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**ESCUELA DE INGENIERÍAS
INDUSTRIALES**

UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica

**Digital twin for SMC's FMS-201 and design of
its screwing station**

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TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Digital twin for SMC's FMS-201 and design of its screwing station

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Resumen

De un tiempo a esta parte, la ingeniería 4.0 ha revolucionado la sociedad y la tecnología con herramientas tan novedosas y útiles como el gemelo digital. Por esa razón, la UCLL junto con la KU Leuven propusieron la primera parte de este proyecto: desarrollar un gemelo digital para la primera estación de FMS-200.

Para ello, con la ayuda de softwares como Siemens NX, Siemens MCD y TIAPortal, se ha creado una réplica digital de la estación suministradora del cuerpo del ensamblaje.

Por otro lado, para ofrecer un servicio más completo del sistema modular que nos compete, se ha diseñado y presupuestado una estación alternativa de atornillado con tecnologías neumáticas y eléctricas.

Palabras clave – Gemelo digital, FMS-200, Siemens NX, Siemens MCD, Estación de atornillado.

Abstract

In the last few years, engineering 4.0 importance has been increasing until becoming an essential part of our lives and jobs. So much so that, the UCLL with the collaboration of KU Leuven, has suggested the first part of this project in which a digital twin is to be created.

Using different software like Siemens NX, Siemens MCD and TIAPortal, the digital replica was developed for the body supply of the flexible integrated assembly system FMS-200

The second part of this project laid in the design of a screwing station, using pneumatic and electric technologies to replace the robotic arm suggested by SMC.

Keywords – Digital Twin, FMS-200, Siemens NX, Siemens MCD, Screwing machine.

Faculty of Technology

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Internship report by

Julia Rubio Martín

Candidate for the degree of Professional Bachelor in
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Abstract

In the last few years, engineering 4.0 importance has been increasing until becoming an essential part of our lives and jobs. So much so that, the UCLL with the collaboration of KU Leuven, has suggested the present project in which a digital twin is to be created and implemented. Both institutions work together in the Faculty of Engineering Technology, located in campus Diepenbeek.

A flexible integrated assembly system (FMS-200 of SMC) composed of six stations is owned by UCLL, and the main goal of this project was to create the digital twin of the first station, the body supply. In this station, the assembled product's support is fed and placed in the belt conveyor. The first item to attend to was the creation of the static 3D model of the mechanical components, for what Siemens NX was used. Once all the components were modelled and assembled, the next step was defining dynamic properties in the static model using Siemens MCD (Mechatronics Concept Designer). Last but not least, the virtual system will work like a physical system when it is connected to the PLC program. This objective will be achieved by creating signals in Siemens MCD and linking them to the code with PLCSIM Advanced.

The second part of this project laid in the design, modelling and creation of a seventh station, in which a screwing machine is expected to screw the four screws provided by the previous station. For this purpose, two different design ideas were evaluated, taking into account the difficulty level of implementation, cost and effectiveness, as well as the future educational applications. We are carrying through with the best option.

Keywords – Digital Twin, FMS-200, Siemens NX, Siemens MCD, Screwing machine.

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List of abbreviations

DT	Digital Twin
UCLL	University College Leuven Limburg
MCD	Mechatronics Concept Designer
KU Leuven	Katholieke Universiteit Leuven
RUL	Remaining Useful Life
IoT	Internet of Things
AI	Artificial Intelligence
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
TIA Portal	Totally Integrated Automation Portal
PLC	Programmable Logic Controller
USB	Universal Serial Bus
PLA	Polylactic Acid

1. Introduction

1.1. Motivation

UCLL is an institution that embraces change and progress so adapting to the new reality of technology is always one of its goals. Engineering 4.0, and more concretely digital twins, are the order of the day, that is why creating the DT was proposed as a possible project.

FMS-200 is an automation cell that consist of different independent stations in which an operation of the process is done, achieving a turning mechanism at the end. Now, UCLL owes six stations and uses them for educational purposes. Taking that into account, developing the DT of the stations would add value to the education that students are receiving.

In this perspective, the first idea of the project appeared. It lies in the creation of a DT for the first station.

Besides of that, with the current stations the screws are placed in the body of the piece that FMS-200 aims to assemble, but they are not screwed due to economical inconveniences. As the station suggested by SMC consists of robotic technology, it is too much expensive so UCLL suggests to redesign the screwing station with only pneumatic and electric technology.

1.2. Objectives

This thesis is divided into two different projects connected to FMS-200 of SMC.

The main objective of the first part of the project is to create the digital twin of the first station, called 'Body supply', using Siemens NX and TIA Portal.

Additionally, the second part aims at designing a new screwing station to replace the actual one, which is not working, avoiding the robotic technology that SMC suggests. For this purpose, some secondary objectives were established in order to improve the result and to give the project more chances to be carried out:

- Use an electrical cylinder to provide added value so students can learn and train themselves in a new kind of technology.
- Obtain a low budget, by reusing the components that already exist and employing the resources that UCLL has to avoid buying new material and devices.

1.3. Thesis outline

This first chapter called **Introduction** provides an overview of the motivation as well as the objectives that the project aims to archive. **Background** settles the context of the thesis and presents the tools used to develop the Digital Twin. Later, **Methodology for the DT** describes the process followed to create the digital twin with NX. **Screwing station** provides all the information about the conception and implementation of the new station. *Finally*, **Conclusions** summarizes the results of the project and suggest possible paths for future research.

2. Background

In this chapter, the context of the thesis is going to be presented by an introduction to the industrial revolutions, which will lead to an explanation of digital twin, the most important tool of Industry 4.0 for this project. Besides, the tools that have been utilised for developing the digital twin as well as its background will be introduced.

2.1. Engineering 4.0

Along history, we can find four industrial revolutions that changed lifestyle and the way we work. First of all, it is relevant to explain what is meant by industrial revolution. Initially, it referred to the transition from an agrarian and handicraft economy to other one characterised by manufacturing domain. It entails a completely transformation of society and the world that started in the early 18th century.

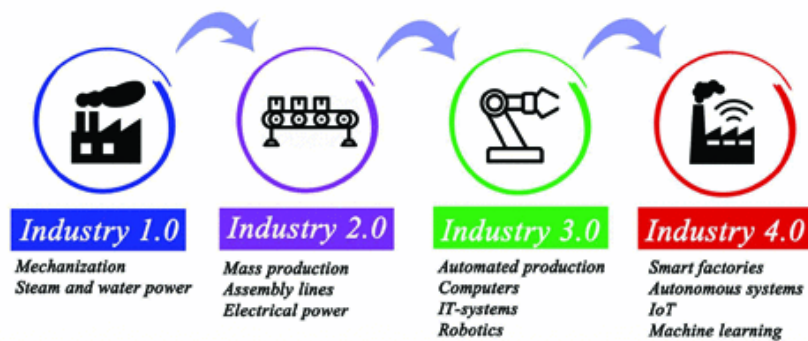


Figure 2-1 The four industrial revolutions (Colombo, et al., 2021)

Figure 2-1 relies on an outline to show the evolution of industry. As we can see, the First Industrial Revolution began through the mechanization of production when water and steam power started to be used. At the end of the 19th century, the Second came up and mass production was implemented as well as electrification. The Third dates back to 1970s and encompassed automated production, robotics, electronics and information technologies. Last but not least, the Fourth Industrial Revolution or Industry 4.0, also known as the digital revolution, embraces automation and data exchange by a combination of the Internet of Things (IoT), big data, CPS and Artificial Intelligence (AI). It is the fusion of different technologies that are blurring the lines between the physical, digital, and biological spheres. (Khan, Arslan, & Ratnarajah, 2022). In other words, in Industry 4.0, all devices are interconnected to each other via Internet.

2.2. Digital Twin

Digital twin technology provides us with the connection between the virtual and physical worlds by a virtual model designed to accurately reflect a physical object or system (Tao, Hu, Liu, & Nee, 2020).

One remarkable feature of DT that makes it unique is its ability to continually adapt to changes in the environment using real-time sensory data. Consequently, it can simulate, forecast and optimize the product and the production system in advance, as well as identify potential issues. Furthermore, DT can be used to predict the RUL, remaining useful life, of the physical object (Farsi, Daneshkhah, Hosseinian-Far, & Jahankhani, 2020), what leads us to the fact that DTs are expected to serve throughout the whole life cycle. This differentiates DT from other alternatives like simulations or CAD models. (Zhang, et al., 2020).

According to Michael Grieves (Grieves, 2005) in one of his presentations at the University of Michigan for Industry, DT is composed by three elements:

- the physical twin in the real world,
- its digital twin in a virtual world, and
- the information that links them.

Figure 2-2 represents the relationship between physical and digital twins in manufacturing applications.

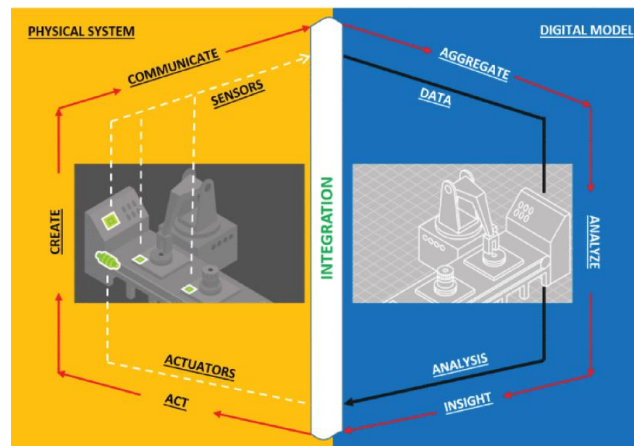


Figure 2-2 DT model of manufacturing application. (Khan, Arslan, & Ratnarajah, 2022)

2.2.1.Applications of DT

DT technology, as a result of engineering 4.0, is based on IoT (Internet of Things), machine learning and sensor and measurement tools. They are already being used to improve industry in different ways such as quality, productivity, efficiency or availability. Below, some of the actual applications of the “digital replicas” are enlisted (Liu, Fang, Dong, & Xu, 2021) (Farsi, Daneshkhah, Hosseinian-Far, & Jahankhani, 2020):

- Manufacturing

In Figure 2-3, the different utilities of a DT are presented when we want to implement it in manufacturing. As we can see, this tool is highly versatile and can bring progress and prosperity to the companies.

DT optimizes and makes efficient manufacturing while reducing the performance of a device. It can as well be utilised to train employees or to manage the risk. Furthermore, DTs are cost-efficient.



Figure 2-3 Utilities of a DT in Manufacturing (Pal, et al., 2021)

- Healthcare

DT can be a useful tool in matter of healthcare since it can be utilized to improve the personalized care that patients receive. Moreover, it is possible to create safer environments in hospitals and analyse the repercussions of potential variations on system performance.

In the healthcare context, it is possible to implement DTs with several roles. For instance, DTs of hospitals, operational strategies, staffing, or wellness programs can be created. It is not rocket science that the target of this technology is diverse. In fact, we can use it to save money, optimise the care provided, carry out maintenance and so on.

To illustrate, Jorge Corral-Acero et al. showed in their article “The 'Digital Twin' to enable the vision of precision cardiology” that DT are actually being used to improve healthcare (Corral-Acero, et al., 2020).

- Supply chain

Digital twins are also used for supply chains since the real-time data are highly useful to forecast the dynamics, notice problematic situations in advance and solve any issues.

Regarding the features of the DTs, they can be used in a wide variety of situations to test design changes, identify bottlenecks or plan the transportation, among other uses.

- Retail

Customer experience has a vital role in retail sector and it can be significantly enhanced by DT. This application consists in the design and creation of a virtual twins for customers and helps in better in-store planning, security implementation and energy management (Miskinis, 2018).

Specifically, DT can create personas in online stores and social media that, according to the information about the individual, gives recommendations about wearing apparels. These kind of avatars are expected to become essential in retail because of the huge rise of online shopping.

- Smart cities

Finally, city planners and policymakers implement DT dovetailed with IoT in order to improve diverse aspects of smart cities such as urban planning. What is more, resources are effectively managed, it is possible to enhance economic advancement/development and they can have an eco-friendly impact.

2.3. FMS-200

FMS 200 system is a flexible automation cell conceived with educational and training purpose, so the users can develop and improve their skills in the field of automation. Since all the components are real and actually used in industry, the knowledge acquired is more significant.

The system can be configured in different ways thanks to its modular features. Therefore, according to the requirements of the company or

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training centre, such as interests or budget, it is possible to modify the configuration by introducing some changes in the stations, as enhancing the amount of them. Each station can work independently so the simplest variation is to work with only one. However, it is possible to add more workstations until ten, getting a complex system.

Figure 2-4 shows the FMS 200 system that includes ten stations. The purpose of this system is to assemble a turning mechanism by using different technologies: pneumatics, hydraulics or robotics, to name but a few.



Figure 2-4: FMS-200 (SMC, FMS-200 - Flexible integrated assembling systems, 2022)

Due to its flexibility, it is possible to obtain a wide variety of final assemblies by changing materials, colours, etc, without problem as each station can adapt and carry out its part of the process.

A master PLC interconnects all the stations through an industrial communication bus, and they can operate at different levels depending on the configuration chosen.

All the stations provided by SMC are listed below.

- **FMS-201: Body supply.** Next chapter includes more info about this workstation since the digital twin will focus on it.
- **FMS-202: Bearing selection/ supply,**

- **FMS-203: Hydraulic press,**
- **FMS-204: Shaft selection/ supply,**
- **FMS-205: Cover selection/ supply ,**
- **FMS-206: Screws supply,**
- **FMS-207: Robotized screwing.** The seventh station integrates robotics technology. The second goal of this thesis is to redesign the station in order to meet the budget, later in this document it will be possible to know more about that part of the project.
- **FMS-208: Automatic warehouse,**
- **FMS-209: Paint drying in oven,**
- **FMS-210: Quality control using artificial vision.**

UCLL and KU Leuven own an FMS 200 system that is used by students to learn about automation in a practical context. It is employed in different subjects and levels, such as bachelor or master, what shows how versatile it is.

Currently, the system is composed by six stations, more specifically, FMS-201, 202, 204, 205, 206, 208, in this order. A seventh station is going to be created and placed between the screws supply and the automatic warehouse.

2.3.1. Body Supply

In the first part of this project, we are going to focus on the body supply, which is the first station. Here, the base or support of the work piece is fed. The station is shown in Figure 2-5, SMC provides this combination of devices and pieces and has been assigned with the name of FMS-201.

Digital twin for SMC's FMS-201 and design of its screwing station

Table 2-1 (SMC, FMS-200 - Flexible integrated assembling systems, 2022) shows some remarkable aspects and features of FMS-201.

FMS-201 900x580x1480mm	Modules	Sensors (type & quantity)	Input / Output
	Base feeding Position verification Displacement Rejection of incorrect base Insertion on pallet	Auto switch, Reed type (x8) Vacuum pressure switch (x1) Inductive (x1)	Digital 14/10
	Other devices (quantity)	Actuators (type & quantity)	
	Vacuum pad (x4)- Vacuum ejector (x1) Three-colour indication light (x1) Breakdown simulation system (x1)	Pneumatic linear (x6)	

Table 2-1: FMS-201 characteristics. Source: (SMC, FMS-201 - Body supply, 2022)



Figure 2-5: FMS-201 (SMC, FMS-201 - Body supply, 2022)

2.4. NX and Mechatronics Concept Design

Siemens NX software is an advanced and powerful integrated solution that can be considered an umbrella CAD drawing program. However, the NX tool is not only about 2D and 3D modelling, it encompasses computer-aided design (CAD), engineering (CAE) and manufacturing (CAM), what makes NX remarkably flexible and high-end. It also enables users to make the most of the DT. (Siemens, NX: Products. Siemens Digital Industries Software, 2022)

Some alternatives or competitors are CATIA (which has also been used for the development of this thesis), Autodesk Inventor or Creo Elements/pro.

As an add-on module for NX we can find Mechatronics Concept Design, MCD, a tool used to convert the static models created in NX into realistic models by attributing them dynamic properties.

Since we are looking for a digital twin, we need a model of which parts interact with the others like in real life, hence physical and kinematic properties must be assigned with MCD. Later in this thesis, some of the features available in this module will be detailed.

Furthermore, MCD allows linking the model to a PLC since it can equip the model with sensors and actuators and their respective signals.

Siemens MCD makes it possible to link created CAD drawing to a PLC and thus simultaneously mechanical design, electrical design and software engineering. This software makes it possible to really test the virtual environment. This by using sensors and actuators and by adding physical properties to the model as previously mentioned with digital twin.

2.5. PLCSIM Advanced and TIA Portal

TIA Portal is a software engineering framework used to implement automation systems in a quick and intuitive way. With TIA Portal, it is possible to develop, commission, operate, maintain and even upgrade having as a result a cost, effort and time efficient software (MathWorks, 2022).

This project aims to develop a DT, therefore a virtual PLC need to be simulated and that the exact purpose of the SIMATIC S7-PLCSIM Advanced software.

PLCSIM Advanced tool is used to create and commission a virtual controller that allows the user to avoid using a real PLC. This tool only works with S7-1500 and ET 200SP, which are the most common Siemens controllers.

3. Methodology for the DT

The key aspect discussed in this chapter will be the generation of the DT for the body supply. Firstly, the static model of NX will be presented, followed by the creation of the dynamic properties in MCD. Later, it is going to be explained how the model was associated with TIA Portal and PLC having as a result the final DT.

3.1. Static model

Figure 3-1 shows the static model of the body supply with all the components positioned. The process that must be followed to obtain it starts with the modelling of each component. Once all of them have been created, they must be assembled using the proper constraints. For this thesis, new

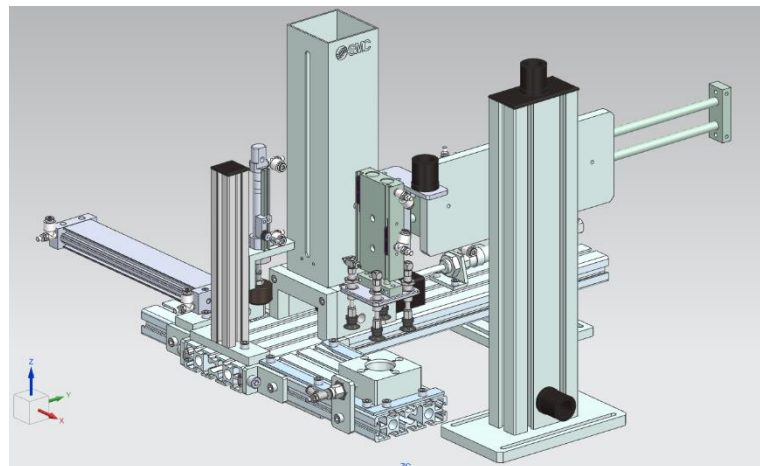


Figure 3-1 Static model

models and assemblies were created but, in the end, the static model used was the one that SMC provided.

Due to the absent of assembly constraints, some of them should be created to guarantee the correct functioning of the station. Additionally, sensors must be added to control cylinders' strokes.

Next chapters will illustrate how we can assign dynamic properties to the model so that a dynamic model can be created.

3.2. Rigid body

As we briefly introduce in the last section, the objective we want to accomplish in this chapter (and the following ones) is to create a dynamic model in order to allow physical simulations. Mechatronics Concept Designer (MCD) NX add-on will be the software used (Siemens, Learn-/Training Document. DigitalTwin@Education Module 150-005. Creation of a Dynamic 3D Model Using the Mechatronics Concept Designer CAE System, 2020).

After opening the static model file, we can find the MCD application by going to the 'Application' tab and, in the submenu 'More' in the 'Design' menu group, clicking on 'Mechatronics Concept Designer' (see Figure 3-2).

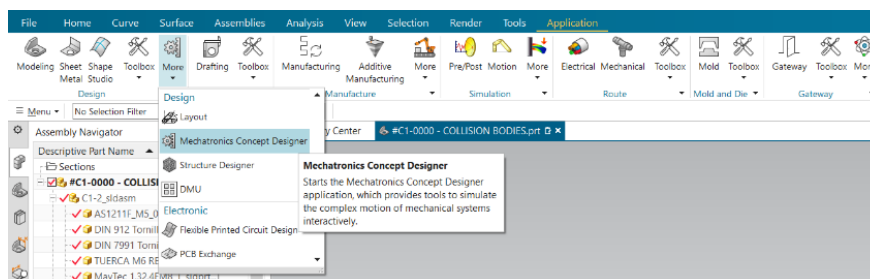


Figure 3-2 Opening MCD

Another way to open MCD is using the Command Finder at the top right of the screen and typing "Mechatronics Concept Designer".

As the first basic dynamic property, individual components must be defined as Rigid Bodies so they become movable bodies that react to actions of external forces. RBs have mass and inertia, that is why forces like, for instance, gravity have a visible effect in the model. 'Rigid Body' button can be found in the 'Home' tab (see Figure 3-3). The new window shown in Figure 3-4 will appear.

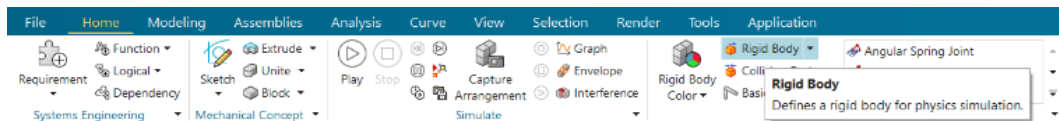


Figure 3-3 Rigid body

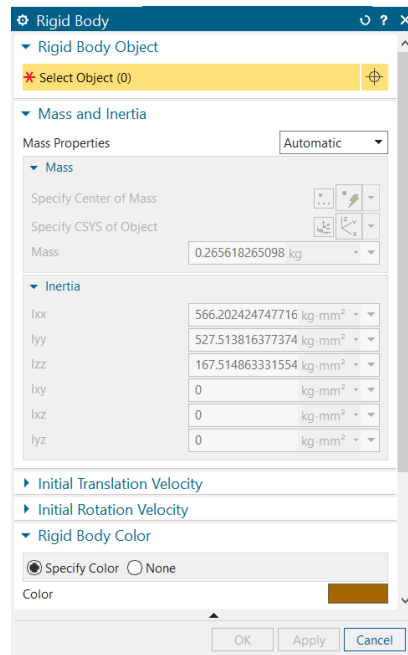


Figure 3-4 Rigid Body window

We must select the object that we want to define as a rigid body and leave the mass properties set to 'Automatic'. Besides, it is convenient to change

the name so it will be tidier. In this thesis, they are name in the following way: *RB_NameOfTheComponent*.

After defining all the rigid bodies, we can have an overview of all of them by going to the 'Physics Navigator', on the left side of the screen; in the Resource bar.

Now, by clicking the 'Play' button in the 'Simulate' menu group, the simulation will start and all the components defined as RB will fall down since now they have mass and the gravity affects them. Clicking the Stop button will finish the simulation.

3.3. Fixed joint

The effect of rigid bodies is undesirable when talking about components falling. Therefore, fixed joint function gives us the option to attach components to a support, leaving them without any degree of freedom. There are two ways to use this property.

On one hand, we can select a base, which must be another rigid body, so the attachment refers to that second body. For instance, in the union between cylinders CXSWM20-150-Z73L and CXSM15-50-Z73L it is essential to select a base.

On the other hand, if no base is selected, the rigid body will be connected to the background, what implies not movement at all. Most of the fixed joint implemented in this project will be like these.

3.4. Collision body

The next step is allowing the interaction between the components when they come into contact. In other words, we want to make the models “collision bodies” so they can collide with other models. See Figure 3-5.

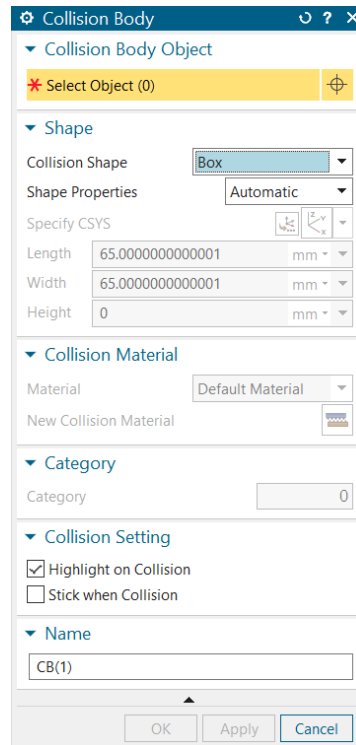


Figure 3-5 Collision body window

MCD provides us with various collision shapes and, for every single model, we need to use the one that fits better with the piece and its purpose. The most complex and accurate shape is called ‘Mesh’. This is the only shape that allows us to create an interior body. However, it is not always the best option since it needs more computing capacity during a simulation than simple shapes.

A notorious remark about the definition of collision bodies is that a rigid body of the model does not have to exist.

3.5. Sliding joint

The property that gives linear movement along a vector to a rigid body is “sliding joint”. It is essential defining as a sliding joint every cylinder so the ejector heads do not fall down and there is harmony between their movements in physic and digital worlds.

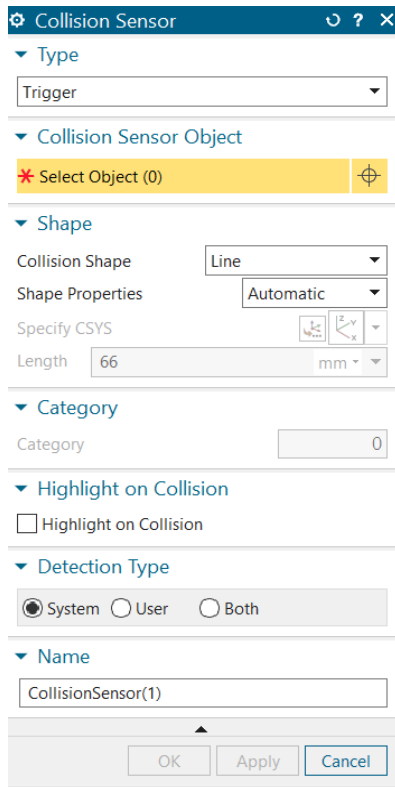
3.6. Collision sensor and position control

In this section, two dynamic properties from the field of electrics are presented.

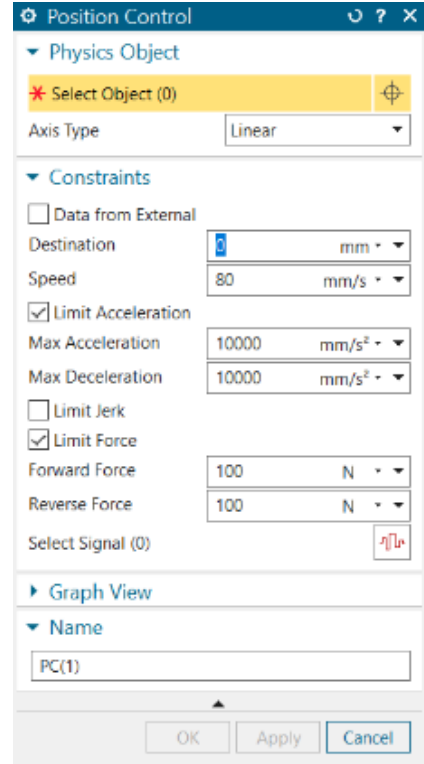
In order to detect collision or contact with a component, we have to define it as a collision sensor. The collision will create a signal, which is usually a Boolean signal. Figure 3-6 (a) shows the window that appears to generate collision sensors

Besides, MCD has another useful property called position control that provides with a controlled movement along a specified axis. This property has to be associated to an actuator with a kinematic component, such us transport surface or sliding joint.

In this case of study, there are only sliding joints in the ejectors and the goal is moving the ejector heads up to two positions. Firstly, the extension and then the retraction. Two different position controls must be created. Figure 3-6 (b) shows the window of this command.



(a) Collision sensor window



(b) Position control window

Figure 3-6 Collision and position control windows

3.7. Object source

Object source is a dynamic property used to automatically generate replicas of a body during the simulation at regular intervals. It is possible to trigger the property by a time interval or by an event.

In station FMS-201, work pieces are fed to the circuit so it makes sense that an object source is applied to the piece in order to be able to provide more than one.

3.8. Object sink

At the end of the piece's trajectory, the vacuum turns off and the piece is finally delivered to the conveyor belt. This project only encompasses the first station so, at the end of the trajectory, the piece must disappear. For this purpose, an object sink can be created. This is a property that we can assign to a collision sensor.

When a body from an object source touches the object sink, it is removed permanently.

3.9. Material

To assure a smooth movement of the piece along the track, different materials can be created changing some properties such as the friction. Figure 3-7 shows the collision material window, that we can find following these steps in MCD: Home > Mechanical > Collision material.

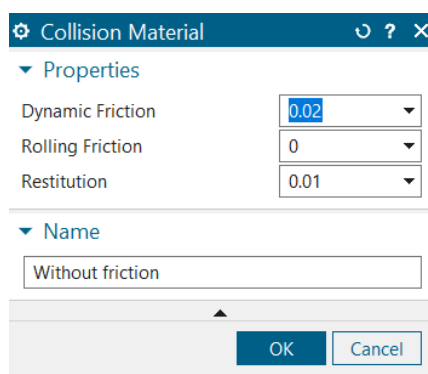


Figure 3-7 Collision material window

The default material is ok for most of the collision bodies; however, applying a new material with almost no friction in the track and the rails helps significantly.

3.10. Operation

MCD does not have a property or an option to suck. For this reason, the solution chosen was creating suction pads with a fix joint without attachment.

Firstly, a fixed joint must be made selecting the body that includes the four pads as the base (see Figure 3-8). The attachment must be empty.

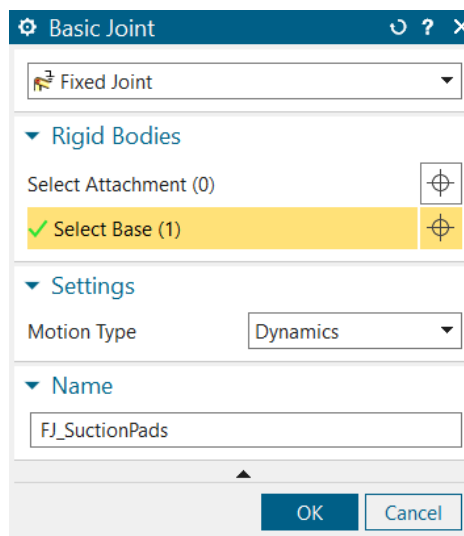


Figure 3-8 Fixed joint without attachment

Secondly, a collision sensor is needed to detect when the pads and the piece find each other. The shape can be a box that includes the four pads.

Once the previous steps are completed, an operation can be created. Figure 3-9 shows the window with all the parameters adjusted according to the function we aim to fulfil. The object selected in the physics object's tab is the fixed joint without attachment. Selecting this attachment in the runtime parameter will enable the possibility of choosing an "object from trigger", which, in this case, is the collision sensor that we have just created. It is essential to change the value of the condition to 'true' so the attachment will be created as soon as the pads touch the piece, action that will be detected by the collision sensor.

In brief, following these steps, a link between the fixed joint and the collision sensor is implemented and, as soon as the suction pads touch the piece, the sensor is activated so the vacuum is simulated and the picker can move the piece. A way to compare the two situations is going to the “Runtime Inspector”, after adding both commands to it, where we will see firstly the attachment with value “(null)” when the collision sensor is not triggered (see Figure 3-10).

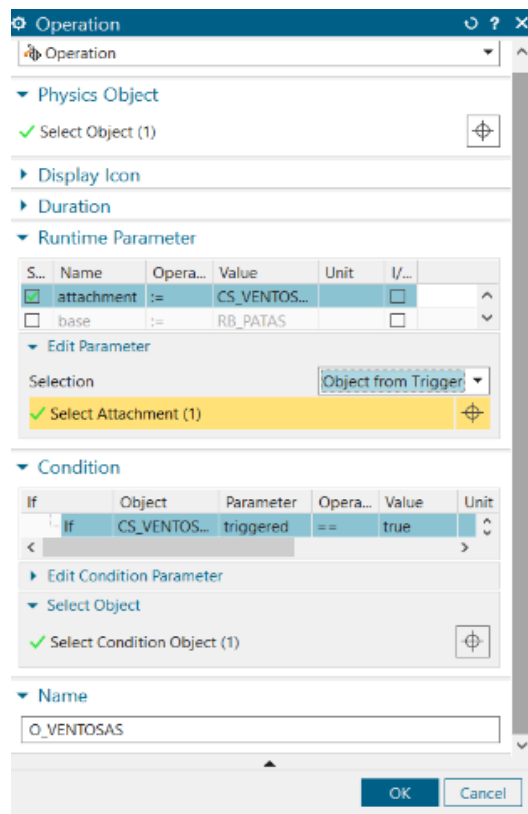


Figure 3-9 Operation window

Later in the simulation, when the piece arrives to its place and it is moment to pick it up, the collision sensor turns into “true triggered” and in the fixed joint the attachment is not longer “(null)”, but the piece. It is possible to see it in figure 3-11.

Digital twin for SMC's FMS-201 and design of its screwing station

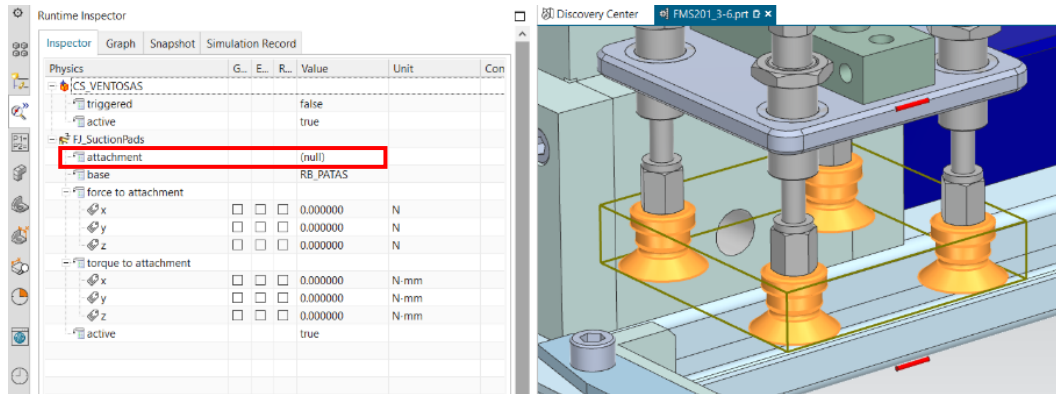


Figure 3-10 Runtime Inspector: Fixed joint without attachment

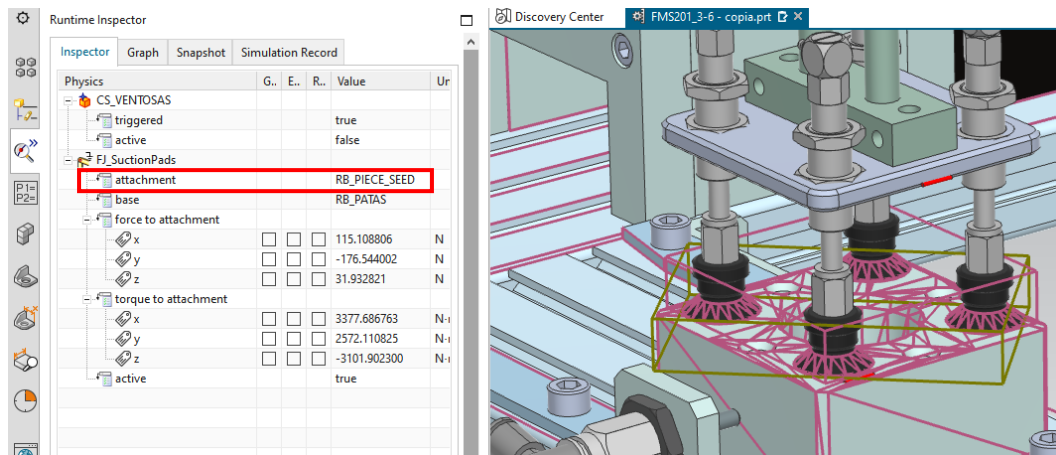


Figure 3-11 Runtime Inspector: Fixed joint with attachment

3.11. Signal, symbol table and signal mapping

The previous sections gather the method to create the static 3D assembly and its dynamization. Building on that, this section concerns with the signal creation so as to enable interaction with a virtual PLC. The signals must be mapped to both MCD and PLCSIM Advanced.

There are at least two different methods to create signals in MCD. On the one hand, we can create signals directly with the command "Signal". Those signals will control physical properties with a runtime expression, in other

words, a non-static value that can change at runtime of a simulation. Later these expressions will be connected to a signal from PLCSIM Advanced.

On the other hand, "Signal adapter" can be use, tool that includes all the signals in one space, and that interconnects signals and runtime expressions.

While creating the signals it is important to pay attention to the parameter name and the IO type, which must be 'active' and 'input' for the signals that correspond to position controls and 'triggered' and 'output' for the collision sensors (See Figure 3-12).

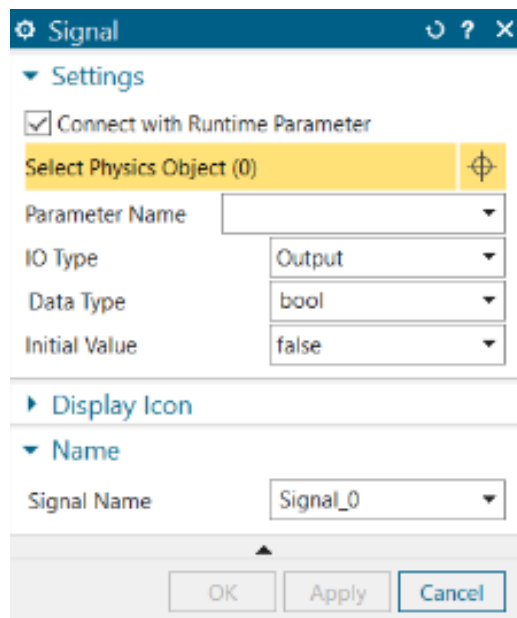


Figure 3-12 Signal window

There is only one exception related to the signal that controls the collision sensor of the suction pads. In this case, we want to activate the signal with PLC (or manually if we just work with MCD) because in the physical model we can activate the vacuum whenever we want, and it will make the code programme easier to implement. Hence, an 'active' and 'input' signal will be adjudicated.

Once all the signals are created, it is time to create a Symbol table. It basically includes all the signals and specify its IO and date type.

Last but not least, a signal mapping must be made. At this point of the DT design it is essential to have PLCSIM Advanced installed in the computer. Otherwise, the mapping will not be plausible. Figure 3-13 shows the interface of this command, which is used to interconnect signals from MCD with signals from an external program, in this thesis TIA Portal.

After opening the command in the “Automation” menu group, we have to select ‘PLCSIM Adv’ as the external signal type and click on “Settings” to establish the instance. Next, we can insert all the tags.

Now, we can map the signals from MCD to the external ones. This is a simple process since both signals should have the same name with one dissimilarity: signals in MCD can only be linked to output signals of a PLC, and vice versa.

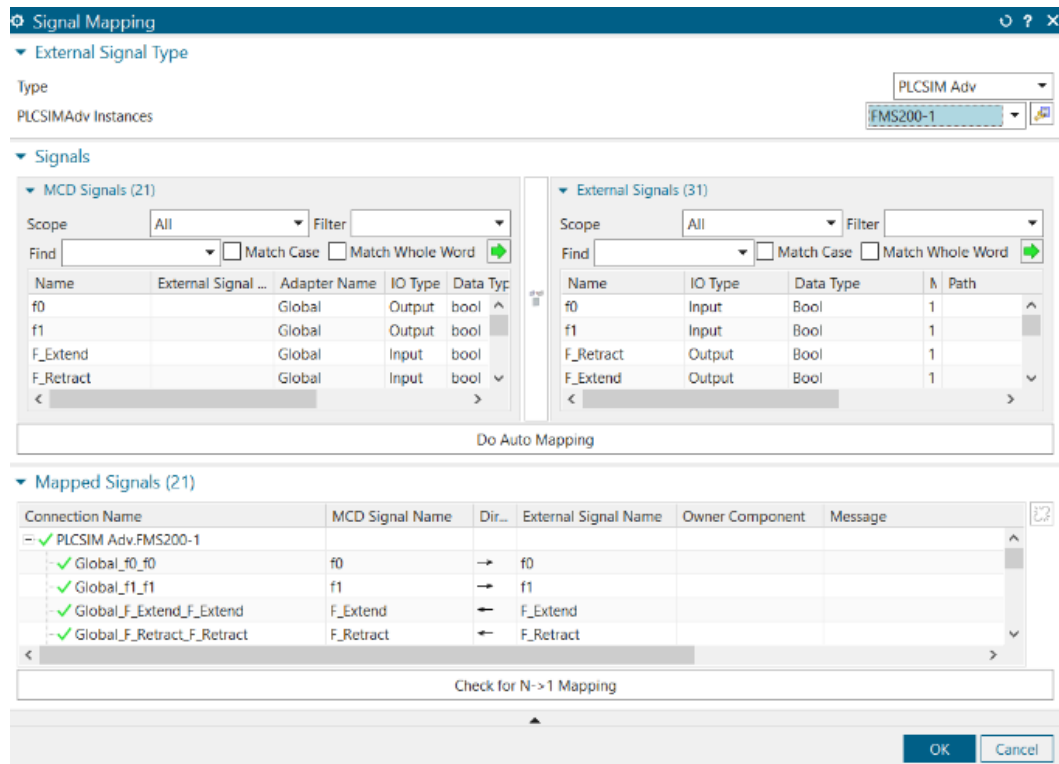


Figure 3-13 Signal mapping window

3.12. Programming in TIA Portal

The previous chapter explained how the signals created in NX and TIA Portal are linked to each other. However, before that step, it is necessary to realize the PLC programming in TIA Portal.

The programmer must start configuring the type of PLC that is going to be used. In this project, PLCSIM Advanced implemented the connection, so an S7-1500 was chosen. One of the tabs of TIA Portal allows us to see the hardware, as Figure 3-14 shows.



Figure 3-14 Hardware: PLC configuration

Next, the signals can be added to TIA Portal. Each sensor provides one input signal and every cylinder needs two, one for the extension and another one for the retraction.

Once all of the signals are created, a variable list will be available in a different tag of the software and a list similar to the one shown in Figure 3-15 should appear.

Now, the graphcet can be programmed. In this part of the process, the programmer is about to assign relations between signals in order to generate a flow of “actions” that will have as a result the program intended. Figure 3-16 shows a segment of the graphcet.

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Variable list									
	Name	Data type	Address	Retain	Access...	Writa...	Visibl...		
1	Start	Bool	%I10.0		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
2	Stop	Bool	%I10.1		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
3	Auto/Man	Bool	%I10.2		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
4	Reset	Bool	%I10.3		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
5	a0	Bool	%I10.4		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
6	a1	Bool	%I10.5		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
7	b0	Bool	%I10.6		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
8	b1	Bool	%I10.7		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
9	suction	Bool	%I11.0		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
10	d1	Bool	%I11.1		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
11	e1	Bool	%I11.2		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
12	f0	Bool	%I11.3		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
13	f1	Bool	%I11.4		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
14	body_presence	Bool	%I11.5		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
15	Emergency	Bool	%I11.6		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
16	Eme_alarm	Bool	%Q4.0		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
17	A_Extend	Bool	%Q4.1		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
18	A_Retract	Bool	%Q4.2		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
19	B_Extend	Bool	%Q4.3		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
20	V+	Bool	%Q4.4		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
21	C_Extend	Bool	%Q4.5		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
22	D_Extend	Bool	%Q4.6		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
23	E_Extend	Bool	%Q4.7		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
24	F_Extend	Bool	%Q5.0		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
25	no_material_alarm	Bool	%Q5.1		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
26	VAP+	Bool	%Q5.2		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
27	Time_wait	Time	%MD0		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
28	F_Retract	Bool	%Q5.4		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
29	E_Retract	Bool	%Q5.5		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
30	D_Retract	Bool	%Q5.6		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
31	C_Retract	Bool	%Q5.7		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
32	B_Retract	Bool	%Q6.0		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		

Figure 3-15 Input-output list

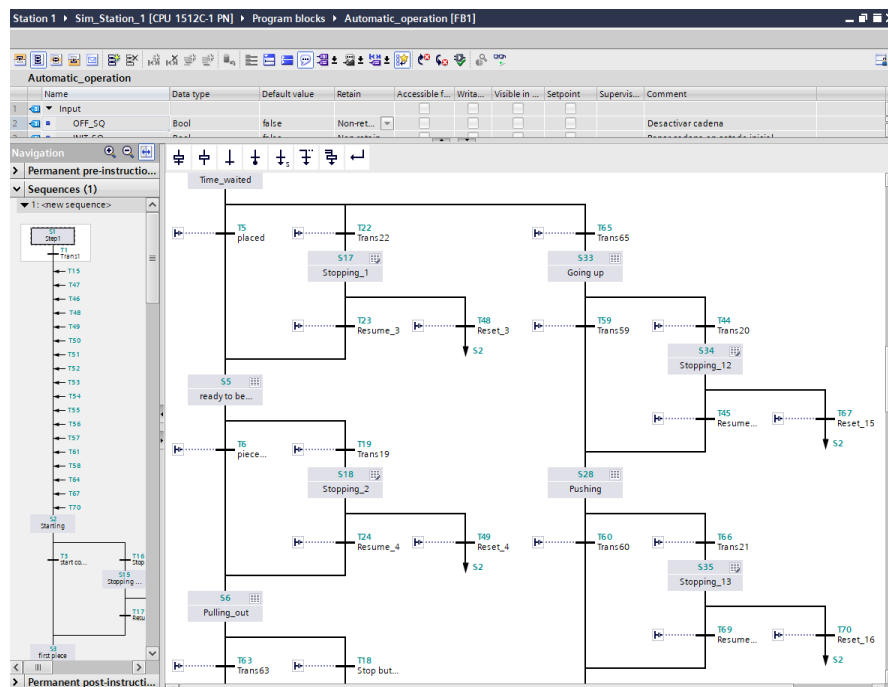


Figure 3-16 Graphcnet

Finally, PLCSIM Advanced creates a virtual PLC with an instance that allows the simulation. Figure 3-17 presents the layout of the software.

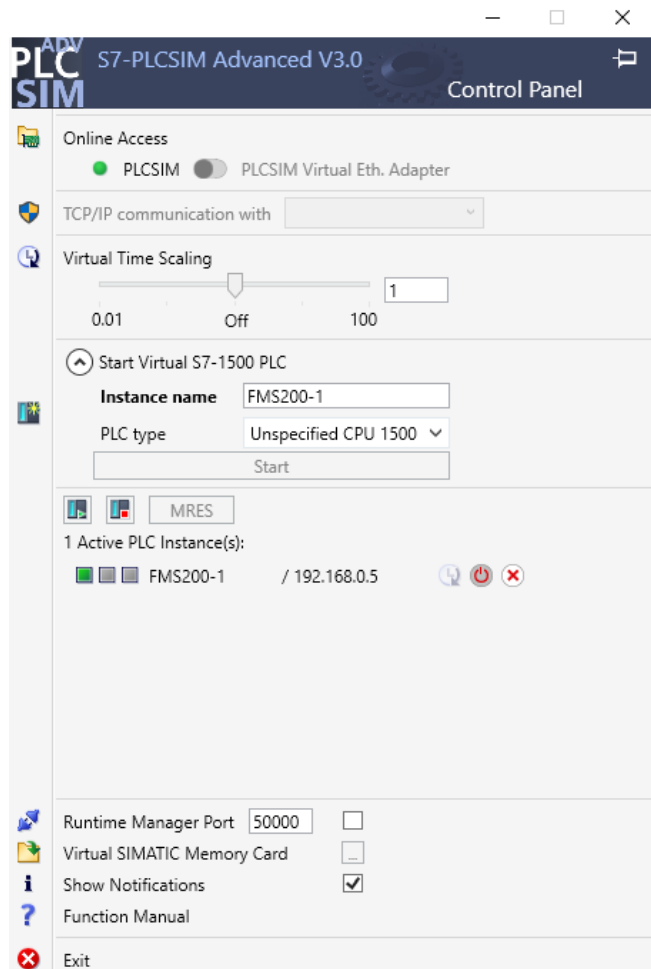


Figure 3-17 PLCSIM Advanced

After this whole process, the DT is finalised and it is possible to work with it.

4. Screwing station

This chapter gathers all the information about the process followed to create the screwing station of FMS-200.

4.1. Context and general description

As it was explain before, FMS-200 does not need all the stations to work properly and educational establishments like UCLL can choose to have more or less stations. In this case, the strewing station was omitted since FMS-207 is a robotized screwing (see Figure 4-1), in other words, it involves robotics technology, which, even though it extends the didactic capacities considerably, requires a big investment.



Figure 4-1 FMS-207 - Robotized screwing (SMC, FMS-200 - Flexible integrated assembling systems, 2022)

At the beginning of this project the station we are about to build was not empty. On the contrary, an unsuccessful model laid there. Some time ago,

Digital twin for SMC's FMS-201 and design of its screwing station

UCLL tried to create a new design without industrial robots but it failed because of its inaccuracy. Figure 4-2 shows what was in the table before this project started. There is one component out of the working space, which consists in the support of the piece. It was in charge of transporting the piece



Figure 4-2 Previous station



Figure 4-3 Previous station's screw driver



Figure 4-4 Previous station's "picker"

from the first position to the place where the screwdriver worked. Besides, it had a mechanism to spin the piece so all the screws could be screwed.

Apart from that, we could find the screwdriver on the left side and the device used to pick the piece from the conveyor belt. Figures 4-3 and 4-4 show a different perspective of both parts.

The aim of this part of the project was to design a new concept for the station, successful and as cheap as possible, having in mind its didactic mission.

4.2. Ideas of design

The major problem in the previous design implemented by UCLL was the support of the piece. It was a rotatory platform that also was able to move along a track. The source of inaccuracy was the rotation, as it worked in a pneumatic way instead of being electric.

Consequently, that component had to be removed and the first idea for replacing it was a simple track, similar to the Body support's one (see Figure 4-5 (a)). In this scenario, the piece would be placed by the vacuum already existent in the track and a cylinder would move it until the first position. This place should be reached when the piece finds an obstacle, another cylinder's head. Then two screws will be screwed, the obstacle would disappear and the first cylinder would complete its stroke. After placing the piece in this second location, the screwdriver will take on the two remaining screws. Finally, other cylinder would lead the piece until the end of the track and the vacuum will place the piece again in the conveyor belt.

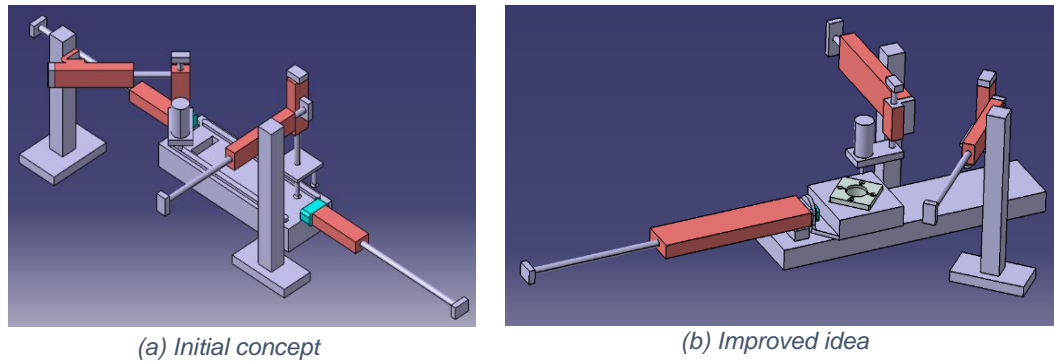


Figure 4-5 Main ideas

In this option, seven cylinders are required. Nevertheless, four of them can be reuse from the former station. This entail buying three cylinders, two of them pneumatic and one electric, since, according to the geometry of the piece (see appendix with the drawings), the screwdriver needs three different positions (see Figure 4-6).

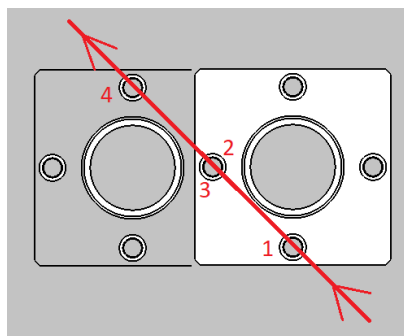


Figure 4-6 Screw driver tour path

After evaluating this first idea, some changes were suggested to improve it and make it cheaper (see Figure 4-5 (b)). The logical way to save money in this project is reducing the number of cylinders. This was the main goal of the second idea, in which eventually only five cylinders were required and just two of them had to be bought.

To move the piece in the track, two cylinders were used and one more was utilised to stop the piece in the exact place acting like an obstacle. At first sight, this last cylinder was not resistant enough so it was risky to use it. On top of that, having two cylinders just to move the work piece was not cost-efficient. Therefore, the second idea puts faith in one electric cylinder that can reach the intermediate position accurately and that has attached a box so, during the retraction, the piece follows the cylinder's head. In the next

section, you can find the different ideas proposed (and carried out) for the box. Reducing the play between box and piece the precision for screwing is not disrupted.

Another essential point is the orientation of the piece. Since the screws are not in the corners of the piece but in the middle of each side, the screwing machine had to reach three different positions and an electrical cylinder was needed. To avoid this, it is possible to change the relative position of the piece by rotating it 45° . The track shall make an angle of 45° with its previous position and the box must have the place for the piece adjusted to this condition. This way, the square made up with the four screws has parallel sides with the track. Figure 4-6 (b) shows the idea. After this correction, the screwing machine can work with a pneumatic cylinder of which stroke is the length of the square's side described earlier (see appendix with the drawings).

That aside, the machine used to pick the piece from the conveyor does not change.

4.3. 3D printing

The final idea involved a box attached to the cylinder that needed to be bought or created. Owing of the particular features required to match it with the piece, the cylinder and the design in general, 3D printing it was the solution chosen.

For this purpose, two different ideas were modelled. It is essential to bear in mind that the box must resist the pressure and possible movements while the screw machine is working. The first idea (see Figure 4-7) is a box with two stories.

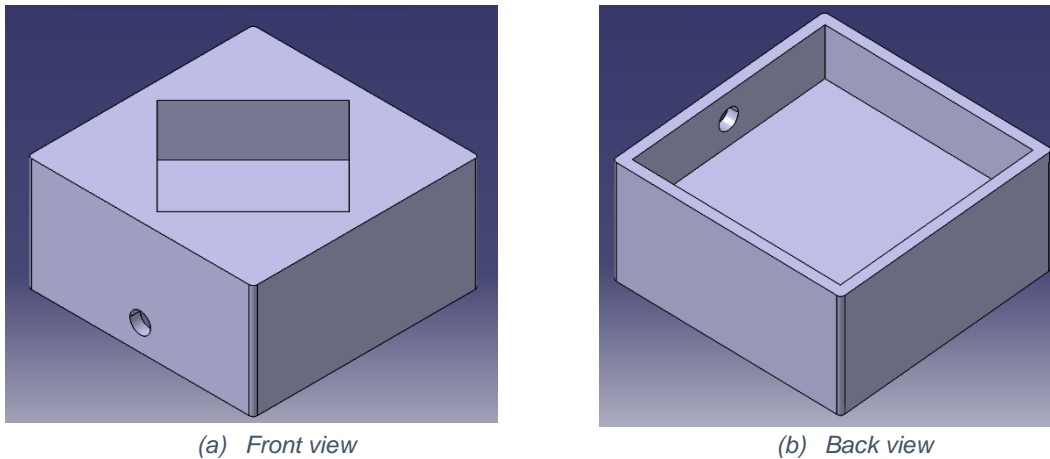


Figure 4-7 First box model

The piece must be turned 45° so as to the screwdriver just need two different positions. In this first idea, the first floor is empty and its mission is to create a solid support for the piece as well as to join the box with the cylinder. On the other hand, the second floor is supposed to hold the piece and avoid its movement.

Secondly, another box model was created (see Figure 4-8). This one is smaller and the coupling is made in a different way. Basically, the body of this box is the second storey of the first box.

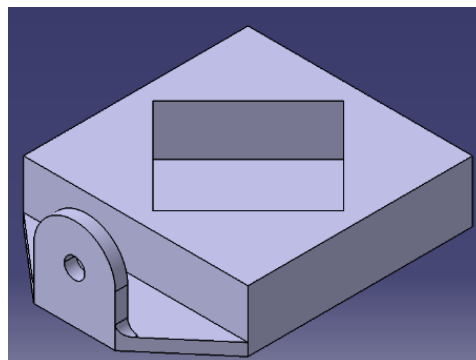


Figure 4-8 Second box model

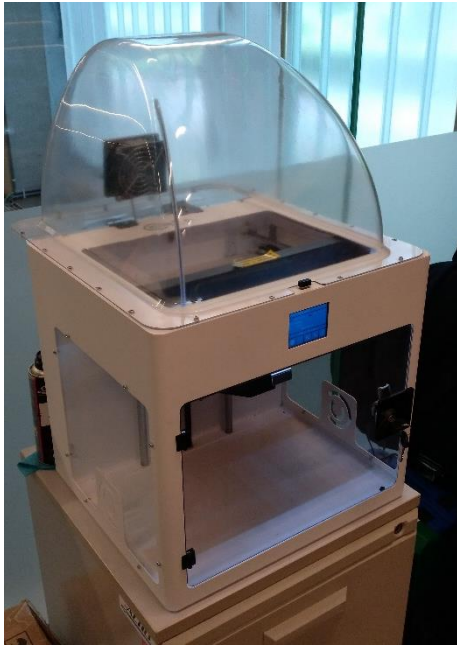
The 3D printer used in this project is called “Craftbot” and you can see it in Figure 4-9. First, there is the printer as it is showed in catalogues and then you can see the actual printer that ACRO has in campus Diepenbeek.

These devices are connected with a software called Craftware.

First of all, the models of the box were modelled in CATIA. Secondly, the CAD files were imported to Craftware as a slt files. To save time, we

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printed both models at once so in the software's interface appeared both. With Craftware we can select some features such as the density of the mesh that must be created to support the empty gaps.



(b) ACRO's Craftbot



(a) Craftbot from catalogue (Craftbot, 2022)

Figure 4-9 Craftbot

Some of the useful information given by the programme can be found below (see Table 4-1).

Properties	
Percentage of filler	30%
Time required	17:35:22
Material	PLA
Length of material needed	105'8m

Table 4-1 Printing features

As it is mentioned in Table 4-1, the material used to print the boxes is polylactic acid, also known as polylactide (PLA). Craftbot uses filaments with different materials. In Figure 4-10 we can see an example of the filaments needed.



*Figure 4-10 PLA filament
(Craftbot, 2022)*

PLA is a thermoplastic polyester, what means that it becomes mouldable or flexible when the temperature increases enough and solidifies upon cooling. It is made out of renewable and organic resources such as corn starch or sugar cane but it does not need different technologies or equipment as plastics. Table 4-2 shows some of the properties of PLA.

Property	Value
Heat Deflection Temperature (HDT)	52 °C
Density	1.24 g/cm ³
Tensile Strength	50 MPa
Flexural Strength	80 MPa
Impact Strength (Unnotched) IZOD (J/m)	96.1
Shrink Rate	0.37-0.41% (0.0037-0.0041 in/in)

Table 4-2 PLA properties (TWI, 2022)

PLA is the second most consumed bioplastic in the world and its characteristics are quite similar to polypropylene (PP), polyethylene (PE) or polystyrene (PS). Furthermore, PLA is the filament material used par excellence in 3D printing.

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Once the material is settled, some parameters of the printer are settle too. The printer has a USB Memory Stick that must be use to transfer a GCode into the device. Before starting the process, cleaning the glass plate with alcohol it is essential. Then, the file will be chosen and the operations will start. The first step is heating the plate (parameter called **B** in Figure 4-11 (a)) and the head used to extrude the material (parameter called **H** in Figure 4-11 (a)).



(a) Printer's screen before starting

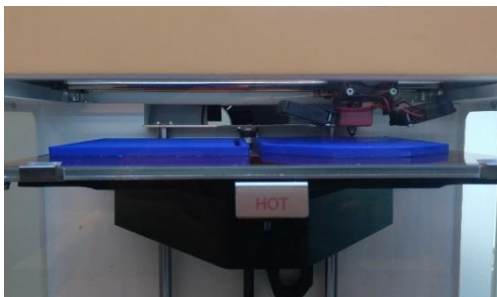


(b) Printer's screen after finishing

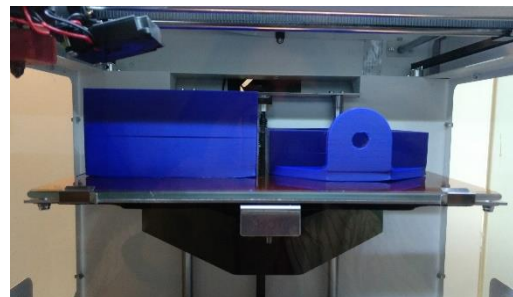
Figure 4-11 Printer's screen

Taking into account the information given by Craftware, it takes more than 17 hour to complete both models. In Figure 4-12, we can see the pieces after 4 hours of printing and when they were finished.

After the whole process, the printer's screen shows what we can see in Figure 4-11 (b). On this occasion, the time employed was 20:48:30, more than the one estimated by Craftware, and the length of filament 105.761m.



(a) After 4 hours printing



(b) Pieces finished

Figure 4-12 Printing stages

4.4. Workshop

This section briefly outlines the process carried out in order to make some pieces needed in the screwing station. Earlier, it has been highlighted the goal of reach a reduced budget for this part of the project, and, because of it, most of the pieces are going to be reused from the previous station.

However, likewise the 3D printed boxes, UCLL does not have some pieces that can be either bought or made. In this case, we opted for the second option.

In appendix A of drawings, we can find the three kind of pieces that must be order to the workshop. All of them are supports for other pieces: the one called “support” adjusts the height and offers support for the cylinder that moves the piece along the track; then, “small base” will support the track and “big base” will support the picker and the screwdriver.

Since they are simple pieces the creation process consists of three stages: sawing, milling and drilling.

All the pieces have the same height, hence they are made from the same block of aluminium. Firstly, a saw must cut them according to their shape, which is available in the Appendix A. The machine used for this purpose is shown in Figure 4-13.

For the remain operations, the same machine is going to be used: 3-axis CNC milling machine XYZ KMX 2000 (see Figure 4-14).

The mill must cut the corners in a chamfer as well as the oval silhouettes that will be used to attach the supports to the table. For its part, the drill is in charge of the different holes that the pieces have.

Digital twin for SMC's FMS-201 and design of its screwing station



Figure 4-13 Saw



Figure 4-14 KMX 2000

4.5. Budget

A relevant aspect of this second part of the project was the budget. For this reason, this section tries to show an accurate estimated cost by evaluating four key aspects: cost of human resources, cost of the pieces created in the workshop, cost of 3D printing and cost of the components bought.

To start with, a mechanical engineer for the design of the station composes the human team with a programmer, who must be in charge of the development of the program. Furthermore, a senior engineer expert in PLC programming will be required to supervise the fulfilment of the goals and the appropriate progress of the work. Table 4-3 presents the average salaries that are going to be considered for calculating the final budget.

	€/month	€/hour
Junior programmer	3.180	19,88
Senior programmer	7.660	47,88
Junior mechanical engineer	3.260	20
Senior mechanical engineer	7.840	49

Table 4-3 Average salaries. Sources: (Salaryexplorer, Mechanical Engineer Average Salary in Belgium 2022, 2022) , (Salaryexplorer, Developer / Programmer Average Salary in Belgium 2022, 2022)

With regard to the pieces made in the workshop, the salary of the workshop mechanic has been bared in mind as well as the material. These factors contribute to the final price in a measure that table 4-4 shows.

Material [€]	27
Hours of work [h]	6
Mechanical chief salary [€/h]	23,44
Cost [€]	167,63

Table 4-4 Cost of the workshop pieces. Source: (Salaryexplorer, Mechanic Average Salary in Belgium 2022, 2022)

In the second place, an estimation of the 3D printing cost is justified in table 4-5.

Electricity's price [€/kWh]	0,2994
Electricity consumed [kW]	0,5
Price per hour [€/h]	0,1497
Hours of use [h]	20,81
Cost of electricity [€]	3,12
Junior mechanical engineer [€/h]	20
Design time [h]	3,5
Senior programmer [€/h]	47,88
Preparation time [h]	0,5
Cost [€]	93,94
Amortization [€]	6
Material's cost [€/kg]	25,37
Length used [m]	106
Weight [kg/m]	0,003
Material costs [€]	8,07
3D printing costs [€]	111,12 €

Table 4-5 Cost of the 3D printing

Last but not least, the cost of the new devices must be taken into account. For this project, three cylinders have to be bought. However, the price of these components are not included in the last budget but must be consider when implementing the station.

Finally, Table 4-6 collects all the individual costs reaching the final budget of the entire project.

Digital twin for SMC's FMS-201 and design of its screwing station

	Hours	Cost
Preliminary researches and ideation		
Junior mechanical engineering	30	611 €
Junior programmer	5	99,38 €
Senior programmer	4	191,50 €
Design, programming and execution		
Junior mechanical engineering	130	2.648,75 €
Junior programmer	50	993,75 €
Senior programmer	15	718,13 €
3D printing costs		111,12 €
Workshop pieces cost		167,63 €
Total budget		5.541 €

Table 4-6 Budget

5. Conclusions

The purpose of this final chapter is to offer an overview of the results of the project as well as some ideas of improvements. It will also review the limitations of the study and propose opportunities for future research.

5.1. Results

First, this thesis aimed to develop a digital twin of the body supply station. The results indicate that the DT has been developed correctly and completely. The implementation has been carried out by two different software, NX and TIA Portal, what has led to the culmination of the project.

In view of these results, it can be concluded that the digital twin has been an absolute success.

Additionally, the second part of the project strived for creating a new design of the screwing station avoiding robotic technologies. This objective was satisfactorily fulfilled and, along this document, the new design has been explained and compared to other options. Besides, parts of the station have already been created.

5.2. Future work

Since this thesis has two distinguishable parts, this section will separately focus on both topics.

On the one hand, the digital twin was a success since it worked properly. However, UCLL owns six different stations of FMS-200 and after finishing the screwing stations there will be seven. Hence, creating the digital twins of the rest of the stations will provide a global insight of DT and this concrete system.

On the other hand, due to the delays of the order, it has not been possible to receive the new cylinders before the end of this thesis so the logical next step should be to install them and check the proper behaviour of the station.

Besides of that, this station could be improved by changing the screwdriver for an electric one. This way it will be possible to control the position and speed. This will be a remarkable improvement since the actual machine is too fast and it can generate diverse problems in the implementation.

5.3. Ideas of improvement

Saving energy in manufacturing processes is an important issue in industry since the economic profit is the main goal for most of the companies. This project has been developed in an educational environment and the use of FMS-200 is mainly instructive. However, the components are used in real industries so it could be interesting to suggest some ideas and give an overview of saving solutions.

Through this energetic approach, we propose to save energy in the vacuums. In more than one station, vacuum pads are used to move the

piece. However, the power of suction used is more than what is needed so reducing it can entail a significant save of energy and money.

Furthermore, all of the cylinders are propelled in both ways, extension and retraction. Nevertheless, some of them are capable of going back to their place when the flow of air stops. Therefore, not propelling them in the retraction will also suppose saving.

Appendix A

Drawings

H G F E D C B A

4

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2

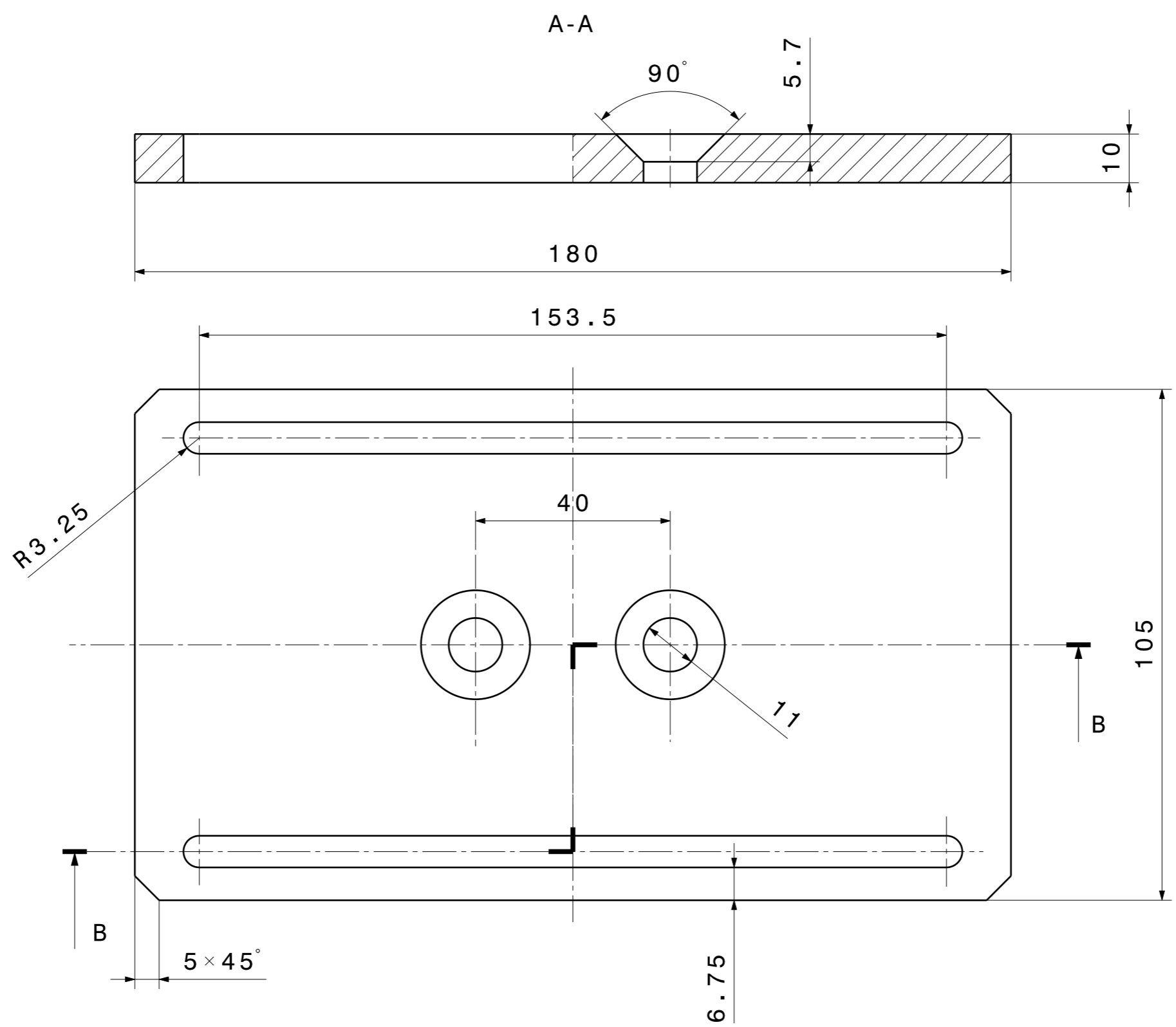
1


4

3

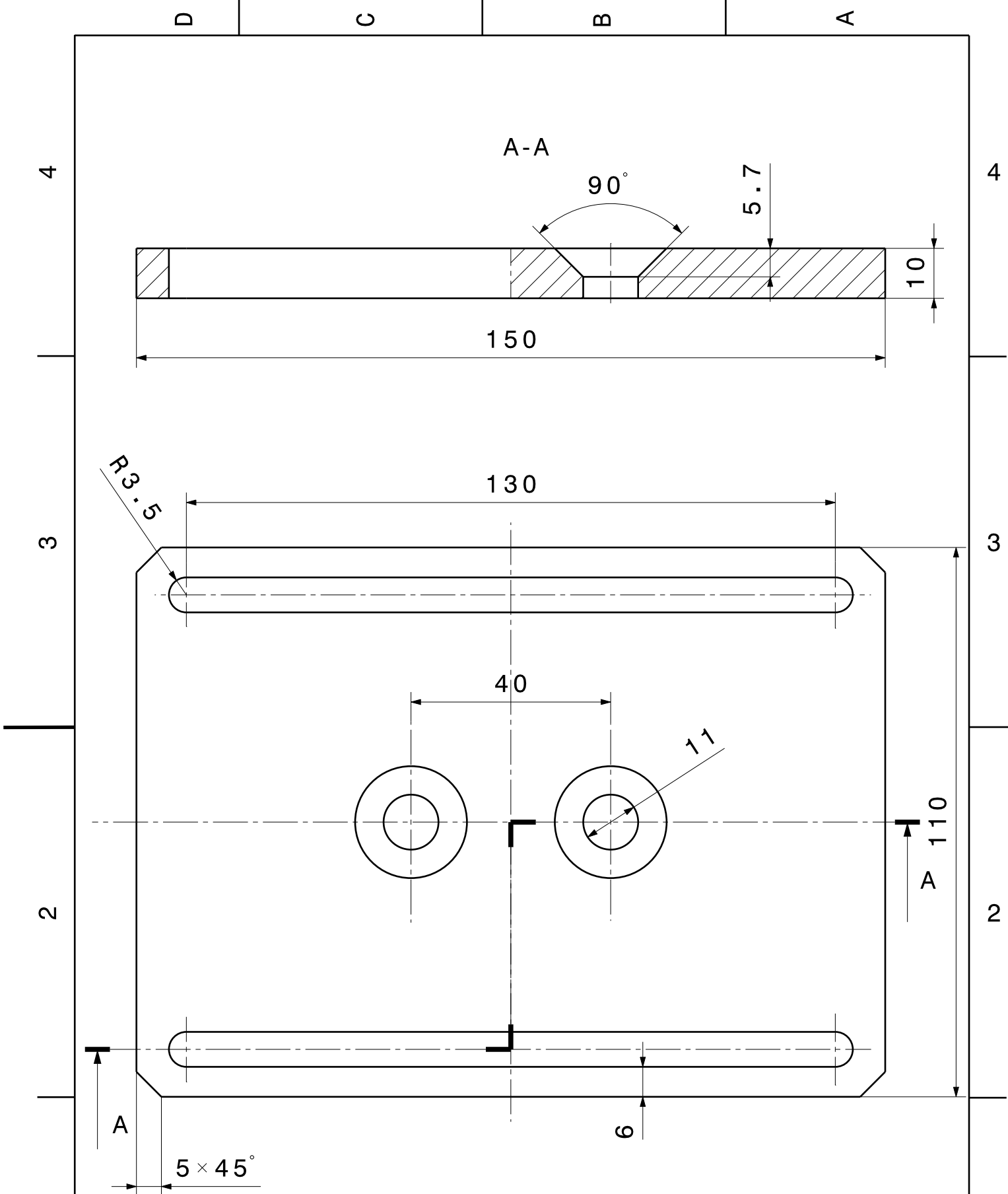
2

1



Project Screwing station	UC Leuven Limburg		
	Big base		
Signature: 	SCALE 1:1	DATE 19/05/2022	SHEET 1/6
Designed by: Julia Rubio Martín	Mechanical Engineering		SIZE A3

H G B A



Project: Screwing station	UC Leuven Limburg		
	Small base		
Firma	SCALE 1:1	DATE 19/05/2022	SHEET 2/6
Designed by: Julia Rubio Martín	Mechanical Engineering		SIZE A4

D C B A

4
3
2
1

4
3
2
1

D

C

B

A

4

4

3

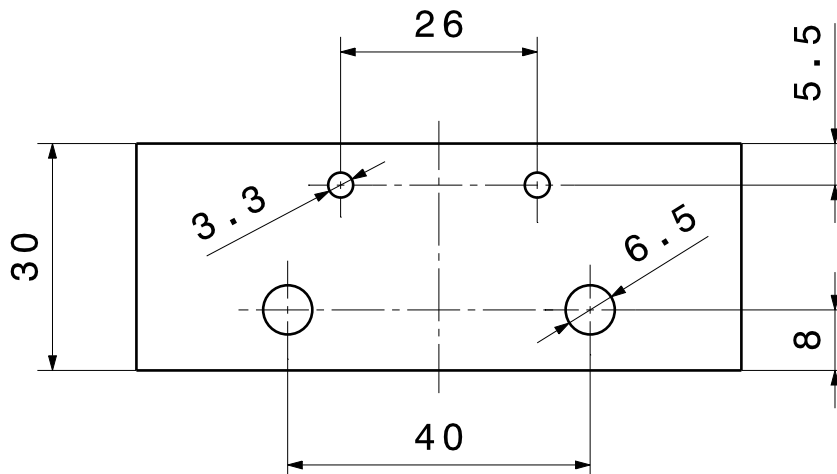
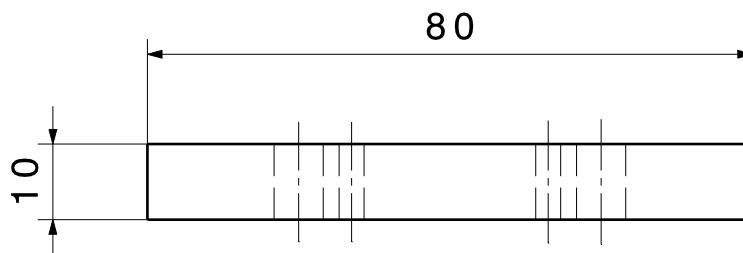
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2

2

1

1



Project:
Screwing
station

UC Leuven Limburg

Firma



Support

SCALE
1:1

DATE
19/05/2022

SHEET
3/6

Designed by:
Julia Rubio Martín

Mechanical
Engineering

SIZE
A4

D

C

B

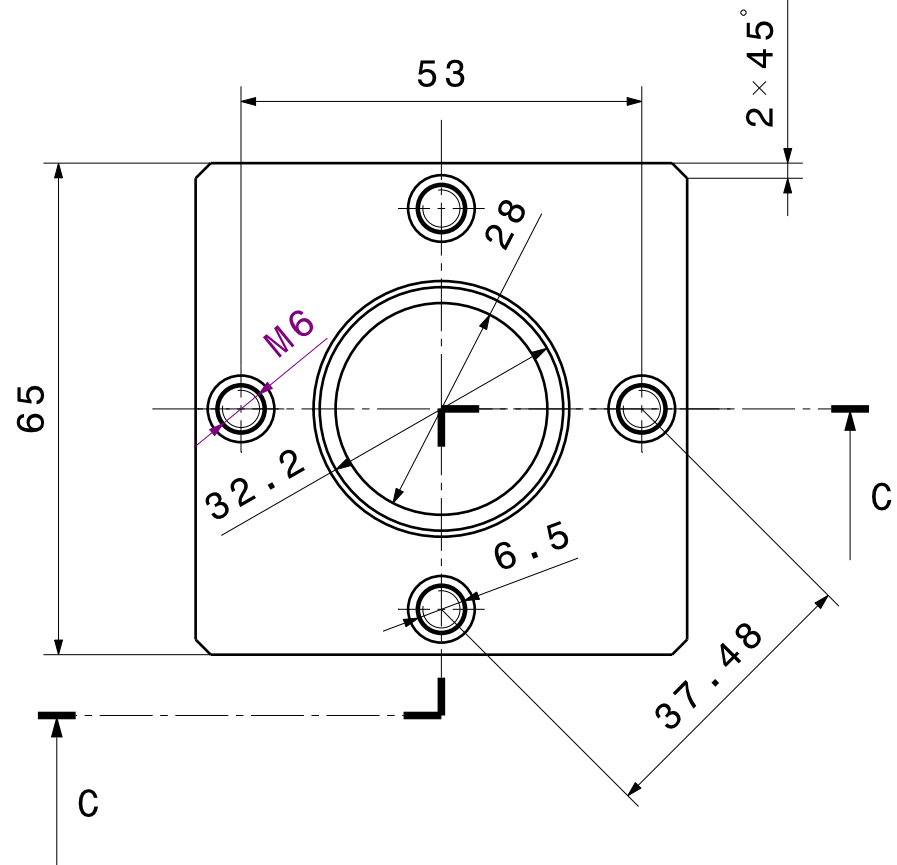
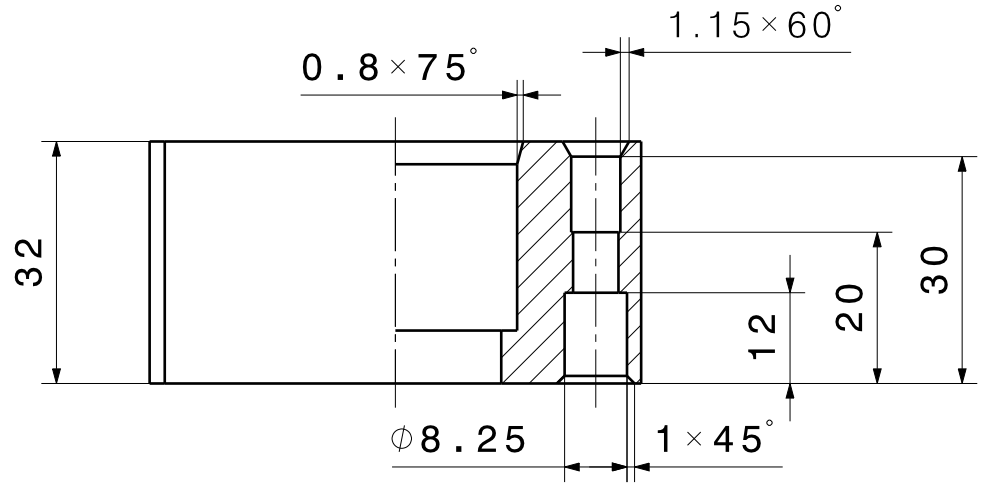
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4
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D C B A

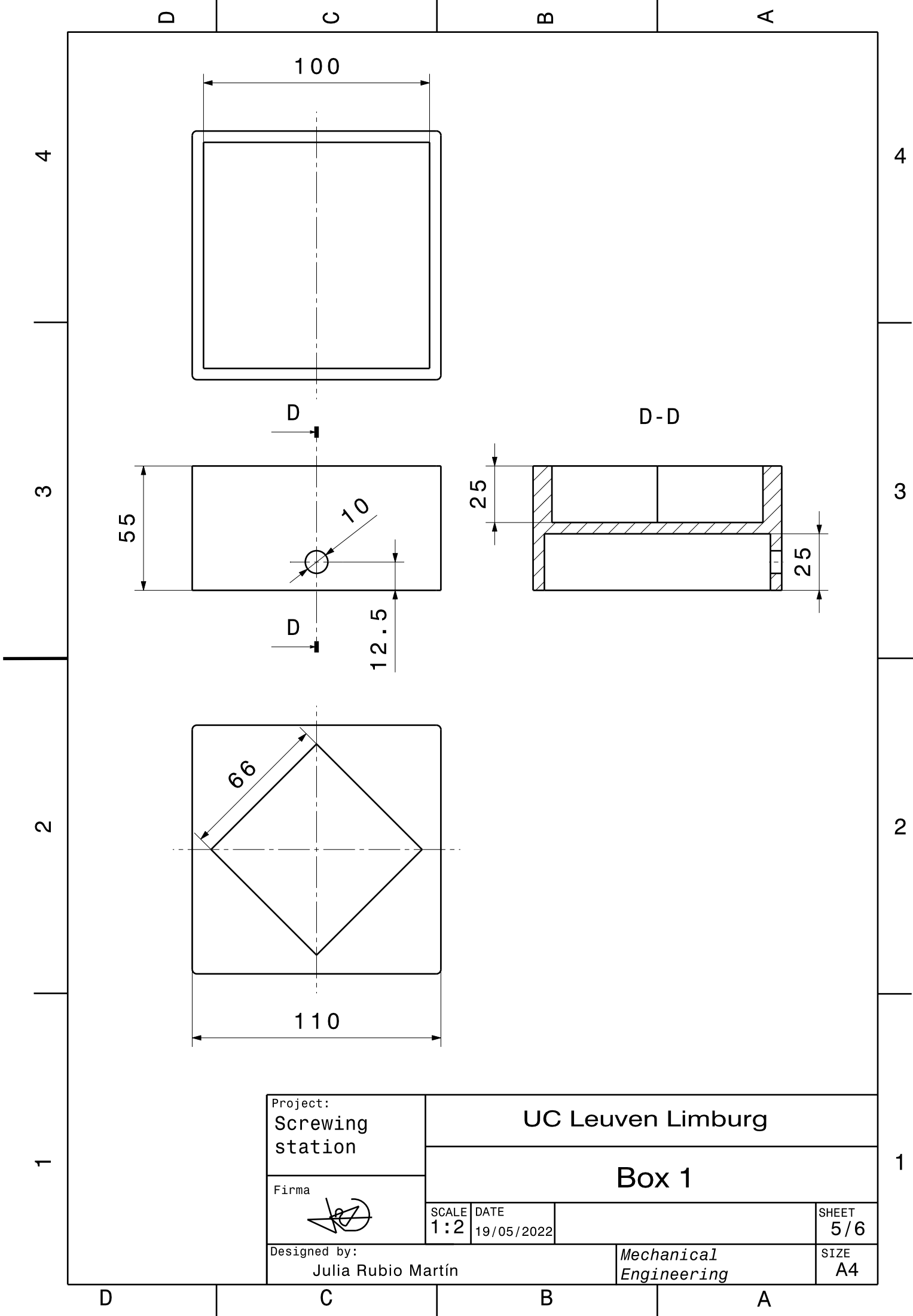
4
3
2
1

C-C



Project: Screwing station	UC Leuven Limburg		
	Piece		
Firma 	SCALE 1:1	DATE 19/05/2022	SHEET 4/6
	Designed by: Julia Rubio Martín		Mechanical Engineering

D C B A



Project:
Screwing
station

UC Leuven Limburg

Firma


Box 1

SCALE
1:2

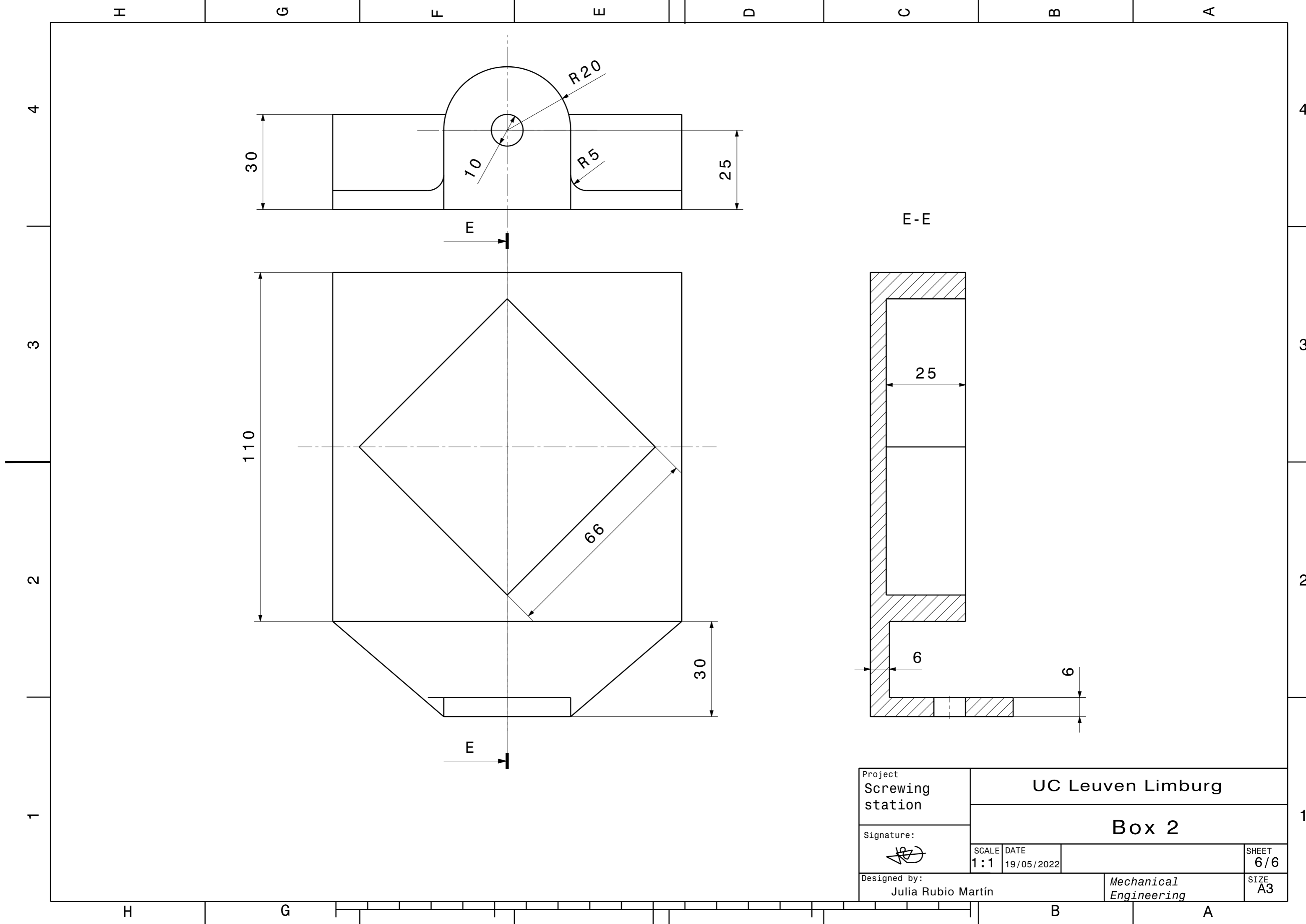
DATE
19/05/2022


SHEET
5/6

Designed by:
Julia Rubio Martín

Mechanical
Engineering

SIZE
A4



Project Screwing station	UC Leuven Limburg		
	Box 2		
Signature: 	SCALE 1:1	DATE 19/05/2022	SHEET 6/6
Designed by: Julia Rubio Martín	Mechanical Engineering		SIZE A3

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