for the stand

Step 2: Making the practical stand

The stand made of Pal is in the picture below:

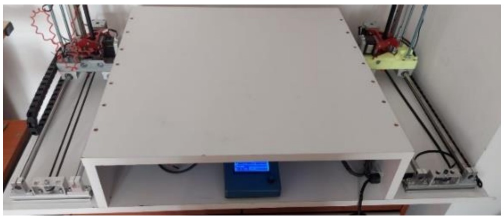

Fig.19 The stand made of PAL

Step 3: Toothed wheel bearing brackets

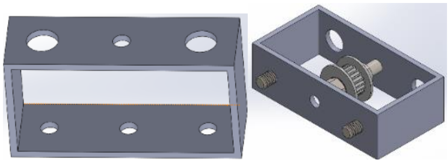

Fig.20 Toothed wheel support

The bracket is used for mounting and securing the Gt2
It is made of aluminum and has an M5 thread for threading the screw.

Step 4: Making a movement sled

Fig.21 Sled carcass order

The mobile sled aims at easing the control of the machine, it executes a movement similar to a drawer, and allows accessibility to the lcd.

Step 5: Mechanical assembly

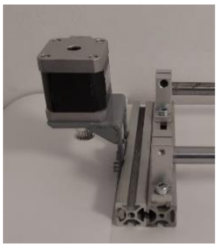

Fig.22 Assembling the motor to the bracket

The motor mount has been designed in steel; it has an internal clearance to allow the belt to move easily.

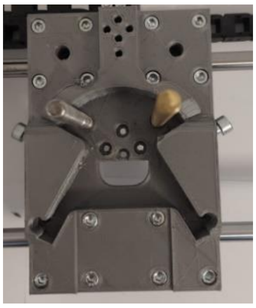

Fig.23 Movement support

The support for longitudinal movement is 3D printed and is designed to support the runners, the 2020 profile and to allow a movement of the Mgn12H linear guide moving vertical parts.

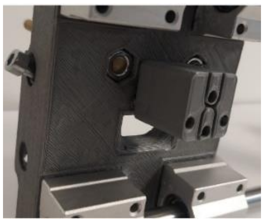

Fig.24 Belt fastening

The belt fastener is 3D printed it has M4 threaded inserts attached which are hot inserted

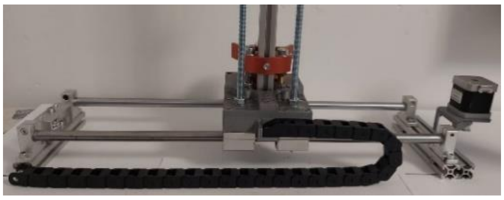

Fig.25 Final assembly

The final assembly is detailed in the picture below, it has a cable carrier chain, linear guides, the parts listed above as well as 2020 profiles that serve as legs.
Vertical and horizontal movement is provided by Gt2 belts.
The assembly of the elements is done manually

4. Driver calibration

For accuracy and safety in use, the following calibration steps are used:

Step 1
Resistance check
Drv8825 uses a resistance of 0.068 Ω

Fig.26 Ramps 1.4

Step 2
Identify parameters:
Rated motor current: 1.68 A
Minimum operating voltage: 8 V
Internal resistance (Rsense): 0.05 Ω
Operation in a 10% safety zone
V_{ref} =0.6

$$V_{ref} = rated_{current} * Minimum_{voltage} * Internal_{\ resistance} \quad (1)$$

The calculation shown for driver calibration is below:

$$V_{ref} = 1.68 * 8 * 0.05 = 0.672\text{V} \quad (2)$$

Step 3
Measure the voltage value using a multimeter.
Set the multimeter to the DC voltage measurement scale (Vcc).
Check if the Ramps 1.4 board is powered from an external current source.

Fig.27 DC voltage measurement

Step 4
Set the potentiometer to the value of V_{ref} =0.6
A value higher than 0.6V will cause the Drv8825 driver to heat up.
The motor may heat up and the motor torque decreases
Potentiometer adjustment is done by turning the potentiometer trigonometrically, the value of the V_{REF} voltage will decrease, and by turning the potentiometer clockwise, the value of the V_{REF} voltage will increase.

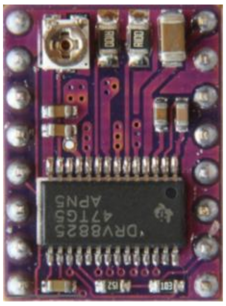

Fig.28 Driver Drv8825

4.1 Useful calculations:

$$Axle_{spur\ wheel} = \frac{Number_{of\ teeth} * steps}{2 * \pi} \tag{3}$$

The number of teeth used for the gearwheel is 20 teeth. The pitch is the distance between 2 teeth, this distance is 2 mm for the GT2 gearwheel.

Fig.29 GT2 Pulley

Detailing and calculating relationships

$$Axle_{spur\ wheel} = \frac{20*2}{2*\pi} = 6.36\ mm \tag{4}$$

Formula for complete rotation:

$$Complete_{Ratio} = Number_{of\ teeth} * steps \tag{5}$$

Calculated ratio:

$$Complete_{Ratio} = 20 * 2mm = 40mm \tag{6}$$

4.2 Elements used, making the control housing
Below are detailed the elements used in the construction of the CNC:

Fig.30 Case

The casing is recovered from an older printer, it has undergone some modifications such as:
Hole punching for the insertion of couplers, interior modifications, as well as adaptation for the

Fig.31 Control elements

Arduino mega 2560 programming board.
The component parts for programming are:

- Arduino mega 2560
- Ramps 1.4
- Drivere Drv8825
- Lcd

Fig.32 Stepper motor NEMA 17

A stepper motor is a common component in the construction of cnc 3d printers, lasers or cnc routers.
An important criterium in choosing a stepper motor is the motor torque.
Torque = force x distance

5. Conclusions and further objectives

Design and physical execution are synchronized.

3D printing was a defining factor in this work as most of the parts were made using this process.

The research is ongoing, cutting polystyrene with heated wire is a way of prototyping and executing different shapes from polystyrene.

So far, the research has reached the assembly and calibration plan, below you can see the further goals I want to go through

- CNC parameterization and programming
- Testing
- Temperature variation in current
- Temperature variation during cutting
- Temperature variation in relation to wire length
- Temperature variation as a function of cutting distance
- Variation of cutting width in relation to feed speed

6. Bibliography

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