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DEPARTAMENTO DE EVALUACIÓN PROFESIONAL

"ANALYSIS OF THE CONSTRUCTION OF EXPERIMENTAL PHYSICAL MODELS OF MEDICAL DEVICES IN THE BACHELOR OF MEDICAL BIOENGINEERING USING CNC TECHNOLOGY"

TESIS
QUE PARA OBTENER EL TÍTULO DE
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PRESENTA
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Content

I. Background

A. Numerical Control (CN) and Computerized Numerical Control

Numerical Control (NC) is a system that allows the position of a physical element to be always controlled, NC, involves controlling a machine tool through a set of coded instructions that include numbers, letters, and symbols. These instructions are designed to be understood by the machine's control unit (MCU) [1]. CNC (Computer Numeric Control) is a modern technology that utilizes an internal microprocessor. This computer is equipped with memory registers that store different routines, enabling it to manipulate logical functions [2].

Over the last fifty years, NC technology has emerged as a significant advancement in the manufacturing industry. This innovation has not only led to the creation of novel manufacturing methodologies and increased production capacity but has also facilitated improvements in product quality and greater stability in manufacturing costs [3].

Concerning to the increasing demand for precise components from expanding sectors like aerospace, medical, automotive, and electrical industries [4], the market for CNC machining has experienced significant expansion over the past six years and it is anticipated to continue growing, reaching a worth of $129 billion by 2026 [5].

1. Uses of CNC machines

CNC systems have been used in the development of different technologies. There is a wide range of CNC machines available, and this number continues to grow due to advancements in technology. Here is a brief list outlining some of the categories in which CNC machines belong [2]:

- Mills and Machining centers.
- Lathes and Turning Centers.
- Drilling machines.
- Routers.
- Water jet and Laser profilers.
- Benders, Winding and Spinning Machines.

- Flame cutting machines.
- 3D Printers.
- Punch presses, etc.

B. Bachelor of medical bioengineering

The bachelor's degree in Medical Bioengineering from UAEMéx (Unversidad Autónoma del Estado de México), offered at the School of Medicine, in its 2010 curriculum, establishes:

"The Bachelor's Degree in Medical Bioengineering supports the medical practice of diagnosis, treatment and therapy, through development and innovation, evaluation and management, and the optimal use of technology, to expand access coverage, generate cost-effective solutions according to the new needs of the user population, and, above all, offer a better quality of care to patients" [6].

"In the Degree in Medical Bioengineering, ways of thinking, research methods and professional intervention from various disciplines converge. On the one hand, from the disciplinary field, the contributions of Economic and Administrative Sciences (Administration, Evaluation and Planning), of Natural and Exact Sciences (Chemistry, Physics and Mathematics), of Philosophy (Epistemology and Ethics), of Engineering (Design, development and innovation of technology, Electricity, Electrotechnics, Mechanics, Modeling and Prototyping), and Health Sciences (Anatomy, Cell Biology, Biological Sciences, Medical Sciences, Physiology, Morphology, and health-disease processes). On the other hand, the application of Technologies concretizes its development in interdisciplinary contributions, such as the analysis of biomedical signals, biomaterials, radiation dosimetry, medical tele informatics, biomedical instrumentation, modeling and simulation of biosystems, and medical robotics" [6].

1. Graduate profile

The Graduate in Medical Bioengineering of the School of Medicine at UAEMéx is a professional who collaborates, with multidisciplinary teams, in health care and the improvement of the quality of life of the human being in the field of technology applied to direct medical service to the patient (diagnosis, prevention, treatment and rehabilitation). He is a professional specialized in the processes of management, evaluation, development and innovation of technology for human medicine [6].

Based on the description of Medical Bioengineering degree, the following applications of CNC were identified.

2. Uses of CNC in the bachelor of medical bioengineering

a) Design

In Medical Bioengineering, design encompasses the process of creating and developing solutions to address challenges in healthcare and medicine. This involves designing medical devices, diagnostic tools, prosthetics, implants, and other technologies aimed at improving patient care, diagnosis, treatment, and quality of life [7].

b) Computer-aided design

Computer aided design (CAD) refers to the utilization of computer systems to facilitate the development, modification, analysis, or enhancement of a design. Instances of such applications comprise the analysis of stress-strain in components, the dynamic response of mechanisms, calculations of heat transfer, and programming of numerical control parts [7]. Overall, CAD plays a crucial role in the design and development of innovative medical devices and technologies in Medical Bioengineering, enabling engineers to create sophisticated designs, optimize performance, and bring products to market more efficiently.

c) Computer-aided Manufacturing

Computer-aided manufacturing, (CAM), refers to the use of numerical control (NC) software programs to generate step-by-step instructions that guide computer numerical control (CNC) machine tools in producing high-quality parts. CAM is used by manufacturers in various industries to create precise and detailed parts [8]. Overall, CAM plays a crucial role in the manufacturing of medical devices and components in biomedical engineering, enabling engineers to translate their designs into physical products efficiently and accurately. CAM technology contributes to the development of innovative healthcare solutions by facilitating precision manufacturing, customization, and optimization of medical devices.

In design and manufacturing applications, CNC serves as the foundation for operating many devices used in the processes. Today one of the most prevalent manufacturing techniques involves machining engineering plastics, a trend that has gained traction alongside the rise of 3D printing technology, Figure 1 shows one of the most popular 3D printers, notable for its compact size and the wide variety of compatible materials.

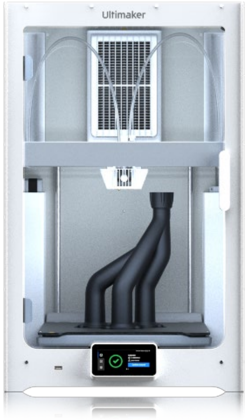


Illustration 1. Ultimaker 3D printer S7 (9)

d) Experimental Physical models

An experimental physical model in biomedical engineering refers to a tangible representation or prototype of a biological system, medical device, or physiological process. These models are used for research, testing, validation, or educational purposes, with the intent to simulate a real-world scenarios. These models can be used to study the behavior of a system or component under different conditions, or to test and evaluate the performance of a new design or technology. Experimental physical models can be designed and constructed using a variety of techniques, such as 3D printing, machining, or molding, and they can be made from a wide range of materials, including metals, plastics, and composites. The accuracy and reliability of an experimental physical model depend on the quality of its design and construction, as well as the materials used [9].

e) Rapid prototyping

The process of Rapid Prototyping (RP) is often defined as a method of creating precise components directly from computer-aided design (CAD) models, usually within a few hours, and with minimal human involvement [9].

C. Robotics

“Robotics is concerned with the study of those machines that can replace human beings in the execution of a task, as regards both physical activity and decision making”. The cultural origins of robotics run deep. For centuries, humans have been striving to find alternatives that can replicate their actions in different interactions with the world around them. This quest has been driven by various factors, including philosophical, economic, social, and scientific principles [10].

1. Medical devices

The definition of medical devices according to the Official Mexican Standard NOM-241-SSA1-2021, Good Manufacturing Practices for Medical Devices, is as follows:

“Instrument, apparatus, utensil, machine, software, implantable product or material, diagnostic agent, material, substance or similar product, to be used, alone or in combination, directly or indirectly in human beings; with some(s) of the purposes of use:

— Diagnosis, prevention, surveillance or monitoring, and/or auxiliary in the treatment of diseases;

— Diagnosis, surveillance or monitoring, treatment, protection, absorption, drainage, or aid in the healing of an injury;

— Replacement, modification or support of the anatomy or a physiological process;

— Life support;

— Control of conception;

— Disinfection of medical devices;

— Disinfectant substances;

— Provision of information through in vitro examination of samples taken from the human body, with fine diagnostics;

— Devices that incorporate tissues of animal and/or human origin, and/or

— Devices used in in vitro fertilization and assisted reproductive technologies;

And whose main purpose of use is not through pharmacological, immunological, or metabolic mechanisms, however, they can be assisted by these means to achieve their function. Medical devices include health supplies from the following categories: medical equipment, prostheses, orthoses, functional aids, diagnostic agents, supplies for dental use, surgical and healing materials, and hygiene products.” [11]

a) CNC in medical devices.

In medical devices we can find an endless number of CNC applications, in equipment, such as beds, stretchers, imaging equipment such as the one shown in figure 1, where the CNC is used for the positioning of the patient, the x-ray tube and the digital x ray detector, robotic surgery equipment, assistance and rehabilitation systems, etc. but also in so many manufacturing process for these devices.

Illustration 2. Siemens Multitom Rax (12)

D. Impact of practice cases in medical bioengineering

Learning in the lab is an effective way to gain practical skills, think critically, communicate, and collaborate with others, and transform the world. It is an experience that allows future engineers to get closer to reality and connect theory with practice, using experimentation to prove or disprove hypotheses [12].

II. Problem statement

In the literature, advantages of incorporating practical cases in the teaching of Medical Bioengineering can be found, even more so various universities such as UNAM, UAM and IPN include subjects that allow the construction of prototypes. However, due to the multidisciplinary nature of this degree that combines medical and engineering knowledge, the relevant transmission of knowledge and skills in terms of prototyping processes and rapid tools for the implementation of medical bioengineering systems in the teaching-learning process is difficult. The CNC makes it possible to influence the implementation of various manufacturing technologies aligned with the research activities of medical bioengineering, since numerical control is used in the modes of operation of bioprinters, laser cutters, additive manufacturing systems (3D printing), subtractive manufacturing (manufacturing systems by chip removal) and positioning of many medical devices such as tomographs, brachytherapy equipment, x-rays, among others. From the above, the research question is defined: With what practices can the teaching of the CNC be implemented in the Bachelor of Medical bioengineering?

III. Justification

Teaching CNC in Medical Bioengineering is essential due to its critical role in manufacturing precise medical devices, rapid prototyping, experimental physical models, quality control, saving time and cost in production. Furthermore, CNC technology finds extensive applications across various medical devices.

Learning CNC during the Bachelor of Medical bioengineering program has a significant impact in several aspects:

1. Development and Improvement of technical skills and competency training: Learning to operate CNC machinery entails mastering a high level of technical skills and knowledge in areas such as mechanical design and the fabrication of various medical devices. These devices encompass a wide range of applications, including endodontics, orthodontics, printed circuit boards (PCBs), orthotics, prosthetics, exoskeletons, assistance and rehabilitation systems, robotic surgery, surgical tools, robotic imaging systems, mechanisms, and robotic systems used in laboratories. Proficiency in CNC not only enhances expertise in this specific field but also translates to valuable skills applicable across various domains within biomedical engineering and general engineering.

2. Acceleration of innovation: CNC technology empowers medical bioengineers to rapidly and precisely develop and prototype medical devices. This expedites the innovation and development process within the medical bioengineering industry, leading to substantial improvements in patients' quality of life. The integration of metal-mechanical manufacturing tools with additive manufacturing systems facilitates the production of prototypes and experimental physical models in shorter timeframes. This accelerated pace of innovation enables quicker iterations and advancements in medical device design and functionality.

3. Competitiveness in the labor market: Medical bioengineers with proficiency in CNC usage tend to be more competitive. Knowledge of CNC can distinguish a candidate and make them more appealing to employers.

IV. Objective

A. Overall objective

To develop a set of CNC laboratory practices, designed for students enrolled in the Bachelor of Medical Bioengineering program at the School of Medicine at UAEMéx.

B. Specific objectives

1. To define the benefits, advantages, scope, and limitations of the implementation of the CNC laboratory practices in Medical Bioengineering program of UAEMEéx.

2. To analyze the possible applications in the subjects taught in the 2010 Medical Bioengineering program of UAEMéx.

3. To analyze practical cases in the subjects taught in the 2010 Medical Bioengineering program of UAEMéx that can be implemented.

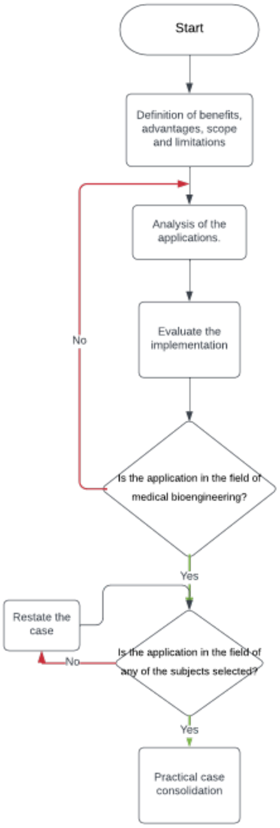
4. To propose 2 practical cases as a teaching-learning procedure through challenges in the professional environment linked to design and prototyping, according to the 2010 Medical Bioengineering program of UAEMéx.

V. Methodology

In this work, the methodology involves the utilization of a CNC system located within the facilities of UAEMéx. Acquired in 2016 specifically for the Electronics Laboratory of the Medical Bioengineering program. Documentation of the CNC's initial condition, as well as the setup process, was conducted.

The methodology for analyzing the construction of experimental physical models of medical devices within the Medical Bioengineering program, leveraging CNC technology, is outlined.

The methodology has a sequential development, where one stage depends on the previous one.



To define the benefits, advantages, scope, and limitations of the implementation of the CNC laboratory practices in Medical Bioengineering program.

During this section, information will be collected on the advantages, scope, and limitations of the implementation of the CNC in the degree in medical bioengineering, the main sources that will be consulted are:

- Articles and publications referring to the use of CNC technology in medical bioengineering: the database of web pages will be explored.

To analyze the possible applications in the subjects taught in the 2010 Medical Bioengineering program of UAEMéx.

During this section, the 2010 Medical Bioengineering program will be analyzed, which has 61 subjects. We focused on the learning units of the engineering branch, especially in subjects:

- Electrical circuits (Circuitos eléctricos)
- Assistance and rehabilitation systems (Sistemas de asistencia y rehablitación)
- Computer drawing (Dibujo por computadora)
- Digital electronics and signal processors (Electrónica digital y procesadores de eñales)
- 3D Modeling (Modelado de objetos en 3 dimensiones)
- Introduction to biomedical instrumentation (Introducción a la instrumentación biomédica)
- Medical robotics (Robótica médica)
- Ergonomics and human factors (Ergonomía y factores humanos)

To analyze practical cases in the subjects taught in the 2010 Medical Bioengineering program of UAEMéx that can be implemented.

Together with professors of the career, proposals for practices that can be implemented in the subjects proposed are analyzed, prioritizing practices related to design and prototyping.

To propose 2 practical cases as a teaching-learning procedure through challenges in the professional environment linked to design and prototyping, according to the 2010 Medical Bioengineering program of UAEMéx.

2 cases will be consolidated in collaboration with subject teachers, where CNC technology must be used in response to a challenge in the world of work, such as the creation of PCBs, positioning error analysis, rapid prototyping, etc.

VI. Development

Defining a CNC system as "a system that allows the position of a physical element to be always controlled", two significant applications emerge within the field of medical bioengineering. The initial application involves the utilization of CNC systems in manufacturing processes, while the second pertains to the integration of CNC systems within various medical devices [13]

Benefits, advantages, scope, and limitations of the implementation of CNC practices in the degree in medical bioengineering.

As indicated in the "Bachelor of Medical Bioengineering" section, the degree encompasses diverse disciplines, including engineering, specifically emphasizing the field of design, development, and innovation of technology, as well as the modeling and creation of prototypes. CNC systems align seamlessly with each of these disciplines [6].

Referring to the benefits, advantages, scope, and limitations of the implementation of CNC practices in the degree in medical bioengineering we defined the following:

Benefits and advantages.

1. The use of CNC is related to the purposes of the degree.

2. Development and Improvement of technical skills and training of competencies: Learning to use the CNC requires a high level of technical skills and knowledge in mechanical design, tools for endodontics, orthodontics, printed circuit boards (PCBs), orthotics, prosthetics, extractors, exoskeletons, assistance and rehabilitation systems, robotic surgery, surgical tools, robotic imaging systems, mechanisms, robotic systems in laboratories, etc. This knowledge is useful not only in the field of CNC, but also in other fields of biomedical engineering and engineering in general [14].

3. Acceleration of innovation: CNC enables medical bioengineers to quickly and accurately develop and prototype medical devices. This accelerates the process of innovation and development in the medical bioengineering industry, which can have a significant impact on the quality of life of patients. Metal-mechanic manufacturing

tools in conjunction with additive manufacturing systems help to obtain prototypes and experimental physical models in less time [15].

4. Competitiveness in the labor market: Medical bioengineers who have skills in the use of CNC can be more competitive in the labor market. Knowledge of the CNC can make a candidate stand out and be more attractive to employers.

Scope, and limitations:

Regarding the scope and limitations of the implementation of the practices, these focus more on the capacity of the equipment and compatible materials. Exposed below.

Speaking of modeling and prototyping, the CNC represents the following advantages:

Precision and Accuracy:

CNC technology allows for highly precise and accurate machining, which is crucial in medical bioengineering for creating intricate and custom components with tight tolerances [16].

Customization for Patient-Specific Applications:

CNC machining enables the production of patient-specific implants, prosthetics, and medical devices tailored to individual anatomical variations [17].

Material Versatility:

CNC can work with a variety of materials, including metals, polymers, and ceramics, offering flexibility in material selection for bioengineering applications [18].

Time Efficiency:

CNC machining processes are generally faster than traditional manual methods, contributing to quicker production and turnaround times [18].

Reproducibility and Consistency:

CNC ensures the reproducibility of components, crucial for mass production and maintaining consistent quality in medical devices [19]

Scope:

Manufacturing of medical devices:

CNC is widely applicable in the production of medical devices or components of medical devices such as PCBs, surgical instruments and many other devices or components [20]

Prosthetics and Orthotics:

CNC machining is valuable for creating custom prosthetic and orthotic devices to improve comfort and functionality [21]

Research of biocompatible materials:

CNC facilitates the machining of biocompatible materials for research and development to create safe and effective medical solutions [22]

Medical device systems.

Many complex devices use CNC systems to control components, such as CT scanners where the table on which the patient is placed, and the x-ray tube are often controlled by CNC systems to ensure precise positioning during scanning.

Limitations

Cost of Equipment and Maintenance:

CNC machinery and the associated software can be expensive, posing a financial barrier for smaller research or medical facilities [23].

Limited to Certain Materials:

While CNC can work with a variety of materials, there may be limitations in machining certain materials.

The analysis of the learning units was carried out in accordance with what was stated in the study programs of the 2010 Medical Bioengineering program obtained through the Departamento de Desarrollo Curricular, Department of Curriculum Development of the Dirección de Estudios Profesionales, Directorate of Professional Studies of UAEMéx. The objectives of the proposed educational programs were analyzed. Table 1 shows these objectives.

Learning Unit	**Objectives of the learning unit.**
Analysis and synthesis of mechanisms	Analyze and synthesize mechanical devices that are applied in bioengineering
Assistance and rehabilitation systems	Evaluate assistance and rehabilitation problems in bioengineering and its associated devices to develop proposals for systems that solve current problems.
Computer drawing.	Model and animate mechanical devices that are applied to bioengineering by computer.
Digital electronics and signal processors	Analyze the elementary components to design combinational and sequential digital systems that allow understanding the operation of digital signal processors.
Electrical circuits	Analyze and predict the behavior of electrical circuits composed of resistive, capacitive, and inductive elements, excited by ideal and non-ideal sources of voltage or direct or alternating current, focusing on the modeling of the behavior of real electronic circuits and the analogies of these with physiological systems
Ergonomics and human factors	Analyze, design, install and maintain technology for diagnosis and therapy. Design and adapt technological equipment and systems for the comprehensive rehabilitation of people with disabilities.

Introduction to biomedical instrumentation.	Analyze the elementary components that constitute a biomedical instrumentation system, focusing on the use of signal processing systems for data acquisition, to design and build a biomedical instrumentation system, guaranteeing that the signal to be recovered is correctly acquired in terms of its frequency components and the specific resolution.
Medical robotics	Analyze robotic systems for medical applications from the definition of the problem being addressed to the safety aspects necessary for the patient, for the medical equipment and for the robotic system.

Table 1. Objectives of learning units analyzed. [24], [25], [26], [27], [28], [29], [30]

A. CNC Machine implementation

To implement the practices, a CNC milling machine had to be installed. While the School of Medicine possessed such equipment in its Robotics laboratory, it had failed into disuse. Consequently, efforts were made to reinstall it in the Robotics laboratory. This effort involved finding compatible software for the equipment's controller and identifying an operating system compatible with the selected software. However, a significant challenge arose during this process due to the equipment's controller, which interfaces with the computer through a parallel port—an outdated technology. Despite exploring various potential solutions, all of them required modifications to the controller, which proved impossible due to the complexity of its assembly and the associated costs. As a result, it was decided to use a computer equipped with a parallel port and identify software compatible with this port, alongside a compatible operating system. Subsequently, the commissioning process was initiated, followed by comprehensive testing to ensure the equipment's proper functionality.

Robotics lab houses a PcDeacitec CNC machine —a desktop mini router. This system comprises three components: the machining unit, the control console, and the computer interface.

B. CNC Machine characterization

This section describes the characteristics of the CNC installed in the Robotics laboratory in the School of Medicine of UAEMéx. All the technical information was obtained from the constructor manual: [31].

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Number of axes: 3

Number of spindles: Single

1. Dimensions

	Long	Width	High
Dimension (cm)	50	40	40

[31]

	X Axis	Y Axis	Z Axis
Travel (mm)	200	300	800

[31]

2. Axes and rails

X, Y & Z mechanical train sliding: Chrome-coated rails with block sliding systems. Packaged ball trains and bearings, with coupling shafts for ball bearings. [31]

3. Motors and structure

The 3 axes are powered by Nema 23 stepper motors.

Model	Step angle	Motor length	Rated current	Phase resistance	Phase inductance	Holding torque	Lead wire	Rotor inertia
Single Shaft	°	mm	A	Ω	mH	$Kgfcm$	No.	gcm^2
	1.8	56	2.8	0.9	2.5	12.6	4	300

[31]

Maximum speed with load: 4,000 mm/min

Cutting speed: 0.0 to 2,000 mm/min

Spindle:

Power	Speed	Motor length	Voltage	Rated current	Holding torque	Weight	Collet	Cooling
W	RPM	mm	V	A	$Kgfcm$	Kg	ER 11	Air cooled
300	3,000-12,000	175	12.0 - 48.0	6	2.34	0.8		

[31]

Collet:

Model	Diameter	Clamping range
ER11	mm	mm
	11.5	1.0-7.0

4. Limitations

5. CNC Controller Interface

The device features an integrated fan and thermal fuse mechanism. It offers manual control over spindle rotor speed via a potentiometer, along with switches for spindle and system motors. Additionally, it is equipped with an emergency stop button for added safety [31].
127 V powered Unit.

6. Communication ports

- Parallel port.
- DIN industrial: Control port for the 3 axes.

7. Software

Controller was designed to be used with “Mach3” Software.

“Mach3 turns a typical computer into a CNC machine controller. It has an extensive array of features that offer exceptional value to users requiring a comprehensive CNC control package. Mach3 works on most Windows PCs to control the motion of motors (stepper & servo) by processing G-Code” [26] Mach 3 was used because of the controller [32].

C. Practices.

After analyzing the characteristics of the CNC, the costs of compatible tools, their availability in our city and the applications of the machine, together with the objectives of the proposed subjects, it was decided to develop two practices to propose.

Due to the size of the machine, the power of the spindle and the size of the CNC collet, the most used tools are engraving, cutting, and drilling bits, within these there are a multitude of variations, mainly in the engraving bits where the angle changes. of the tip, however, for practices the most common bits on the market was considered V30°*0.1 mm.

Knowing the limitations of the CNC, we looked for subjects in which practices could be proposed that align with its objectives. Two theoretical-practical subjects were chosen. For the first practice, the chosen subject was electrical circuits where the objectives of the subject are aligned. with the design and construction of technology for solving problems. In practice, the construction of a printed electrical circuit, present in all electronic devices, is proposed. For the second practice, ergonomics and human factors due to the affinity to design and its syllabus where materials and technology are studied in the ergonomic design process, in this practice the aim is to generate a final product, contemplating the entire design process.

The practices were developed so that students know manufacturing methods for making prototypes. The practices could easily be implemented in other subjects in which the design and construction of physical models is studied or even use other technologies available at School of Medicine like 3d printers.

VII. Results

A. Practice 1: PCB Milling

Objective.

The primary goal of this practice is to provide students with hands-on experience in the rapid prototyping of a Printed Circuit Board (PCB) for biomedical systems using CAD-CAM software, and CNC machining techniques. Through this practice, participants will gain valuable insights and skills in the seamless integration of design, prototyping, and manufacturing processes essential in the development of advanced biomedical systems.

For this practice, the schematic of an ECG was made in the Multisim [33] software, the PCB was modeled with the Ultiboard [34] software, the G code was generated in Flatcam [35] and finally it was exported to Mach 3 for machining.

B. Practice 2: Cutting soft materials

Objective

The objective of this practice is to learn about the CAD-CAM process and generate a final product, a piece, either for study, integration into a more complex system or any other purpose that the student has.

For this practice, a pair of gears was modeled in AutoCAD [36] software, the G code was generated in Aspire [37] and finally exported to Mach 3 for machining.

This practice seeks to develop rapid prototyping design skills. Soft materials are widely used for these tasks. Furthermore, the practice elucidates the CAD/CAM process, empowering students to seamlessly transfer their acquired knowledge to various design endeavors, including 3D modeling and additive manufacturing applications.

Files used for the development of both practices can be found at: https://github.com/LuisValdes2000/CNC-G-codes

VIII. Conclusion

In conclusion, the implementation of CNC practices in the Bachelor of Medical Bioengineering curriculum holds significant promise for enhancing students' practical skills and knowledge in medical device design and prototyping. Through the systematic methodology outlined in this work, we have explored the benefits, limitations, and applications of integrating CNC technology into medical bioengineering education.

While CNC technology offers enormous potential in medical bioengineering, it is essential to recognize its scope and limitations. Our analysis has identified the extent of error to CNC operations (0.05 mm), highlighting the importance of precision and calibration to achieve the desired results. In addition, limitations such as the workspace of $0.08\ m^3$ that limits the size of the parts to be machined and the power of the spindle that limits the materials that can be worked with are soft materials, without considering metals and the thicknesses to be worked from said materials to bits.

Practical exercises carried out as part of this work have demonstrated various applications of CNC technology in medical bioengineering. From PCB milling for biomedical systems to precision machining of parts for study and integration into complex systems, CNC has proven invaluable in facilitating rapid prototyping and design iteration.

Looking ahead, there are several avenues for future research and development in the integration of CNC practices in medical bioengineering education. One such initiative involves the creation of comprehensive manuals of exercises, providing students with structured guidance and resources to maximize their learning outcomes. These manuals can encompass a wide range of CNC applications, from basic machining techniques to advanced design challenges, fostering continuous skill development and innovation.

IX. Annexes

A. CNC MACHINE PRACTICE MANUAL

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UNIVERSIDAD AUTÓNOMA DEL ESTADO DE MÉXICO

FACULTAD DE MEDICINA

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ROBOTICS LABORATORY

CNC MACHINE PRACTICE MANUAL

BY: LUIS VALDÉS AGUIRRE

2023

Content

Introduction to CNC

Numerical Control (NC) is a system that allows the position of a physical element to be always controlled, NC, involves controlling a machine tool through a set of coded instructions that include numbers, letters, and symbols. These instructions are designed to be understanded by the machine's control unit (MCU) [1]. CNC is a contemporary technology that utilizes an internal microprocessor. This computer is equipped with memory registers that hold different routines, enabling it to manipulate logical functions [2].

CNC technology enables the automated control of machine tools, including 3D printers using "G-code," to execute precise and repeatable machining operations.

In the last fifty years, NC technology has emerged as a significant advancement in the manufacturing industry. This innovation has not only led to the creation of novel manufacturing methodologies and increased production capacity but has also facilitated enhancements in product excellence and greater stability in manufacturing expenses [3], and also in the creation of prototypes and in many stays in the design process.

Concerning to the increasing demand for precise components from expanding sectors like aerospace, medical, automotive, and electrical industries [4], the market for CNC (Computer Numeric Control) machining has experienced significant expansion over the past six years and it is anticipated to continue growing, reaching a worth of $129 billion by 2026 [5].

CNC Machine

In School of Medicine's Robotics laboratory, we have got a little CNC machine, brand: PcDeacitec, model: XR-200 CNC 2012, country of origin: México. This machine is a mini desktop router and has three main parts: the machining unit, the control console, and the computer interface. The controller computer is an HP Compaq dc7800 Convertible Minitower PC, running Windows 7 (32-bit), with processor: Intel Core 2 Duo [6]. Running Mach 3 [7] for the practices. Our CNC is shown on illustration 1.

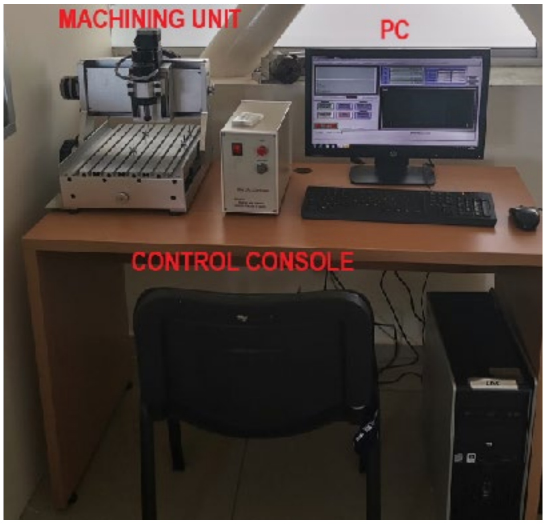


Illustration 1. CNC Machine, located in our robotics lab.

Machining unit

Dimensions:

- Dimensions of the complete machine: Width: 40 cm, Length: 50 cm, Height: 40 cm
- Stroke length in axes: X = 20 cm, Y = 30 cm, Z = 8 cm
- Maximum workpiece thickness allowed in Z axis: 13 cm.

Axes:

- 3 linear axes (X,Y and Z)

Motors:

CNC linear axes in the system are actuated by Nema 23 Stepper motors, here are some of their characteristics.

Step angle	Motor length	Rated current	Holding torque	Rotor inertia	Weight
1.8°	56 mm	2.8 A	12.6 Kgf.cm	300g.cm2	0.7 Kg

- Maximum speed with load: 4,000 mm/min
- Cutting speed: 0.0 to 2,000 mm/min
- ±5% Step angle accuracy (Full step, no load)

CNC machine does not count with limit switches. Our CNC machining unit is shown in illustration 2.

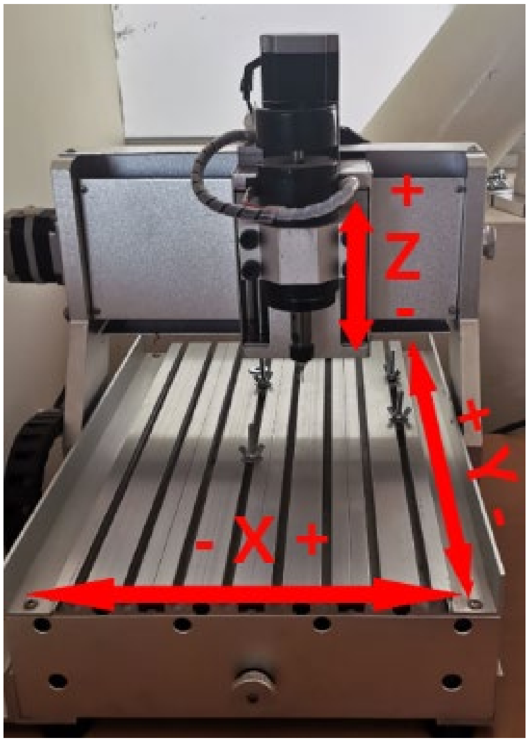


Illustration 2. CNC Machining unit

Spindle

Spindle refers to the rotating component responsible for holding and rotating cutting tools, such as end mills or drill bits. The spindle is a crucial part of the CNC machine, as it is responsible for the actual material removal during the machining process.

- Manually controlled speed.
- 300 W motor.
- Rotary speed: Up to 12,000 rpm.
- Equipped with ER11 collect.

Control console

The controller is one of the essential parts of any CNC machine, there are a lot of industrial controllers, when an industrial controller is not an option there are two popular options.

1. GRBL (G-code reference block library) is an open-source firmware milling controller designed to run on Arduino boards.
2. Mach 3 CNC software is a platform that turns most windows PCs into a CNC machine controller.

Our CNC is controlled by Mach 3.

Control box features:

- 127 V powered.
- Built in fan.
- Thermal fuse system.
- Manual spindle speed control by potentiometer.
- Spindle and motors switch.
- Emergency stop button.
- Control port: X, Y, Z and A axes via Industrial DIN connector (router to controller connection).
- Connection to PC via parallel port.

Computer interface

Mach 3

Mach3 is a software that can transform a regular computer into a controller for CNC machines. It's packed with lots of useful features and offers good value for people who need to control CNC machines. Mach3 runs on most Windows computers and helps control the movement of motors (stepper and servos) by reading and processing G-Code instructions. Even though it has many advanced features, it's considered the easiest CNC control software to use. Plus, Mach3 can be customized and has been used in various applications with different types of hardware.

Mach3 was primarily designed for the parallel port which has become obsolete.

Safety procedures.

A CNC machine is a very complex system with various features and programs that can be either used or customized. The proper use of such a system requires a basic understanding of how it operates, which steps are required to accomplish a certain task and what mistakes are to be avoided [8].

Please consider the following action when using CNC machine

Warning advice:

You should setup the software correctly, it will make the machine works well. If you do not do it well and try to run the machine, it may damage the machine or cause the danger. When you install or setup the machine, please do not turn on the control box, it may cause some damages.

Please do not put the connectors on the control box when it is power on.

Stop the spindle when you want to restart it. The interval of the on/off button time should be at least 30 seconds, when you restart the spindle or turn on the control box again, otherwise it will cause the damages of the control box.

Our machine is 127V, when it is power on, please do not open the control box, do not touch the wiring connectors, and not touch the running bits, please wear the glasses or mask to protect yourself.

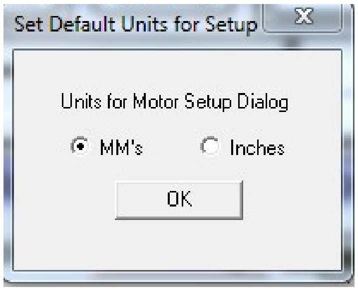
Mach 3 configuration

Before using CNC make sure Mach 3 is configurated the next way.

Start Mach 3. Open “Mach3Mill”, direct access is on desktop.

Native units

Open the “Config” menu, choose “select Native Units” then choose the “MM’s”. As shown in illustration 1.



Set Default Units for Setup

Units for Motor Setup Dialog

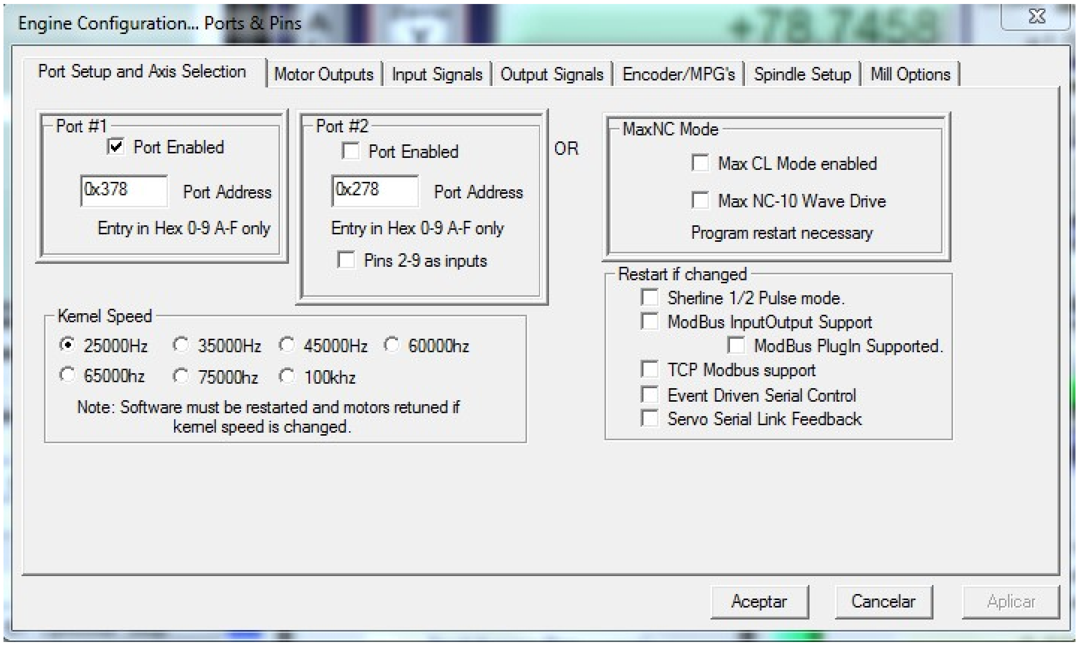
● MM's ○ Inches

Illustration 3. Setup of native units. Make sure to use same units in Mach 3 and in your g-code generator.

Ports and pins config

Port Setup

Open the “Config” menu, choose “Ports and Pins” check only “Port #1” is selected, “0x378” Port defined and 25000Hz Kernel is chosen, choose ok to continue. As shown in illustration 2.



Engine Configuration... Ports & Pins

Port #1
☑ Port Enabled
0x378 Port Address
Entry in Hex 0-9 A-F only

Port #2
☐ Port Enabled
0x278 Port Address
Entry in Hex 0-9 A-F only
☐ Pins 2-9 as inputs

OR

MaxNC Mode
☐ Max CL Mode enabled
☐ Max NC-10 Wave Drive
Program restart necessary

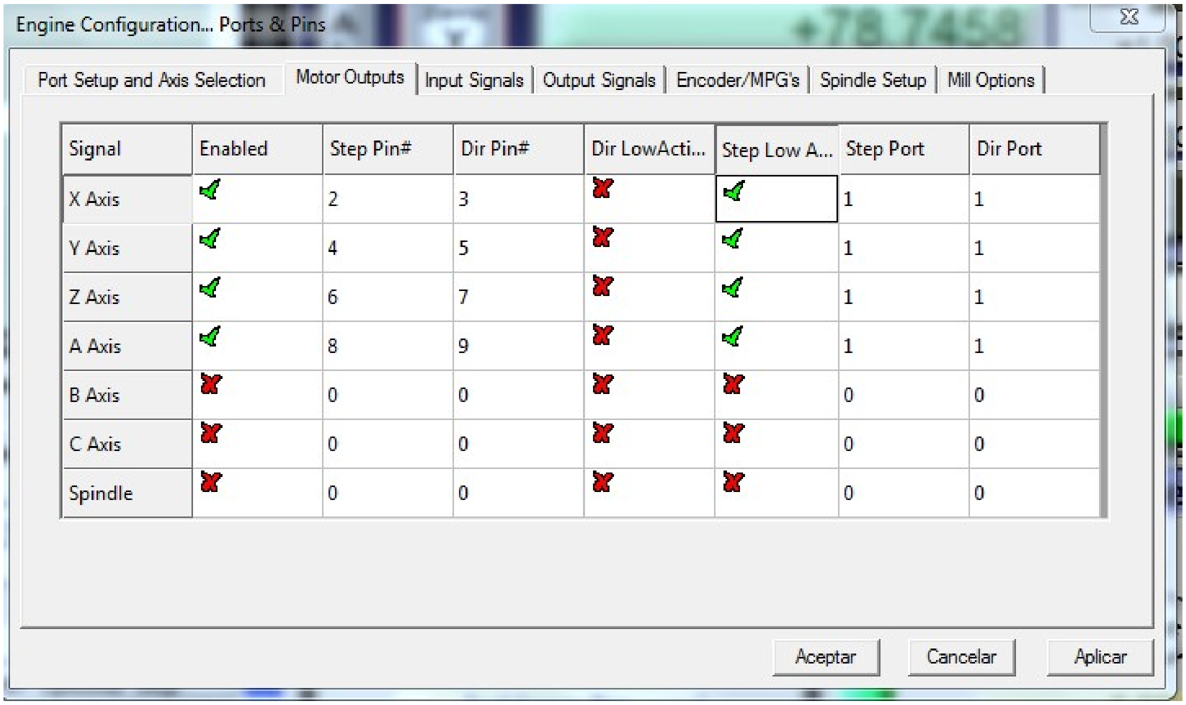
Kernel Speed
● 25000Hz ○ 35000Hz ○ 45000Hz ○ 60000hz
○ 65000hz ○ 75000hz ○ 100khz
Note: Software must be restarted and motors retuned if kernel speed is changed.

Restart if changed
☐ Sherline 1/2 Pulse mode.
☐ ModBus InputOutput Support
☐ ModBus PlugIn Supported.
☐ TCP Modbus support
☐ Event Driven Serial Control
☐ Servo Serial Link Feedback

Illustration 4. Port setup. This is the most common configuration, and the one our controller uses.

Motor Outputs

Click “Motor Outputs” to setup the Pin of the stepper motor as shown in illustration 3.



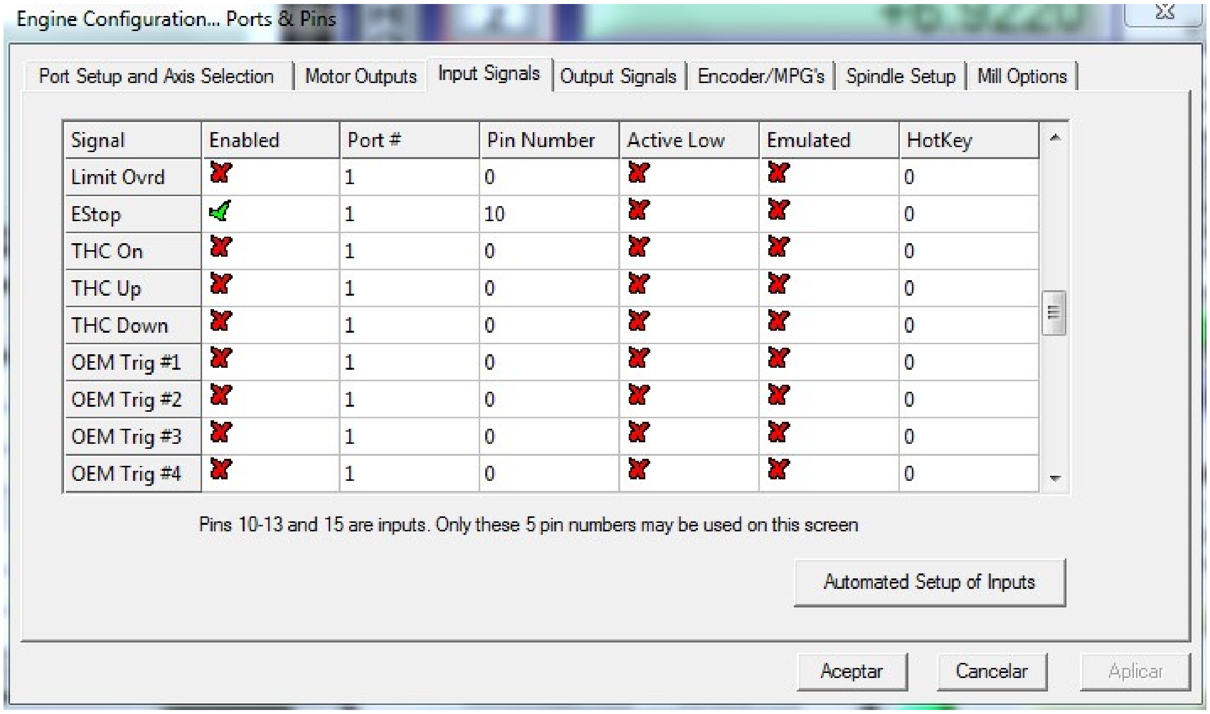
Signal	Enabled	Step Pin#	Dir Pin#	Dir LowActi...	Step Low A...	Step Port	Dir Port
X Axis	✓	2	3	✗	✓	1	1
Y Axis	✓	4	5	✗	✓	1	1
Z Axis	✓	6	7	✗	✓	1	1
A Axis	✓	8	9	✗	✓	1	1
B Axis	✗	0	0	✗	✗	0	0
C Axis	✗	0	0	✗	✗	0	0
Spindle	✗	0	0	✗	✗	0	0

Illustration 5. Motor outputs configuration.

” Dir Low Active" is to set up the Direction of the motor, if you find the running direction of the axis is inverse, you can choose the “Dir Low Active” to change the direction and then sabe the setup.

Input signals

Click “Input signals”, scroll down until you find EStop signal, and set up as shown in illustration 4.



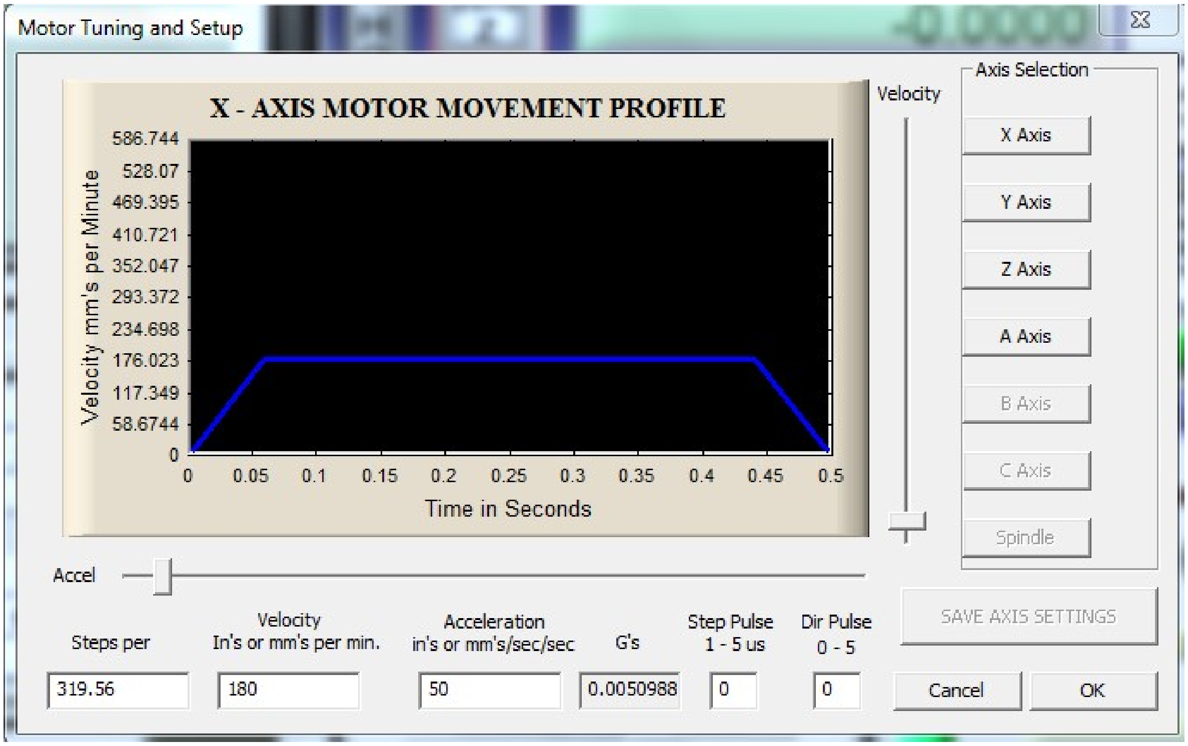
Signal	Enabled	Port #	Pin Number	Active Low	Emulated	HotKey
Limit Ovrd	✗	1	0	✗	✗	0
EStop	✓	1	10	✗	✗	0
THC On	✗	1	0	✗	✗	0
THC Up	✗	1	0	✗	✗	0
THC Down	✗	1	0	✗	✗	0
OEM Trig #1	✗	1	0	✗	✗	0
OEM Trig #2	✗	1	0	✗	✗	0
OEM Trig #3	✗	1	0	✗	✗	0
OEM Trig #4	✗	1	0	✗	✗	0

Pins 10-13 and 15 are inputs. Only these 5 pin numbers may be used on this screen

Illustration 6. Input signals configuration.

Motor tuning

Open the “Config” menu, choose “Motor tuning”. For Linear axes use the configuration shown in illustration 5.



Steps per	Velocity In's or mm's per min.	Acceleration in's or mm's/sec/sec	G's	Step Pulse 1 - 5 us	Dir Pulse 0 - 5
319.56	180	50	0.0050988	0	0

Illustration 7. Motor tunning setup.

Save axis settings.

After all these configurations, we are ready to tool the CNC.

CNC Tooling

Our CNC is equipped with ER11-A type clamping nut, ER11 is compatible with spring collets in a range of 0.5 mm to 8 mm. For now, we count with an 1/8” collet. Clamping nut is a 17mm hex nut.

Collet: A collet is a holding device that forms a collar around the object to be held and exerts a strong clamping force on it when tightened. Collets are commonly used in CNC machines to hold tools such as end mills, drill bits, or other cutting tools.

Clamping Nut: The clamping nut is the part of the collet system that secures the collet around the tool, holding it firmly in place.

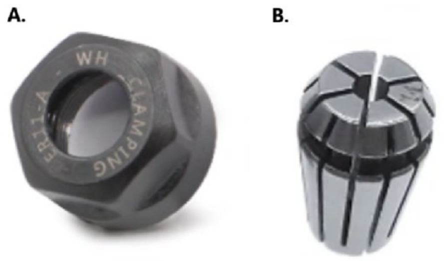


Illustration 8. A. Clamping nut. B. Collet.

When you need to insert a drill or change the tool, (spindle must be stopped) you just need to remove the nut, remove the collet, insert the tool and tighten the nut, for this you will need 2 17 mm wrenches. Please make sure the nut is tightened properly.

Once CNC is tooled, we are ready to turn on and make the final configuration on Mach 3.

Starting CNC

Upon initiating CNC and Mach3 operations, ensure that the three axes undergo automatic self-locking. Inspect the Mach3 interface for the flashing E-stop button; if detected, click the button to halt the process. In case the E-stop button continues to flash even after clicking, verify the status of the E-stop button on the control box. If pressed, rotate it clockwise to release the button (if the driver is power off the E-stop button is twinkling and can not stop).

Once the safety measures are addressed, tool movement can commence. Utilize the keyboard for axis direction control as shown in illustration 8 or employ the Mach3 manual control keyboard through the mouse for manipulating the X, Y, and Z axes. Press the "TAB" key on the keyboard to invoke the MACH manual control interface, it is shown in illustration 9.

CNC Zeroing

Move the tool to your (0,0,0) point. For x and y there is no biggest problem if you do not know where it is, when you open your g-code file, Mach 3 immediately displays the tool cutting path and define them correctly.

Ideally, to define the z axis, it is recommended that the tool be barely in contact with the material to be worked; however, doing this with a simple glance is difficult. There are newer methods, however our controller does not allow us to implement them.

To define point 0 in z, it is recommended to place a sheet of paper on the object to be worked on and move it while the tool lowers carefully, manually, point 0 will be as soon as the sheet can no longer move freely.

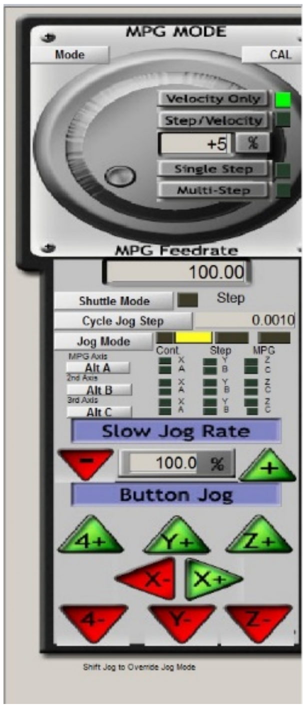


Illustration 10.Mach 3 manual control interface, it appears after pressing "tab".

Illustration 9. Keybord control interface.

CAD/CAM and Rapid prototyping

Computer Aided Design (CAD)

Computer aided design (CAD) refers to the utilization of computer systems to facilitate the development, modification, analysis, or enhancement of a design. Instances of such applications comprise the analysis of stress-strain in components, the dynamic response of mechanisms, calculations of heat transfer, and programming of numerical control parts [9].

Computer Aided Manufacturing (CAM)

Computer-aided manufacturing (CAM) refers to the use of numerical control (NC) software programs to generate step-by-step instructions that guide computer numerical control (CNC) machine tools in producing high-quality parts. CAM is used by manufacturers in various industries to create precise and detailed parts [10].

In applications related to design, the CNC is the basis of operation of many of the devices used in the processes, within the most common within the degree we find the machining of engineering plastics commonly with 3D printers, soft metals and mostly in rapid prototyping.

CAM (Computer Aided Manufacturing) software converts the digital CAD design into toolpaths that the CNC machine will follow. CAM software can be integrated with CAD, and it helps create efficient toolpaths for manufacturing the designed part [11]

Rapid prototyping (RP)

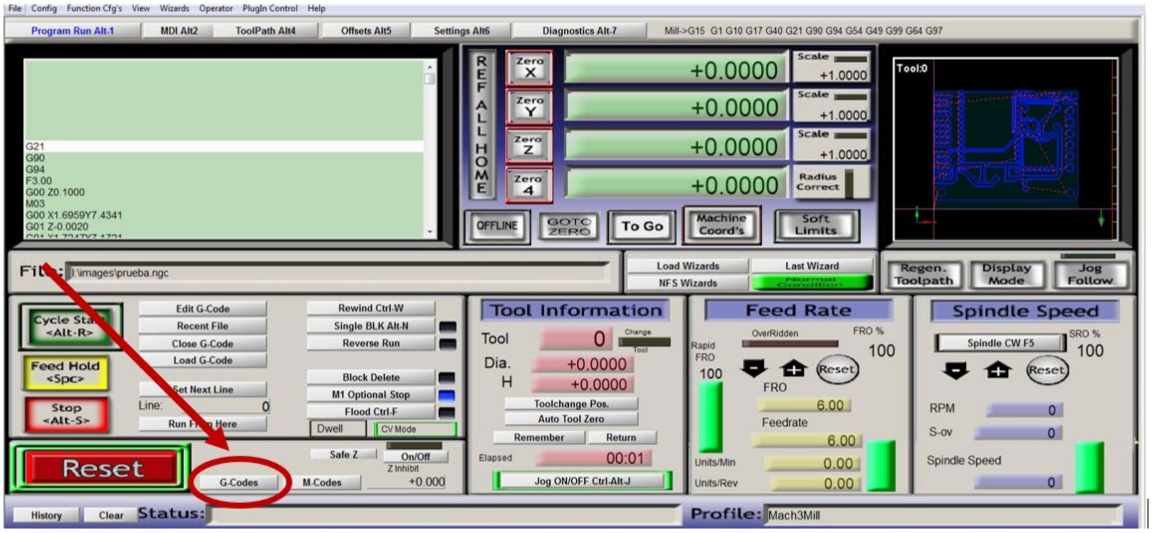
Rapid Prototyping (RP) is a cutting-edge method within the realm of Computer-Aided Manufacturing (CAM), defining a process for creating precise components directly from Computer-Aided Design (CAD) models. This innovative approach stands out for its ability to transform virtual designs swiftly and accurately into tangible prototypes. Typically completed within a few hours, the RP process minimizes human involvement and offers an efficient bridge between digital concepts and physical prototypes [12].

G-code

G-code is a programming language used to guide and direct CNC (Computer Numerical Control) machines. It consists of instructions that the microcontroller in the CNC machine can read and interpret, guiding the movement of the cutting tool and controlling various machine functions. G-code commands are organized in blocks, with each block controlling a specific CNC machining operation. The G-code language is essential for instructing the CNC machine on how to operate, and it is often generated using CAM (Computer Aided Manufacturing) software. G-code commands include instructions for rapid travel, linear and arc movements, dwell, tool selection, unit settings, and more. Understanding G-code is crucial for effectively communicating with a CNC machine and is a key part of the CAD/CAM process in manufacturing and engineering [13], [14].

Differences exist in the G-code lists across various CNC manufacturers. Not all machines support the same set of G-codes, and variations arise based on specific features or multi-axis machining capabilities of individual machines. It's important to note that certain machines may introduce additional G-codes beyond the standard set [14].

You can access the summary of commands used by Mach 3 in home view, pushing G code button, it is next to the "Reset" button, indicated in illustration 10.



```
G21
G90
G94
F3.00
G00 Z0.1000
M03
G00 X1.6959Y7.4341
G01 Z-0.0020
```

File: I:\images\prueba.ngc

Illustration 11. G-code button opens a summary of commands and their meanings, used by mach 3 and its .

Additive and subtractive manufacturing

Additive manufacturing (AM)

Additive manufacturing (AM) comprises a set of contemporary manufacturing technologies employed for the creation of three-dimensional prototypes based on CAD models. These methodologies share a common approach, adding and bonding materials layer by layer to construct objects. They are often referred to as layered manufacturing techniques. Diverse AM processes employ distinct methods to build and consolidate layers. Certain processes utilize thermal energy from lasers or electron beams directed through optics to melt or sinter (coalesce without melting) metal or powder. Alternatively, other techniques involve inkjet-type printing heads for precision spraying of binders or solvents onto powdered ceramic or polymer materials [15]. AM is relatively the newest manufacturing technique.

Subtractive manufacturing

SM or machining is a technology that is already mature and with a high level of development. It consists of the removal of material in the form of chips or small particles by conventional or advanced processes. As advantages of the SM stand out its ability to produce parts of complex geometries with high levels of dimensional quality, shape and surface finishes; being able to be much superior to those obtained through other processes [16].

These techniques offer unique advantages each one is useful in different ways, but CNC is an underlying thread connecting these methodologies. CNC ensures precise control in both additive and subtractive processes, dictating the movements of machinery and tools. This technological commonality underscores the interconnectedness of these manufacturing methods, emphasizing the reliance on CNC as a cornerstone of manufacturing.

Practice No. 1: PCB milling

Objective: The primary goal of this practice is to provide students with hands-on experience in the rapid prototyping of a Printed Circuit Board (PCB) for biomedical systems using Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM) software, and CNC machining techniques. Through this practice, participants will gain valuable insights and skills in the seamless integration of design, prototyping, and manufacturing processes essential in the development of advanced biomedical systems.

Materials

- Cooper clad board
- Engraving bit
- Cutting bit
- Drilling bit

Software

FlatCAM [17]

FlatCAM is a CAM free software that allows you to take your designs to a CNC router. You can open Gerber, Excellon or G-code, edit it or create from scratch, and output G-Code [18]. Isolation routing and milling holes are the main tasks we will use from FlatCAM to create our g-codes.

Preamble

PCBs are the platform upon which electronic components such as semiconductor chips and capacitors are mounted. It provides the electrical interconnections between components and is found in virtually all electronics products [19].

There are numerous PCB fabrication techniques available for PCB prototyping such as PCB milling, PCB laser printing, optically controlled mask less lithography technique using Digital Micromirror devices (DMD), etc. [20] In these practice we will use PCB milling. Which is a subtractive technology where we will remove parts of the cooper layer to generate the routes, we need to connect our components and isolate them from others.

PCB milling, also known as mechanical etching, is the fastest, cleanest, high-performance and economical PCB prototyping process today [18].

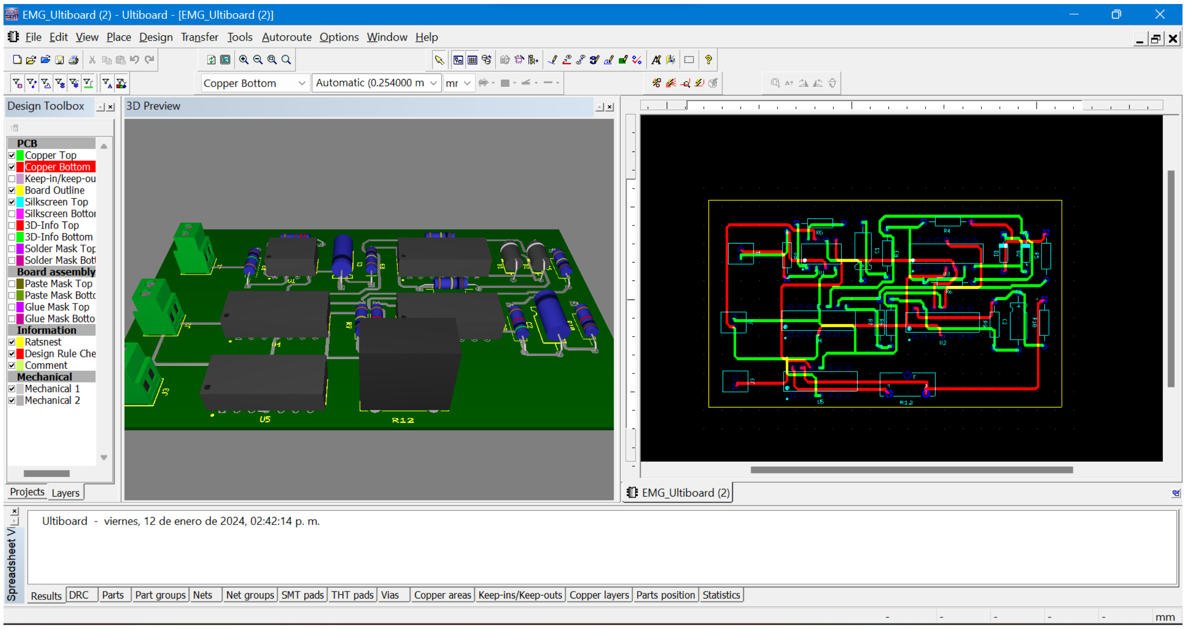
PCB Fabrication.

1. PCB Layout design.

Numerous CAD tools, including Proteus and Multisim (Ultiboard), feature PCBs design modules facilitating the translation of schematic diagrams into board layouts. Certain software options even offer automated path generation. Specialized PCB design tools such as Altium and Eagle are also available. The initial phase involves transforming the conceptual circuit schematic into a board layout, determining the precise placement of components and copper traces.

Upon component placement, connections are established through copper traces on either a single or double side of the board. These traces can be configured with varying styles, angles, widths, distances, etc. Components are strategically arranged to achieve a compact and small PCB design. The final step entails a thorough design check for potential errors. Common issues identified) include insufficient clearance distance between traces, inappropriate trace widths or drill sizes, and potential overlap between pads or traces.

From our CAD software, we will obtain 2 files or more, depending on the number of layers of our PCB, the first is the Gerber (.gbr) file and the Excellon (.drl) file. Neither of both files are not directly applicable for milling machine control as they do not specify the geometry of the conductive tracks. Instead, they delineate the trajectory of pattern apertures for the photo-plotter's lamp. To facilitate milling machine operation, it becomes imperative to derive the tool path that instructs the tool in generating the desired track. So, we need to generate the tracks with our CAM software. Illustration 11 shows the design of a PCB, schematics were designed in Multisim, just as a circuit simulation is done, then you just need to transfer them to Ultiboard, place the parts, generate the routes and finally you can export files we will need to generate our PCB.



Ultiboard - viernes, 12 de enero de 2024, 02:42:14 p. m.

Illustration 12. PCBs 3D view and layout.

2. CAM G-code generation

CAD systems outputs PCB fabrication data, gerber and excellon files. We need to generate the tracks with CAD software, in these case FlatCAM. And from FlatCAM we will also generate the board cutout. FlatCAM asks us to indicate the desired parameters of our tools to get the results, such as depth of the tool while cutting, the cutting diameters, etc. So, we will get 3 g-code files from Flatcam.

3. CNC milling

We can now use our g-codes in Mach 3, we just need to export them, tool the CNC, make the appropriate tool changes and PCB will be done. Is recommended to make engraving, drilling, and cutting, in that order.

Development

We review the PCB procedure, so de development of these practice must be as follows:

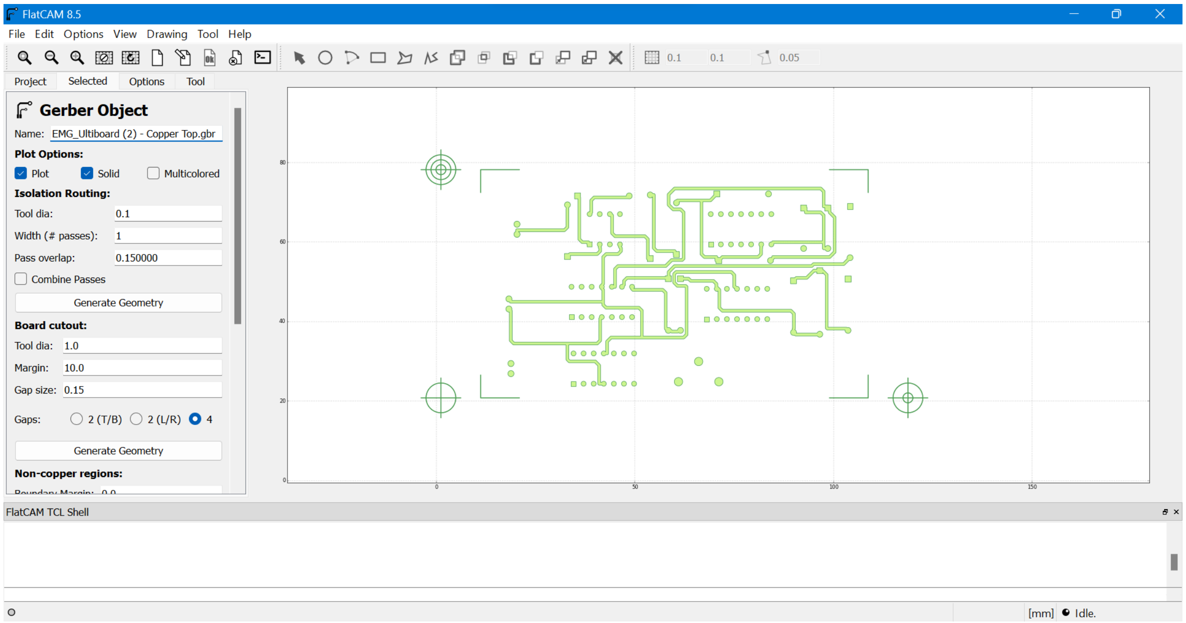
1. PCB layout design.

Use the software of your choice for PCB design. Please note that FLATcam only allows the use of two layers. We recommend that the tracks are never less than 1mm thick, it can be done, however, when there are many tracks, it can become a limitation and generate continuity in parts of the PCB that should not be there.

2. CAM PCB Generation.

We recommend the use of FlatCAM due to its friendly interface; you can use any software designed for the task. When GRBL file is loaded in FlatCAM you just need to select it and configure parameters, enter the diameter of the engraving bit, and click on generate geometry, it will generate the view shown in illustration 9. It's recommended to use a V 30° 0.1mm engraving bit.

Tool diameter d: Diameter of the cutting tool. Width (# passes): Width of the insulation path in number of cutting tool diameters. Pass overlap: Fraction of the tool diameter to overlap each step.



Name: EMG_Ultiboard (2) - Copper Top.gbr

Plot Options:

☑ Plot ☑ Solid ☐ Multicolored

Isolation Routing:

Tool dia: 0.1

Width (# passes): 1

Pass overlap: 0.150000

☐ Combine Passes

Board cutout:

Tool dia: 1.0

Margin: 10.0

Gap size: 0.15

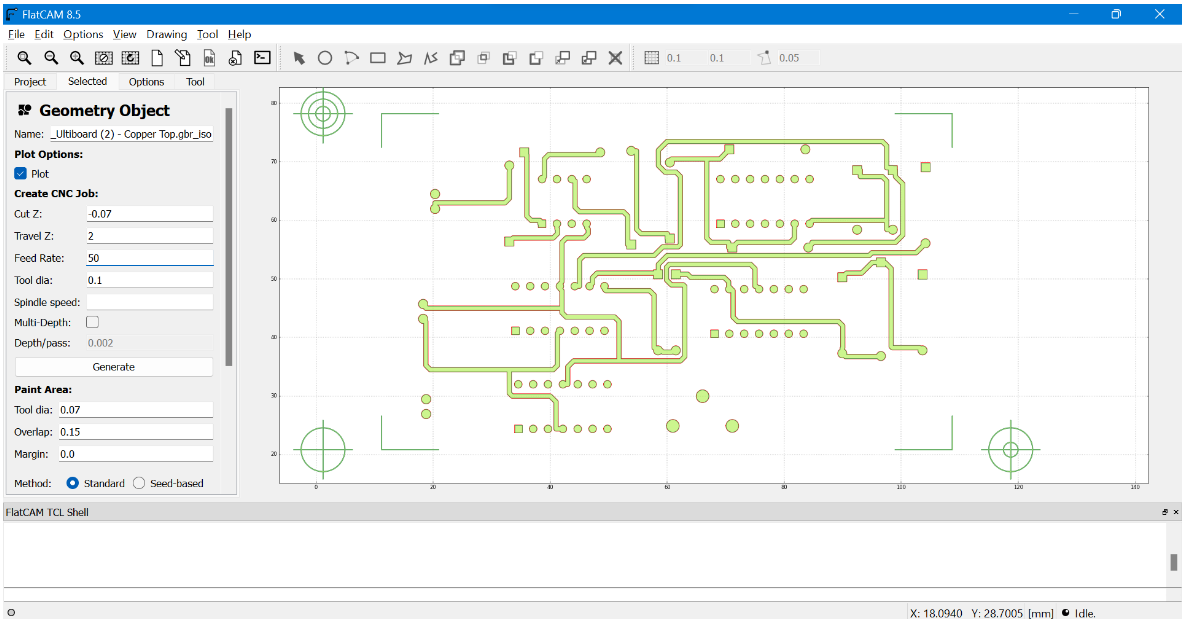
Gaps: ○ 2 (T/B) ○ 2 (L/R) ● 4

Non-copper regions:

Boundary Margin: 0.0

Illustration 13. GBR project.

When we clicked on “Generete Geometry” FlatCAM generates a fresh geometry object in "Project" menu, bearing an identical name as the Gerber object but with an appended "_iso" postfix. The associated options can be found in the "Selected" section as shown in illustration 10. To examine the results closely, zoom in on the plot by clicking on it and utilizing the "2" and "3" keys for zooming in and out.



Name: _Ultiboard (2) - Copper Top.gbr_iso

Plot Options:

☑ Plot

Create CNC Job:

Cut Z: -0.07

Travel Z: 2

Feed Rate: 50

Tool dia: 0.1

Spindle speed:

Multi-Depth: ☐

Depth/pass: 0.002

Paint Area:

Tool dia: 0.07

Overlap: 0.15

Margin: 0.0

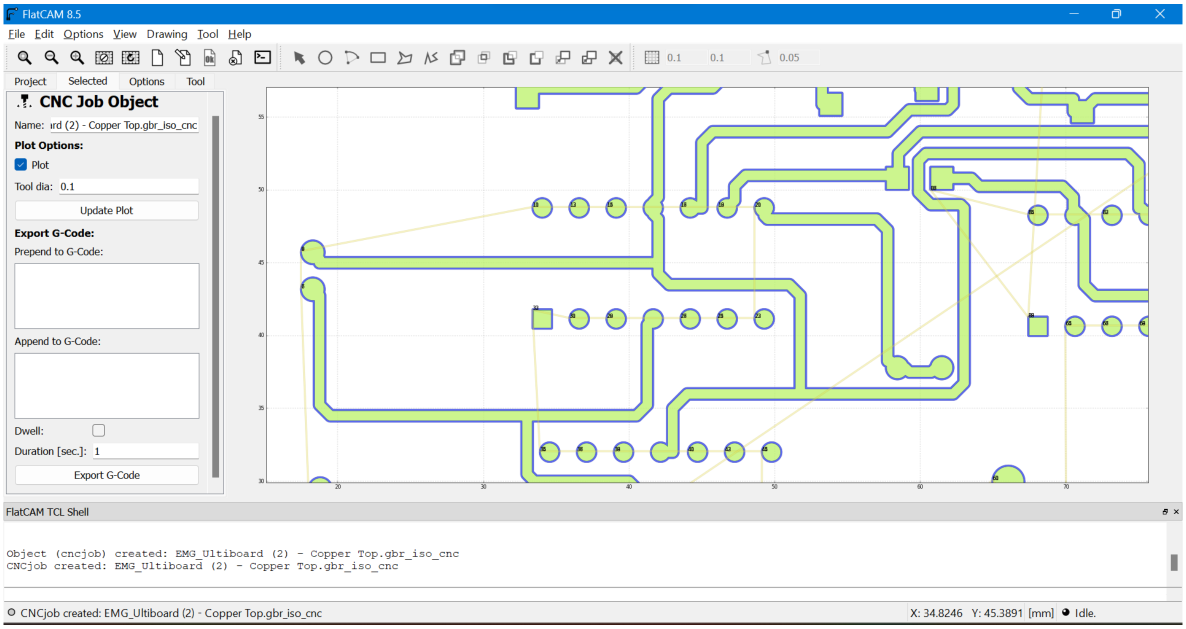
Method: ● Standard ○ Seed-based

X: 18.0940 Y: 28.7005 [mm] Idle.

Illustration 14. Geometry generated, vectors to be followed by our CNC machine (in red).

For this new geometry, we need to specify parameters: Cut Z, Travel Z, Feed rate, Tool diameter, and generate our CNC file.

After clicking on generate, A CNC Job object has been added to your project select it to see options. Tool paths are shown on the plot. Blue are copper cuts, while yellow are travelling (no cutting) motions.



Name: ırd (2) - Copper Top.gbr_iso_cnc

☑ Plot

Tool dia: 0.1

Dwell: ☐

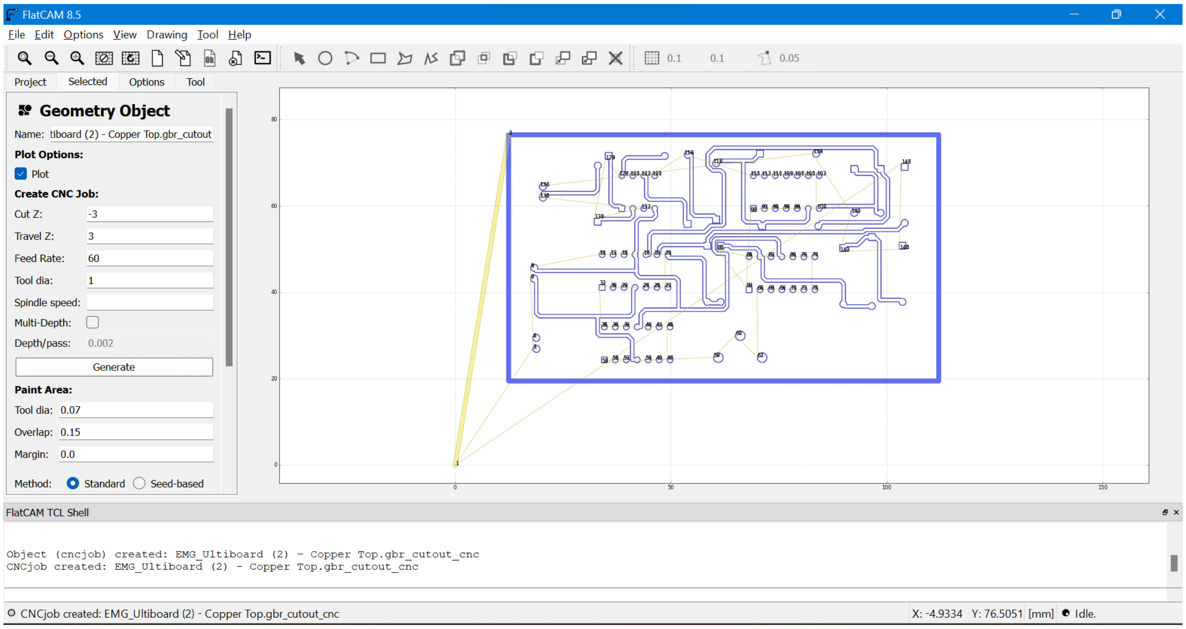
Duration [sec.]: 1

```
Object (cncjob) created: EMG_Ultiboard (2) - Copper Top.gbr_iso_cnc
CNCjob created: EMG_Ultiboard (2) - Copper Top.gbr_iso_cnc
```

CNCjob created: EMG_Ultiboard (2) - Copper Top.gbr_iso_cnc X: 34.8246 Y: 45.3891 [mm] Idle.

Illustration 15. CNC toolpaths generated, yellow lines represent tool travelling and blue ones represent machining places.

You will finally export that file and save it as .ngc file to open it on mach 3.



Name: tiboard (2) - Copper Top.gbr_cutout

☑ Plot

Cut Z: -3

Travel Z: 3

Feed Rate: 60

Tool dia: 1

Spindle speed:

Multi-Depth: ☐

Depth/pass: 0.002

Tool dia: 0.07

Overlap: 0.15

Margin: 0.0

Method: ● Standard ○ Seed-based

```
Object (cncjob) created: EMG_Ultiboard (2) - Copper Top.gbr_cutout_cnc
CNCjob created: EMG_Ultiboard (2) - Copper Top.gbr_cutout_cnc
```

CNCjob created: EMG_Ultiboard (2) - Copper Top.gbr_cutout_cnc X: -4.9334 Y: 76.5051 [mm] Idle.

Illustration 16. View of engraving and cutting routes. Cutting route (cutout board) is thicker because it was specified that a thicker tool will be used.

For drilling file is the same procedure and you can generate cutout board with the PCB file, FlatCAM just allows creating squared cutout boards, if you want an specific shape you can do it in the cad software you made the PCB, export it to FlatCAM and generate a g code through it.

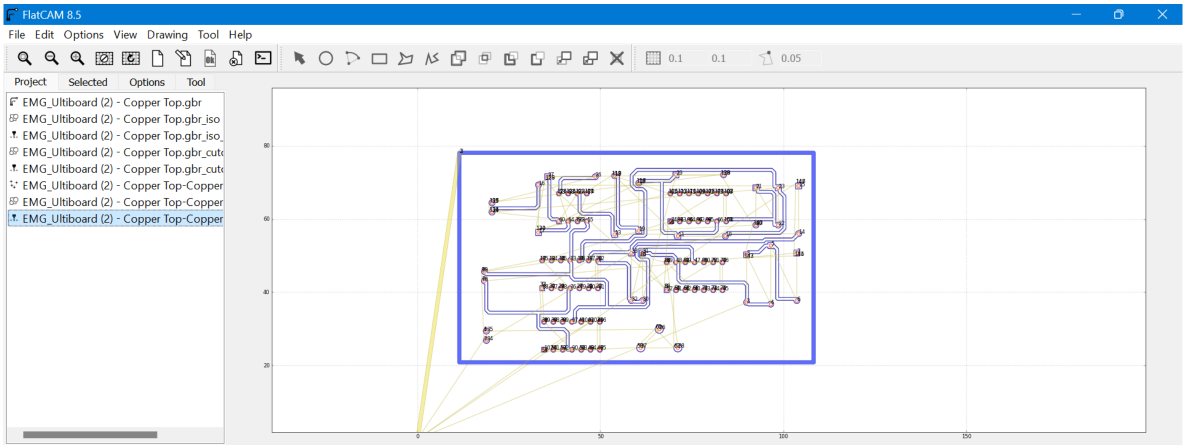
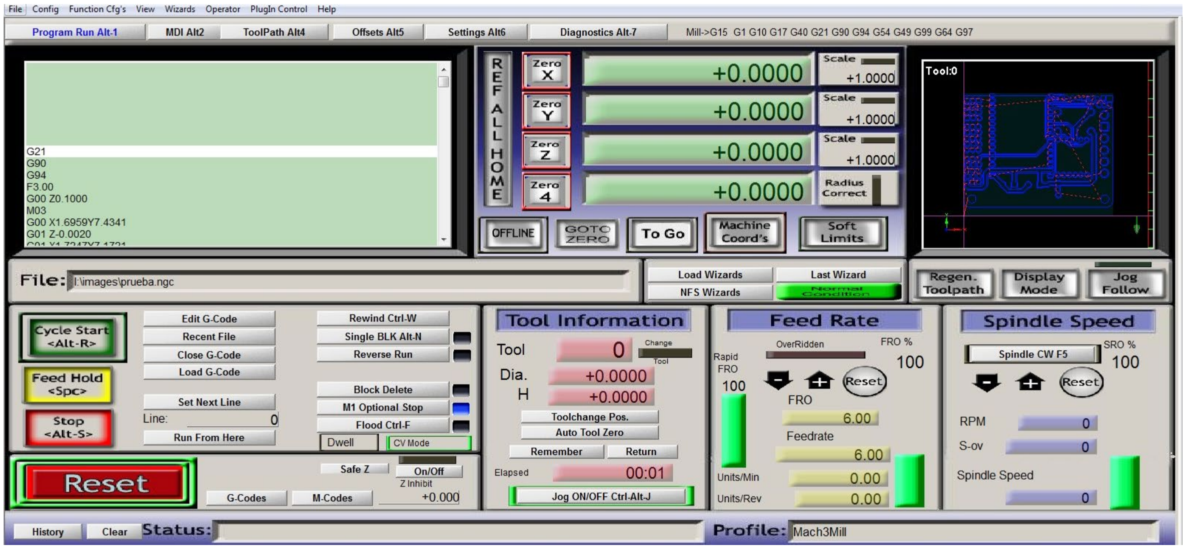


Illustration 17. Final view of the project in flatcam, cutting path, engraving path and milling path

3. CNC milling

To load a g-code in Mach 3 you just need to go to file menu, and click on "Load G-Code", immediately you will see the code and the toolpath mach 3 generated using the zeroing you did, as shown in illustration 12.


```
G21
G90
G94
F3.00
G00 Z0.1000
M03
G00 X1.6959Y7.4341
G01 Z-0.0020
```
File: I:\images\prueba.ngc

Profile: Mach3Mill

Illustration 18. Mach 3 home view.

On the CNC, the plate, or any material we work with must be fixed, and for the cutting and drilling processes, an MDF board must be placed under the plate to be worked on.

After doing this we can start the cycle in the CNC. And then load the remaining cutting and drilling files.

In this case, we used a 5 x 10 cm single sided copper clad board, the copper coating is 1.5 mm. so CNC engraving was deeper than that.

Illustration 19. CNC machine working.

Practice No. 2 Cutting soft materials.

Objective

The objective of this practice is to learn about the CAD-CAM process and generate a final product, a piece, either for study, integration into a more complex system or any other purpose that the student has.

Materials

- MDF (Maximum 9 mm) or acrylic (Maximum 9 mm)
- Engraving bit
- Cutting bit

Software.

Aspire 3D [21]**.**

Aspire 3D is a CAD/CAM software, Aspire provides a powerful yet intuitive software solution for creating and cutting parts on a CNC router. There are tools for 2D and 3D design and calculation of toolpaths [21].

Preamble.

Subtractive manufacturing technique allows the manufacture of prototypes from different materials and with varied shapes. Our CNC can work with a wide range of materials; however, it is limited by the power of the spindle and the tools we have, hence the materials chosen for this practice.

Machining, cutting, and engraving are important tasks in rapid prototyping, each is developed with different tools, and they lead to different results, and it is of utmost importance to choose the correct tare according to the goal. So, you must identify the complexity of the piece to be done and the feasibility of each task.

Development.

1. Design.

In this case, since Aspire it is a CAD/CAM software, we can make the designs to be manufactured from the same software, however, we can also import vectors or work with DWG or DXF files generated in Autodesk [22]. So, when we have the design of the part to be cut in Autodesk, we must save it and later open it in Aspire. We can open the file, where we can already include margins, or we can just import the vectors and continue modifying them in Aspire. For this we just must go to the “file” menu and select “open” or “import”. Illustration 14 shows the file in AutoCAD, the box around the gear is the margin with which we will work in Aspire.

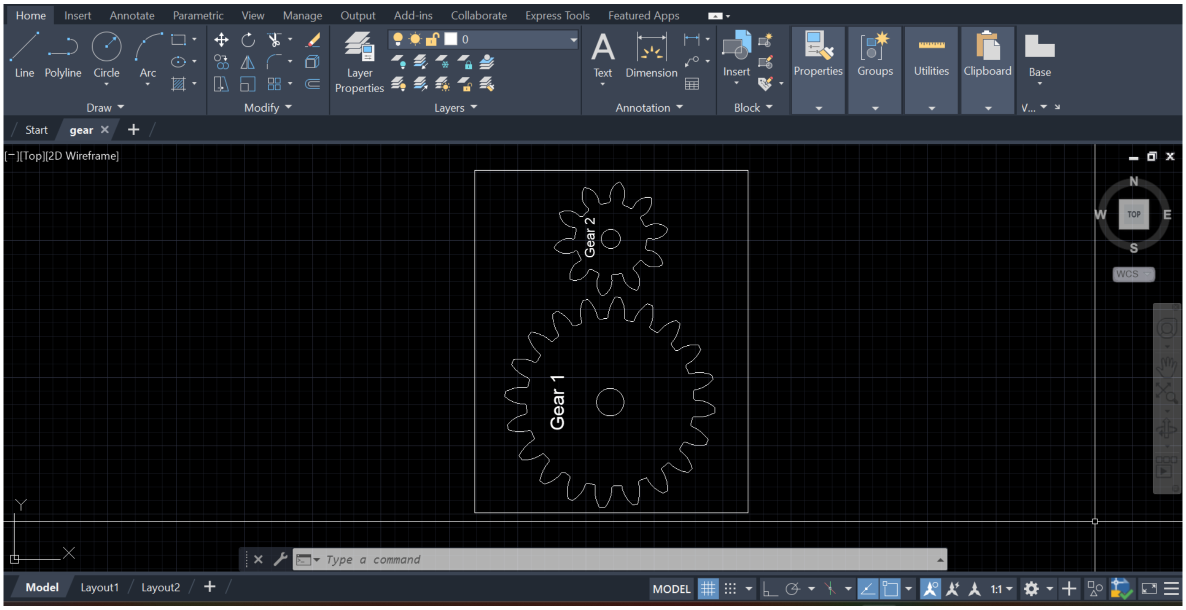
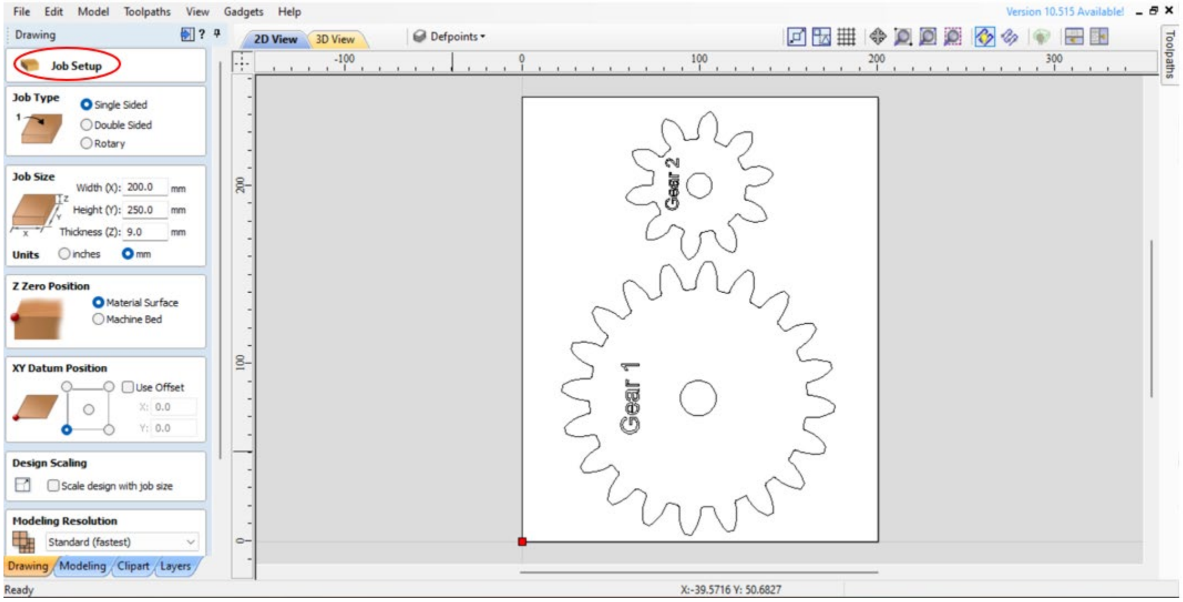


Illustration 20. Gear Autocad design.

You can also import 3D designs and work on them in Aspire.

2. Toolpath generation

When opening the DWG files in Aspire, we will get the view shown in the image, where we must specify the job settings (left side menu): size, job type, z position 0, reference position, the scale and resolution of the work. We always recommend using the standard resolution, mainly due to working times. At the end, in job setup we scroll down and press "ok", this will allow us to edit the design from the "Drawing" menu or begin configuring the toolpaths.



Job Type
● Single Sided
○ Double Sided
○ Rotary

Job Size
Width (X): 200.0 mm
Height (Y): 250.0 mm
Thickness (Z): 9.0 mm
Units ○ inches ● mm

Z Zero Position
● Material Surface
○ Machine Bed

XY Datum Position
☐ Use Offset
X: 0.0
Y: 0.0

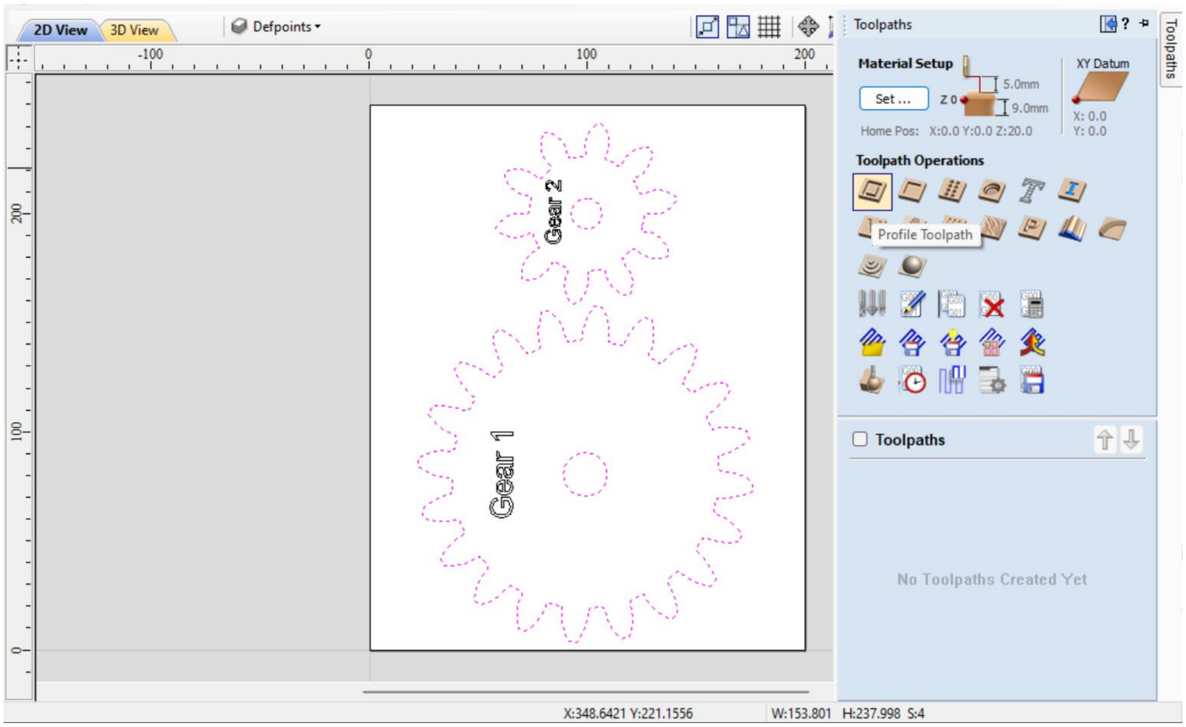
Design Scaling
☐ Scale design with job size

Modeling Resolution
Standard (fastest)

Illustration 21. Home view in Aspire when opening a DWG file. On the left side you can see the job setup menu.

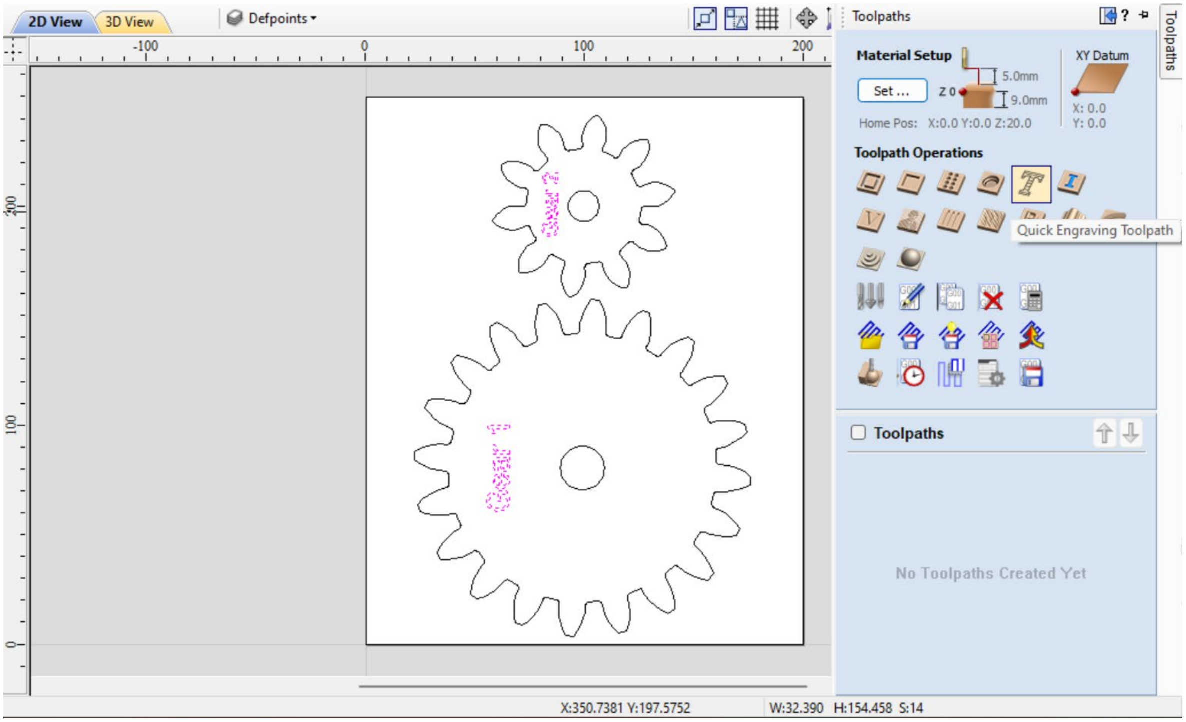
When we import vectors, we first need to specify the job set up and then import the vector and then we can place it wherever we want.

To begin with the configuration of the toolpaths, we must select the vectors that we want to use, in this case, we are going to generate the toolpaths for the gear cut, we select the vectors by clicking on them, for a multiple selection we must hold down the shift key, when selected, they will turn purple with a dotted line. Having selected the vectors, we must go to the "toolpaths" menu, on the right side, illustrations 21 and 22 show cutting and engraving options from toolpaths menu.



X:348.6421 Y:221.1556 W:153.801 H:237.998 S:4

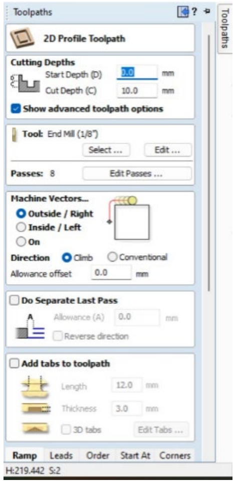
Illustration 22. Vectors to which toolpaths will be generated selected in purple.



X:350.7381 Y:197.5752 W:32.390 H:154.458 S:14

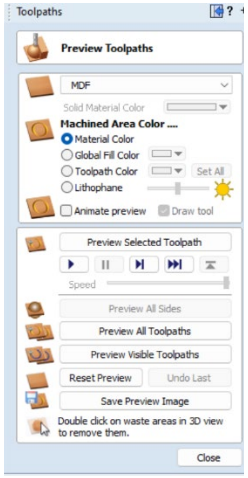
Illustration 23. Vectors to which toolpaths will be generated selected in purple, in this case, they are selected to generate an engraving toolpath.

The menu offers us different operations, in this case, we are interested in the cutting operation or "profile toolpath", we select it and the image menu will be displayed, where we will specify the cutting depth, the tool to use, the number of passes between others, in 9 mm materials it is recommended to use at least 5 passes, after having chosen the configurations, we must click on "Calculate", this will generate a new toolpath and take us to a new view, where we can observe the vectors to follow by the CNC, it takes us to the "preview toolpaths" menu, where we can view all the toolpaths that we have generated. After we generated a toolpath, FlatCam generates a 3d view, shown in illustration 25, where we can simulate the operation.



Start Depth (D) 0.0 mm
Cut Depth (C) 10.0 mm
☑ Show advanced toolpath options
Tool: End Mill (1/8")
Passes: 8
● Outside / Right
○ Inside / Left
○ On
Direction ● Climb ○ Conventional
Allowance offset 0.0 mm
☐ Do Separate Last Pass
Allowance (A) 0.0 mm
☐ Reverse direction
☐ Add tabs to toolpath
Length 12.0 mm
Thickness 3.0 mm
☐ 3D tabs
H:219.442 S:2

Illustration 25. Profile toolpath menu.



MDF
Solid Material Color
● Material Color
○ Global Fill Color
○ Toolpath Color
○ Lithophane
☐ Animate preview ☑ Draw tool
Double click on waste areas in 3D view to remove them.

Illustration 24. Preview toolpaths menu.

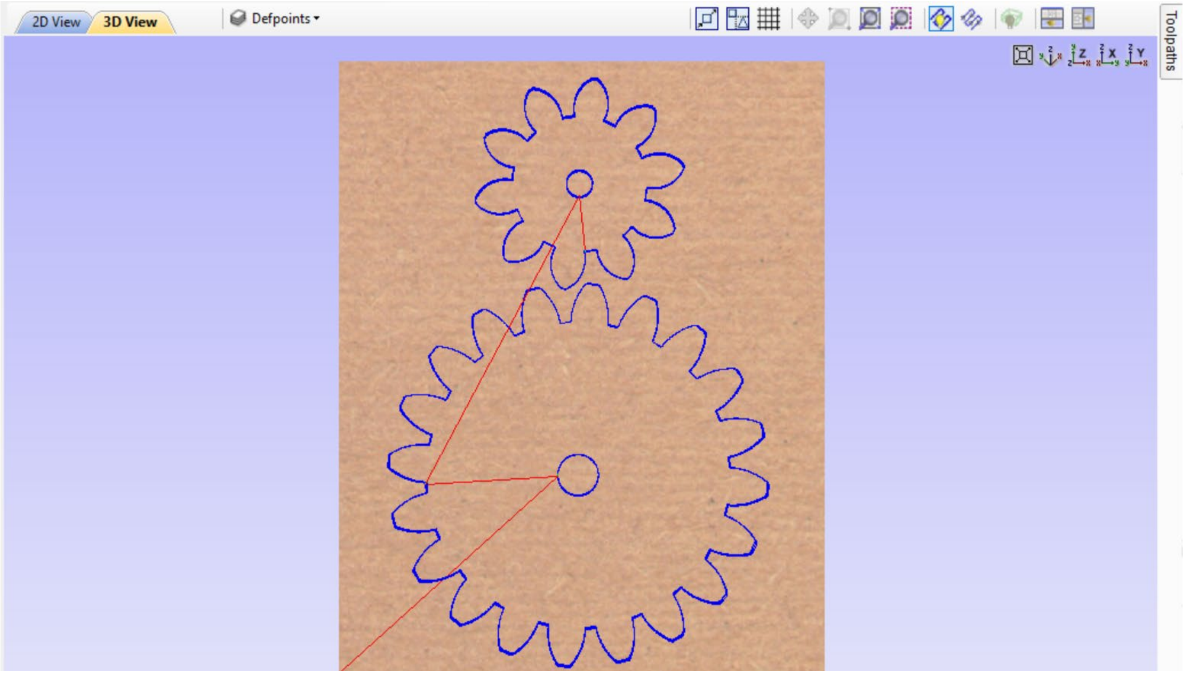


Illustration 26. 3D view of the cutting toolpath, when generated.

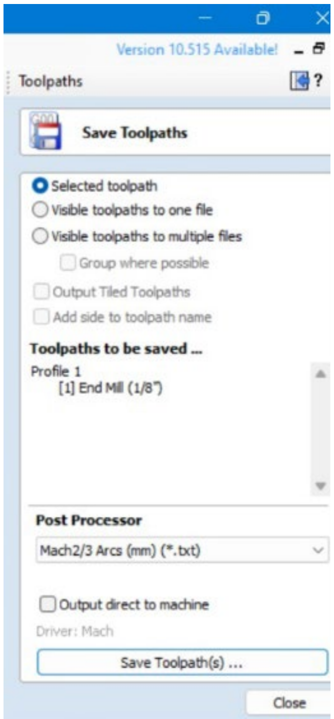
3. G code generation.

Having calculated the toolpath, we have generated a new toolpath, now we must generate a g code with that toolpath. To do this, we must close the "Preview toolpaths" menu and in the "toolpaths" menu, we must select the toolpath to save and select "save toolpath", as shown in illustration 19.

Illustration 27. In toolpaths menu, select save toolpath.

In the “Save Toolpath” menu to generate the G code, it is extremely important that in the “Post proessor” option we choose “Mach2/3 Arcs (mm) (*.txt)”, as shown in the illustration 20, to have a code compatible with our controller. When generating the g code, we just have to open it in mach 3 and start machining our part. Go to practice 1 point 3 in development “3. CNC Milling” for more details.

When cutting MDF or acrylic it is recommended to use a medium speed on the spindle.



● Selected toolpath
○ Visible toolpaths to one file
○ Visible toolpaths to multiple files
☐ Group where possible
☐ Output Tiled Toolpaths
☐ Add side to toolpath name

Toolpaths to be saved ...
Profile 1
[1] End Mill (1/8")

Post Processor
Mach2/3 Arcs (mm) (*.txt)

☐ Output direct to machine
Driver: Mach

Illustration 28. Save toolpath menú.

As shown in illustration 16 Aspire offers us different operations such as cutting, engraving, among others, for all operations it is the same process, you just have to select the correct tools, it also include 3D operations.

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