

## Design and automation of CNC milling machine for the machining process of printed circuits

### Diseño y automatización de una fresadora CNC para el proceso de mecanizado de circuitos impresos

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#### Abstract

This article describes the design and automation of a CNC milling machine for the machining process of printed circuitboard with THT (Through Hole Technology) technology. Aswell as the use of one arduino to control the actuators of displacement of the three axes (X, Y, Z) of the CNC machine. Describe the application of manufacturing in the area of electronics to facilitate the design and construction of card electronic and the extensive application of the prototype in the materials processing industry, also explained in detail the advantages and disadvantages that presents the use of the CNC technology regarding the environmental impact caused by electronic waste generated in the traditional design process. Design of the prototype and the calculations necessary to carry out the PCB manufacturing process as well as the description of the different stages of operation will be presented.

**Milling machine CNC, Machining, Printed circuit, Automation, CAD**

#### Resumen

Este artículo describe el diseño y la automatización de una fresadora CNC para el proceso de mecanizado de placas de circuito impreso con tecnología THT (Through Hole Technology). Así como el uso de un arduino para controlar los actuadores de desplazamiento de los tres ejes (X, Y, Z) de la máquina CNC. Describe la aplicación de la fabricación en el área de la electrónica para facilitar el diseño y la construcción de tarjetas electrónicas y la amplia aplicación del prototipo en la industria de procesamiento de materiales, también se explican en detalle las ventajas y desventajas que presenta el uso de la tecnología CNC con respecto al impacto ambiental causado por los residuos electrónicos generados en el proceso de diseño tradicional. Se presentará el diseño del prototipo y los cálculos necesarios para llevar a cabo el proceso de fabricación de placas de circuito impreso, así como la descripción de las diferentes etapas de funcionamiento.

**Fresadora CNC, Mecanizado, Circuito impreso, Automatización, CAD**

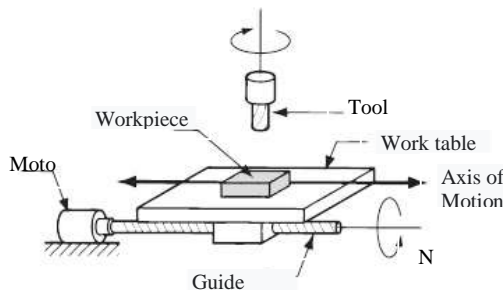
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**Introduction:**

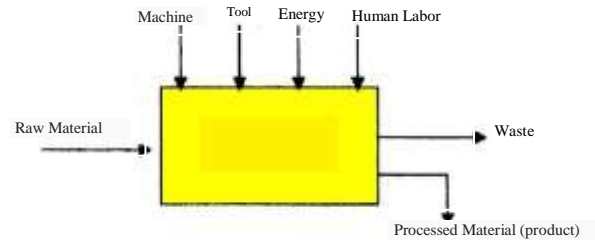
The development of new technologies have permitted easy work for the human beings, the automation and robotic today are the pioneers of the contribution in the industries areas, this is possible thanks to the discovery and development of more intelligence systems with day by day are implemented in the sectors, With the technology of numeric control a way has been accomplished of programable automation that permits control of the actions of a machine and be able to do machined works, this is thanks to the data of the CN that represents relatives positions within a mass of work and a piece work, the program of pieces gives details of the commands that follow the process of the machine, which every command specifies a position or a movement that the machine does by the coordinates X-Y-Z, meanwhile the unit of control of the machine (MCU) stores the program and it executes it, converting every command of actions within the equipment of processing doing a sequence step by step to transform the initial piece of work on the finished piece (Kalpakijan y schimid 2008).

The process systems for the CN consist of a mass of work, which the piece of work is steady and able to move respecting the tools or the holding head, the mass of work is able to move thanks to the rotary guiding screw, which it es controlled by the motor (for example, a motor step by step). The distance that the work table travels respecting the step of the guiding screw with every revolution, the step is given by the units (mm/thread) or mm/rev (see figure 1) (Groover, 2009)



**Figure 1** Motor and guide screw arrangement in a NC positioning system  
Source: (Groover, 2008)

Generally, the process to realize the manufacturing involucrate the combination of the machines, tools, energy and manual work and this is realized every time like a succession of operations (see figure 2).



**Figure 2** Manufacturing as a technical process  
Source: (Herrera, s.f).

On this day the modern manufacturing uses widely the computerized numeric control machine (CNC) which the difference to CN consists of a integrated computer, where the operator of the machine can program and modify the programs in a direct way, prepare them in different parts and store them, this way it is obtained a automated piece (Groover, 2008).

These machines permit the grand variety of finishes with different materials of engineering that normally will take a person much time to do, details like the geometry and precision of the material the manufacturing is a tedious process that requires a lot of patience and ability. The advantage of using the technology of the CNC. Permits design the pieces of grand precision in operations of machining that remove the excess of material of the initial piece of work which permits the resulting form to obtain the geometry desired. Next, on the chart 1 presents the advantages y disadvantages of a CNC machine

Advantages	Disadvantages
Greater precision	Elevated cost
Simulation of processing's	Greater grade of operator specialization
Reliability	Need of calculations and programming
Reduction of waste	Elevated cost of maintaining
Reduction of human error	Elevated pieces and tools of manufacturing

**Chart 1** Advantages and disadvantages of a CNC machine  
Source: (Gutierrez & Salvador, 2015)

Once comprehended the basic principals of the functions of a CNC machine is moment to apply this brilliant technology in other areas where involucrate design processes and material finishes. It was proposed to build a model of a milling machine CNC focused in the area of electronics, specifically for the design of imprinted circuits plates (PCB).

Remember that an imprinted circuit is a plate or platelet of assailant material build generally in pertinax o epoxi material. It possesses in one or two faces, sheets of thin copper, which connects the pins of the different components that conform a electronical circuit. The montage of the components it is done by orifices practiced on the plate or in case of the technology of superficial montage, welded directly on the conducted sheets (see figure 3) (Paula Budris,2013)



**Figure 3** design of a imprinted circuit  
Source: (AI Delta, 2013)

This technology will permit to do a design of a electronic circuit much more comfortable than the art arsenal process, allowing to obtain designs in a faster form, clean and economically. Without the need to pass by the process of imprinting , ironing, reelevating principally the elimination of pollution solutions, product of the electronical waste (Ocampo & Jesus Deras 2015 )

### Problem

Doing the design of a imprinted circuit plate is, traditionally, a tedious process and art arsenal. It is necessary to dispone of patience and a lot of attention and expertice to achieve a design without errors and to accomplish a series of rules according to the selected scheme to build (Budris Paula, 2013)

In the last years it has incremented the use of new technologies to accelerate the process of mechanizing of PCB, it has generated problems in the elaboration of imprinted circuits in a art arsenal way, consecutively the use of inadequate methods impact on the bad quality of imprinted circuits.

In their case the majority of the errors committed are because of the bad use of the tools during the elaboration process of the PCB, the result; damage of the paths conductors deviation of the orifices where are inserted the electronical components, like economical loss for the reimprinting of the circuits.

Other aspects in handcrafting design, is the use of ferric chloride to attack in a corrosive way the plate and remove the unnecessary copper, the use of this pollution potential involucrate a high Ambiental impact and exposer to who manages it without the adequate security ways. In base of the norm ISO 14001, Every public institute or industrial sector need to create or have a environmental plan for the use of pollution waste, that is why that after engraving the circuit over the plate the final waste needs to be stored in a resistant recipient and never throwing it away in the interpore because of the grand ecological damage it may cause that it will do, with the objective to persevere the natural resources.

### Objetivo

Implementar mejoras en el área de ingeniería electromecánica, utilizando los principios de manufactura y máquinas herramienta, para diseñar una fresadora CNC que automatice proceso de mecanizado de circuitos impresos, con el fin de disminuir los residuos electrónicos e incrementar la calidad y presentación de una tarjeta electrónica.

### Objective

Implement improvements in the electromechanical engineering area, using the principles of manufacturing and machine tools, to design a CNC milling machine that automates the machining process of printed circuits, in order to reduce electronic waste and increase the quality and presentation of an electronic card.

### Specific objectives

- Design good quality electronic cards, with the technical design specifications.
- Carry out functional tests on other materials, and extend the field of application of the prototype.

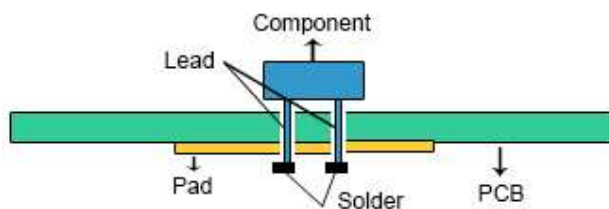
## Theoretical framework

### Types of technologies in PCB

For PCB design, there are two types of technology that depend on the assembly of the electronic elements.

#### Through-Hole Technology (THT)

They are components, large or medium, that have to go through the PCB so that they can be mounted, in order to be able to be soldered at the bottom of the board. This method is the most used for providing the most traditional design characteristics, since the materials used for its manufacture can be easily obtained (see figure 4).



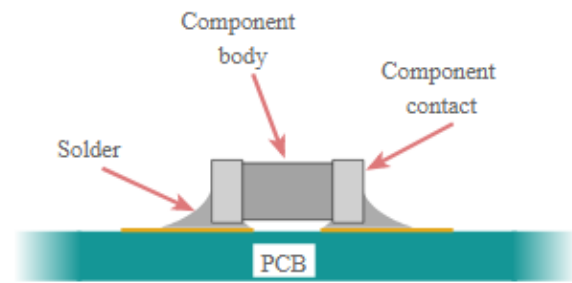
**Figure 4** Through-Hole Technology (THT)  
Source: (PCBCART, 2018)

#### Characteristics

- To make the components pass through the plate it is necessary to drill making the process a little more expensive.
- THT components are generally easier to come by.
- Homemade prototypes of printed circuits are generally designed with this type of technology.
- Their circuits are usually large.
- Its components are simpler to weld but difficult to remove.

#### Surface Mount Technology (SMT)

They are small or millimeter components that you don't have to go through to the PCB in order for them to be mounted. These are welded on the same side of the plate as it is on (see figure 5).



**Figure 5** Surface Mount Technology (SMT)  
Source: (Electronicsnotes, 2018)

#### Characteristics

- PCBs are generally cheaper as large holes do not have to be drilled.
- SMT components are generally more difficult to come by.
- Homemade prototypes are rare.
- Their circuits are usually smaller.
- SMT components are difficult to solder, but easier to remove.

#### SMT components have two variations:

##### Surface Mount Device (SMD)

They have the connection pins on the side to facilitate their assembly.

##### Ball Grid Array (BGA)

They have their connection pins underneath it, so their assembly can only be carried out in special ovens. This solution is common in microprocessors or graphics processors, which have too many connection pins.

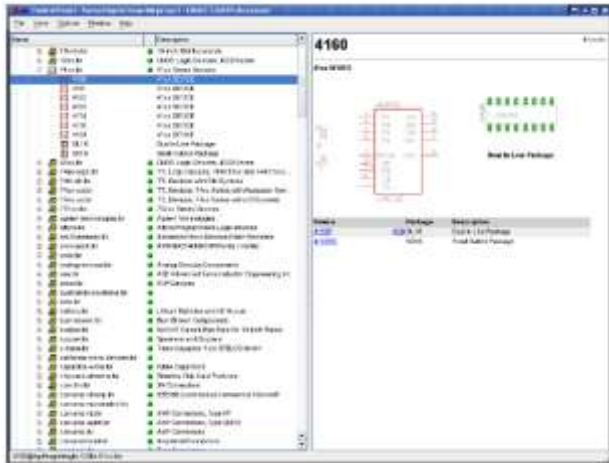
These PCBs use both types of technologies to create different products.

According to the types of PCB technology, the most used is THT, due to the availability of materials in the market, it is the most traditional. This method is summarized in the following points.

- Design phase
- Manufacturing phase
- Assembly phase
- Test phase

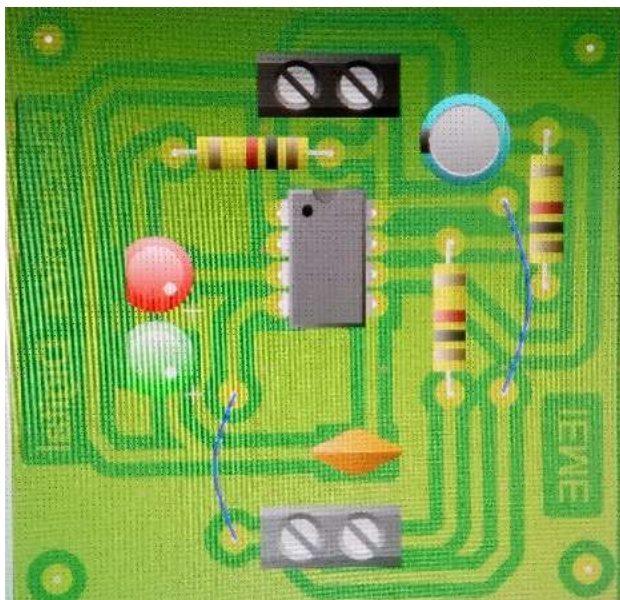
## Design phase

In this phase, the electronic circuit is designed in CAD software. Today there are a variety of programs for electronic design that provide different characteristics, but the function is the same, depending on the creativity of the designer, excellent designs can be obtained. The software has the necessary component libraries to carry out a schematic design (see figure 6).



**Figure 6** Schematic capture module  
Source: (Autodesk-CadSoft, 2016)

The schematic design is the representation by means of symbols of each electronic component that in turn allows making the connections between each element. Added to this, we proceed to create the Layout (Board) design (see figure 7).



**Figure 7** Board layout  
Source: (Own Elaboration, 2018)

## Manufacturing phase

According to the instructions of Fernando Rey, to manufacture a printed circuit board using the toner transfer method, the following must be carried out:

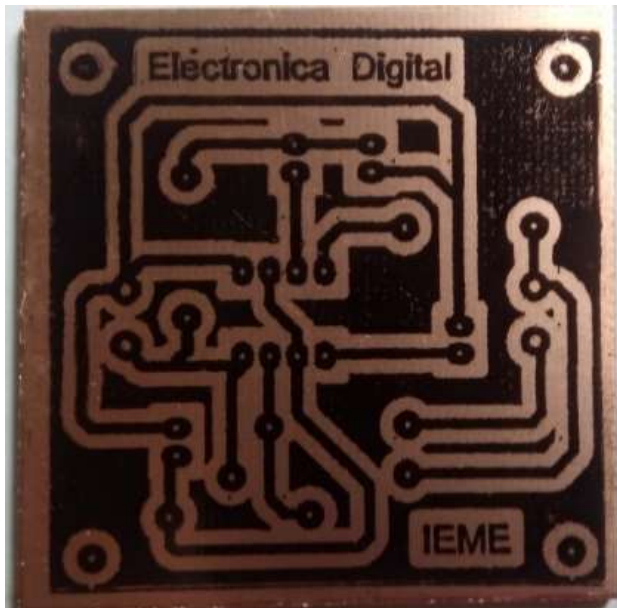
### Board preparation

Once the design phase is finished, the plate is prepared, according to the dimensions specified in the digital design, the phenolic plate must not have impurities (grease, dirt particles) that can prevent the transfer of the circuit pattern. The surface of the plate is lightly polished with a fine damp sandpaper to remove any excess burrs produced by cutting, it is advisable to wet the plate with water and clean it with a clean cloth or paper (see figure 8).



**Figure 8** Preparation of the single-sided phenolic plate  
Source: (Hetpro store, 2018) PCB printing and embossing on phenolic plate

Once the design of the PCB is finished, a prototype is generated to check the functionality of the design, there are several techniques to do it, one of the most effective is the printing with toner, to apply this technique the file is needed to print on a special paper of transfer. The transfer paper should be placed on the design side of the copper side of the phenolic plate and fasten the paper with adhesive tape so that it does not move, with the hot iron pressure should be applied to the heat transfer paper, making circular movements throughout the plate making sure that the paper does not move. Subsequently, it must be immersed in warm water to remove the transfer paper with the fingertips, after removing it completely it must be verified that all the toner has adhered to the plate (See figure 9).



**Figure 9** Copying the circuit pattern to the board  
Source: (Own Elaboration, 2018)

### Chemical attack

Once the design is embodied, the plate must be corrosively attacked to remove the unnecessary copper, for safety it is necessary to place mouth covers and latex gloves to pour the ferric chloride into a plastic or glass container, completely submerge the plate phenolic in the ferric chloride, let the acid act for approximately 5 minutes (See figure 10), discard the ferric chloride in a waste tank for storage. Pour water on the plate to eliminate any residue of the substance, verify that the parts that were not covered have been completely eliminated, with a water sandpaper the toner is removed from the copper parts that were covered, until the copper. Check that the PCB has been just like the design software.



**Figure 10** Chemical attack of the board with the circuit pattern  
Source: (Own Elaboration, 2018)

### Drilled and welded components

Once the board is ready, the holes where the THT technology components will be mounted are drilled, this is done using the islands created on the board as a guide. Usually a Dremel is used with bits of 0.7 mm (components), 1 mm (connectors and bridges) and 1.5 mm (terminals). Once the components are inserted, their terminals are soldered into the holes using tin (see figure 11).



**Figure 11** Assembly of electronic components.  
Source: (Own Elaboration, 2018)

### Test phase

To verify the correct operation of PCB manufacturing, several tests must be carried out:

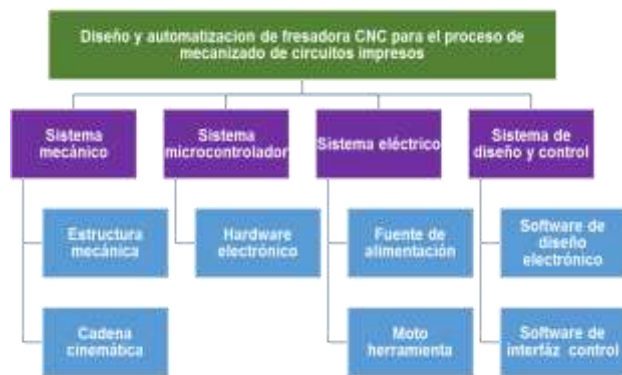
- Verification of the PCB before assembling the components.
- Verification of components

Visually and with a multimeter, you should check for shorts or broken tracks. If possible, the problems detected should be repaired. Implementation of a CNC milling machine for PCB machining Based on the experience obtained in the manufacture of printed circuit boards in a traditional way, it was necessary to look for a new manufacturing alternative, the proposed solution was the automation of this process, with the aim of obtaining designs in a clean, safe, fast and low cost.

With the CNC device designs will be made by removing material (milling and drilling).

### Functional profile of the prototype

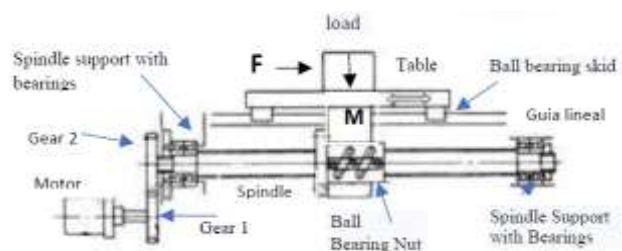
The prototype system is divided into 4 main systems, as well as the operating subsystems (See figure 12).



**Figure 12** Block diagram of the operating systems of the CNC milling machine

Source: (Own Elaboration, 2018)

**Mechanical system:** Integrated by the mechanical structure, it is the support element of the entire kinematic chain (See figure 13). The mechanical system is made up of three positioning axes, three stepper motors (step motor) designed for precise and discreet positioning on the work table.



**Figure 13** Elements that make up the kinematic chain of a CNC milling machine.

Source: (Alcira, 2018)

**Microcontroller system:** Made up of the Arduino uno electronic devices, it is the motherboard that will be used as a communication element between the machine and the computer. This is made up of the Shield CNC complements that contains an open source GRBL library and converts the G code commands into electrical signals to move the motors in steps (Geekfactory, 2018). Finally Drivers A4988 destined to control stepper motors (See figure 14).



**Figure 14** Arduino Microcontroller System

Source: (Soloelectrónicos, 2018)

**Electrical system:** Consisting of a variable power supply of 5-36 V at 1A to power electronic devices. It has a forced convection cooling system.

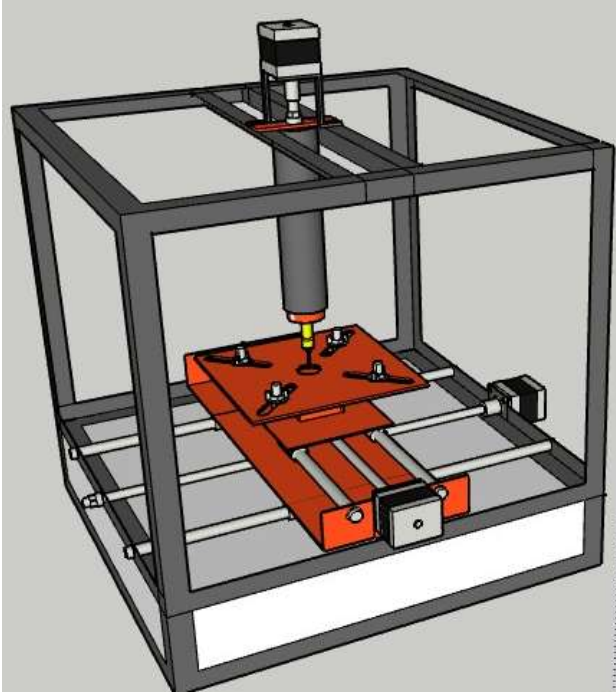
**Design and control system:** Integrated by automated CAD software for electronic PCB design, the free version EAGLE 9.1.0 software was used as a tool (CadsoftUSA.com, 2018). In this way, an open source vector graphics editor was used, for this case the Inkscape 0.92.3 tool that can be downloaded freely (Inkscape Contributors, 2018) to vectorize the electronic design image and later convert to code G. Finally, the GrblControl software will be used in its version 0.8.1 (GitHub, 2018). to control the GRBL-based CNC machine through console commands that will allow you to monitor the status of the machine, as well as view the G code file.

## Methodology

### Design and build

#### Mechanical structure

For the construction of the prototype, a steel angle of 3/4 X 1/8 of an inch (0.375 mm) thick was used, the choice of this material was carried out taking into account the mechanical resistance and how economical it presents compared to other materials. . The elaboration of the design was carried out using the SketchUp design software (SketchUp.com, 2018) (See figure 15).



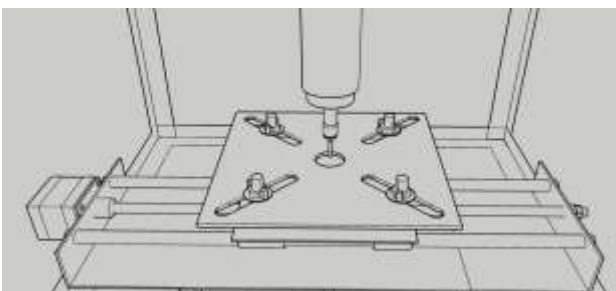
**Figure 15** Design of CNC milling machine  
Source: (Own Elaboration, 2018)

### Main spindle (z axis)

The Z axis is aligned with the spindle axis. Therefore it is in vertical form. The support column is made up of two concentric tubes of different diameter with the aim of transmitting a fluid movement between them, inside there is an 8 mm spindle that will determine the depth at the time of machining the piece.

### Work table (x, y axis)

The X axis is aligned with the table. And the Y axis, perpendicular to the worktable. A 3 mm steel base plate was used in the locking table system, sufficiently rigid to carry out machining. It has an adjustable working dimension, the design range is 5x5 cm the minimum and 10x15 cm the maximum. The PCB is held by means of a movable clamping flange (See figure 17).



**Figure 17** Work table  
Source: (Own Elaboration, 2018)

### Motor tool

As a rotary machine, a DC motor was selected with a tool holder to hold the cutting tool (See figure 16).



**Figure 16** Motor tool  
Source: (Own Elaboration, 2018)

### Final design

The final presentation of the CNC milling machine (See figure 18), all the previously described systems have been incorporated.



**Figure 17** Final construction of the prototype  
Source: (Own Elaboration, 2018)

### Calculation memory

Calculation of width of tracks according to the current

In PCB design, the track width must be calculated so that it can withstand the passage of electrical energy through the connections and does not overheat. To calculate the track width, the following must be considered:

1 Oz / ft<sup>2</sup> = 35 microns thick

2 Oz / ft<sup>2</sup> = 70 microns thick

3 Oz / ft<sup>2</sup> = 70 microns thick

Equations for the calculation of track thickness

The designs must always have thickness variations, so to withstand the current in the tracks, the width must be modified, for the calculation of this the following formulas are used: (Aprende.Org, 2018)

$$\text{Area} = \left(\frac{I}{k_1 \cdot \Delta T \cdot k_2}\right)^{1/k_3} \quad (1)$$

Where:

I = Peak current

$\Delta T$  = Temperature difference

k<sub>1</sub>, k<sub>2</sub>, k<sub>3</sub> = Constants for calculation

For the temperature difference follow this formula:

$\Delta T = T_{\max} - T_{\text{environment}}$  usually  
 $T_{\text{environment}}$  it is 25°C

If the tracks are in the upper and lower layers of the PCB the values for the constants k are as follows:

k<sub>1</sub> = 0.0647

k<sub>2</sub> = 0.4281

k<sub>3</sub> = 0.6732

If the tracks are on the inside of the PCB

k<sub>1</sub> = 0.0150

k<sub>2</sub> = 0.5453

k<sub>3</sub> = 0.7349

For example, if you want to obtain the track width for a PCB that will only have the upper layer, and you want a maximum of 50 ° C and a maximum current of 1st.

Then:

$$\Delta T = 50^\circ C - 25^\circ C = 25^\circ C$$

$$I = 1A$$

$$k_1 = 0.0647$$

$$k_2 = 0.4281$$

$$k_3 = 0.6732$$

$$\text{Thickness} = 1 \frac{\text{Oz}}{\text{ft}^2}$$

In PCB design programs, different measurements such as "th" or "mm" can be used to place or create components that go on the PCB, it is convenient to know the conversion between units so as not to make design errors and the entire PCB in the same measurements.

$$1 \text{ inch} = 25.4 \text{ mm}$$

$$1 \text{ th} = \frac{1}{1000} \text{ inch}$$

This means "Thousandth of an inch" or one thousandth of an inch. You can say then:

$$1000 \text{ th} = 25.4 \text{ mm}$$

So that:

$$1 \text{ th} = \frac{25.4}{1000} \text{ mm} = 0.0254 \text{ mm}$$

It follows that:

$$1 \text{ mm} = 39.37 \text{ th}$$

$$0.1 \text{ mm} = 3.937 \text{ th}$$

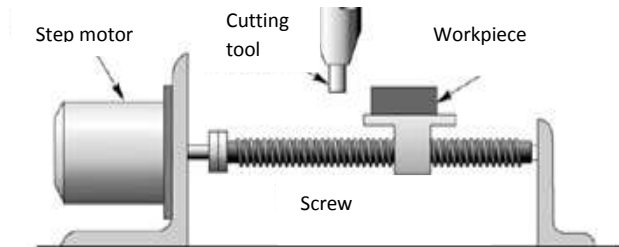
Added this we proceed to convert 5.471 th to mm:

$$5.471 \text{ th} \frac{1 \text{ mm}}{39.37 \text{ th}} = 0.138 \text{ mm}$$

In PCB design software, the minimum movement that can be made, if working in millimeters, is 0.1 mm, on the other hand if working in th, it is th. It is recommended to use th, as the movement of each electronic component is more precise. It should be taken into account that the thickness of each track must be calculated when the consumption current changes for each component of the PCB, for example in the power stage the tracks will be wider, while the tracks in the control stage they are minors. In PCB manufacturing it is better to leave more copper than to remove it, because if there is a very large space without copper it is more difficult to manufacture.

Machining calculations

To calculate the machining of the PCB, it is necessary to know the technical specifications of the mechanical and electrical components of the kinematic chain to determine each of the parameters. (See figure 18).



**Figure 18** Elements of the kinematic chain  
Source: (Hughes, 2006)

The motor that was selected as the main travel actuator was the Nema 17 stepper motor (See figure 19). Table 2 shows the technical specifications of the motor.



**Figure 19** Nema 17 stepper motor  
Source: (Bricogeeek, 2018)

Nema 17 stepper motor	
Type of motor:	Bipolar
Voltage:	12 V
Current:	0.4 A
Pitch angle:	1.8°
Arrow diameter:	5 mm
Torque	4 kg-cm

**Chart 2** Nema 17 stepper motor technical specifications  
Source: Self Made

Cutting tool (cutter)	
Cutting edge diameter	0.1
Feed / tooth (f)	0.13
Material	Tungsten carbide
Cutter rake angle	20°

**Chart 3** Cutting tool technical specifications.  
Source: Self Made

Printed circuit board	
Plate thickness	1.25 mm (varies from 0.8 a 3.2 mm)
Copper layer thickness	0.015 inch (0.04 mm)

**Chart 4** PCB technical specifications  
Source: Self Made

Calculation of cutting precision

To calculate this parameter, you must first calculate the number of steps the motor must take to make a complete revolution. It can be obtained from the following formula:

$$N_p = \frac{360^\circ}{\alpha} \tag{2}$$

Where:

$N_p$  = Number of steps / lap  
 $\alpha$  = Motor pitch angle [°]

Substituting the values in the formula, we have:

$$N_p = \frac{360^\circ}{1.8^\circ} = 200 \text{ steps / lap}$$

As the transmission element, the conventional screw was selected, which work by friction, there is a nut and a screw, the nut rotates around the screw and the thread generates friction between both profiles. This type of screw was selected with the aim of having greater precision in machining. The result with the threaded rods is very acceptable as they are cheaper and easier to obtain (See figure 20).



**Figure 20** Conventional screw  
Source: Self Made

Therefore, the stepper motor has a minimum movement  $1.8^\circ$  / step, to make a full turn ( $360^\circ$ ), it has to make 200 steps and a spindle with a pitch of 1.4111 mm.

The cutting precision is calculated with the following formula:

$$\text{Cutting precision} = \frac{\text{Spindle pitch}}{\text{Number of steps / lap}} \quad (3)$$

Substituting the values in the formula, we obtain:  $\text{Cutting precision} = \frac{1.4111 \text{ mm}}{200} = 0.00705 \text{ mm}$

### Drilling parameters

Calculation of undeformed chip thickness

$$t_c = \frac{2fd}{D}$$

Where:

$f$  = Feed per drill tooth (mm / tooth)

$d$  = Cutting depth (mm)

$D$  = Drill tip diameter (mm)

The material to be machined is copper with a layer of insulation, the advance of the cutter can be obtained in boards (Recommendations in milling operations).

**Replacing the variables in the equation, we obtain:**

$$t_c = \frac{2(0.13 \frac{\text{mm}}{\text{tooth}})(0.04 \text{ mm})}{0.1 \text{ mm}} = 0.104 \frac{\text{mm}}{\text{tooth}}$$

Cutting speed

The cutting speed in a drilling operation is the surface speed at the outside diameter of the bit. It is specified this way for convenience, although most cutting is actually done at the slowest speeds near the axis of rotation. To set the desired cutting speed in drilling, it is known that the rotational speed of the milling machine spindle is 5700 rev / min, then:

$$v = \pi DN \quad (\text{Equation 6})$$

Where:

$v$  = cutting speed in mm / min

$D$  = Drill diameter ( $\frac{1}{8}$  inch) or mm

$N$  = spindle speed in rev / min

Replacing the variables in the equation, we obtain:

$$v = \pi \left(\frac{1}{8}\right) (5700) = 2238 \frac{\text{inch}}{\text{min}} = 56855 \frac{\text{mm}}{\text{min}}$$

### Forward speed

Feed, or feed rate, is the distance the tool travels horizontally for each revolution of the part (mm / rev or inches / rev).

$$f_r = Nfn \quad (4)$$

Where:

$f_r$  = Feed speed (mm / rev)

$N$  = Milling spindle speed (rev / min)

$f$  = Feed (0.13 mm / tooth)

$n$  = Number of teeth on the cutter (1)

### Material removal speed

It is the volume of material removed per unit of time, with units of  $\text{mm}^3 / \text{min}$ ,  $\text{cm}^3 / \text{s}$  or  $\text{in}^3 / \text{min}$ . It is calculated with the following formula:

$$RMR = wdf_r \quad (5)$$

Where:

$RMR$  = Material removal rate ( $\text{mm}^3 / \text{min}$ )

$w$  = Cutting width (mm)

$f_r$  = Forward speed (mm/min)

$d$  = depth of cut (mm)

Replacing the variables in the equation, we obtain:

$$RMR = (741)(0.1)(0.04) = 2.964 \approx 3 \frac{mm^3}{min}$$

### Machining power

The machine tool transmits the power of the drive motor to the workpiece, where it is used to cut the material. The effectiveness of this transmission is measured by the efficiency factor of the machine tool, E. It can be calculated as follows:

$$P_C = K_p \cdot C \cdot RMR \cdot W \quad (7)$$

Where:

$P_C$  = Power at the cutting tool

$K_p$  = 2.48 (Power constant for copper)

$C$  = 1.15 (Power constant)

$RMR$  = 3 (Material removal rate)

$W$  = 1.1 (Tool wear factor)

Replacing the variables in the equation, we obtain:

$$P_C = (2.48)(1.15)(3)(1.1) = 9.4 W$$

### Engine power

This is the power to transmit to the cutting tool, which is defined by the following equation:

$$P_m = \frac{P_C}{E} \quad (8)$$

Where:

$P_m$  = Engine power (W)

$P_C$  = 9.4 (Power on cutting tool)

$E$  = 0.90 (Machine tool efficiency factor)

Replacing the variables in the equation, we obtain:

$$P_m = \frac{9.4}{0.90} = 10.4 W$$

### Drilling Parameters

#### Cutting speed

The cutting speed in a drilling operation is the surface speed at the outside diameter of the bit. It is specified this way for convenience, although most cutting is actually done at the slowest speeds near the axis of rotation.

To set the desired drilling cutting speed, it is necessary to determine the rotational speed of the drill by its diameter. Then (Groover):

$$v = \pi DN \quad (9)$$

Where:

$v$  = cutting speed in / min

$D$  = Drill diameter  $\left(\frac{1}{32} \text{ inch}\right)$  o mm

$N$  = spindle speed in rev / min

Replacing the variables in the equation, we obtain:

$$v = \pi \left(\frac{1}{32}\right) (5700) = 600 \frac{\text{inch}}{\text{min}} = 14214 \frac{\text{mm}}{\text{min}}$$

### Forward speed

For drilling, feed  $f$  is specified in mm / rev (in / rev). The recommended speeds are roughly proportional to the diameter of the bit; the highest feeds are achieved with large diameter bits. Since there are generally two cutting edges at the tip of the bit, the chip thickness does not cut (chip load) taken at each cutting edge is half the feed.

$$f_r = Nf \quad (10)$$

Where:

$f_r$  = feedrate (mm / rev)

$N$  = 5700 Rotation speed (rev / min)

$f$  = 0.025 Feed (mm / rev))

Replacing the variables in the equation, we obtain:

$$f_r = (5700)(0.025) = 142.5 \frac{\text{mm}}{\text{min}}$$

#### Material removal speed when drilling

Material removal rate (RMR) in drilling is the volume of material removed per unit of time. For a drill with a diameter  $D$ , the cross-sectional area of the drilled hole is  $\pi D^2 / 4$ .

$$MRM = \frac{\pi D^2}{4} f_r \quad (11)$$

Where:

$D$  =  $\frac{1}{32}$  inch (Bit Diameter)

$f_r$  = Feed (mm / min)

Replacing the variables in the equation, we obtain:

$$\text{MRM} = \frac{\pi(0.79375)^2}{4} (142.5) = 70 \frac{\text{mm}^3}{\text{min}}$$

## Conclusions

With the development of the project and an exhaustive investigation, a functional prototype was implemented that would allow machining processes (milling and drilling), and applying the basic manufacturing concepts together with the operating principles of a three orthogonal axis milling machine (X, Y, Z), driven by stepper motors.

After defining the problems presented in the electromechanical engineering students in the elaboration of printed circuits in a traditional way, the problem was solved by applying a new method of elaboration of the printed circuits eliminating the use of contaminants, such as ferric chloride (FeCl<sub>3</sub>).

Areas of opportunity were identified to extend the field of application, which is not limited to working with a single material, since tests were carried out with other materials, such as wood and acrylic. This analysis was based on tests, as well as improvements in its design and operation. That is why a new design methodology for the elaboration of printed circuits was implemented.

The main characteristics of the equipment was the PCB design technology for mounting components THT (Through-Hole Technology) or through holes, which only allows one design layer and is easier to manufacture. In addition, this new method allows to elaborate circuits of greater complexity, quality and presentation.

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## References

Alciro. (s.f). Friction, torque and inertia. August 2018, by Alciro Website: [http://www.alciro.org/alciro/Plotter-Router-Fresadora-CNC\\_1/friccion-par-inercia\\_248.htm](http://www.alciro.org/alciro/Plotter-Router-Fresadora-CNC_1/friccion-par-inercia_248.htm)

Anonymous. (2018). Surface mount technology and SMT devices. August 2018, from Electronics-notes Website: [https://www.electronics-notes.com/articles/electronic\\_components/surface-mount-technology-smd-smt/what-is-smt-primer-tutorial.php](https://www.electronics-notes.com/articles/electronic_components/surface-mount-technology-smd-smt/what-is-smt-primer-tutorial.php)

Aprende.Org [Carlos Slim Foundation]. (2018 August 24). Track width calculation according to current. [Video]. Retrieved from [https://aprende.org/pages.php?r=.cfcs\\_course&tagID=7928&load=10181&n=1&brandID=&program\\_origin=](https://aprende.org/pages.php?r=.cfcs_course&tagID=7928&load=10181&n=1&brandID=&program_origin=)

Budris Paula (2013). Electronics Technician (1st ed). Buenos Aires: Dalaga.

CadsoftUSA. (July 20, 2018). PCB design software. Google LLC. Autodesk Retrieved from <https://www.autodesk.com/products/eagle/free-download>

Electronic only. (s.f). ARDUINO. August 2018, from only electronics Website: <https://soloelectronicos.wordpress.com/category/arduino/page/5/?iframe=true&preview=true%2Ffeed%2F>

Fernando Rey. (s.f). How to make a printed circuit board using the tonner transfer method (plate method). August 2018, from the Website: [http://usuarios.tinet.cat/fmco/download/Tutorial\\_placas.pdf](http://usuarios.tinet.cat/fmco/download/Tutorial_placas.pdf)

Geekfactory. (2017). GRBL CNC Shield for Arduino. August 2018, from Geekfactory Website: <https://www.geekfactory.mx/tienda/shields-arduino/shield-cnc-grbl-arduino/#>

Github. (2015). GRBLControl. August 2018, from Github Website: <https://github.com/trasz/grblControl>

Gutiérrez, G., & Salvador, R. (2015). Experiences in the automation of the construction of printed circuits with an open source CNC machine. Technological Magazine.

Herrera, F. (s.f). Introduction to manufacturing. Manufacturing processes, (1), pp. 1-10

HeTPro. (2018). One-sided phenolic plate August 2018, from HeTPro Website: <https://hetpro-store.com/placa-fenolica-una-cara-de-10cm-x-10cm/>

Inkscape contributors. (July 30, 2018). Download. Google LLC. Inkscape Project Recovered from <https://inkscape.org/es/release/0.92.3/>

Kalpakjian, S. and Schmid, S. R (2008). Manufacturing Engineering and Technology (5 ed.) Mexico: Pearson Education.

M.P. Groover (2007). Fundamentals of Modern Manufacturing. 3 ed. Mexico: McGraw-Hill, 2007.

ISO standards. (June 15, 2018). ISO 14001 Environmental Management. Google LLC. ISO Standards Retrieved from <http://www.normas-iso.com/iso-14001/>

Ocampo, J. & de Jesús Deras, I. (2015). Integrated Application for PCB Construction using CNC Technology and Automatic Surface Adjustment. Innovare: Magazine of Science and Technology.

PCBCART. (s.f). Printed circuit board assembly process (PCBA). August 2018, from PCBCART Website: <https://www.pcbcarter.com/article/content/pcb-assembly-process.html>

SketchUp. (2018). Draw in 3D. August 2018, from SketchUp Website: <https://www.sketchup.com/>