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ESCUELA DE INGENIERÍAS INDUSTRIALES

UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica

3D pen based robotic printing

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TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO:	3D pen based robotic printing
ALUMNO:	Elena Palomares Agúndez
FECHA:	03/06/2025
CENTRO:	Centro en la universidad de destino
UNIVERSIDAD:	Vilnius Gediminas Technical University
TUTOR:	Doc. dr. Andrius Dzedzickis

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

DEPARTMENT OF MECHATRONICS, ROBOTICS AND DIGITAL MANUFACTURING

Elena Palomares Agúndez

3D PEN BASED ROBOTIC PRINTING

Final Bachelor's Project

Study programme MECHATRONICS AND ROBOTICS,

Code 612LEX048

Vilnius, 2025

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

DEPARTMENT OF MECHATRONICS, ROBOTICS AND DIGITAL MANUFACTURING

APPROVED BY
Head of Department

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Vytautas Bučinskas
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Elena Palomares Agúndez

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Supervisor: Andrius Dzedzickis ________ ________
(Title, Name, Surname) (Signature) (Date)

Vilnius, 2025

DECLARATION OF AUTHORSHIP IN THE FINAL BACHELOR'S PROJECT

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Elena, Palomares Agúndez

Faculty of Mechanics

ERASMUS

IN THE COURSE PROJECT

22/05/2025

(Date)

I declare that my Course Project entitled **3D pen based robotic printing** is entirely my own work. I have clearly signalled the presence of quoted or paraphrased material and referenced all sources.

I have acknowledged appropriately any assistance I have received by the following professionals/advisers: ____________________

____

The academic supervisor of my Course Project is **Doc. dr. Andrius Dzedzickis**

No contribution of any other person was obtained, nor did I buy my Course Project.

ELENA PALOMARES AGÚNDEZ

(Signature) (Given name, family name)

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF MECHANICS
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APPROVED BY
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(Date)

Production and Manufacturing engineering study field

Mechatronics and robotics study programme,

State code 612LEX048

TASK FOR BACHELOR THESIS

14 March 2025 No. APA01
Vilnius

For student Elena Palomares Agundez

Bachelor Thesis title: 3D pen based robotic printing

The Final work has to be completed by 22 May, 2025.

TASK FOR FINAL THESIS:

Initial data:

Aim of the task is to develop a technological solution enabling the use of a regular 3D printing pen with an industrial robot. IT is necessary to develop a pen holder and a corresponding control system compatible with Yaskawa robots. The weight of the device should not be more than 2 kg. It should use regular 1.75 mm printer's filament.

Explanatory part:
1. Introduction. Analysis of analogical devices. Substantiation of the taken technical decision.
2. Overview of specific nodes. Decision on component type best suited for application.
3. Calculations needed for the design process.
4. Description of the construction and operational principle. Kinematical and electrical block schemes, and an algorithm.
5. General requirements for safe working and environmental protection and for the development of the device.
7. Evaluation of economic indicators of the designed or upgraded device.
8. Final conclusions and recommendations.
9. Literature reference list.

Drawings:
1. General drawing of the device (1 sheet A1);
2. Assembly drawing of the device (node) (1 sheet A1);
3. Kinematic scheme (0.25 sheet A1);
4. An operating algorithm (0.5 sheet A1);
5. The structural scheme of the device (0.25 sheet A1);
6. The work drawing of the 2 chosen parts (2×0.25 sheet A1);
7. Economic indicators (0.5 sheet A1).

Supervisor .... Doc. dr. Andrius Dzedzickis
(Signature) (Academic Title, Name, Surname)

Task accepted
……………………………………..
(Student‘s signature)
Elena Palomares Agundez
(Student‘s Name, Surname)
2025-03-14
(Date)

Vilnius Gediminas Technical University
Faculty of Mechanics
Department of Mechatronics, Robotics and Digital Manufacturing

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Bachelor Degree Studies **Mechatronics and Robotics** study programme Bachelor Graduation Thesis 3

Title: **3D pen based robotic printing**

Author **Elena Palomares**

Academic supervisor **doc. dr Andrius Dzedzickis**

Annotation

The object of this project is to design an end-effector that allows mounting a 3D pen to a robotic arm, acting as a 3D printer. It has been developed a robust and lightweight support where the pen would be introduced. This support ensures that the pen remains stable during the movement of the robot. This device is intended to be easy to implement and compatible with various Yaskawa robotic arms that could be used in education or prototyping.

The design includes a dedicated space for a servomotor that activates the pen’s extrusion mechanism. This allows the system to control when the filament is extruded based on programmed commands. Moreover, a filament presence is also integrated to detect if filament is being fed correctly. If the filament runs out, the system alerts the user so it can be replaced, helping to avoid failed prints.

The operation can be partially autonomous, the robot can follow a defined path and print independently, or the user can choose to control the extrusion manually. This setup provides flexibility for testing, educational use, or small-scale functional prototyping.

Keywords:

3D printing, robotic arm, Additive Manufacture (AM), 3D pen, filament, extrusion, support.

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Pirmosios pakopos studijų **Mechatronikos ir robotikos** programos bakalauro baigiamasis darbas 3

Pavadinimas: **Robotinis spausdinimas naudojant 3D rašiklį**

Autorius **Elena Palomares**

Vadovas **doc. dr Andrius Dzedzickis**

Kalba

	Lietuvių
X	Anglų

Anotacija

Šio projekto tikslas – sukurti roboto įrankį leidžiantį pritvirtinti 3D rašiklį prie roboto rankos, veikiančios kaip 3D spausdintuvas. Jis buvo kuriamas kaip tvirtas ir lengvas laikyklis, kuriaame būtų tvirtinamas 3D rašiklis. Šis laikiklis užtikrina, kad rašiklis išliks stabilus roboto judėjimo metu. Šis įrenginys yra skirtas lengvai įdiegti ir suderinamas su įvairiomis Yaskawa robotinėmis rankomis, kurios gali būti naudojamos švietimui ar prototipų kūrimui.

Konstrukcijoje yra skirta vieta servovarikliui, kuris aktyvuoja rašiklio ekstruzijos mechanizmą. Tai leidžia sistemai valdyti, kada išlydytas plastikas turi būti išspaudžiamas pagal užprogramuotas komandas. Be to, yra integruotas spausdinimo vielos jutiklis, kad būtų galima nustatyti, ar viela tiekiama tinkamai. Jei viela baigiasi, sistema įspėja vartotoją, kad ją būtų galima pakeisti, taip išvengiant nesėkmingų spaudinių.

Veikimas gali būti iš dalies autonominis, robotas gali sekti apibrėžtą kelią ir spausdinti

Prasminiai žodžiai: 3D spausdinimas, roboto ranka, priedų gamyba (AM), 3D rašiklis, viela, ekstruzija, laikiklis.

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INTRODUCTION

Nowadays, 3D printing is one of the technological advancements increasing over the recent years. It has applications in many fields and currently is very common use this method to manufacture parts. The most usual application is in traditional 3D printers, but designs can also be created in other ways.

Object of project.

The main objective of this thesis is to develop a functional and efficient support to integrate a 3D printing pen into a robotic arm. This option provides us with the possibility of personalized designs and a more flexible fabrication, to manufacture the components. Otherwise, there are more solutions for customizing 3D-printed components. The choice would depend on materials, budged and, of course, the level of precision required.

The development of additive manufacturing technologies nowadays is booming, with many ways to create 3D parts. In this project, the focus will be on the use of 3D printing pens, as they are a flexible and very accessible option for the public. They allow users to make simple prototypes or small-scale models with a low budget and without needing complex equipment.

Nevertheless, 3D printing pens are limited when we try to use them in automated processes, especially because they do not have a good system to fix them to robotic arms. This makes it difficult to use them in specific tasks where movement needs to be controlled and accuracy becomes important.

The goal of this project is to design a support that allows a 3D printing pen to be securely attached to a robotic arm. This support will be strong, safe, and adaptable to the pen’s shape. It will also avoid unwanted movement during use and help guide the pen properly while printing. With this system, it will be possible to use 3D pens in automatic operations, giving new possibilities for educational use, basic manufacturing, art, and prototyping. The design will consider safety, stability, and easy for installation.

1 OVERVIEW OF ANALOGIC CONSTRUCTIONS

Throughout the project, different solutions will be studied to determine the best approach compared to other 3D printing methods. Nowadays, there are a lot of options due to obtain 3D-printed parts. The most relevant cases, and those most similar to the problem addressed, are:

1.Robotics 3D printing

2.Direct Ink Writing

3.3D Pen Printing

1.1 Robotics 3D printing

The integration of 3D printing in robotics has significantly changed how robotics are designed, manufactured or utilized. This innovative technology facilitates the production of complex components with considerable precision and accuracy, alongside enhanced cost-effectiveness and operational efficiency. Its potential applications are notable in fields such as the expedited development of prototypes, the fabrication of customized parts, and the emerging area of soft robotics (a technology that emulates the structure of living organisms through the utilization of flexible materials). Examining these applications allows for a clearer comprehension of the significant impact of robotics 3D printing on industrial practices.

The advancements observed in robotics over recent years have been substantial. Thanks to advances in materials, smarter software, and inventive manufacturing methods, progress has been unfolding like an ongoing, unpredictable experiment. These breakthroughs keep merging high-tech ideas with everyday practicality. Among these advances, 3D printing (also known as additive manufacture or AM by its acronym) has emerged as a key factor for the development of complex and profitable designs. Unlike other traditional methods that imply cutting or machining material, so resting material, 3D printing builds objects layer by layer from digital models implemented in their software. This point of view allows us to create geometries that without 3D printing would be very difficult and expensive to achieve.

One important and innovative use of this technology is 3D printing through robotics arms. As opposed to traditional 3D printers, robotics arms offer major flexibility, since they can move in multiple axes (three or more). This aptitude makes easier the production of complex geometries and parts that would be impossible to manufacture with a traditional printer. Moreover, the arms can operate continuously without any interruptions, so it reduces production time in wide-size projects.

1.1.1 Components of robotics 3D printing

The principal component is the robotic arm (Fig. 1), which can move in multiple axes and offer great flexibility to print in different angles and positions, allowing the creation of complex geometries.

Device No.1. Robotic arm (Fig. 1).

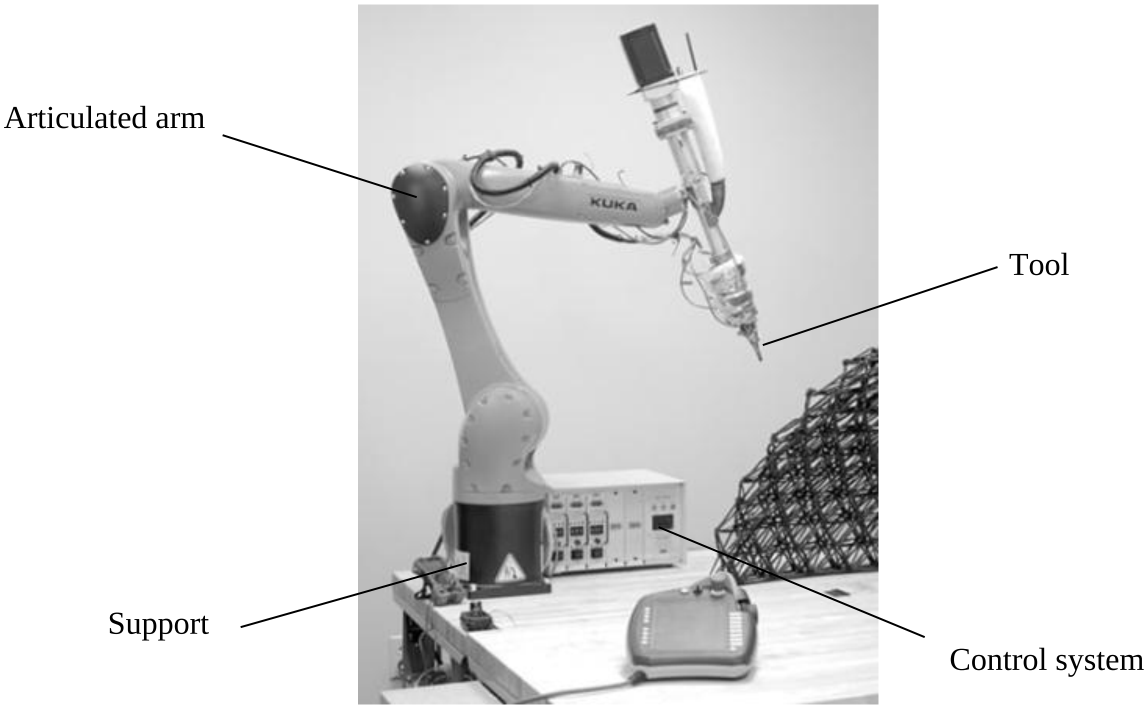


Fig. 1.1. Robotic arm.

(The Top Robotic Arm 3D Printing Solutions - 3Dnatives, n.d.)

Another fundamental element is the control system; it requires special software which is in charge of regulating the movement of the robotic arm and the material extrusion. This software sends accurate instructions to the arm, determines the trajectory and guarantees the correct deposition of the material layers.

There is also the extruded head, it is situated in the wrist of the robotic arm, (Fig 2), which is the component where the filament goes out and the printing material is deposited when is necessary. The extruder is integrated into the robotic arm by the tool and follows the instructions given by the control system (software).

Fig. 1.2. Extruder head.

(The Top Robotic Arm 3D Printing Solutions - 3Dnatives, n.d.)

1.1.2 Printing techniques by robotic arm

1.- Fused Deposition Modelling (FDM): This is the most widely used method, especially for creating prototypes. It extrudes thermoplastic through a hot nozzle so that it forms solid structures. The most common materials are PLA and ABS.

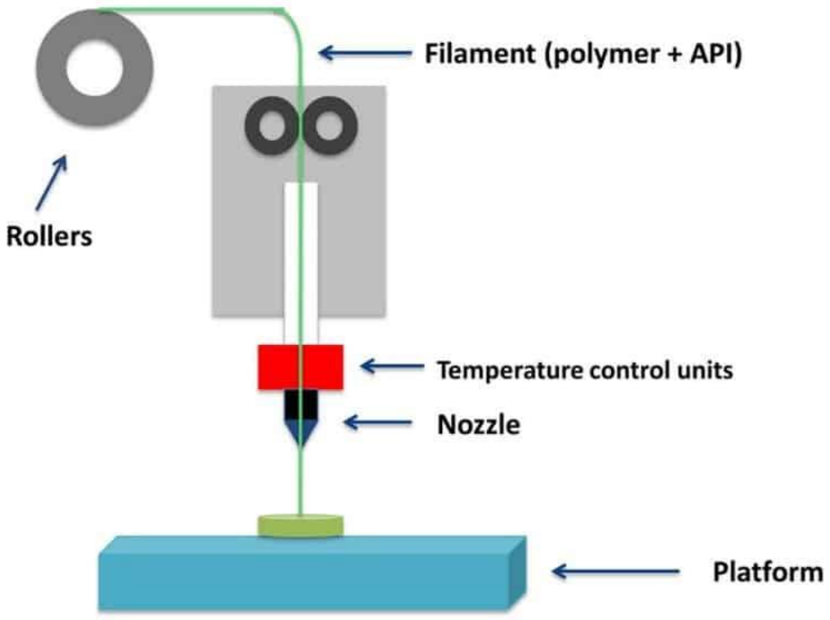


Fig. 1.3. Fused Deposition Modelling.

(What Is FDM 3D Printing? n.d.)

2.- Selective Laser Sintering (SLS): This technique uses a laser source to fuse powdered material into solid parts. It is often used to create high-strength parts. It uses ceramic or metal powders and sinters plastic. This technique has extremely excessive costs because of its suitable mechanical properties.

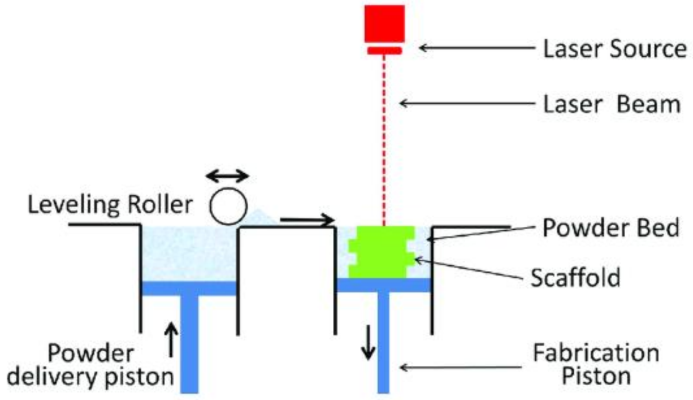


Fig. 1.4. Selective Laser Sintering

(Song et al., 2024)

3.-Stereolithography (SLA): Uses a light source to solidify liquid resin layer by layer. Professionals choose this technique because of the smooth surface finishes and the high precision. The materials used in this technique are resins that can cure with UV light. It is expensive but there is no surface finish processes needed (when the solidification is over), although, it is fragile when there are humid environments.

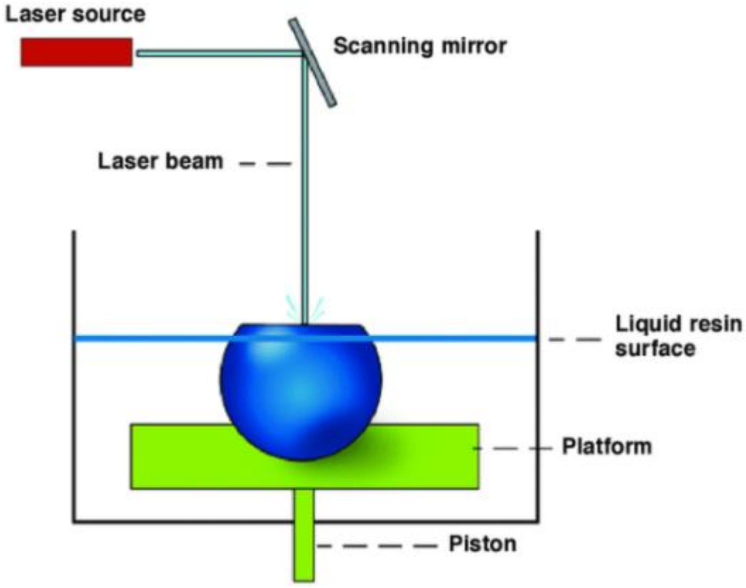


Fig. 1.5. Stereolithography

(Naeem, n.d.)

1.1.3 The 3D printing process

To print with this device, first, the part is designed by CAD software. Then, the design becomes a compatible archive with the robotics 3D printer software. This software determines the quantity of material and the extrusion speed. Subsequently, the robotic arm starts to move following the scheduled instructions, it deposits successive layers of the selected material. Once all the layers are completed, a finishing process, like cooling or sanding, could be necessary.

1.1.4 Companies of robotics 3D printing

1. MX3D:

MX3D is quite well-known for its ambitious plan to 3D print a steel bridge using robot arms. The company uses KUKA robotic arms that have welding heads to push out metal and make big objects. This project got a lot of attention worldwide because they used metal 3D printing together with the robots' ability to print straight into a 3D space. MX3D focuses on high-performance 3D printing for metal and structural parts. This technology has important uses in building design and making things in factories.

2. Ai Build

Ai Build, based in the UK, is another important company in the field of robot-assisted 3D printing. They use software powered by artificial intelligence to control robot arms for big industrial 3D printing jobs. The company focuses on making incredibly detailed, large parts that normal 3D printers cannot manage. Ai Build collaborates with robot arms from KUKA, and they create solutions for industries like planes, cars, and building.

3. Branch Technology

Branch Technology is a company that focuses on 3D printing for buildings. They have come up with a distinct way of printing called Cellular Fabrication (C-Fab), that lets them print light and natural-looking panels that can be used in construction. The company uses robot arms with extruders to print these structures using materials like plastic and carbon fibre. Branch Technology has introduced an innovative way of using robotic 3D printing, because it makes it possible to create big parts for buildings that are hard to make with normal building methods.

1.1.5 Applications for 3D printing in robotics

1.-Rapid prototyping: 3D printing enables engineers to make rapid prototypes; this facilitates engagement and testing. In comparison with traditional manufacturing methods, which require much time and higher costs, 3D printing by robots accelerates the design validation and future modifications. Some examples are mounts for sensors or motor.

2.-Customised parts for robots: Personalization is one of the main advantages of 3D printing in robotics. It is possible to design robots with adaptable components for specific functions or environments. This flexibility is especially useful in fields of investigation, where oftentimes is needed custom-made solutions.

3.-Complex geometries and light structures: 3D printing enables fabricating light structures with complex geometries. These intricate geometries would not be possible to make by other conventional methods due to the need of removing material or the imitated tools. For example, it is possible to create parts that provide endurance and reduce weight, something crucial in applications where 3D printing is essential for manufacturing, like drones or mobile robots.

4.-Soft robotics: Other particularly innovative developments is the application of 3D printing in soft robotics. These robots, made of flexible materials, have the ability to deform and adapt to the environment. 3D printing allows for accurate control of the design of these components, which are usually complex and require special manufacturing processes.

1.1.6 Benefits of 3D printing for robotics

Cost reduction: A significant advantage of robotic 3D printing is that unlike traditional robotics systems that require molds and expensive tools, which makes production more expensive; 3D printing for robotics do not require costs of the initial process because there is no need to use specialized tools. Moreover, the use of the material is optimized, so the waste of the material is reduced.

Design freedom: The integration of robotics with 3D printing enables the creation of customized and optimized designs. Engineers and designers can explore new possibilities without the restriction of traditional manufacturing methods that have impediments in complex geometries and take more time to manufacture.

Lightweight parts: moreover, the structure it creates is strong but also lightweight it can be developed and evaluated in shorter periods. This accelerated iteration enables quicker evaluation and refinement of designs.

1.1.7 Limitations and Challenges of Robotics 3D Printing

Despite the advances in robotic 3D printing, the material option is still limited in comparison to other manufacturing methods. For some uses where high-performance materials are required with strength, durability, and heat resistance applications are not able to be used in robotic 3D printing.

Although robotic 3D printing has high precision, it does not always achieve the required surface finish for some parts. Sometimes, it is needed to apply postproduction processes, like sanding and polishing, so it becomes more expensive and slows the process.

While 3D printing is ideal for prototyping and small-scale production, it faces challenges when scaling up to mass production. The speed of printing and material limitations may not make robotic 3D printing suitable for large-volume manufacturing.

1.2 Direct Ink Writing

Direct Ink Writing (DIW) is a 3D printing technique in which a viscous ink is extruded through a nozzle to create structures layer by layer, forming a three-dimensional object. This technique has become popular in applications that require custom structures with specific mechanical and functional properties.

1.2.1 The 3D Printing Process

Firstly, the ink must be prepared so that it is formed with the right viscosity and rheology to flow under pressure and solidify after extrusion. This can include many materials, such as polymers, ceramics, or even living cells (for bioprinting).

To select the proper ink, some properties are required:

1.-It must have adjustable viscosity; it should have sufficient fluidity to flow through the nozzle but also be viscous enough to maintain the shape after the deposition of the material.

2.-The rheology must be controlled. DIW ink must exhibit a shear-thinning behaviour because it facilitates extrusion and ensures structural stability. This means that the more it is moving or forcing, the more fluid it becomes

3.-Curing properties need to be proved; depending on the material, the ink can solidify through cooling, drying, chemical reactions, or UV radiation.

Next, the ink is placed in a cylinder and is carried through a nozzle through pneumatic, mechanic or piezoelectric pressure. The key is to control the pressure and the extrusion speed to get an accurate deposition.

The DIW process is about using an ink whose flow is controlled by an external pressure that applies the force, allowing it to be extruded and then solidified to maintain the desired shape.

After, for the deposition layer by layer, the nozzle follows a line determined by a CAD archive and it deposits the ink in the predefined patterns. The ink maintains its form because of its rheological behaviour.

Finally, depending on the selected material, some additional processes like curating, drying, or sintering can be necessary. The part also had to pass through a thermic treatment if the material selected is ceramics or metals to eliminate the agglutinant and densify the structure.

Device No.3. 3D Printing process by DIW. (Fig. 6).

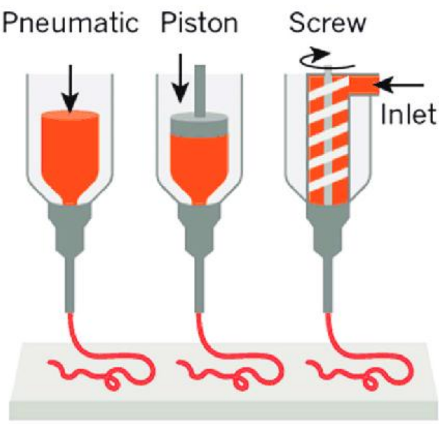


Fig. 1.6. DIW Printing Method

(Ink-Based 3D Printing Method, n.d.)

1.2.2 Applications for Direct Ink Writing

1. Energy and electrochemical storage: 3D printing in storage devices like batteries has benefited from DIW. This technique makes possible manufacturing electrodes with optimized architectures that maximize mass loading and improve the ionic and electronic transfer efficiency. Furthermore, it allows the use of functional materials with uniform distribution, leading to higher energy density and improving cyclic efficiency.
2. Biomedicine and artificial tissues: DIW is used to print scaffolds for biomedical engineering, biosensors, and customized medical devices. The ability to print porous structures with precise geometry allows the manufacture of implants that imitate the mechanical and biological properties of the natural tissue, facilitating cellular regeneration.
3. Ceramics and refractory materials: Printing ceramics by DIW has opened new opportunities in manufacturing for aerospace and electronics industry, and high-temperature applications. This has created the possibility of making three-dimensional customised structures with advanced ceramics, resulting in better mechanical resistance and improved thermal conductivity in specific products.
4. Flexible electronics devices: The possibility of printing circuits and components on flexible substrates has increased the development of portable electronic devices. DIW allows driver ink deposition on unconventional surfaces, making it easier to integrate sensors and other electronic components in clothes and IoT (Internet of Things) devices.

1.2.3 Advantages and Limitations of DIW

The principal advantage covers the flexibility in material selection, so it is possible to use a wide range of inks including polymers, metals, ceramics, and biomaterials. There are more advanced features like customized structures with complex geometries and adjustable properties depending on the desired application. It also has lower costs compared to other additive technologies. DIW requires less expensive infrastructure and generates less waste of materials.

However, DIW also faces some limitations:

Viscosity and rheological control of ink: Maintaining consistent ink properties throughout the printing process can be challenging and difficult. If the ink properties are not the required properties, the cost would maximise.

Curing time and structural stability: Depending on the material, some objects may require post-processing treatments to enhance their mechanical properties.

Resolution and printing speed: Although DIW allows for high precision, compared to other techniques like stereolithography (SLA), it can be slower.

1.2.4 Prospects of DIW

Advances in ink formulation and the integration of new printing strategies are expanding the capabilities of DIW. It is expected that in the coming years, developments will be:

1.-Smart inks with properties capable of responding to external stimuli such as temperature, pH, or electric fields.

2.-Hybrid Printing Systems combining DIW with other additive manufacturing techniques to improve material properties.

3.-Process Optimization using artificial intelligence to enhance the precision and efficiency of material deposition.

As 3D printing technology continues to evolve, it can be expected to see even more innovative transformations in how robots are designed, produced, and deployed. The integration of advanced materials, improved printing techniques, and innovative design approaches will likely lead to the development of more efficient and cost-effective robotic systems in the future.

1.3 3D Pen Printing

The 3D printing pen is a revolutionary tool that allows users to draw three-dimensional objects in the air or on flat surfaces. This portable device uses the principles of 3D printing technology to extrude plastic filament, which solidifies almost instantly, enabling the creation of designs and models. This research paper explores the components, working mechanism, advantages, and disadvantages of 3D printing pens, highlighting their increasing significance in design, prototyping, and artistic expression.

3D printing has been recognized as one of the most transformative technologies of the 21st century. Traditionally, 3D printing involves large, industrial machines capable of creating complex objects layer by layer from digital models. However, with the advent of the 3D printing pen, the technology has been condensed into a portable, user-friendly tool, giving individuals the freedom to create 3D objects without requiring a computer or large-scale printing setup.

The idea of the 3D printing pen emerged as a natural evolution of traditional 3D printing technology, driven by the desire for more accessible, user-friendly tools for both professional and personal use. Early forms of 3D printing technology, developed in the late 20th century, allowed for large-scale, industrial 3D printers that could produce complex objects, from prototypes to full-scale models. However, these printers were expensive, large, and required detailed technical knowledge to operate.

In the early 2010s, a group of innovators sought to take the concept of 3D printing and make it portable and accessible. The first commercial 3D printing pen, 3Doodler, was launched in 2013 by a group of engineers and designers. It was the first pen-like device capable of extruding melted plastic, allowing users to draw in the air and create 3D objects by freehand. This pen utilized technology similar to 3D printers, but on a much smaller scale, and was designed with simplicity in mind.

Since then, the market for 3D pens has grown, with companies expanding their offerings and introducing new features to meet the demands of artists, educators, and professionals. Today, 3D printing pens are used in the worlds of art, design, education, and prototyping.

1.3.1 Types of 3D Printing Pens

There are several types of 3D printing pens available on the market, each designed with different functionalities and features to cater to various needs. The primary types of 3D printing pens can be categorized as:

Basic 3D printing pens: These pens are simple, entry-level devices aimed at casual users, including children and hobbyists. Basic models typically offer adjustable temperature controls and a basic extruding mechanism. They are ideal for beginners who want to experiment with 3D drawing and design but do not require elevated levels of precision or advanced features.

Advanced 3D printing pens: Advanced pens offer additional features such as fine-tuned extrusion control, temperature regulation, adjustable speed, and compatibility with different filament types like ABS, PLA, and even flexible filaments. These pens are suitable for professionals and more serious hobbyists who require precision and versatility in their work.

Kids-Friendly 3D pens: These pens are designed with safety and ease of use in mind. They often feature lower operating temperatures to prevent burns and have simpler mechanisms that make them ideal for younger users.

1.3.2 Major Manufacturers of 3D Printing Pens

3Doodler: As the pioneer of 3D printing pens, 3Doodler has established itself as one of the leading manufacturers. The company offers a variety of pens for different skill levels, from beginners to professionals. The 3Doodler Create+ and 3Doodler Start are some of their most popular products. 3Doodler pens are known for their reliability, ease of use, and wide filament compatibility.

Fig. 1.7. The best seller 3Doodler pen

(3Doodler Start+ Essential 3D Pen - Impresoras3d.Com, n.d.)

MYRIWELL: Myriwell is another significant player in the 3D pen market. The Myriwell 3D Pen is one of their best-selling models, designed to be affordable and user-friendly. The brand is known for offering budget-friendly options that still provide an excellent quality user experience, making it popular among beginners and schools.

Fig. 1.8. Myriwell RP-300B

(Myriwell® 3d Pen and 3d Printer Designer/Manufacture – Myriwell3dpen, n.d.)

Scribbler: Scribbler offers a range of 3D pens that target both novices and experienced creators. Known for their ergonomic design and ease of use, Scribbler pens like the Scribbler V3 offer adjustable speed and temperature settings, making them suitable for more intricate and controlled designs.

Fig. 1.9. Scribbler V3

(Scribbler 3D Pen V3 New Awesome Design Model Printing 3D Pen for Doodling Drawing 3D Pen Tool with L: Amazon.In, n.d.)

XYZPrinting: Known for its 3D printers, XYZPrinting also manufactures 3D pens such as the da Vinci 3D Pen. These pens are designed for versatility, with some models supporting a variety of filament types, including ABS, PLA, and TPE. XYZPrinting pens are often marketed as an affordable option with excellent quality.

Fig. 1.10. The da Vinci 3D Pen

(XYZprinting Da Vinci 3D Pen, n.d.)

Lix: Lix produces one of the slimmest 3D pens on the market, known for its sleek, pen-like design. The Lix Pen is favoured by users looking for a more compact and lightweight pen, providing high precision for delicate work.

Fig. 1.11. Lix pen

(Lix Pen – LixV3GlobalStore, n.d.)

1.3.3 How a 3D Printing Pen Works

The 3D printing pen operates on the same principles as a 3D printer, using extrusion technology to deposit material in a controlled manner.

The pen uses thermoplastic filaments, commonly PLA or ABS, which are inserted into the pen through a loading mechanism. These filaments come in diverse colours and are the building blocks for creating three-dimensional structures.

After, a heating element melts the filament inside the pen. Once melted, the plastic is pushed out of the pen's nozzle in a steady stream. The user controls the extrusion rate through buttons on the pen, allowing for precise application.

When the melted filament leaves the nozzle, it begins to cool and solidify almost instantly, allowing the user to shape it into three-dimensional objects. The ability to control the speed of extrusion and the temperature is essential for achieving smooth and consistent lines.

Unlike traditional 3D printers, a 3D printing pen does not require a print bed. The user can draw directly in the air, creating free-standing structures. It also works on flat surfaces, allowing for more controlled and detailed designs. Nevertheless, the precision acquired with a 3D pen is smaller than one´s with a 3D printer.

1.3.4 Parts and Components of a 3D Printing Pen

A 3D printing pen consists of several key components, each playing a vital role in its functionality.

Nozzle: The nozzle is the part of the pen through which the melted plastic filament is extruded. It typically features a fine opening that controls the diameter of the extruded plastic. Some pens come with interchangeable nozzles to allow for various levels of precision.

Heater: Located inside the pen, the heating element is responsible for melting the plastic filament. It heats the filament to a temperature where it transitions from a solid to a liquid state, making it ready for extrusion.

Drive mechanism: This component controls the movement of the filament into the heating element. It is typically powered by a motor that pushes the filament through the pen's internal tube toward the nozzle.

Cooling system: The cooling system is responsible for rapidly solidifying the melted filament after it has been extruded. This is crucial for maintaining the structural integrity of the design and ensuring the plastic cools before it deforms.

Temperature control system: Many 3D pens come with adjustable temperature settings, which control the heating element's temperature. This is essential because different filaments, such as PLA or ABS, require different temperatures to melt and extrude correctly.

User interface (buttons): The buttons on the pen allow the user to control the extrusion speed, temperature, and occasionally, the direction of the nozzle. Some advanced models even feature a display screen that shows settings and adjustments.

Fig. 1.12. Components in a 3D pen

(Lápiz 3D: Las Mejores Opciones Disponibles En El Mercado Actual - 3Dnatives, n.d.)

This process can be comparable with a hot silicone pistol, where the fond material solidifies when it gets colder, allowing the build of stable structures. But drawing in 3D requires coordination and practice. It is recommendable to start with simple designs and, when the skill is acquired, it is time to try more difficult parts. For beginners, it is useful to try bidimensional templates about which is possible to draw and then assemble 3D structures.

1.3.5 Advantages of 3D Printing Pens

1.-Creativity and artistic expression:

The ability to unleash creativity is one of the best advantages. Artists, designers, and hobbyists can use them to bring their ideas to life by making drawings in three dimensions. This is particularly beneficial for creating sculptures, models, and intricate designs that would be difficult with traditional methods.

2.-Accessibility and ease of use:

Unlike traditional 3D printers, which require a computer and a person who knows how CAD software is used, 3D pens are easy to use, making them accessible to children and adults. The pen allows us to create spontaneous creations, without needing specialized knowledge in CAD software, so everyone can utilize it.

3.-Affordable prototyping:

For engineers and designers, 3D printing pens offer a cheap way to create prototypes. They can quickly sketch ideas or test designs more practically. This process can complement traditional prototyping, offering a low-cost and quicker alternative for conceptual testing.

4.-Portability:

Another advantage of a 3D printing pen is its portability. It allows users to take it anywhere. Unlike a 3D printer, a 3D pen can be carried around easily, the only thing that could be needed is a plug.

5.-Skill development:

3D pens are a good educational tool. They help students understand basic principles of engineering, design, and 3D printing technology. By using a 3D pen, students can improve their spatial thinking and motor skills.

1.3.6 Disadvantages of 3D Printing Pens

Limited precision: While 3D printing pens allow for creative freedom, their precision is not on par with that of professional 3D printers. The handheld nature of the device makes it difficult to achieve delicate details, especially in more complex designs.

Material limitations: The types of materials compatible with 3D pens are limited, primarily to thermoplastics like PLA and ABS. Some pens can accommodate flexible filaments, but the variety of materials is much more constrained compared to 3D printers.

No support structures: Unlike 3D printers that can generate support structures for intricate designs, 3D pens rely on the user's skill to manage the construction of more complex objects. Without a support system, it can be challenging to create certain designs without them collapsing.

Difficulty in control: 3D pens can be messy to use, especially for beginners. The melted plastic can spill out or smear, making it harder to achieve clean, professional results. Additionally, it requires precise control from the user to prevent mistakes.

Limited build volume: 3D pens are designed for smaller-scale creations. For larger projects, the user may need to spend a significant amount of time building up layers or work within the constraints of the pen’s size limitations.

The 3D printing pen is a great tool that makes 3D printing more available to normal users. Even though it is not very precise and does not work with as many materials as a real 3D printer, it has many good points. It is creative, cheaper, and easy to carry around. As the technology gets better, these pens might improve a lot and solve some of the current problems. People use them for art, learning, or simple designs, and they are becoming useful for both beginners and professionals.

2 OVERVIEW OF SPECIFIC NODES

2.1 Structure and Internal Functioning of the 3D Pen.

A 3D pen looks like a normal pen but has a heating system and works with plastic filament. When the filament gets hot, it becomes soft, and the pen lets you draw shapes in the air or on a surface. The plastic gets hard after a few seconds, so you can continue building little by little.

The 3D printing pen that is going to be used in this project is the RP500A (Fig. 13), which is a 3D printing pen that is easy to use and light.

Fig. 2.1. Selected pen.

(Wholesale Jer RP500A-Best Cheap 3d Printing Pen for Beginner, Jer RP500A-Best Cheap 3d Printing Pen for Beginner Suppliers, Manufacturers - Jer, n.d.)

It works with a power adapter, a power bank, or a USB port, no need to connect AC/DC adapter (Fig. 14). The three lights on the top are the indicators of the speed, which can be adjusted to low, medium and fast speed. At the bottom is the power indicator.

Fig. 2.2. Power and filament insertion of the 3D pen

(Wholesale Jer RP500A-Best Cheap 3d Printing Pen for Beginner, Jer RP500A-Best Cheap 3d Printing Pen for Beginner Suppliers, Manufacturers - Jer, n.d.)

Moreover, the lowest button switches between ABS/PLA temperature, red for ABS, green for PLA. There is a motor driven rollers for pushing filament (Fig. 15), so that the heated filament is extruded by the nozzle. It quickly starts solidifying. This 3D pen is a simple tool for drawing and creating with filament, and it can be used in school, at home, or for small projects.

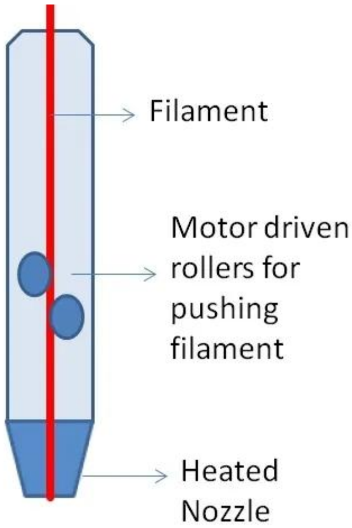


Fig. 2.3. Inside a 3D pen

(3D Pens: Everything You Need to Know, n.d.)

2.1.1 Materials

This kind of pen usually uses PLA, ABS or UV resin, but the specific pen is going to be used only allows PLA or ABS. This pen uses a 1.75 mm filament, but PLA is easier and safer; moreover, it is biodegradable, and it has a better smell. Also, PLA needs less heat to be used. As it seems in Fig. the filament is going to be used is PLA because it has better characteristics.

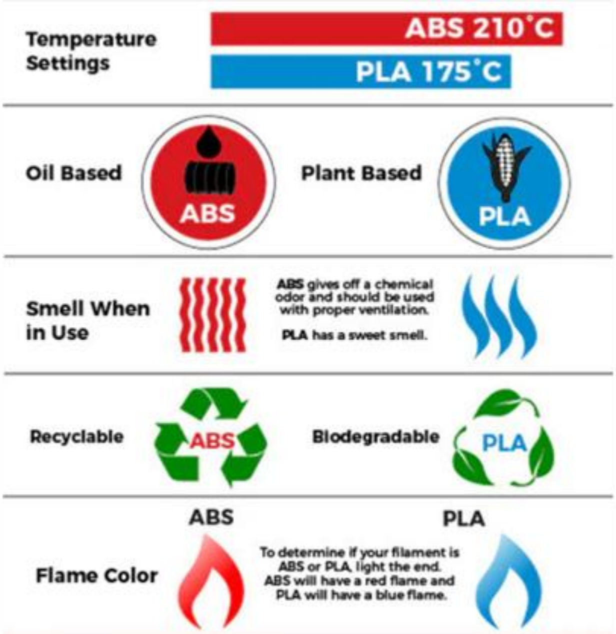


Fig. 2.4. Characteristics of ABS vs PLA

(ABS vs. PLA Filament for a 3D Printing Pen - MYNT3D, n.d.)

2.1.2 Features

Some pens have buttons to control the plastic, while others require you to press. There are models with different nozzles and screens to see the temperature, and some can work with USB or batteries. This one needs to stay connected while you use it.

2.1.3 Instructions and components

Inside the pen box there are some instructions of what the correct manner of use of this 3D pen step by step is, to not getting confused.

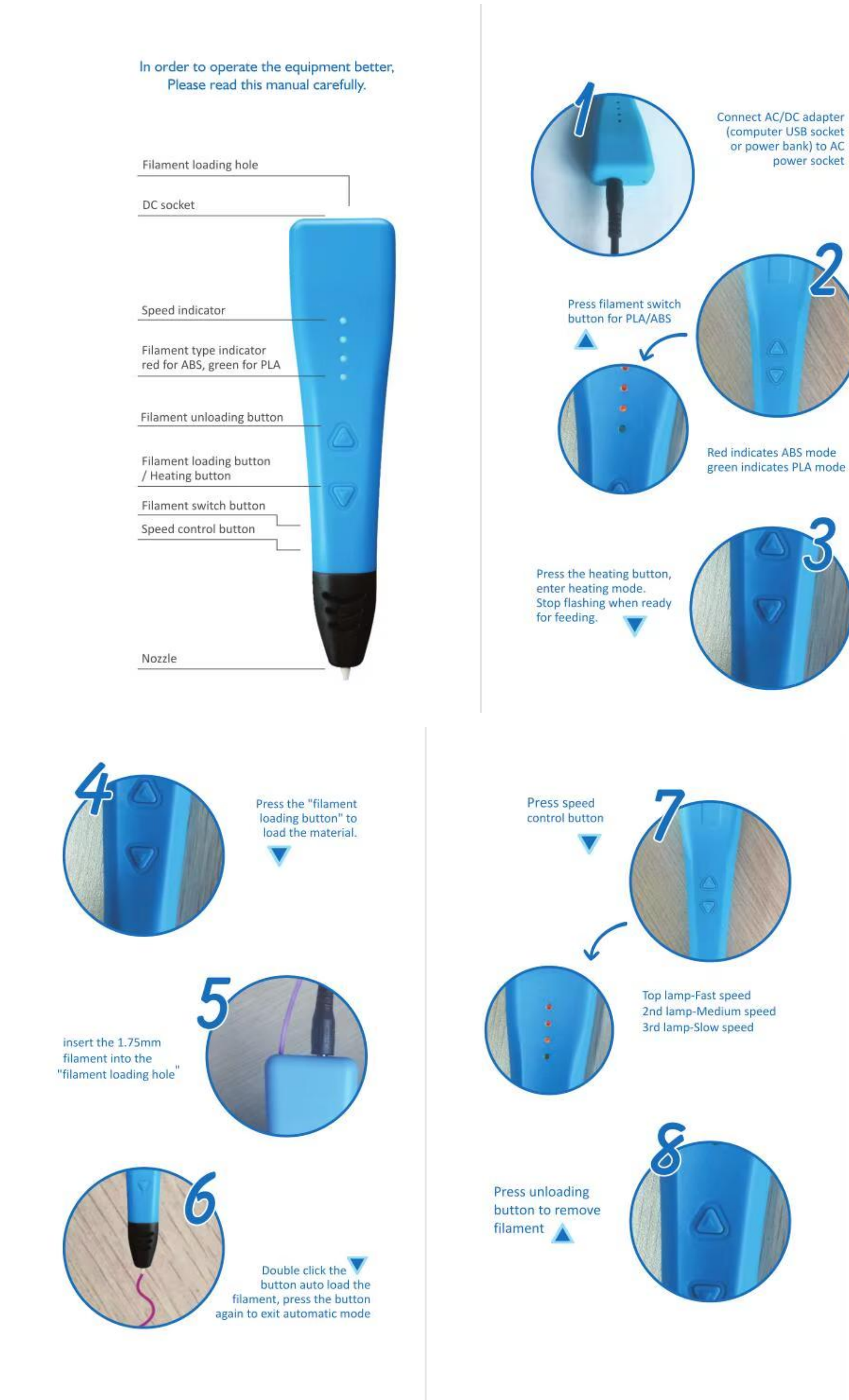


Fig. 2.5. 3D pen instructions

(Bolígrafo 3D RP500A Para Niños, Pluma de Impresión 3D de Alta Temperatura, Bolígrafo de Dibujo 3d, Filamento Pla 1,75 - AliExpress 44, n.d.)

3 CALCULATION OF PROJECT

For this project involving a 3D pen with controlled movement and extrusion, calculations are important for achieving the desired precision. These calculations depend on the accuracy of the pen and the capacity of positioning of the robotic arm. Moreover, other devices like servomotor must also be compatible with the requirements of the pen. Understanding these parameters through calculation allows for a more predictable and precise output from your 3D printing process.

3.1 Specifications and accuracy

The RP500A 3D pen has a precision of around 0.7 mm. It is good for making simple shapes and creative figures, but not for very small or detailed things. This is because the nozzle is 0.7 mm, so it cannot draw thinner lines.

The pen is attached to the Motoman HC10DPT robotic arm. This robot has particularly good precision in movement, with repeatability of ±0.05 mm. That means the robot can move to the same point many times with an error of 0.05mm, almost none. Thanks to this, the robot helps to make the drawing more stable and cleaner. It does not move or shake like a hand, so the pen makes better lines. Even if the pen is not for detailed work, the robot makes the result more controlled than humans.

The temperature can be adjusted between 190 and 230 degrees Celsius, depending on the type of filament. There are three different speed levels to control how fast the filament comes out.

The pen is small and light, with a size of 150 mm × 21 mm × 36 mm and a weight of only 50 grams and the Motoman HC10DPT is allowed to manage about 10 kg above, so the weight would not be a problem. Using both together is an innovative idea to create simple 3D models with better quality. It is useful for making prototypes or artistic work.

Table 3.1. 3D pen specifications

(Wholesale Jer RP500A-Best Cheap 3d Printing Pen for Beginner, Jer RP500A-Best Cheap 3d Printing Pen for Beginner Suppliers, Manufacturers - Jer, n.d.)

Parameter	**Specification**
Product Name	RP500A 3D printing pen
Power supplier	AC/DC adapter, power bank or computer USB output
Nozzle diameter	0,7mm
Printing material	1,75mm ABS/PLA Filament
Temperature	190-230ºC
Speed adjusts	3 speed level
Pen size	150*21*36mm
Net weight	50g
Warranty	One year warranty
Certification	FCC, ROHS, CE
Package content	3D pen, AC/DC adapter, USB cable, user manual, 3 color filament

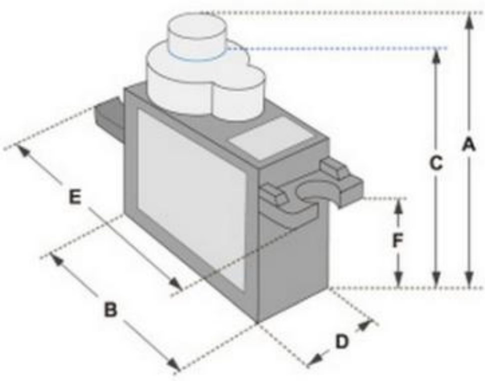
3.2 Servo motor

To allow the pen to extrude when commanded by the robotic arm, a servo motor will be installed. This motor will be programmed in Arduino to activate or deactivate according to the signal received from the arm. The servomotor chosen is Servomotor SG90.

Fig. 3.1. Servomotor SG90

(Servomotor SG90 RC 9g - UNIT Electronics Arduino Micro Servo, n.d.)

The servo motor will first be connected to the ESP32 using power, signal, and ground wires. Once the servo receives power, it will be positioned on the pen's switch, so it can press the buttons to make the pen extrude or not. This action will be controlled through ESP32 code that makes the servo rotate to press both buttons.



Dimensions & Specifications
A (mm) : 32
B (mm) : 23
C (mm) : 28.5
D (mm) : 12
E (mm) : 32
F (mm) : 19.5
Speed (sec) : 0.1
Torque (kg-cm) : 2.5
Weight (g) : 14.7
Voltage : 4.8 - 6

Fig. 3.2. Specifications of the servomotor

(Servomotor SG90 RC 9g - UNIT Electronics Arduino Micro Servo, n.d.)

3.2.1 Calculation on servo

Torque of the servomotor:

$$\tau = \frac{2{,}5\mathrm{N}}{\mathrm{cm}} \cdot \frac{\frac{9{,}8N}{kg}}{\frac{100m}{cm}} = 0{,}245\mathrm{N/m} \tag{3.1}$$

Radius of the arm selected (from centre to end): r=15mm

Force (F) = Torque (τ) / Radius (r):

$$\mathrm{F} = \frac{0{,}245N/m}{\frac{15mm}{1000m/mm}} = 16.33N \tag{3.2}$$

The servomotor will be able to press the button of the 3D pen, knowing that normal buttons are significantly lower than the force that the servo could make.

3.3 Small Slot Sensor

The slot sensor connects to the ESP32 with three wires (like the servo): power, signal, and ground. The sensor is situated where the plastic string goes. Its job is to see if the string is there, or if it is over. When the string is going through the sensor, it sends one signal to the ESP32. If the string runs out, it sends a different signal.

Fig. 3.3. Slot Sensor SK-206NA-W

(Interruptor Óptico Sensor Fotoeléctrico Micro En Forma De F Sensores De Ranura De Fotomicro De Horquilla Óptica - Buy Micro Photoelectric Sensor Opticle Fork Photomicro Slot Sensors Optical Switch Sensor Product on Alibaba.Com, n.d.)

Table 3.2. Specifications Slot sensor

(Interruptor Óptico Sensor Fotoeléctrico Micro En Forma De F Sensores De Ranura De Fotomicro De Horquilla Óptica - Buy Micro Photoelectric Sensor Opticle Fork Photomicro Slot Sensors Optical Switch Sensor Product on Alibaba.Com, n.d.)

Model		SK-206NA-W	
Working principle	Photoelectric sensor	**Switching frequency**	6.06kHz
Housing style	Shape K	**Repeat accuracy**	<0.03mm
Optical working principle	Through-beam	**Hysteresis**	<0.2mm
Light Source	InfraredLED, 940nm	**Operating Voltage**	5~24V DC
Slot Width	5.0mm	**Power Consumition**	<=16mA
Salot depth	5.8mm	**Connection Method**	2m/4-core cable
Detecting object	1.2x1.8mm	**Dimensions**	24.0x14.0x6,5mm
Indicator light	Red LED	**Material**	ABS
Response time	0.33ms	**Weight**	0.023kg

3.4 Static study

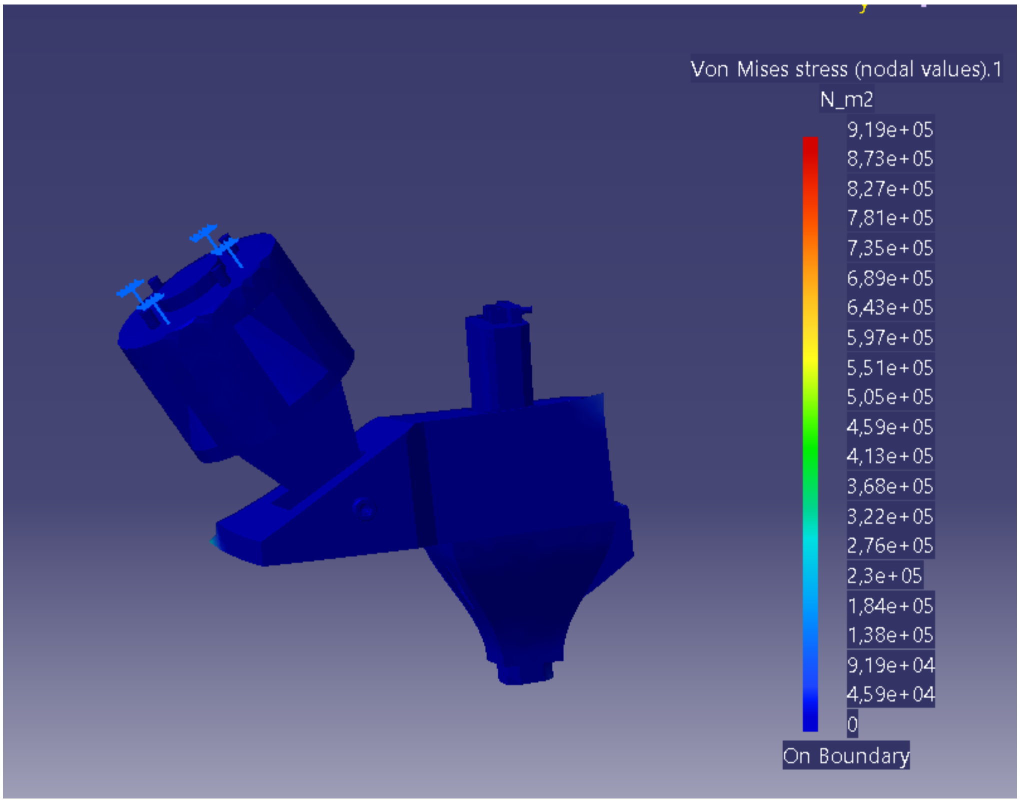


Fig. 3.4. Static study from Catia v5

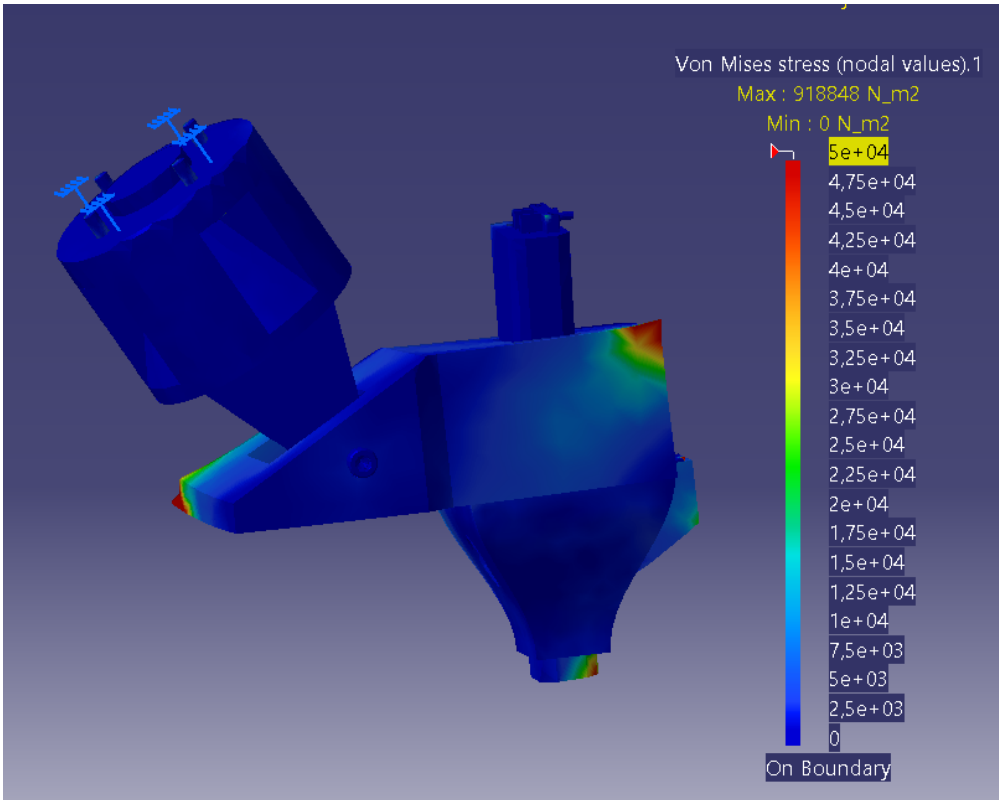


Fig. 3.5. Static study 2 from Catia v5

The first picture shows the finite element analysis (FEA), the selected criteria is Vom Mises. It is an analysis that checks if the parts would resist forces without breaking.

The colour distribution represents the magnitude of the stress in some zones of the parts. Blue zones are for low efforts and red zones for higher ones, according to the image, the highest stress is almost 1MPa, it is marked in red, it is barely visible, but it is in the surface where the servomotor and the lower part are in contact. But the stress is low compared to the limit of the PLA that goes from 45 MPa to 70 MPa, so the part will not break for sure.

In the second image the scale of VM stress is lower but it is easier to analyse where zones are more delicate than others besides all of them endure without any problem the stress. The zones that are in red are the boundaries as it is normal in several parts because the forces usually accumulate in corners and edges.

In the static study the forces that are considered is the weight from all the parts and the servomotor, the sensor and the pen. There are also some forces on the top of the pen to take into account the filament and the weight of the connection of the pen.

3.5 Translational displacement

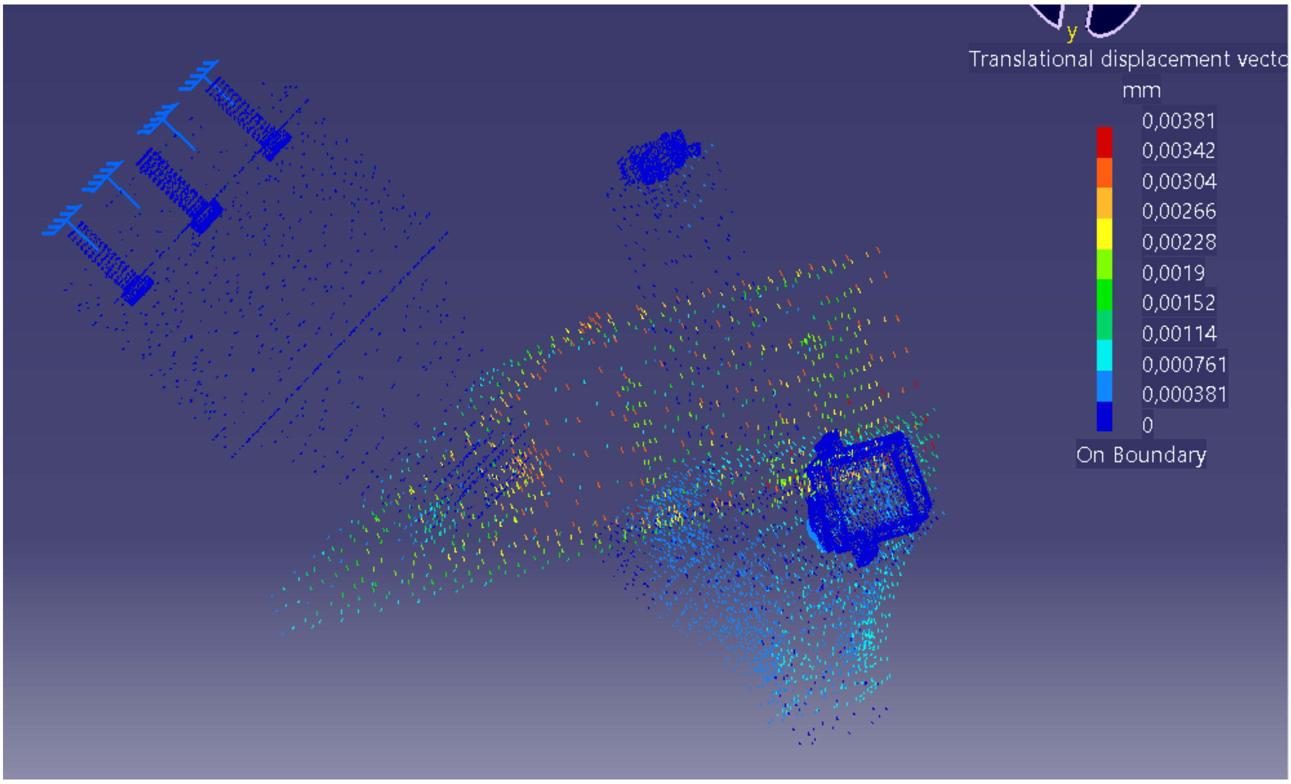


Fig. 3.6. Displacement of the device from Catia v5

There is a minimum translational displacement, the zone that haves most movement is the medium part of the attachment, and the maximum displacement is 0,00381 mm and in the bottom part is about 0,00051mm. This does not generate any problem because the movement is practically depreciable, it is low, and it does not nearly affect accuracy.

3.6 Estimated error

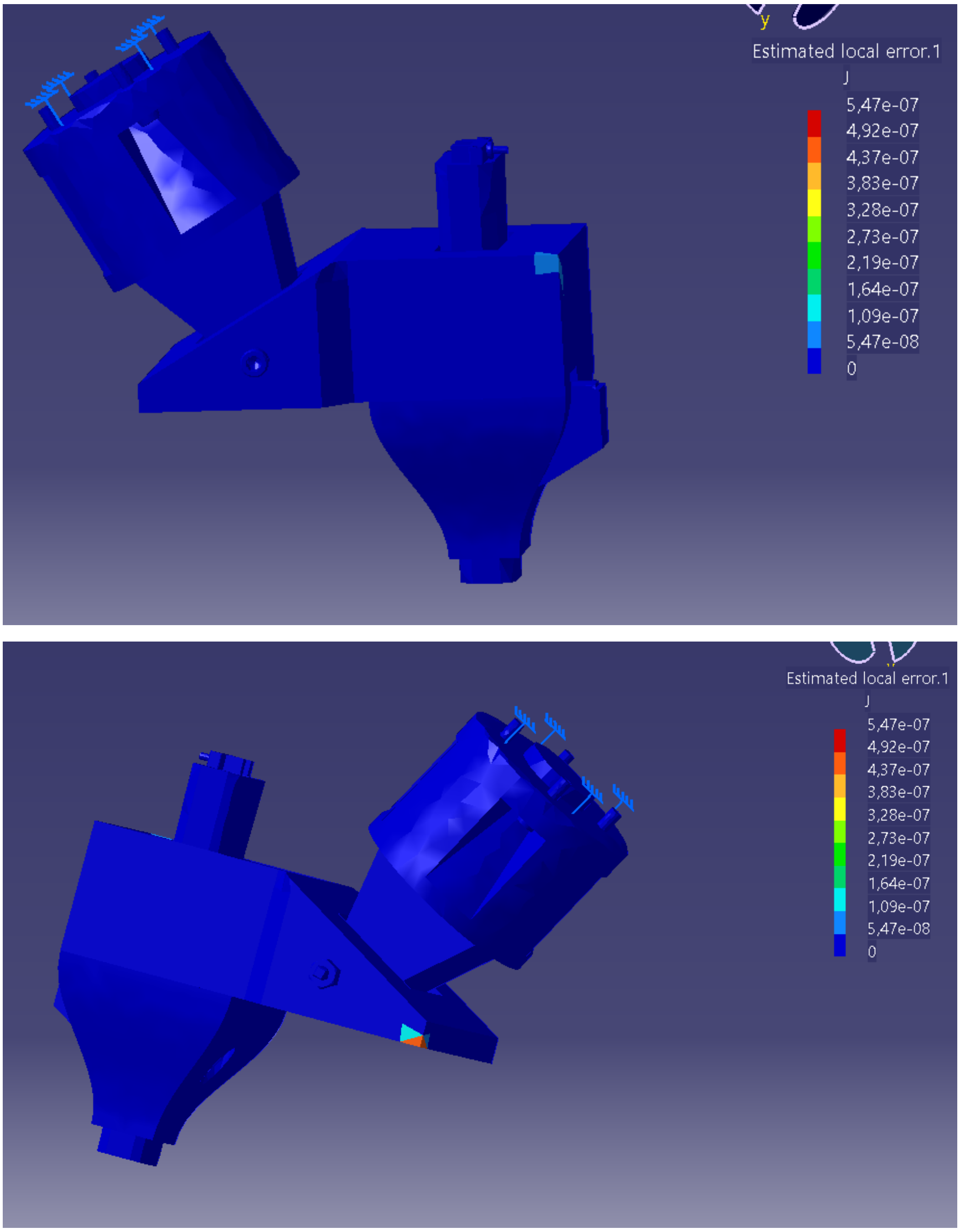


Fig. 3.7. Estimated error

This image shows the estimated local error, the colour areas show how the calculation turns aside in various places of the device. Red areas are the ones with the highest error (4,47e-07), that are in the left corner of the middle part, and blue ones have almost no errors. In this case the error is minimum, even the biggest one.

4 DESCRIPTION OF THE CONSTRUCTION AND OPERATIONAL PRINCIPLE

A 3D printing pen works because the parts inside do things together to push out the filament out. First, you put the filament in its hole. Then, a small motor uses it to push it to a hot place inside the pen. There, the plastic gets melted. After it melts, the plastic comes out through a nozzle. This hole is about 0.7 millimetres. The robot moves the pen on something flat or even in the air. There is also a possibility of changing how fast the plastic comes out by using different speeds.

The project integrates a 3D printing pen with a controlled motion system. The core components include a 3D pen (RP500A), a servomotor (SG90), slot sensor, and an ESP32 microcontroller acting as the central control unit. The filament and the interior of the pen are also elements to consider in the kinematics scheme.

4.1 Kinematics scheme

This diagram shows a simplified view of the mechanical parts working together in the 3D printing system. The servomotor (labelled 1) is connected to a mechanism associated with the 3D pen itself (right part). The servomotor's rotational movement controls the extrusion of filament from the pen via a button, and there is also a linear movement involved, for positioning the filament through the nozzle.

The main objective of the servomotor is to press the button. This button makes the mechanism work, so the filament starts to go inside the pen to melt for later extrude. This mechanism has two rollers that force the filament to go into the pen. When the filament is melted, it will pass throw the nozzle.

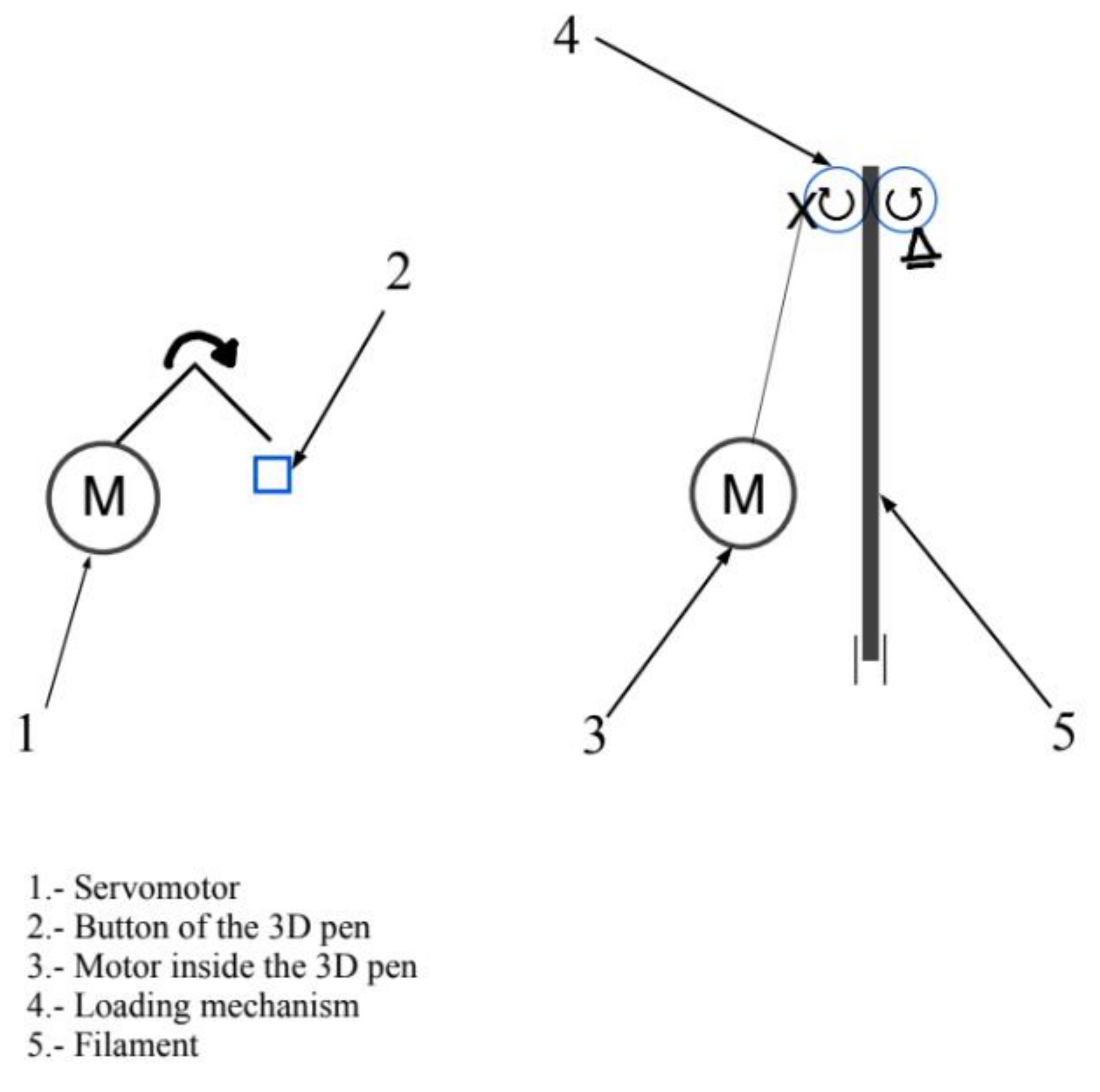


Fig. 4.1. Kinematic scheme

The servomotor (number 1) is the part that makes things move here. The 'M' inside the circle refers to the motor. The line going from it to that little curved arrow shows how it turns. So, the servo gives us a turning motion.

This turning from the servomotor then goes to the 3D pen mechanism (the right scheme). It connects to that blue round thing (labelled 2), which is a button from the 3D pen. This button makes another motor to start (labelled 3) turning the next component of the pen, this turning comes straight because of the button is pressed by the servo. This motor inside the pen makes the rollers (number 4) spin for the pen to work, like pushing out the plastic.

The interesting part of the scheme is how this turning motion from the servo (via the blue button) is linked to the filament bar going down. This shows that the turning movement of the servo gets changed into a straight down movement of the filament inside the pen. An important element inside the 3D pen mechanism is the blue component, which is the button responsible for initiating filament extrusion. The mechanical connection between the servomotor's rotational output and this button indicates that the servomotor directly controls the activation of filament flow. As the servomotor rotates, it engages with this button, the extrusion process starts.

The vertical black bar, representing the filament, is strategically positioned within the diagram to show its path during extrusion. When the button, controlled by the servomotor, is activated, the filament is advanced through the pen.

Within the 3D pen assembly itself, the motor marked with an 'M’ plays a crucial role in the filament feeding process. The 'X' signifies the entry point into this motor. This internal motor is responsible for the continuous, metered feeding of the filament towards the heating element of the pen, where it is melted and extruded. Activating the servo motor, signals the internal feeding motor to advance the filament.

Therefore, the servomotor (1) acts as the controller for the on/off or start/stop of the filament extrusion by manipulating a button on the 3D pen (2). Simultaneously, the internal motor within the 3D pen manages the ongoing feeding of the filament. This coordinated action allows for controlled deposition of material during the 3D drawing process.

4.2 Electric-block scheme

The provided image is an electric diagram illustrating the electrical connections and signal flow within a system that includes a 3D printing pen, a servomotor, a sensor, and an ESP32 microcontroller because it is the central control unit. It depicts how power is distributed to various components and how signals are exchanged between them to facilitate the operation of the system. The diagram uses different coloured arrows to distinguish between high-voltage AC power, low-voltage DC power, and control/feedback signals. Each labelled box represents a specific electronic component or module within the system.

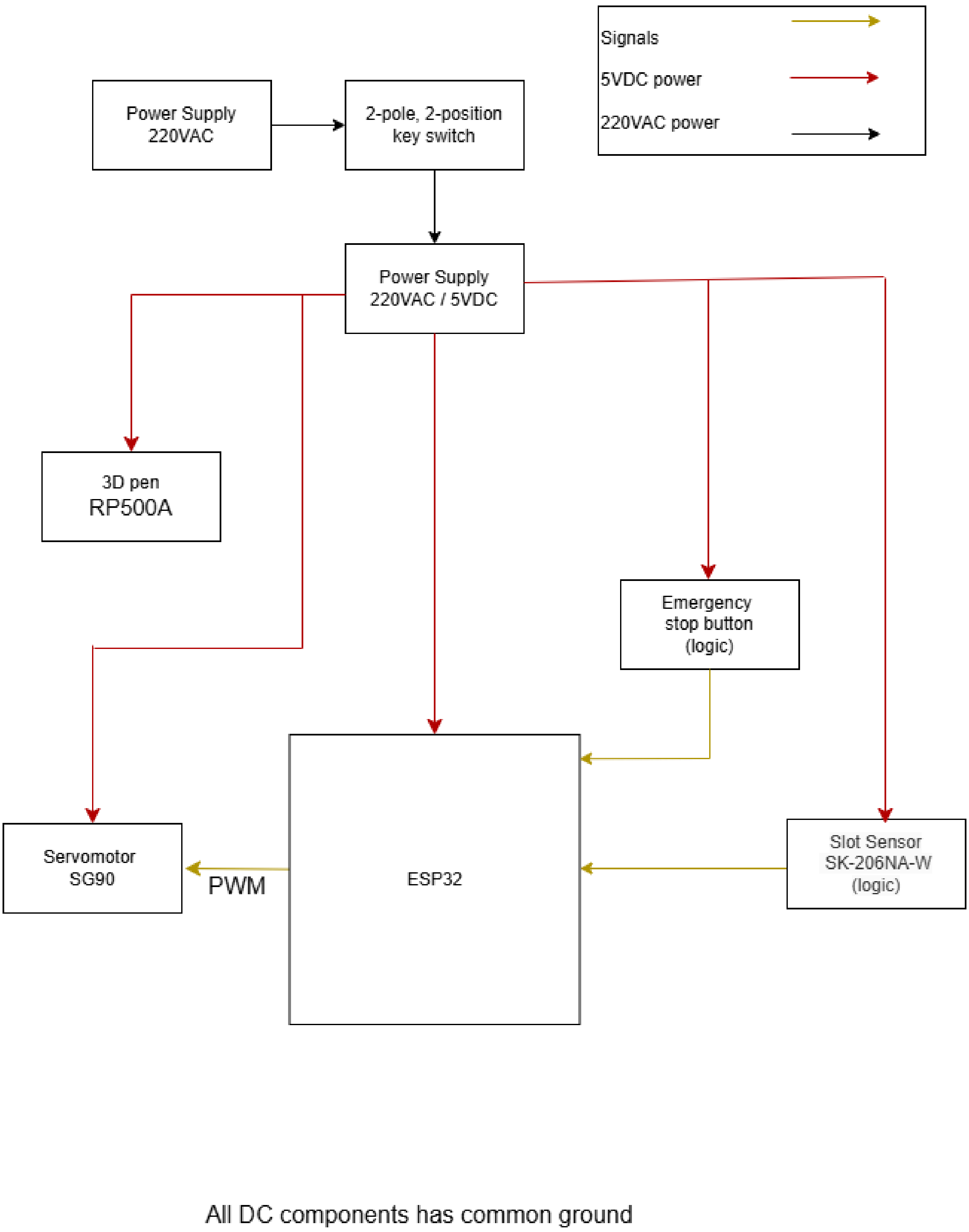


Fig. 4.2. Electric-block scheme

Each block represents a different device in the scheme:

Power Supply (230VAC): This block represents the primary AC power source, operating at 230 Volts Alternating Current (VAC). This is the initial power input for the system.

2-pole, 2-position key switch: This is a manual switch with two poles (independent circuits it can control) and two positions (ON and OFF). It serves as a main power switch for the entire or parts of the system, allowing the user to disconnect the power.

Power Supply (220VAC / 5VDC): This is a power conversion unit. It takes the 230VAC input from the mains (and steps it down and rectifies it to provide a 5 Volts Direct Current (VDC) output. This 5VDC is a common voltage for powering microcontrollers and low-power electronic components like the ones which are used for this project.

3D pen RP500A: This is the 3D printing pen itself. It receives 230VAC power, likely to heat up its extrusion mechanism to melt the filament.

Servomotor SG90: This is a small rotary actuator that can move to specific angular positions. It operates on a lower DC voltage (5VDC provided by the second power supply) and is controlled by pulse-width modulation (PWM) signals, usually generated by a microcontroller like the ESP32.

ESP32: This is the central microcontroller unit. It is a system-on-a-chip that integrates processor, memory, and Wi-Fi/Bluetooth capabilities. It can receive inputs from sensors and other components like the emergency stop button, process that information, and send out signals to control other devices like the servomotor. It is powered by 5VDC supply.

Emergency stop button (logic): This is a safety mechanism. When activated, it sends a digital signal (a logic level) to the ESP32. The ESP32 would then be programmed to react to this signal, by halting the operation of the motors and potentially the 3D pen for safety.

Slot Sensor SK-206NA-W (logic): This is a sensor designed to detect the presence or absence of an object in a slot; in this case it detects the filament of the pen. It outputs a digital signal (a logic level) to the ESP32, indicating the sensor's state. This could be used for detecting the position of a component.

4.3 Algorithm of management of device or node

This diagram illustrates the step-by-step process that the 3D pen system follows to initialize, heat up, and begin extruding filament. It outlines the checks and actions performed by the system, including errors overseeing for connection issues and monitoring for filament presence.

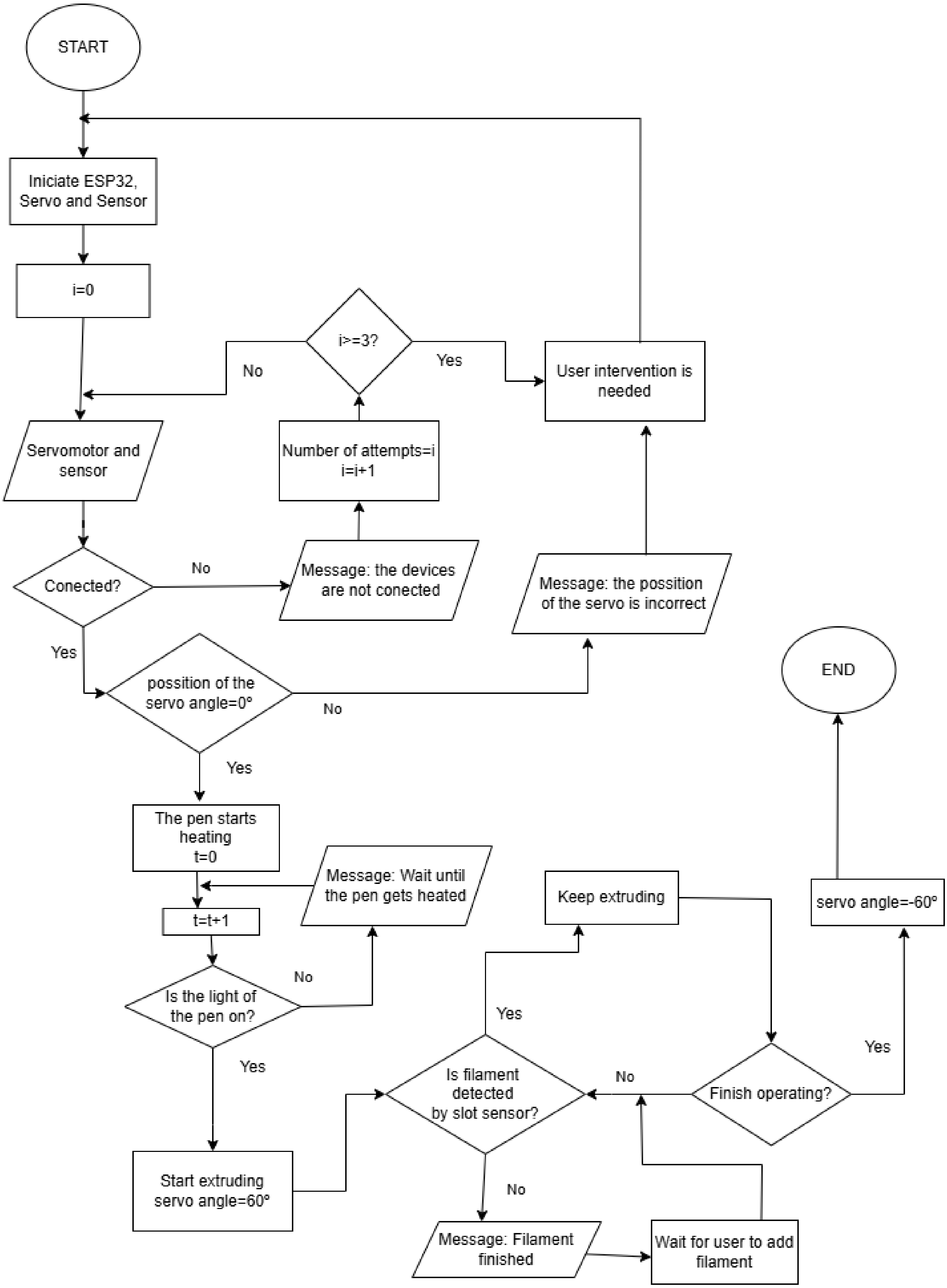


Fig. 4.3. Algorithm of management of mechatronic system

The process begins with the initialization of the core components: the ESP32 microcontroller, the servomotor, and the slot sensor. Following initialization, the system performs a diagnostic routine to verify the communication integrity between these elements. If connectivity issues are detected over a series of attempts, the process asks for the need for user intervention.

Upon successful connection, the system verifies the initial angular position of the servomotor (0º). An incorrect starting position triggers the termination of the process because the parts would not be properly assembled. If the servo is correctly positioned, the 3D pen's heating cycle begins, with the system monitoring if the pen is ready by checking its indicator light.

Once the pen reaches the operational temperature, the system commands the servomotor to a specific angle (Start extruding servo angle = 60) to initiate filament extrusion.

Later, a sensor monitors the presence of the extruded filament. If filament is detected, the extrusion process continues. Otherwise, if the filament is not detected, the system enters a state of “Keep extruding” and checks if the operation is intended to finish. If not, it prompts user intervention, indicating a lack of filament.

The diagram shows a path from "Keep extruding" directly to "servo angle =-60º" and then to "END". This indicates that once the system begins extruding, it continues to hold the servo at that angle for the duration of the extrusion process, and then when it is over it turns to “servo angle =-60º" and the operation concludes.

The other branches leading to "END" are triggered by connection issues, incorrect initial servo position, or a user-indicated finish after filament detection failure.

5 WORK SAFETY

5.1 General provisions and requirements for safe working and environmental protection

5.1.1 Installation

The pen must be fixed strongly to the robotic arm, so it does not move or fall while working. To do this, it should be attached using safe materials and parts. In this case, we use four screws and a top part that connects with a bottom part to keep the pen in place.

Before starting the work, it is important to evaluate the fixation with all the movements of the robotic arm. The pen must not hit anything around. If there is any collision, the system has a kind of joint (like a patella) that helps protect the pen and the holder. This part allows the pen to rotate a little and absorb the impact.

Only turn on the machine when everything is correctly installed and safe to use.

5.1.2 While the robot is working

Keep your hands and face away from the robotic arm when it is moving.

Never touch the hot tip of the pen while it is working.

Be sure you can stop the robot fast if something goes wrong. There is an emergency stop button, or you can disconnect the power.

5.1.3 Electrical safety for this system

Always check the cables before starting. Make sure they are not losing or in the way of any moving parts.

Do not put wires near the hot areas of the pen.

When you want to do maintenance, first turn off and unplug both the robot and the pen.

5.1.4 Supervision during use

Never leave the robotic arm working without someone watching it.

If it is not possible to stay close, use a camera or sensors to control it safely.

It is also better to work with a protective area or cover around the robot to avoid accidents.

5.2 General safety and environmental rules for any device

This part explains basic safety and environmental measures for devices in general, not just for the robotic arm. These rules help to avoid accidents and protect the workspace.

5.2.1 Basic alerts

Always check that the device is ready before using it.

Make sure nothing is broken, missing, or losing.

If something looks wrong, stop and fix the problem before continuing.

Wear gloves, glasses, or other protection if necessary.

5.2.2 Emergency stop system.

All machines should have an emergency stop button that is easy to reach. This button is used to stop the machine quickly if something dangerous happens. Every person using the machine must know where this button is and how to use it.

5.2.3 Before turning on the power

Make sure all parts are in place and the cables are connected properly.

Keep flammable objects and body parts away from the machine before switching it on.

5.2.4 After finishing the work

When the work is done, turn off the power and unplug the machine.

Wait for hot parts to cool down before touching them.

Then clean the work area and check that everything is safe.

Store the device correctly if it is not going to be used again soon.

5.2.5 Fire safety

Keep flammable materials away from the machine, especially if it produces heat. There is always a fire extinguisher nearby.

If you see smoke or smell something strange, turn off and unplug the device immediately.

6 ECONOMIC CALCULATION

The economic cost and profitability of the system for a 3D pen developed in this thesis. For this reason, a table has been made with the total elements that are needed to construct the device. It shows the identification of the elements together with the quantity necessary to produce one unit and the price of the element. All the prices include VAT invoice. The following is a table of the cost per unit produced in material costs.

Table 6.1. Material costs

Number	Item	Quantity	Price per unit	Sum
1	Servomotor GS90	1	3,90 €	3,90 €
2	Slot sensor sk206	1	4,72 €	4,72 €
3	ISO 1207 SCREW M5x20	4	0,10 €	0,40 €
4	ISO 1207 SCREW M5x45	2	0,24 €	0,48 €
5	ISO 1207 SCREW M6x100	1	0,30 €	0,30 €
6	ISO 4034 NUT M6	1	0,09 €	0,09 €
			Total	**9,89 €**

Firstly, the rent of the local is another cost to consider. For a workshop, researching the offer and demand in Lithuania the cost per square meter is 25€, it would be necessary about 40m², so 1000€ the rent of the local.

Moreover, it is necessary to print the three parts that make up the device, for this a 3D printer is a possible solution, it has the required precision, and the selected material is compatible with it. The number of hours that the 3D printer takes for making all the parts is about 26,2 hours as the calculation made in Cura. The time to get the parts and the cost of buying a 3D printer (with the amortization time also) does not benefit the project, so the most economical way for acquiring the separate parts is asking to another company. The cost of the 3D printer has been estimated in 1000€, although there are other cheaper possibilities and other more expensive ones. The material selected for the device is PLA, the typical price ranges for a 1kg spool of standard PLA filament is around 17 € and the salary of an operator is about 15€/h so the time that the employee would be waiting for the parts to get printed would not be worth it. The calculation made is that with that method the assembled parts in one month would be about 6. So, the best way to be more efficient is to ask a company to print the parts.

Table 6.2. Cost of printing

Printed pieces	Middle part	Upper part	Botton part	TOTAL
Weight (g)	390	478	36	904
Printing time (h)	15,2	5	6	26,2
PLA cost (€)	6,63	8,126	0,612	15,368
Electric cost (€)	0,1425	0,1875	0,225	0,555
Sum (€)	6,7725	8,3135	0,837	**15,923**

As the table shows, those are the data that can make an approximation of the cost of our parts, knowing that the company probably has a net profit margin of 10% established and the labour costs must also be included. Also, the amortization of the machinery is also an important cost to consider and the VAT.

The PLA is about 17€/kg (for a company it is cheaper but to play it safe the calculations are done with the higher values), so each part would have a cost of material of 6.63€, 8.13€ and 0.61€ because the parts needed are about 390g, 478g and 36g, respectively. So, adding the electric cost would be 15.93€ both parts without the labour costs and the net profit. Normally, in this time of manufacturing companies the percentage of the labour cost is between 10 and 30, so taking 30% to play it safe and adding the profit mentioned and also a 21% of other costs from VAT. With the assumed calculations, the cost of all parts would be about 31,85 € each complete printed system.

Table 6.3 Costs of ordering parts

PLA and electricity	15,92 €	50%
Workforce	9,55 €	30%
VAT	6,69 €	21%
Net profit	3,18 €	10%
Total	**31,85 €**	100%

Moreover, an operator is required to place the parts to assemble. The estimation to make the adjustments to fasten in the screws is about 30 minutes. The operator will perform the assembly, it is to put the parts placed and to screw in all the parts. In view of the above and knowing that the employee is earning 15€/h and working 20 h/week, the units per month manufactured are about 160 units.

Each product has a cost related to the rent of the local.

Table 6.4. Costs related to the local rent.

Local renting (€)	1000
Hours to produce 1 unit (h)	0,5
Units per month	160
Cost local per unit (€)	6,25

When the costs have been defined, the sum of all is the calculation of the final product.

In terms of the material cost is considered the sensor, the servomotor, all the screws and the manufactured parts that are needed to make the product.

The worker costs are also for each product so, every 30 minutes a new product is assembled.

The total cost of manufacturing each assembled product is estimated. To do so, previous calculations will be used, resulting in a total cost of 62,97 €. To this it is necessary to add the profit that will be obtained by the sale of each unit. The selling price to the public has been set at 69,97 €, leaving a profit of 5,72 €, assuming about 10% benefit per item. Below is a table specifying all costs associated.

Table 6.5. Final costs per item

Cost per unit	
Printed parts	31,85 €
Material cost	9,89 €
Worker cost	7,50 €
Local renting	6,25 €
Total cost	55,49 €
Net profit	6,10 €
Selling price	61,59 €

This pie chart visually represents the distribution of an economic estimation across various categories, including net profit, material costs, workforce cost, local renting, and printed parts costs. The size of each slice is proportional to its percentage contribution to the overall estimation.

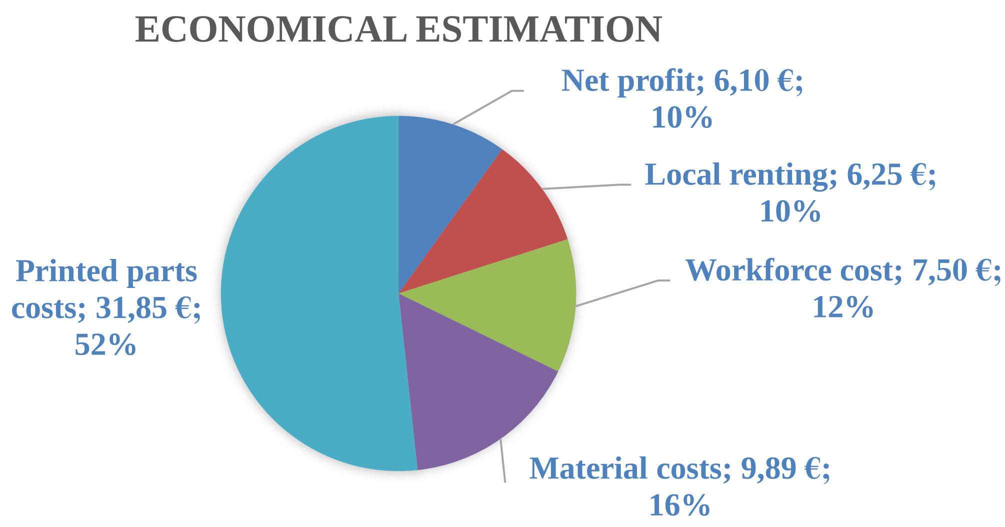


Fig. 6.1. Economical estimation

The pie chart presents a breakdown of an economic estimation, delineating the proportional distribution across several categories. This pie chart illustrates the economic breakdown of this project.

The largest cost, taking up a significant 52%, is attributed to printed parts. Following this, material costs account for 16% of the total, representing the expense of the normalized parts and the electronics devices involved. The workforce cost, which covers labour and employees, makes up 12%. The overhead for local renting is estimated at 10%. Finally, the net profit, the money remaining after all these costs are covered, constitutes the portion at 10%.

6.1 Payback period

The payback period is then calculated. The fix costs are the ones of the rent. For this purpose, the profit obtained per unit sold has been equated to the cost generated by the production of the unit. The equations that model the profit and cost are as follows where q represents the quantity of units sold.

Costs:

$$C(q) = 1000 + 55{,}49q - 6{,}25q \quad (6.1)$$

$$C(q) = 1000 + 49{,}24q$$

Profits:

$$P(q) = 61{,}59q \quad (6.2)$$

Equating both equations results in the point of intersection. This point symbolizes the point at which profit begins to be made on the product manufactured. In this case, it will be necessary to manufacture 81 units to start making a profit. These units represent an economic amount of both benefits and costs of 4.988,79 €.

$$\text{Costs} = \text{Profits} \quad (6.3)$$

$$1000 + 49{,}24q = 61{,}59q$$

$$q = 80{,}97 \approx 81$$

$$P\,(81) \approx C\,(81) = 61{,}59 \text{ x } 81 = 4.988{,}79 \text{ €}$$

This graph represents the relationship between the quantity of units and the associated costs and profit. The point where costs (blue line) intersect with profit (red line) is the break-even point; this point indicates the quantity at which costs and total revenue are equal. At this point, the business starts to generate profit. The x-axis is the quantity and the y-axis is the monetary value.

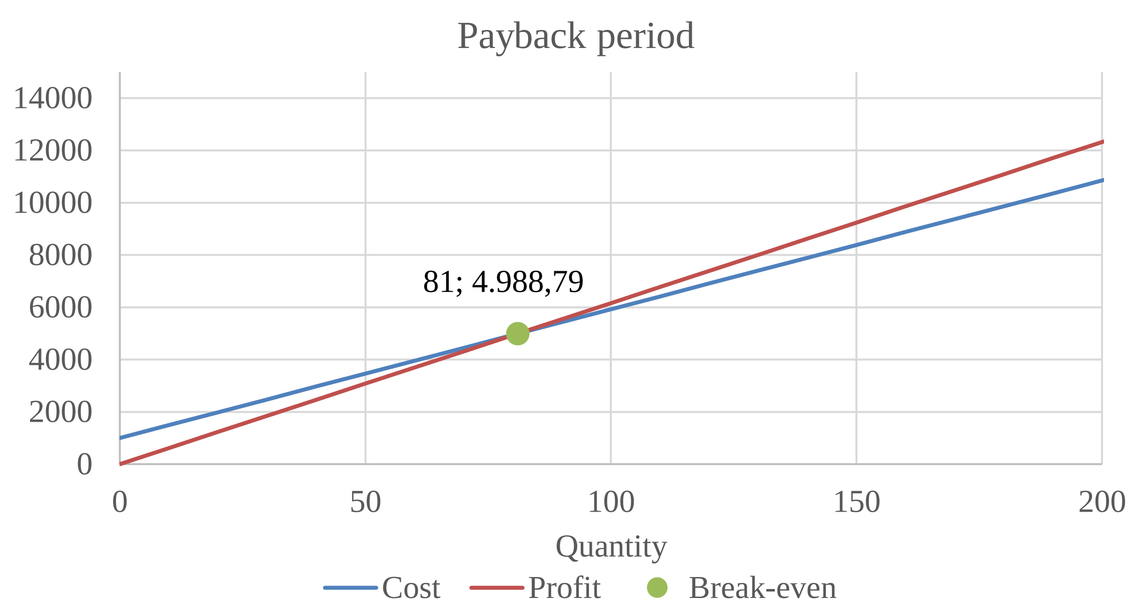


Fig. 6.2. Payback period.

After all the costs and the break-even point analysed, it is concluded that the product is economically viable. The starting point of 1000 € is recovered with the sale of 81 units, a low break-even threshold, but then each unit provides 6,10€ of net profit. These results show that the project will be profitable over time.

7 CONCLUSIONS

This thesis about connecting a 3D pen to a robot arm, with a sensor for when the filament runs out and the servomotor to turn it on without touching it, is a great step forward in mixing manual 3D printing with robots. It shows we can use the 3D pen's flexibility for quick prototypes or fixing things in place, along with the help of robot's accuracy and ability to do things repeatedly without any error.

Adding the sensor to know when the filament runs out is important because it solves a real problem if you are using the 3D pen hooked on the robot without someone watching all the time. It means the robot can work more on its own, and there is less waste of stuff and have fewer mistakes if the filament runs out during the process.

Also, being able to turn the pen on and off with a little motor is really important for making it collaborate with a robot. Not having to touch makes it easier to include in more complex robot tasks and provides ideas for making things in a more controlled way. Moreover, it offers more security for the users because contact is not needed between the pen and the user.

About precision and accuracy:

It is important to be clear about the limitations of this project as well. When using 3D pens, even with robotic assistance, the precision and accuracy fall short compared to traditional 3D printers like FDM, SLA, or SLS. The quality of plastic output, the thickness of each layer, and the uniformity of the prints can vary significantly. As a result, the finished items may not match the desired dimensions or shapes compared to those produced by machines that offer more consistent results. Additionally, achieving intricate details can be quite challenging. The adhesion between layers may also be weaker than what is found in standard 3D printing like FDM, SLA, or SLS.

Normal FDM 3D printers are better for accuracy, and the resin-based ones (SLA/DLP) and powder-based ones (SLS) are even more precise with smoother surfaces and stronger parts, so if the need is accuracy the pen even supported by the arm of the robot is not the best option.

About economic estimation:

In the medium term, the start in the market could be difficult to make a profit but there are some educational centres and technological fairs to make the product be known. After all, it is an innovative product which is not extremely expensive, and it could be a great device for art centres and some small workshops.

This project gives a starting point for using 3D pens for quick ideas, automated repairs, or even making art. If you need really accurate parts, other 3D printing methods are still better, this device does not have the intention of having high precision, the objective of this product is the potability and the low weight.

This project finally shows how a 3D pen works with the help of a robotic arm. Adding smart features like a filament sensor, and a servomotor to allow to remote the pen. Although it may lack the accuracy of a regular 3D printer, its flexibility, transportability, and adaptability for certain applications are significant. This project lets robots do 3D tasks for art, quick fixed and some prototypes. The added features that mitigate potential problems make it more independent.

This is not meant to replace high-accuracy 3D printing. Instead, it is a versatile tool for situations where being quick and working creating free-form shapes is more important. This project is a good starting point for combining the features of 3D pens with the power of robots, opening new ways to use additive manufacturing in different situations.

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LIST OF LITERATURE

3D Pens: Everything You Need to Know. (n.d.). Retrieved 6 May 2025, from https://www.crealitycloud.com/blog/reviews/3d-pens

3Doodler Start+ Essential 3D Pen - impresoras3d.com. (n.d.). Retrieved 9 May 2025, from https://www.impresoras3d.com/producto/3doodler-start-essential-3d-pen/

ABS vs. PLA Filament for a 3D Printing Pen - MYNT3D. (n.d.). Retrieved 6 May 2025, from https://www.mynt3d.com/blogs/projects/abs-vs-pla-filament-for-a-3d-printing-pen

Bolígrafo 3D RP500A para niños, pluma de impresión 3D de alta temperatura, bolígrafo de dibujo 3d, filamento pla 1,75 - AliExpress 44. (n.d.). Retrieved 6 May 2025, from https://es.aliexpress.com/item/1005006007219747.html?src=google&gatewayAdapt=glo2esp

Ink-based 3D printing method (a) schematic of FDM method (b) schematic... | Download Scientific Diagram. (n.d.). Retrieved 5 May 2025, from https://www.researchgate.net/figure/nk-based-3D-printing-method-a-schematic-of-FDM-method-b-schematic-of-DIW-method-46_fig2_328201272

Interruptor Óptico Sensor Fotoeléctrico Micro En Forma De F Sensores De Ranura De Fotomicro De Horquilla Óptica - Buy Micro Photoelectric Sensor opticle Fork photomicro Slot Sensors optical Switch Sensor Product on Alibaba.com. (n.d.). Retrieved 9 May 2025, from https://spanish.alibaba.com/product-detail/F-shaped-Micro-Photoelectric-Sensor-opticle-1600283665509.html

Lápiz 3D: las mejores opciones disponibles en el mercado actual - 3Dnatives. (n.d.). Retrieved 6 May 2025, from https://www.3dnatives.com/es/top-lapiz-3d-boligrafo-3d-160820182/#!

Lix Pen – LixV3GlobalStore. (n.d.). Retrieved 9 May 2025, from https://lixpen.com/

myriwell® 3d pen and 3d printer designer/manufacture – myriwell3dpen. (n.d.). Retrieved 9 May 2025, from https://myriwell.cn/

Naeem, O. A. (n.d.). *A Comparison of Three-Dimensional Printing Technologies on the Precision, Trueness, and Accuracy of Printed Retainers*. Retrieved 30 April 2025, from https://scholarscompass.vcu.edu/etd/6180

Scribbler 3D Pen V3 New Awesome Design Model Printing 3D Pen for Doodling Drawing 3D Pen Tool with L : Amazon.in. (n.d.). Retrieved 9 May 2025, from https://www.amazon.in/Scribbler-Awesome-Printing-Doodling-Drawing/dp/B00WFODEPC

Servomotor SG90 RC 9g - UNIT Electronics Arduino Micro Servo. (n.d.). Retrieved 6 May 2025, from https://uelectronics.com/producto/servomotor-sg90-rc-9g/

Song, Y., Ghafari, Y., Asefnejad, A., & Toghraie, D. (2024). An overview of selective laser sintering 3D printing technology for biomedical and sports device applications: Processes, materials, and applications. *Optics & Laser Technology*, *171*, 110459. https://doi.org/10.1016/J.OPTLASTEC.2023.110459

The Top Robotic Arm 3D Printing Solutions - 3Dnatives. (n.d.). Retrieved 29 April 2025, from https://www.3dnatives.com/en/robotic-arms-3d-printing-141020226/

What Is FDM 3D Printing? (n.d.). Retrieved 29 April 2025, from https://www.3dbeginners.com/what-is-fdm-3d-printing/

Wholesale Jer RP500A-Best cheap 3d Printing Pen for beginner,Jer RP500A-Best cheap 3d Printing Pen for beginner suppliers,manufacturers - Jer. (n.d.). Retrieved 6 May 2025, from https://www.jereducation.com/jer-rp500a-best-cheap-3d-printing-pen-for-beginner_p7.html

XYZprinting da Vinci 3D Pen. (n.d.). Retrieved 9 May 2025, from https://www.anodas.lt/en/xyzprinting-da-vinci-3d-pen

THE ANNEXES

ANNEX 1: Photos of the 3D pen from VGTU

Fig. 0.1 Measurements 3D pen

Fig. 0.2 3D Printing Pen Box

ANNEX 2: Bill of materials.

Format	Zone	Position	Tag	Title	Qty.	Remarks
				Documentacion		
A1			MERS BM 25 EP 01 01 01 00 GV	General View drawing	1	
				Subassemblies		
A1		1	MERS BM 25 EP 01 01 01 00 AD	Mounting 3D pen	1	
				Additional components		
		2		Robotic arm	1	HC10DPT
		3		3D pen	1	RP500A
		4		Slot sensor	1	SK-206NA-W

Respon.depart. Dep. of mech.,rob, and dig. man.	Adviser	Document type: Specification			Status of the document: Educational		
Owner: Vilnius Tech	Prepared by: Elena Palomares	Title: Specification table General View Drawing	Tag				
	Approved by		Issue: A4	Date: 2025-05-15	Lang.: En	Page: 1/2	

Format	Zone	Position	Tag	Title	Qty.	Remarks
				Documentacion		
A1			MERS BM 25 EP 01 01 01 00 AD	Assembly drawing	1	
				Parts		
A3		1	MERS BM 25 EP 01 01 01 01	Lower Part	1	
A3		2	MERS BM 25 EP 01 01 01 02	Middle Part	1	
		3	MERS BM 25 EP 01 01 01 03	Holder	1	
				Additional components		
		4	MERS BM 25 EP 01 01 01 04	3D pen	1	RP500A
		5	MERS BM 25 EP 01 01 01 05	Servomotor	1	GS90
		6	MERS BM 25 EP 01 01 01 06	Slot sensor	1	SK-206NA-W
				Standard components		
		7	MERS BM 25 EP 01 01 01 07	ISO 1207 SCREW M5x45	2	
		8	MERS BM 25 EP 01 01 01 08	ISO 1207 SCREW M5x20	4	
		9	MERS BM 25 EP 01 01 01 09	ISO 1207 SCREW M6x100	1	
		10	MERS BM 25 EP 01 01 01 10	ISO 4034 NUT M6	1	
		11	MERS BM 25 EP 01 01 01 11	ISO 1207 SCREW M2x14	1	

Respon.depart. Dep. of mech.,rob, and dig. man.	Adviser	Document type: Specification				Status of the document: Educational
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	Approved by		Issue: A4	Date: 2025-05-15	Lang.: En	Page: 2/2

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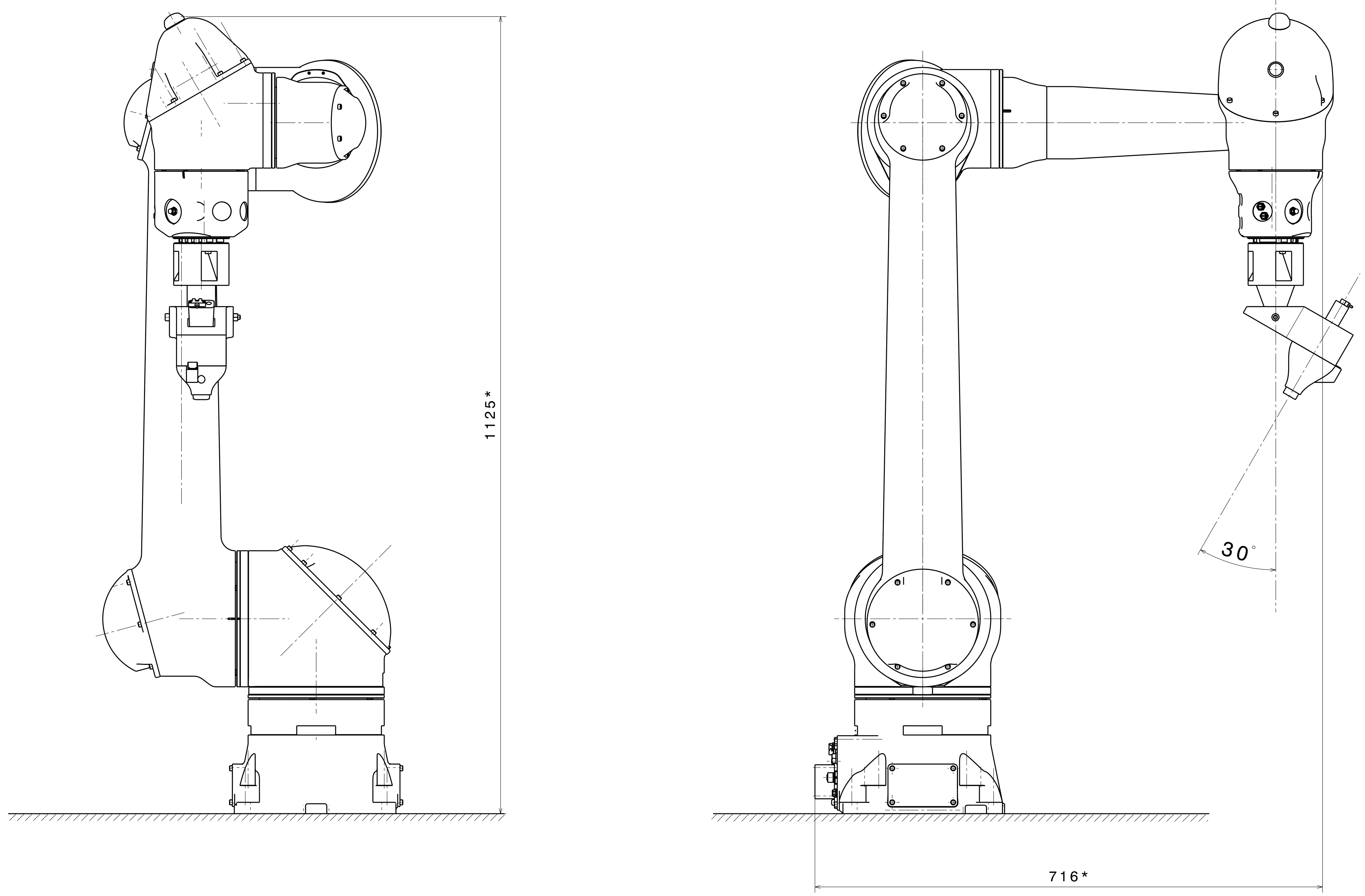
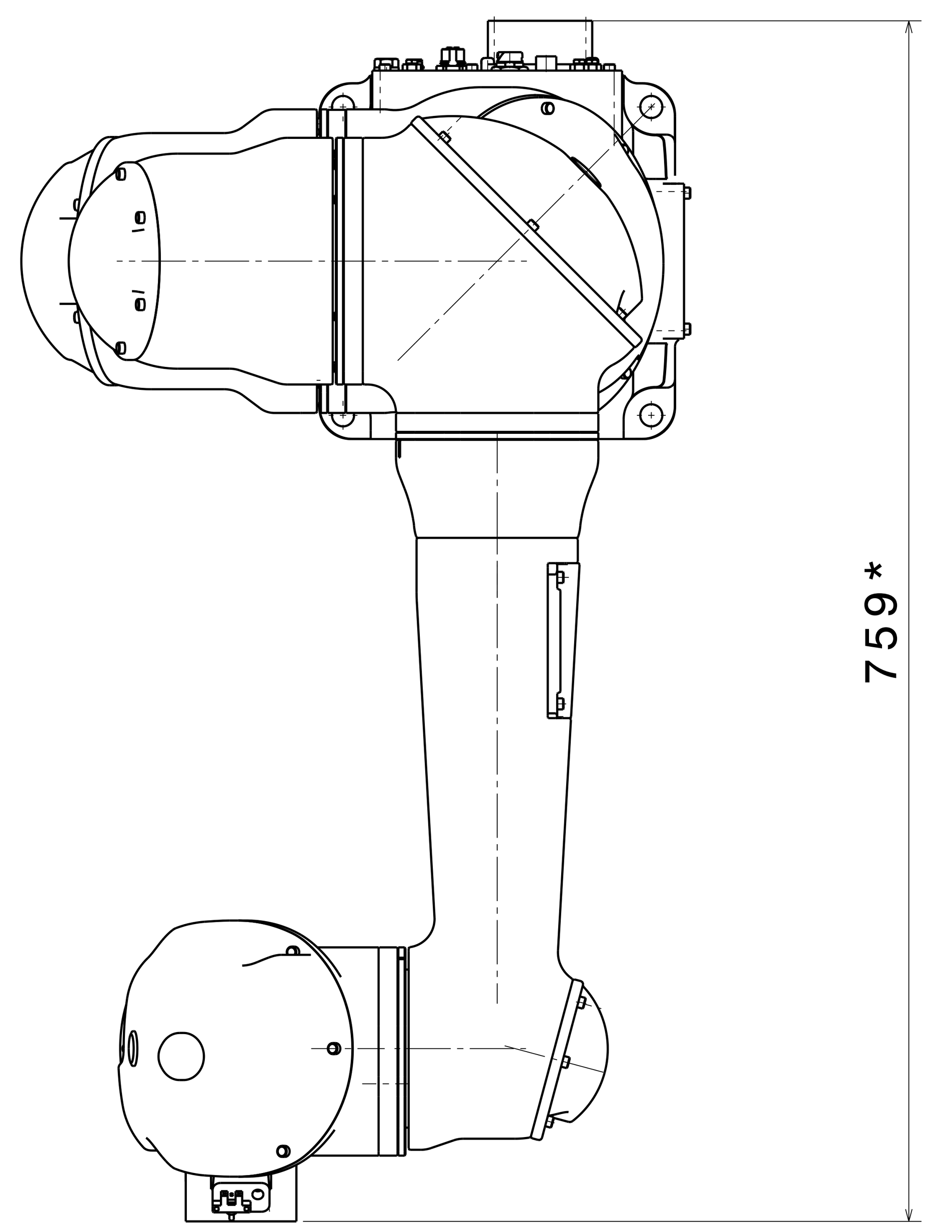
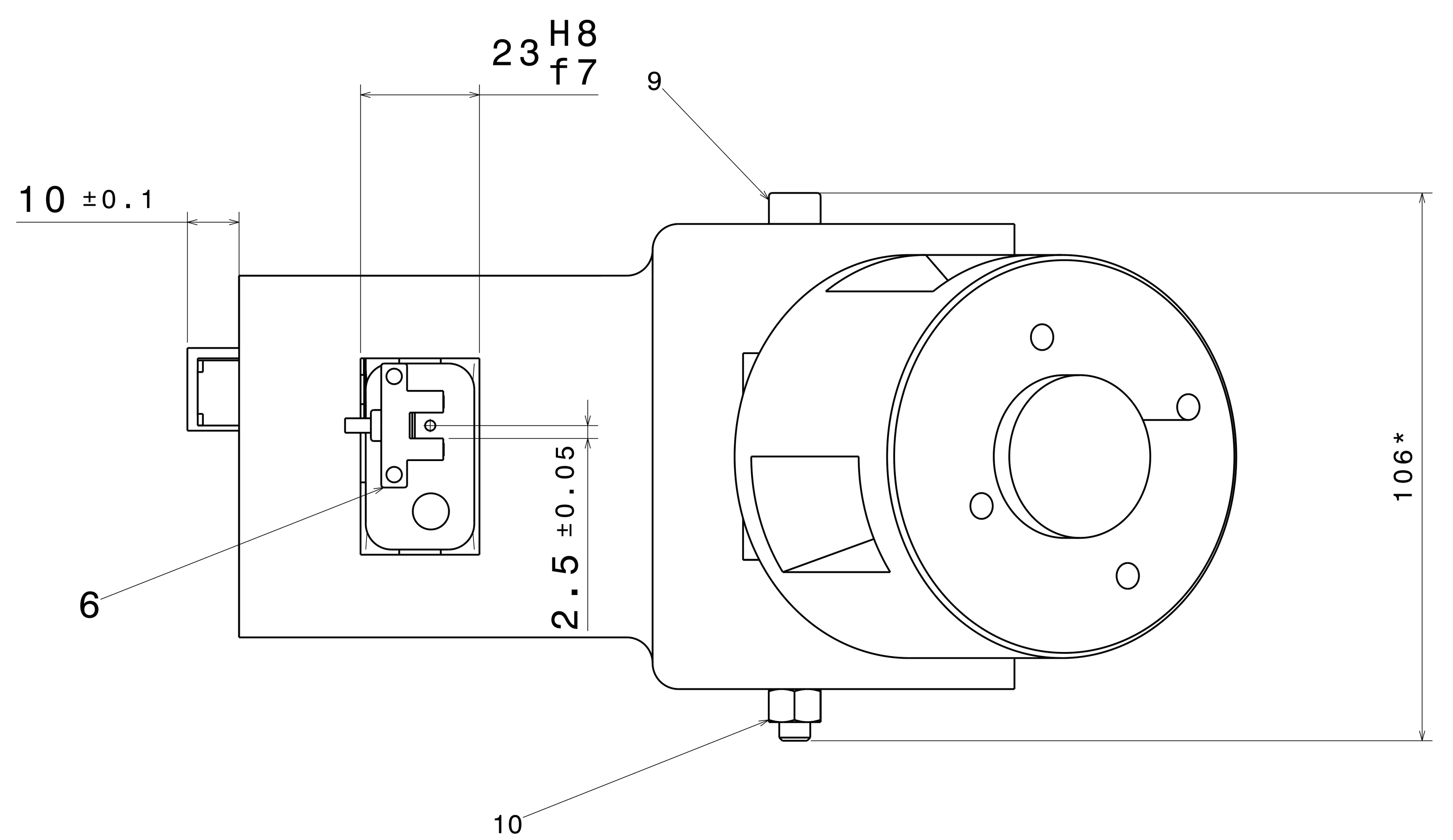




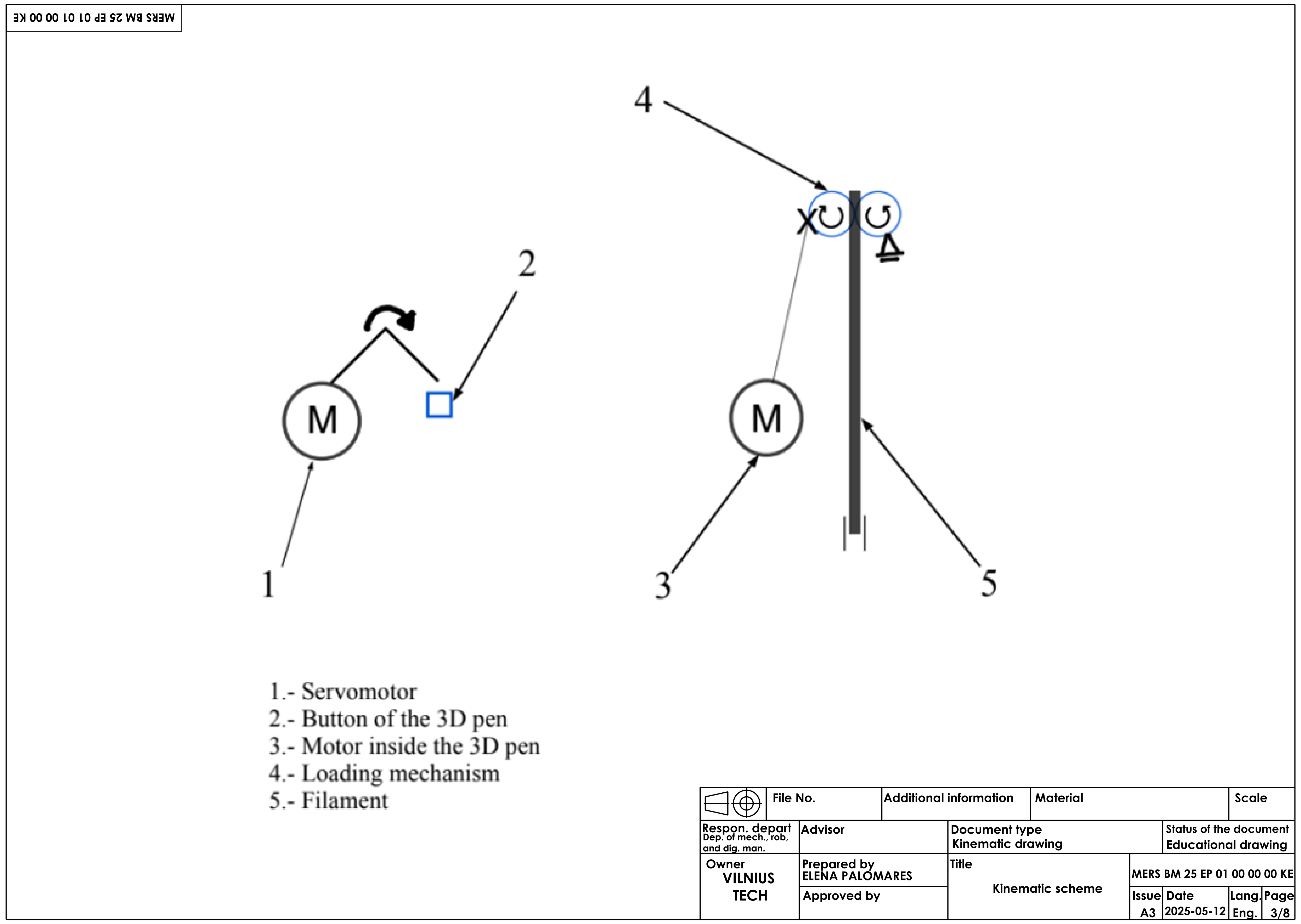
1.-Articulated Robot Arm Motoman HC10DPT
2.-Degrees of Freedom: 6
3.-Payload: Up to 10kg
4.-Mounting: Fixed base
5.-Attachment Method: Standard industrial robot tool flange, secured with a 4 bolt configuration.
6.- * Informational measures

File No.	Aditional information	Material		Scale 1:5
Respon. depart. Dep. of mech., rob. and dig. man.	Adviser	Document type Drawing		Status of the document Educational
Owner VILNIUS TECH	Prepared by ELENA PALOMARES	Title General View	MERS BM 25 EP 01 01 00 00 GV	
	Approved by		Issue 1	Date 15/05/2025 · Lang. Eng. · Page 1/8



1.-The mounting must be fixed to the robotic arm by the 4 metric bolts M5.
2.-The angle of inclination of the pen is chosen so that it can be drawn in any desired way, either on a template or in the air, the angle that forms with the point cero of the robot is 30º.
3.-The servomotor must be inserted in its hole and screwed with the M2 screw.
4.-The pen must be colocated in its hole by pressing before lower and middle parts are screwed together.
5.-Middle and lower part must be screwed with 2 metric bolt M5.
6.-Holder and middle part are the last parts that would screwed and a nut would asure the join.
7.- * informational measures

	File No.	Aditional information	Material	Scale 1:1
Respon. depart. Dep. of mech., rob. and dig. man.	Adviser	Document type Assembly Drawing		Status of the document EDUCATIONAL
Owner VILNIUS TECH	Prepared by ELENA PALOMARES	Title	MERS MB 25 EP 01 01 00 00 AD	
	Approved by	Assembly view	Issue A1 / Date 09/05/2025	Lang. Eng / Page 2/8


4
2
M
M
1
3
5
1.- Servomotor
2.- Button of the 3D pen
3.- Motor inside the 3D pen
4.- Loading mechanism
5.- Filament
File No.
Additional information
Material
Scale
Respon. depart Dep. of mech., rob, and dig. man.
Advisor
Document type Kinematic drawing
Status of the document Educational drawing
Owner VILNIUS TECH
Prepared by ELENA PALOMARES
Approved by
Title
Kinematic scheme
MERS BM 25 EP 01 00 00 KE
Issue A3
Date 2025-05-12
Lang. Eng.
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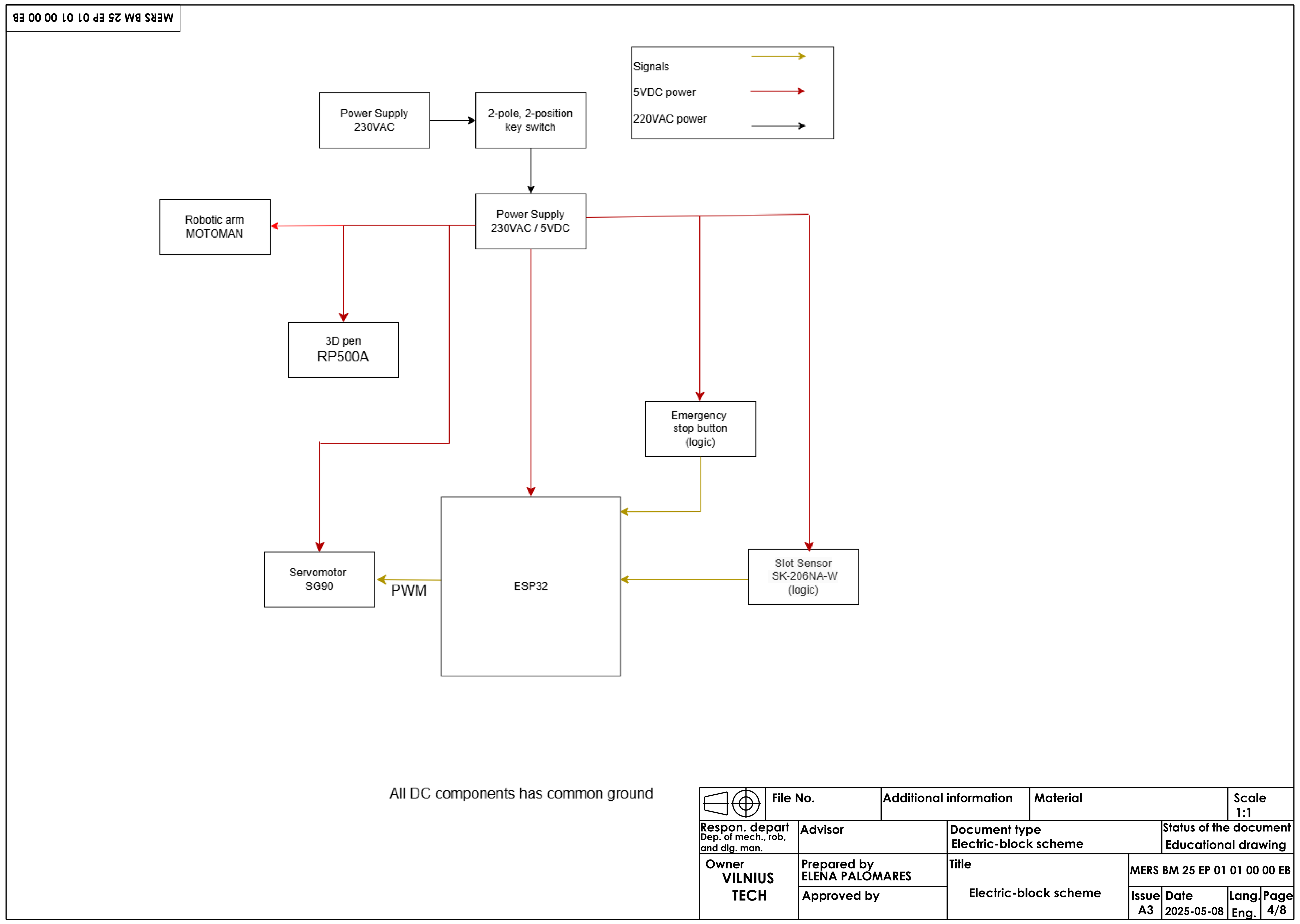
Signals
5VDC power
220VAC power
Power Supply 230VAC
2-pole, 2-position key switch
Robotic arm MOTOMAN
Power Supply 230VAC / 5VDC
3D pen RP500A
Emergency stop button (logic)
Servomotor SG90
PWM
ESP32
Slot Sensor SK-206NA-W (logic)
All DC components has common ground
File No.
Additional information
Material
Scale 1:1
Respon. depart Dep. of mech., rob, and dig. man.
Advisor
Document type Electric-block scheme
Status of the document Educational drawing
Owner VILNIUS TECH
Prepared by ELENA PALOMARES
Approved by
Title
Electric-block scheme
MERS BM 25 EP 01 01 00 00 EB
Issue A3
Date 2025-05-08
Lang. Eng.
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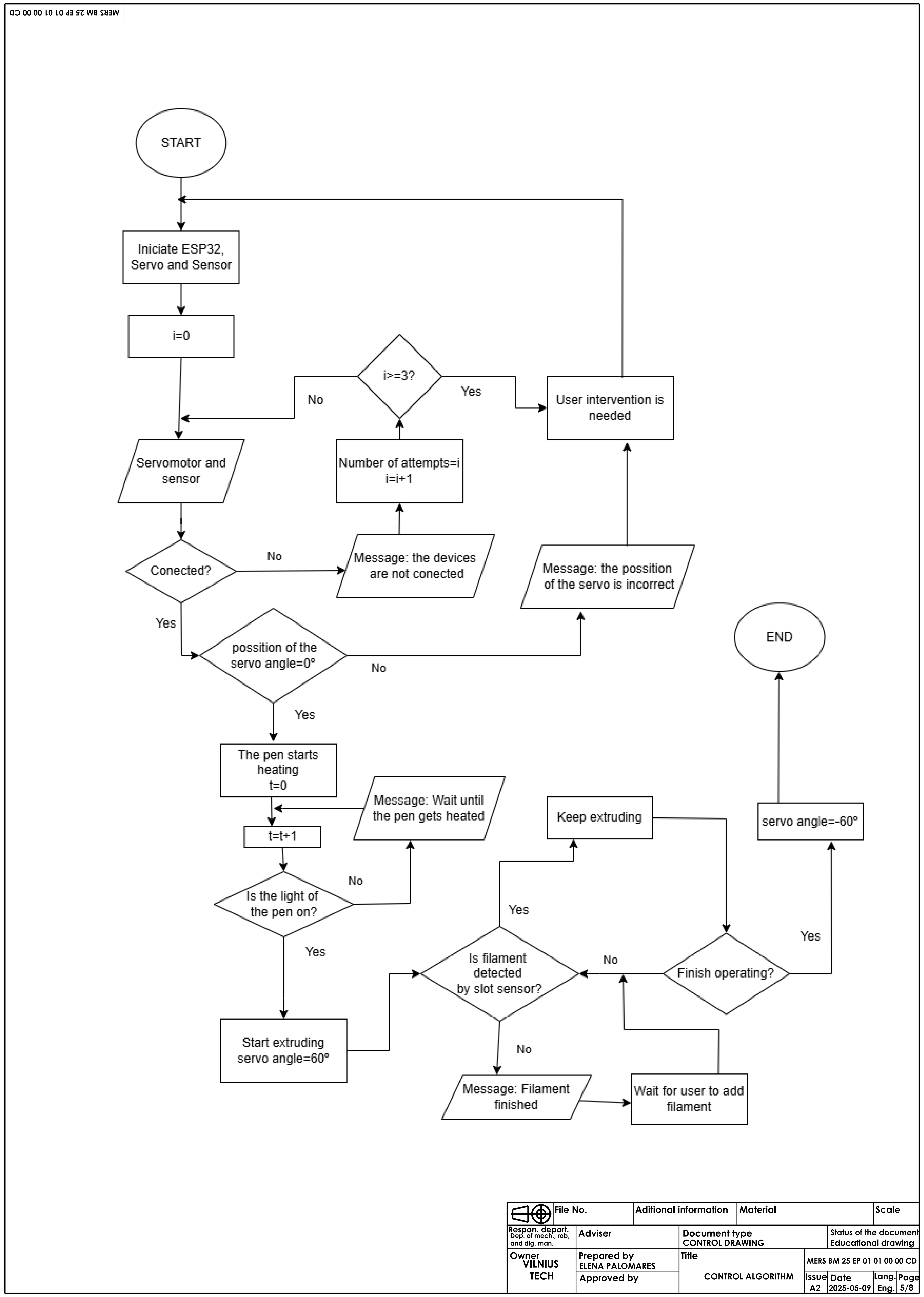
START
Iniciate ESP32, Servo and Sensor
i=0
i>=3?
No
Yes
User intervention is needed
Servomotor and sensor
Number of attempts=i i=i+1
Conected?
No
Message: the devices are not conected
Message: the possition of the servo is incorrect
Yes
possition of the servo angle=0°
No
END
Yes
The pen starts heating t=0
Message: Wait until the pen gets heated
t=t+1
Keep extruding
servo angle=-60°
Is the light of the pen on?
No
Yes
Yes
Yes
Is filament detected by slot sensor?
No
Finish operating?
Start extruding servo angle=60°
No
Message: Filament finished
Wait for user to add filament
File No.
Aditional information
Material
Scale
Respon. depart. Dep. of mech., rob, and dig. man.
Adviser
Document type CONTROL DRAWING
Status of the document Educational drawing
Owner VILNIUS TECH
Prepared by ELENA PALOMARES
Approved by
Title
CONTROL ALGORITHM
MERS BM 25 EP 01 01 00 00 CD
Issue A2
Date 2025-05-09
Lang. Eng.
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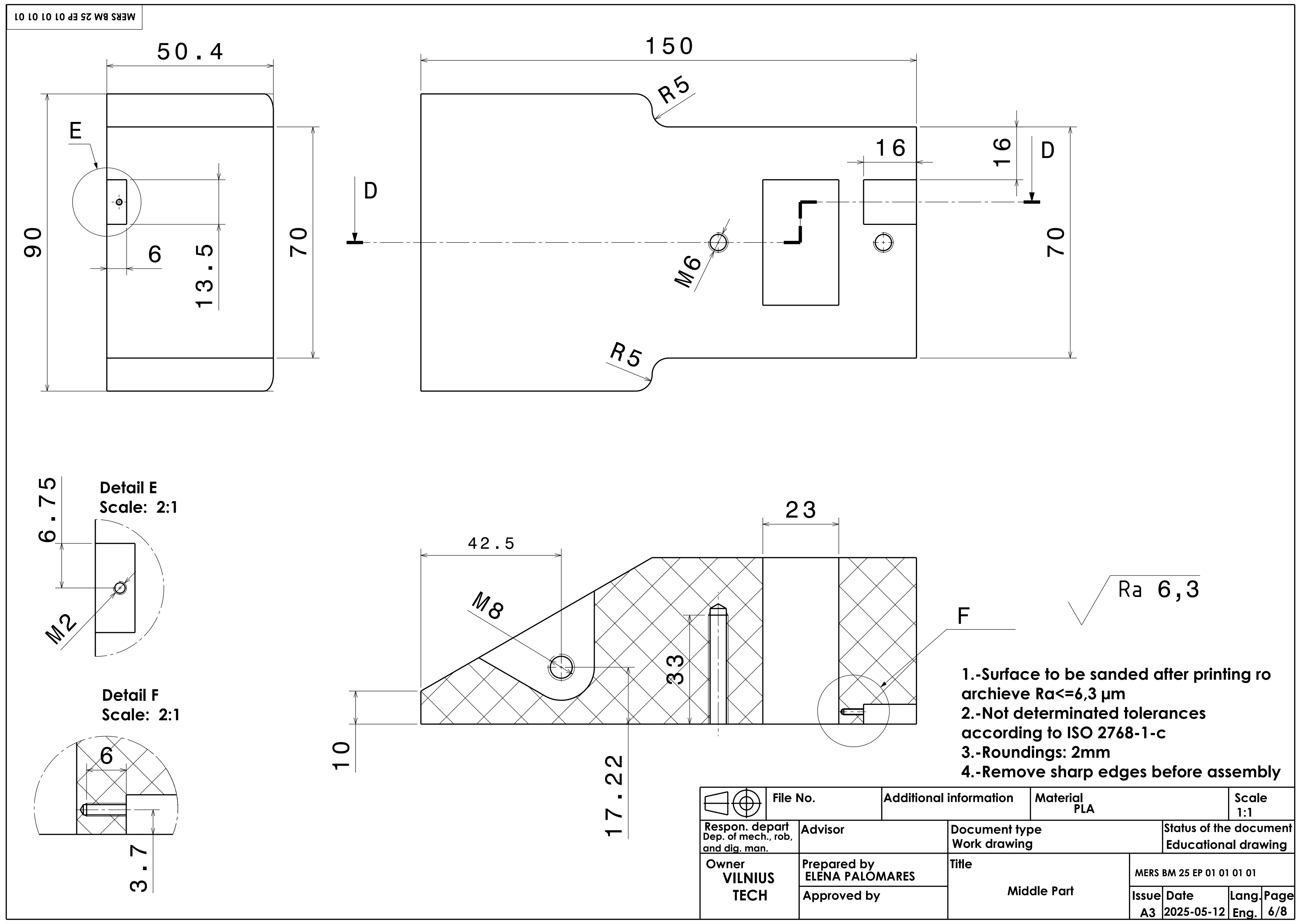
Detail E
Scale: 2:1
Detail F
Scale: 2:1
Ra 6,3
1.-Surface to be sanded after printing ro archieve Ra<=6,3 µm
2.-Not determinated tolerances according to ISO 2768-1-c
3.-Roundings: 2mm
4.-Remove sharp edges before assembly
File No.
Additional information
Material PLA
Scale 1:1
Respon. depart Dep. of mech., rob. and dig. man.
Advisor
Document type Work drawing
Status of the document Educational drawing
Owner VILNIUS TECH
Prepared by ELENA PALOMARES
Approved by
Title
Middle Part
MERS BM 25 EP 01 01 01 01
Issue A3
Date 2025-05-12
Lang. Eng.
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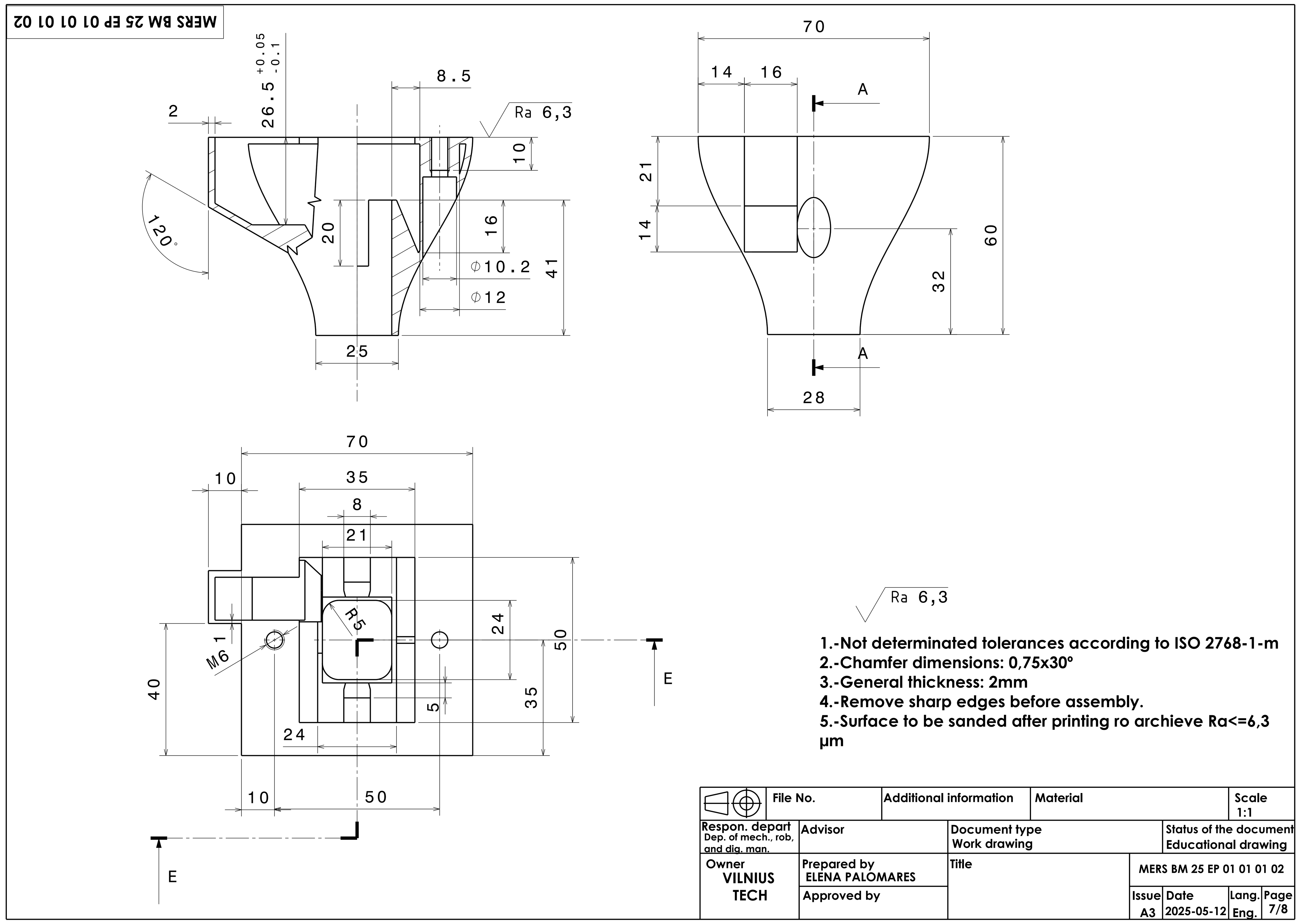
Ra 6,3
1.-Not determinated tolerances according to ISO 2768-1-m
2.-Chamfer dimensions: 0,75x30°
3.-General thickness: 2mm
4.-Remove sharp edges before assembly.
5.-Surface to be sanded after printing ro archieve Ra<=6,3 µm
File No.
Additional information
Material
Scale 1:1
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Advisor
Document type Work drawing
Status of the document Educational drawing
Owner VILNIUS TECH
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Issue A3
Date 2025-05-12
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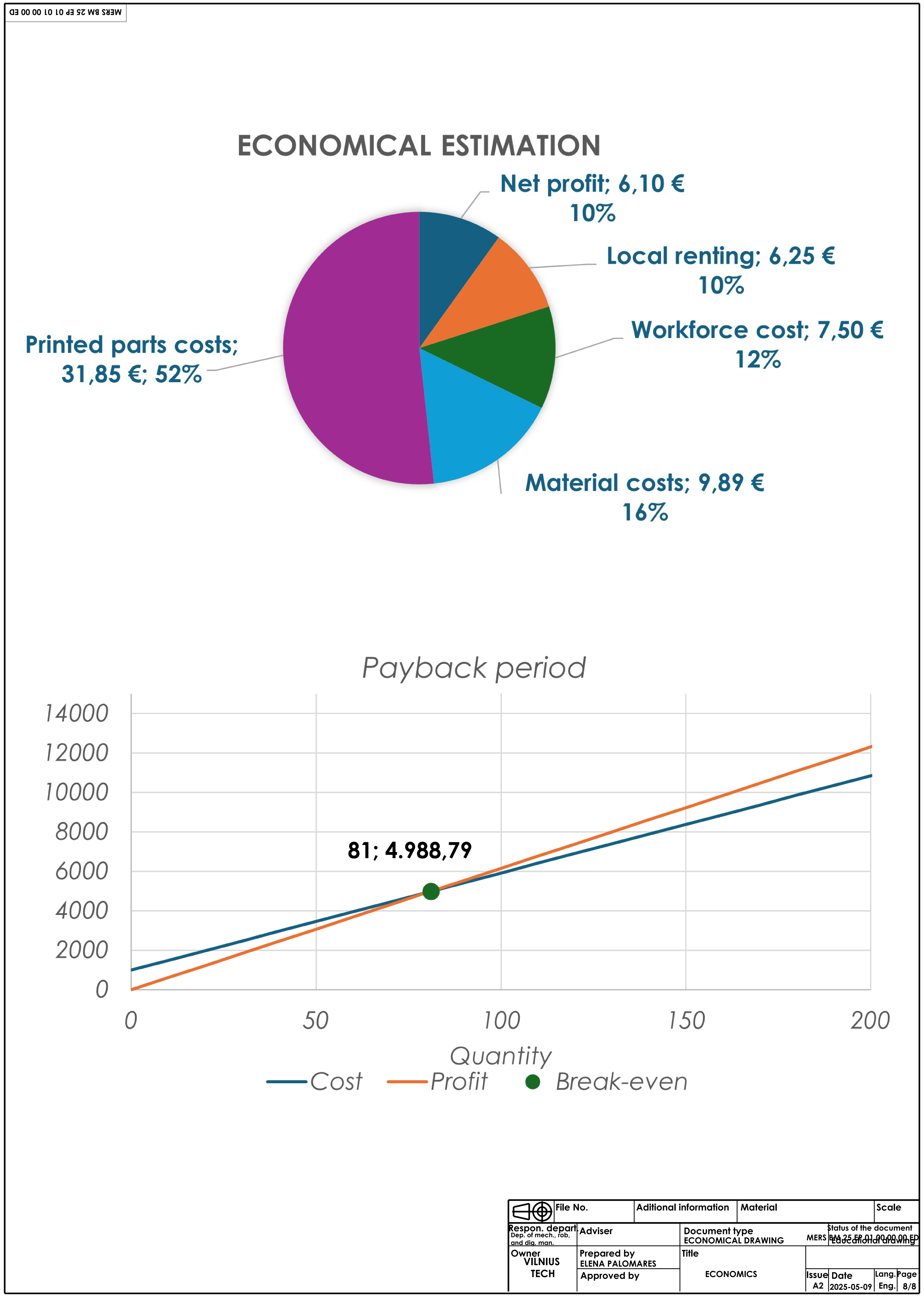
ECONOMICAL ESTIMATION
Net profit; 6,10 € 10%
Local renting; 6,25 € 10%
Workforce cost; 7,50 € 12%
Material costs; 9,89 € 16%
Printed parts costs; 31,85 €; 52%
Payback period
81; 4.988,79
Quantity
Cost
Profit
Break-even
File No.
Aditional information
Material
Scale
Respon. depart Dep. of mech., rob. and dig. man.
Adviser
Document type ECONOMICAL DRAWING
Status of the document Educational drawing
Owner VILNIUS TECH
Prepared by ELENA PALOMARES
Approved by
Title
ECONOMICS
Issue A2
Date 2025-05-09
Lang. Eng.
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