Didactic workstation with Beckhoff electric motors

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Master Thesis

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Abstract

Nowadays, most areas of the industry employ automated systems. As such, knowledge on how each system works, their main components, interactions and software used become a main learning point for all future engineers willing to focus on automation.

As such, the present work intends to upgrade a didactic station for the study of electrical motors by assembling a linear axis driven by a servomotor and configure the software.

To do so, research on didactic stations available in the market was realized, to verify the most common exercises, and verify points of interest related to the operation of motors. Alongside it, a list of all available components was made, to gather knowledge of the available functionalities.

It was required the design and acquisition of a flange/coupling system for the linear axis and the servomotor.

A program, based on Beckhoff's work environment, was developed, providing a basic set of controls, tools, and examples for the users, alongside a simple display of information. The focus of the program was setting up the servomotor to be able to be controlled on different control types, such as torque, position, and velocity.

It was necessary to verify the functioning of these control types, and verify the information acquired via the interface of the program. It was also verified the step response of the system and the loss of steps in the stepper motor due to starting velocity.

Banca Didática Com Motores Elétricos da Beckhoff

Resumo

Atualmente, uma grande parte da indústria opera com base em sistemas automatizados. Desta forma, o conhecimento sobre o funcionamento do sistema, dos principais componentes, interações e softwares utilizados torna-se um ponto principal de aprendizagem para futuros engenheiros de automação.

Assim, o presente trabalho pretende atualizar uma banca didática para o estudo de motores elétricos através da montagem de um eixo linear acionado por um servomotor controlado através da definição de uma interface desenvolvida para o efeito.

Assim, foi realizada uma pesquisa sobre as bancas didáticas disponíveis no mercado, de modo a verificar os exercícios mais comuns e pontos de interesse para o estudo de motores. Ao mesmo tempo, foi efetuada uma lista de todos os componentes disponíveis, com o objetivo de verificar as funcionalidades disponíveis.

Foi necessário o projeto e aquisição de acoplamento e uma luneta para o eixo linear de modo a integrar o servomotor.

Um programa, baseado no ambiente de trabalho da Beckhoff, foi desenvolvido, fornecendo um conjunto básico de controlos, ferramentas e exemplos para os utilizadores, além de fornecer uma interface simples para a visualização de informação. O foco principal do programa foi a configuração do servomotor, de modo a possibilitar o controlo em diferentes modos, como binário, posição e velocidade.

Foi necessário verificar o funcionamento desses tipos de controlo e verificar se as informações adquiridas através da interface do programa eram corretas. Foi verificado, também, a resposta ao degrau do sistema, e a perda de passos do motor passo-a-passo, devido à velocidade de arranque.

Acknowledgement

First, I want to thank my supervisors, Prof. Paulo Abreu, and Prof. Manuel Romano Barbosa, for this big opportunity in this project, and for the liberty on this project, for allowing me to make mistakes, and helping me understand them, allowing me to grow as an Engineer, and as a person, and for the availability to help me and share their knowledge.

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Abbreviations

AC – Alternated Current
CNC – Computer Numerical Control
DC – Direct Current
DVI-D – Digital Visual Interface, digital only
DIN – “Deutsches Institut für Normung” or “German Institute for Standardization”
HMI – Human-Machine Interface
I/O – Input/output
LED – Light-emitting diode
OCT – One Cable Technology
PID – Proportional–Integral–Derivative controller
PLC – Programmable Logic Controller
RAM – Random Access Memory
USB – Universal Serial Bus

1 Introduction

Nowadays, most areas of the industry employ automated systems, ranging from simple transportation systems to fully fledged production systems. As such, knowledge on how each system works, their main components and interactions, compatibility between components and software used by such systems become a main learning point for all future engineers willing to focus on automation.

With this thesis, it is provided a didactic workstation for the students and instructors of the university, with the objective of giving them another platform and means of learning and teaching about one of the main driving components of most automated systems: electric motors.

The focus is to present a variety of examples and information able to show the limitation and uses of servomotors and stepper motors, as an introduction, allowing the students to explore and test the system at their will and pace, giving them a first-hand experience on the inner workings and components required for them to work, while the instructors have tools and the possibility of modifying some parameters of the examples.

The experiments present in the didactic station focus on three topics, the physical and electrical side of the motors, including the study of variables like the speed, position, and torque, and the programming, making use of Beckhoff's work environment. The objective is to provide information, not only on the motors themselves, but also on the software used. By doing so, knowledge on normalized programming languages is given, with the objective of providing an introduction on most of the configurations and setup required for these systems.

For this, it is implemented a linear axis driven by the servomotor, alongside the implementation of a working HMI (Human-Machine Interface) capable of showing the behaviour of the motor, and how it changes with the presence of external influences. A predefined file is provided, with all the program and tools to do a full analysis of a great number of variables associated with the motor. It is also designed an equivalent system for the stepper motor, with the hopes of a future expansion that allows students to verify, not only the use and limitation of a stepper motor, but also the use of both motors as a two-axis table, including communication to coordinate movement, showing the students the level of communication and programming required.

1.1 Contextualization

This project appears in the context of a Thesis for the Mechanical Engineering Master's degree of the "Faculdade de Engenharia da Universidade do Porto".

Based on an available set of two electric motors from Beckhoff, the interest of this project is to create a workstation to provide the physical means for interaction and learning. The motors and respective drives are examples of widely used components in the industry, including, but not limited to, automation lines, numerical control machines (CNC) and robots. The functionalities allow instructors to modify values and possibly the program to better suit the needs of each learning topic.

The thesis also provides insight into the programming of systems using these types of components by presenting the software used, alongside several examples and their code, as to expose readers to the software and its limitations.

1.2 Objectives

The main objective is to fully design a didactic workstation to operate with electric motors, a servomotor, and a stepper motor, from the industrial supplier Beckhoff. A set of experimental tests are provided for both motors, with the objective of highlighting how the system works and showing certain specifications of the involved hardware. As such, the objectives can be defined as the following:

- Design and implementation of a linear axis, driven by the currently available servomotor.
- Design of support and transmission solutions for the currently available stepper motor.
- Creation of a program for the industrial computer, with a user interface.
- Definition of a set of experimental tests for demonstration purposes for both motors.
- Validation of the created experiments.

1.3 Thesis Structure

The present chapter, Chapter 1, introduces the basic information about this thesis, such as the objectives, contextualization, and structure of the work.

The following chapter, Chapter 2, focus on the existing solutions of didactic workstation and the workstation currently available for this work. On this chapter, it is presented five configurations of market available didactic workstations, using them as a basis to gather knowledge and information about this topic. Following that, it is presented the current workstation, and a comparison between them. Based on this analysis it was decided the approach to expand and upgrade the current system.

Chapter 3 delves into the design of the transmission system and presentation of the components of the current workstation and the components provided to expand it, alongside the design of the solutions for the servo and stepper motors. The design focus on a linear axis driven by the servomotor, with the objective of allowing a secure mechanical transmission. For the stepper motor, the focus is the design of a solution based on either a rotational or a linear axis.

Chapter 4 presents the programming software platform and work done with it. This includes the presentation of the virtual HMI developed and the experiments provided, while also showing some of the code used to program the system. For further insight, basic results obtained from several experiments and tests of the system are provided.

Chapter 5 presents conclusions, future ideas and projects related to the work done.

2 Overview of existing didactic stations

This chapter presents various existing solutions for didactic workstations available in the market and the existing system used in this work.

Firstly, it is presented five examples available on the market, gathering information on their components, tests, modularity, and functions. Such points are being researched to understand how these workstations fair in presenting their users with knowledge of the motors and its functionalities, while allowing them to expand and explore these with little restrictions. It is also investigated the types of motors and drives provided by them as to compare them to market available servomotors, to understand compatibilities and functions shared between them. Following the research, it is described the current didactic workstation, and its main functionalities.

To conclude the chapter, it is presented a comparison between them, identifying the possibilities of improvement for the existing system, either through an upgrade of existing components, or through a new design.

2.1 Market Didactic Stations

Computer Controlled Modular Control and Regulation Unit, RYC/T

Designed by Edibon [1, 2], this didactic system has the objective of teaching its users the most important concepts related to electric motors and other systems. As such, our focus is on three available modules:

- RYC, Computer Controlled Teaching Unit for the Study of Regulation and Control [3, 4].
- RYC-SM, DC Servomotor Module [2, 4, 5].
- RYC-CP, Position Control Module [4, 6].

The RYC module (Figure 1) is the main control system, used to simulate a variety of control systems, such as first and second order systems, and allows the simulation of perturbations within the driven systems. Included with this system is a “PID (proportional–integral–derivative controller) Computer Control + Data Acquisition + Data Management Software”, which allows the connection of the module to a separate computer and the ability of controlling and observing information. While this allows to modify the experiments, there’s no information on whether it’s possible or not the creation of custom experiments. It can be concluded, however, that the existence of customization of the parameters, and existence of a simulator for perturbations increases the variety of experiments and situations that can be studied.

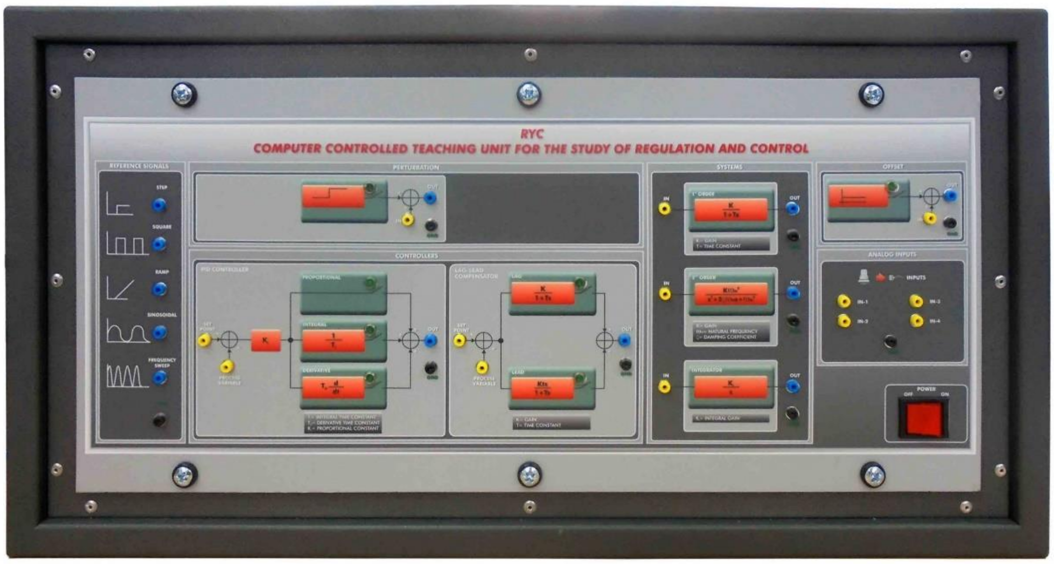

Figure 1 - RYC module [3]

The RYC-SM (Figure 2) and RYC-CP (Figure 3) modules make use of a DC servomotor. In the case of the RYC-SM module, the motor is connected to a gearbox to study the control of system in different ways, such as open loop, closed loop, position or velocity.

Figure 2 - RYC-SM module [5]

Figure 3 - RYC-CP module [6]

The RYC-CP module, while doing basically the same type of study, includes a linear axis, focusing its study on the linear movement.

However, one of the main limitations of these modules is the fact they are only able of conducting experiments while the motors are being controlled in velocity or position control. As such, the study of torque and current is not possible without the acquisition of new components and modification of the modules.

AE-SMI Servomotor Industrial Application

The AE-SMI [7, 8], also known as Servomotor Industrial Application, represented in Figure 4, is a didactic system designed by Edibon. As to showcase the different types of control in a variety of applications, this system allows the user to implement different control types used in motion technology (position control, speed control, torque control, position and speed control, speed and torque control and position, speed, and torque control at the same time), Different modules that represent different types of systems in the industry, like rotary tables, linear axis, conveyor belts are available to be used. This system also allows the integration of an external PLC, allowing it to control the AE-SMI or a specific module, expanding the possibilities and experiments able to conduct.

Figure 4 - AE-SMI and correspondent modules [7]

The system allows a full configuration of the PID parameters, alongside other configurable parameters, such as torque and speed limits, types and configuration of the input, accelerations and decelerations, and others, allowing for a full configuration of the motion being executed. As such, this system works with both mechanical and electrical variables, allowing the user to control the system with both, while being able to limit them to the application it has in mind.

For the configuration, observation and control of the applications, the system can be connected to a computer which, alongside the supplied software, allows its user to configure the parameters, as it was mentioned, and to monitor and analyse the application that it’s currently being used.

As for the modules of this system, aside from the main control module, the system can work and be integrated with other five modules, meant to represent different types of applications of servomotors in the industry [8]:

- Servomotor with adjustable brake.
- Servomotor with linear axis.
- Servomotor with conveyor belt.
- Servomotor with rotary table.
- Servomotor with machine press.

Didactic workstation for the study of servo drives, by WideTech

Provided by WideTech [9], this didactic workstation (Figure 5) presents the different types of motion control of servomotors. It presents a linear axis driven by the servomotor, by using a belt driven mechanism to accomplish such. It comes with an electromagnetic brake and a mass of 2 kg, allowing the user to create physical variations in the system, being the mass on top of the axis, or the brake creating a resistant torque.

Figure 5 - Didactic workstation for the study of servo drives, by WideTech [9]

The system provides the necessary software for the control and modification of parameters of the servo drive. As for the servo drive, it comes with additional input and output connections. The system allows the servomotor to be controlled in position, velocity, or torque, allowing the study of both mechanical and electrical variables, such as position, velocity, torque and current.

MR241E Dynamic Control System Applications Trainer, by Minrry

As perceived in Figure 6, the MR241E [10] is a large workstation for the study of multiple kinds of servomotors and stepper motors. Quoting part of Minrry’s [10] introduction on the product, “through experiments, students and teachers will be familiar with servo motor function features, master control principles, cultivate students’ ability to knowledge and technical skills, it’s suitable for technical schools, colleges, training institute, technician schools.”.

The system features a set of AC and DC servomotors, and a stepper motor for the experiments it aims to provide. A list of these experiments can be seen in the following tables, Table 1, Table 2 and Table 3.

Figure 6 - MR241E Dynamic Control System Applications Trainer [10]

Table 1 - MR241E Dynamic Control System Applications Trainer AC servomotor experiments [10]

AC servo motor – Available experiments
Static test
Principal features and function test
Start function control
Servo position Control
Angular displacement experiment
Linear displacement experiment
Slow down position control
Motor loader test feature experiment

Table 2 - MR241E Dynamic Control System Applications Trainer DC servomotor experiments [10]

DC servo motor – Available experiments
Static test
Principal features and function test
Start function control
Servo position Control
Angular displacement experiment
Linear displacement experiment
Slow down position control
Motor loader feature experiment

Table 3 - MR241E Dynamic Control System Applications Trainer Stepper motor experiments [10]

Stepper motor – Available experiments
Static test
Principal features and function test
Open loop control
Closed loop Control
Angular displacement experiment
Linear displacement experiment
Slow down position control
Step motor loader feature experiment

Equipment set TP 1422: Stepper motor drive technology, by Festo

Being an introductory set of equipment into the stepper motor subject, provided by Festo [11], this system, as seen in Figure 7, provides a stepper motor and an integrated simulation box, alongside a software with introduction to the topic of stepper motors, their application and components.

The simulation box serves as the control centre for the stepper motor, allowing the connection of inputs for the control of the system, while also displaying the state of output variables. According to Festo, “The integrated simulation box allows the connection of the required inputs and displays the states of all-important outputs. This allows convenient operation without any additional hardware. The analogue and digital SysLink interfaces make it easy to integrate the drives in complete systems for explaining additional content.”

Figure 7 - Equipment set TP 1422: Stepper motor drive technology [11]

According to the manufacturer, the basic training content focus on teaching the following [11]:

- Components of a drive system.
- Design.
- Commissioning.
- RPM regulation.
- Homing.
- Positions.
- Ramps.

2.2 Existing Didactic Station

Currently, the laboratory has a didactic station to be worked on. This system was developed by a master student for its thesis [12]. The workstation is seen in Figure 8.

In Figure 9, it’s possible to verify a basic scheme representing the architecture of the workstation.

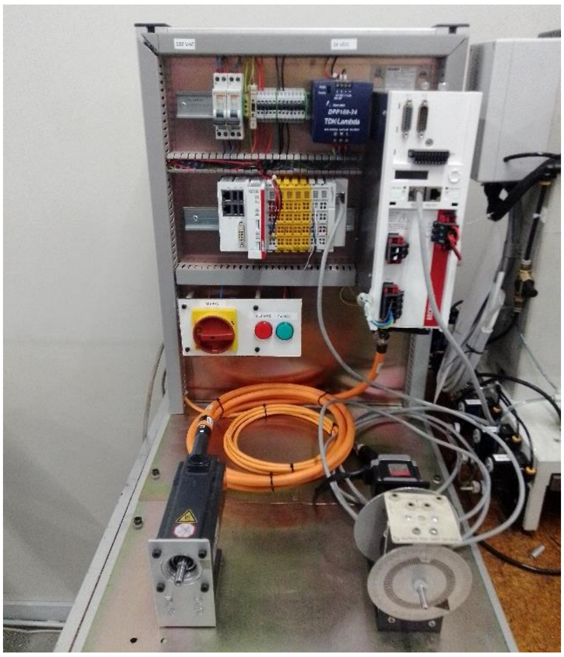

Figure 8 - Available Didactic Station

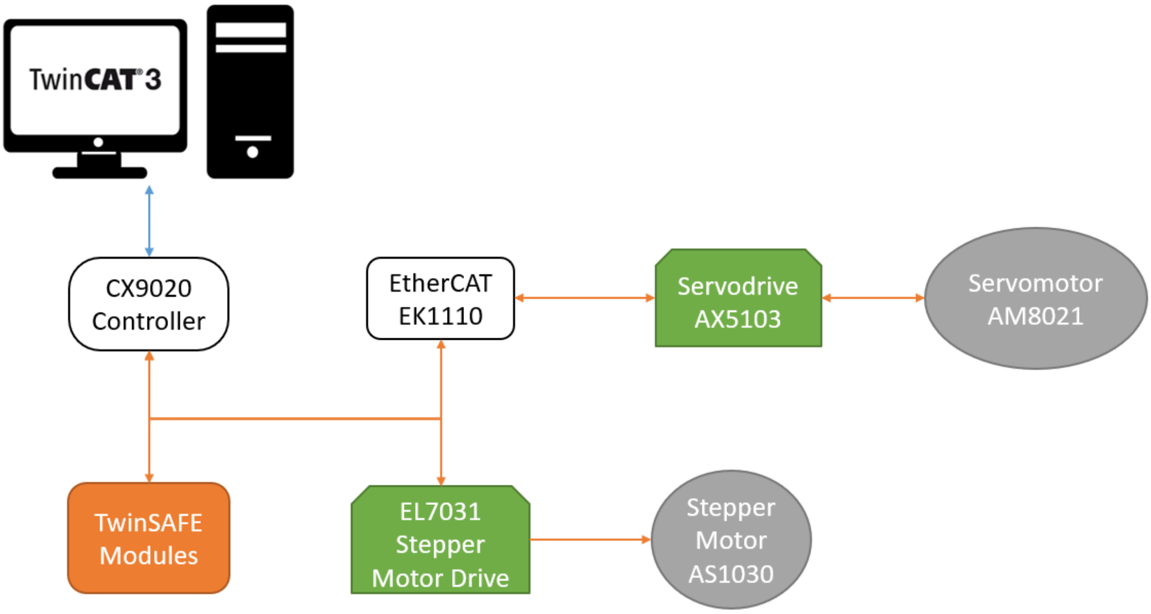

Figure 9 – Structure of the existing didactic station

Status of the station

The station is built around Beckhoff components. Those components (Figure 10 and Figure 11) include:

- An industrial computer, CX9020.
- Three TwinSAFE modules, EL6900, EL1904, EL2904.
- An EtherCAT, EK1110, interface.
- A stepper motor driver, EL7031, and the corresponding stepper motor, AS1030.
- A servomotor driver, AX5103, and the corresponding servomotor, AM8021.

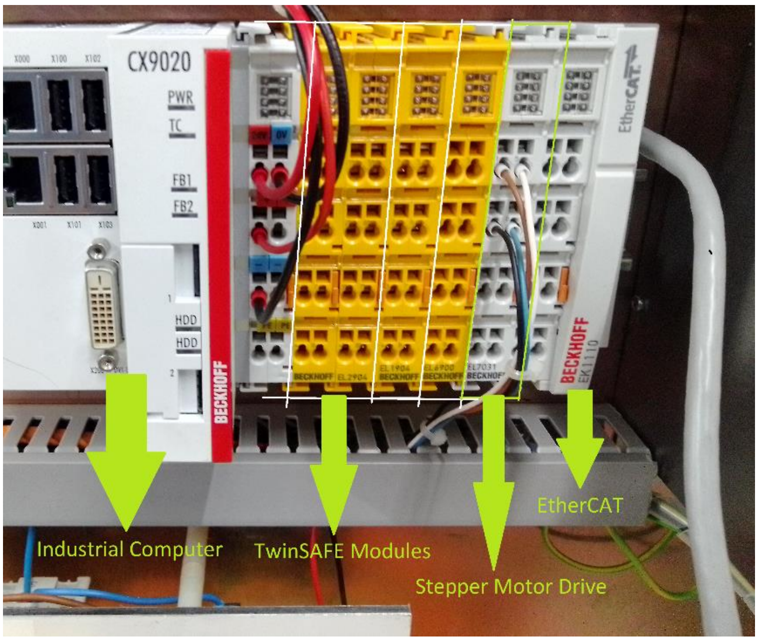

Figure 10 - Didactic Station Components (CX9020, EL6900, EL1904, EL2904, EK1110, EL7031)

Figure 11 - AX5103, Servomotor Drive

The system is connected to a local computer, which serves as the interface between the station and the user. Through this computer, it’s possible to access the HMI screen by opening the programming software, TwinCAT, and logging in to the station, or by downloading the program from the industrial computer. This allows the user to, not only update and verify multiple inputs, outputs, and other variables of the system, change, and update the code, but also run the system as intended.

After the analysis of both the previous thesis and the current system, it was verified that the system worked as it was intended.

Current Program

The current program in the system provides a basic set of examples and information, while being controlled by the following HMI, present in Figure 12.

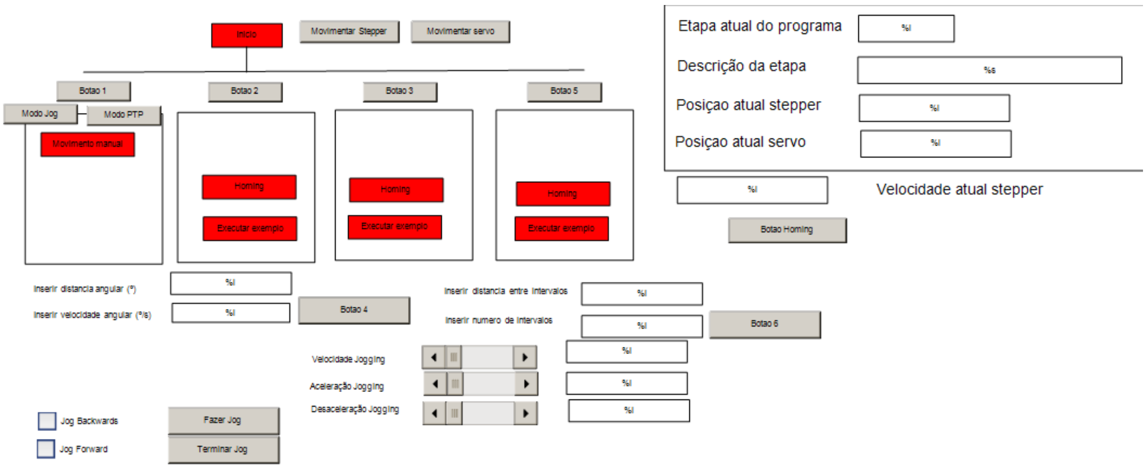

Figure 12 - Current HMI

It was verified that the information that it presented was based on mechanical variables, such as speed and position, with these being displayed on the screen during the tests.

Currently, it provides a basic set of 4 examples for each electric motor, with basic configuration of the operating parameters.

2.3 Conclusion

Providing an insight into some of the available solutions present on the market for the study of motors, it was verified that, unlike the stepper motor, the servomotor had a bigger share when it came into the didactic stations market. Such can be justified since, on the current level of the industry and automation, the servomotors are of a higher importance and usage than the stepper motors, as the servomotors are present in most of the automation systems, from conveyor belts to CNC, due to its qualities as a motor, being extremely precise at all speeds and torques.

In specific, about the didactic systems for servo and stepper motors, it was verified that most of the systems were able to provide a good insight into the control and components of these motors and their drives. It was verified that most of the systems focused solely on the types of motion control and regulation for these motors, while some went further, and applied external forces or even allowed regulation of variables associated with the control loop of the motor and drive as to vary the conditions used to study the mechanical and electrical variables of the motors, such as velocity, torque, current.

Some systems are configured with the motors connected to linear axis and rotational tables, to better simulate a situation where the motor is working in a specific way, with a specific objective, allowing the students to analyse its work in a different perspective, exploring the principles of the motors and controllers.

A summary of these five didactic stations can be seen in Table 4.

Table 4 - Summary on Commercial Didactic Stations

	Didactic Stations				
	Computer Controlled Modular Control and Regulation Unit, RYC/T	AE-SMI Servomotor Industrial Application	Didactic workstation for the study of servo drives	MR241E Dynamic Control System Applications Trainer	Equipment set TP 1422: Stepper motor drive technology
Components	RYC, the main control system. RYC-SM, module with DC servomotor and gearbox RYC-CP, module with DC servomotor and a linear axis Management Software	AE.SMI, the main control system. Five different modules servomotor modules, with different attachments. Integrated PLC. Management Software	Control System Linear axis, attached to a belt driven mechanism, driven by a servomotor. External brake and mass. Software for control and modification of parameters.	Workstation with the control system Set of AC and DC servomotors, stepper motor. Auxiliary components, such as linear axis.	Stepper motor. Simulation / Control equipment.
Study Area / Experiments Available	PID controller configuration and experiment Position and Velocity Control of motors Open Loop / Closed Loop	Seven types of control to experiment. Parameters Configuration of the motors / System. PID controller configuration and experiment.	Effect of resistant forces on the servomotor behaviour. Parameters Configuration of the motor.	Study of the components and features of the motors. Study of Control types for each motor. Parameters Configuration for the motors.	Study of the components and features of the motor. Parameter Regulation. Study of basic variables, such as position and velocity ramps.

As for the current station, the main objective is to integrate a given linear axis, the CKK-110, using the servomotor to power it.

The presence of this linear axis allows for the possibility of verifying the behaviour of the system by adding a mass to the exercises. As such, it provides a method to verify, analyse and learn how a specific set of drive and motor behaves when departed with external forces, such as a weight being carried by the axis or a force that opposes to the movement, and how the type of control influences the way the system behaves under such conditions.

In terms of information, the insertion of new variables to study, such as torque, provides a better insight into the operation and behaviour of the system, and how each of the parameters influence the movement. The secondary objective is to update the system to allow the display of new variables, such as the recently mentioned torque.

When it comes to the code, the objective is to fully rework the code from scratch. To facilitate, encourage the analysis of the code and allow expansion of the program by other users, the code is separated into small sets of sub programs. It is also planned to create an interface that allows the creation of simple tests, with variables and conditions decided by the user.

On the HMI front, the plan is to conduct a full rework, as to display information and include a new set of controls. One of the main points to implement is the Scope View, a digital oscilloscope, available within the Beckhoff controller software. While this cannot be implemented into the HMI due to hardware and software limitations, it is still possible to utilize the feature using the TwinCAT software, and save the information of a specific run, allowing for a more detailed study.

In Table 5 and Table 6, it is presented some planned examples for the system, based on what was seen during the early research phase of didactic stations.

Table 5 - Planned Examples and Features for the Servomotor System

Servomotor Features	Explanation
Basic function test – Back and Forth	Designed to showcase the system at work
Manual Movement - Jog	Designed to allow the user to manually control the motor at will, according to the limits of the code.
Control test	Showcase the different types of control available with the drive (Position, Velocity, Torque)
Position repeatability test	Example focusing on the repeatability variable of the system, requiring the use of a comparator
Personalized Test	Feature that allows the users to create their own movements/tests

Table 6 - Planned Examples and Features for the Stepper Motor System

Stepper Motor Test	Explanation
Basic function test	Designed to showcase the system at work
Jerk test	Example to showcase how the system behaves with different jerk values.
Lost Steps Test	Example to simulate a system that can lose steps. Includes one test for the effect of the velocity on lost steps, and one for an external force.
Manual Movement - Jog	Designed to allow the user to manually control the motor at will, according to the limits of the code.

3 Design and Implementation

In this chapter, the focus is the hardware of the system in play. At the start, it's presented the available components to be used in expanding the didactic workstation, with a small set of information about each component.

After, the focus is on the linear axis connection with the servomotor. This includes design and selection of components necessary to acquire, such as the flange/coupling.

When it comes to the stepper motor, it is presented distinct possibilities for axes to be driven by the motor.

3.1 Available Hardware

CX9020 Controller

The industrial embedded PC, CX9020 [13, 14], by Beckhoff (Figure 13), presented in the didactic station, is the brain of the system, controlling and receiving information from the other components, and storing the code that makes the whole system work.

It combines PC technology with a modular I/O (Input/Output) level, making a compact system. The controller is setup on a DIN (EN 60715) rail, making use of a communication bus system, E-bus, or K-bus, present within most Beckhoff components, that allows the communication between components on the same railing without the need of cables.

The connection of this component to the computer is made through the use of an ethernet cable and the ethernet I/O present in both computers.

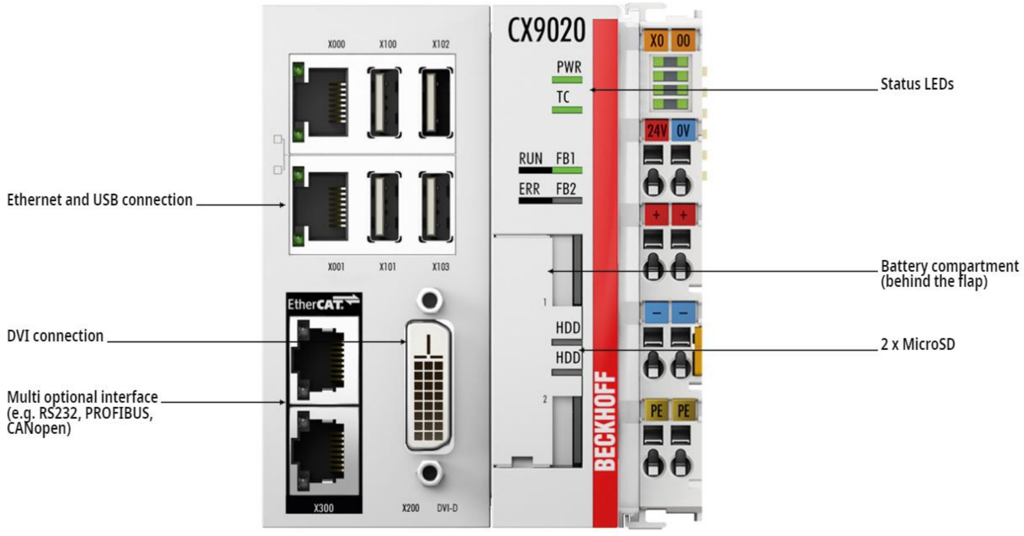

Figure 13 -CX9020 Controller, by Beckhoff [13]

In Table 7, the main specifications of this component are presented.

Table 7 – CX9020 Controller Technical Data [13]

Technical Data	CX9020
Processor	ARM Cortex-A8, 1 GHz
Number of cores	1
Flash Memory	2 x slot for microSD card, 512 MB included
Main Memory	1 GB DDR3 RAM
Persistent Memory	128 kB NOVRAM, integrated
Interfaces	2 x RJ45 10/100 Mbit/s (internal switch), 1 x DVI-D, 4 x USB 2.0
Clock	internal battery-backed clock for time and date
Operating system	Windows Embedded Compact 7, English
Control Software	TwinCAT 2 runtime TwinCAT 3 runtime (XAR)
I/O connection	E-bus or K-bus, automatic recognition
Power supply	24 V DC
Current supply E-bus/K-bus	2 A
Max power consumption	5 W
Max power consumption with loading UPS	9 W
TwinCAT 3 platform level	Economy Plus (30)

TwinSAFE security modules

The TwinSAFE modules present in the station are components dedicated to the safety of the environment, users, and components of the system. These range from stand-alone control to distributed control, while also including the pre-possessing of data through a system-integrated software.

Currently, the following modules are in use, Figure 14 to Figure 16:

- EL6900, a dedicated safety control module [15].
- EL1904, a digital input terminal for sensors, with 4 channels [16].
- EL2904 , a digital output terminal, presenting 4 channels [17].

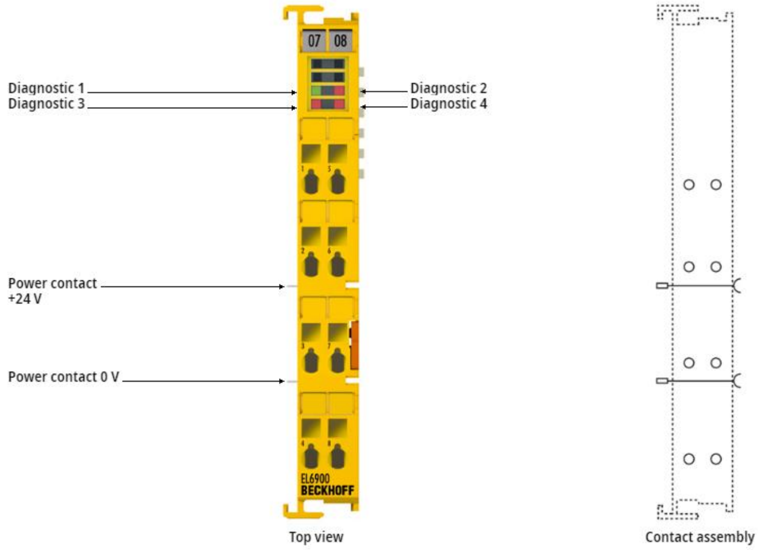

Figure 14 – EL6900 [15]

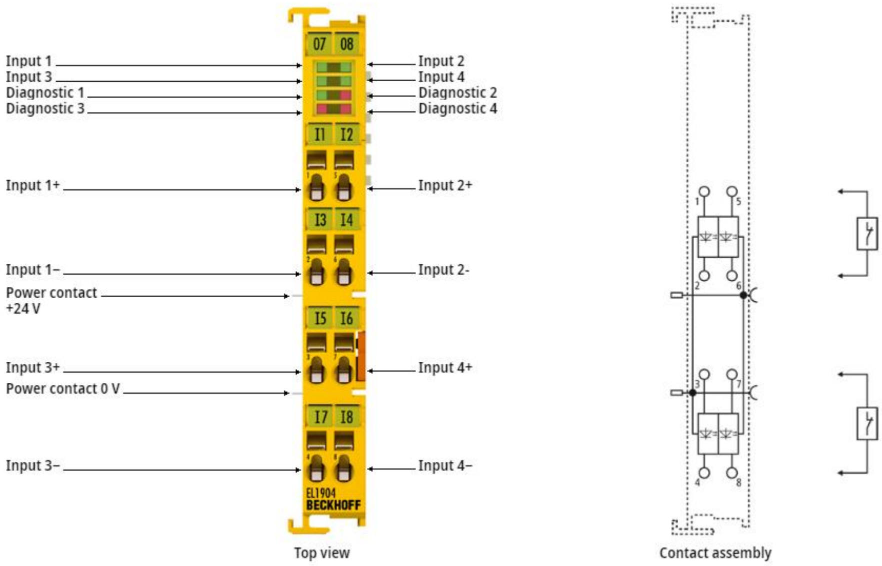

Figure 15 – EL1904 [16]

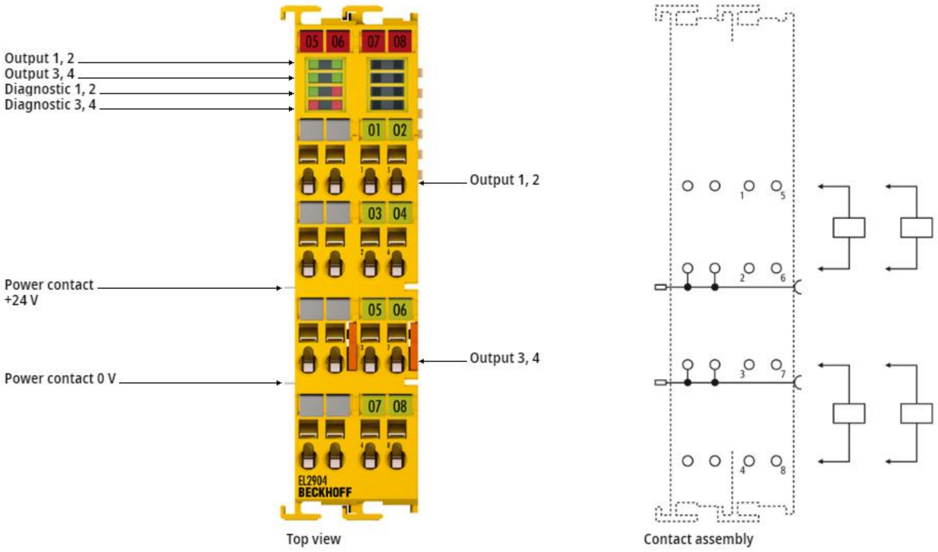

Figure 16 – EL2904 [17]

These modules are connected directly in the railing, making use of the Bus Terminal System of Beckhoff, allowing the system to transfer safe and standard signals. They work on the fail-safe principle, also known as Fail Stop, completely shutting down the system and energy whenever the failure of a component, part or system can lead to a dangerous situation [18, p. 13]. In Table 8, Table 9 and Table 10 it is presented some of the main specifications of these three modules.

Table 8 – EL6900 Technical Data [18, p. 16]

Technical Data	EL6900
Number of inputs	0
Number of outputs	0
Specification	Link unit between safe input and output signals
Protocol	TwinSAFE/Safety over EtherCAT
Cycle time	Approx. 500µs/according to project size
Supply Voltage	24 V DC

Table 9 – EL1904 Technical Data [19, p. 17]

Technical Data	EL1904
Number of Inputs	4
Status Display	4 (one green LED per input)
Response time	4 ms
Input process image	6 bytes
Output process image	6 bytes
Supply voltage	24 V DC

Table 10 – EL2904 Technical Data [20, p. 18]

Technical Data	EL2904
Number of Outputs	4
Status Display	4 (one green LED per output)
Output Current per channel	Max. 500 mA, 20 mA with “Current Measurement Active” parameter enabled
Input process image	6 bytes
Output process image	6 bytes
Supply Voltage	24 V DC

EL7031 Stepper Motor drive

For the control of the stepper motor, the system uses the EL7031 [21, 22], a stepper motor drive (Figure 17). This component is specially designed to be a compact EL EtherCAT terminal format, a format that closely resembles the form of the TwinSAFE modules. This format allows the drive to be mounted on DIN rails and make use the of bus terminal system for communication.

Its parameters are configurable, allowing to be tweaked to the motor and applications requirements, together with two digital inputs for limit switches. In conjunction with the CX9020 controller, and due to limitations of this driver, it’s only possible to use the micro-step function, allowing for a full 64 micro-steps per full step to be performed by the system.

Table 11 offers more insight into the specifications of the drive.

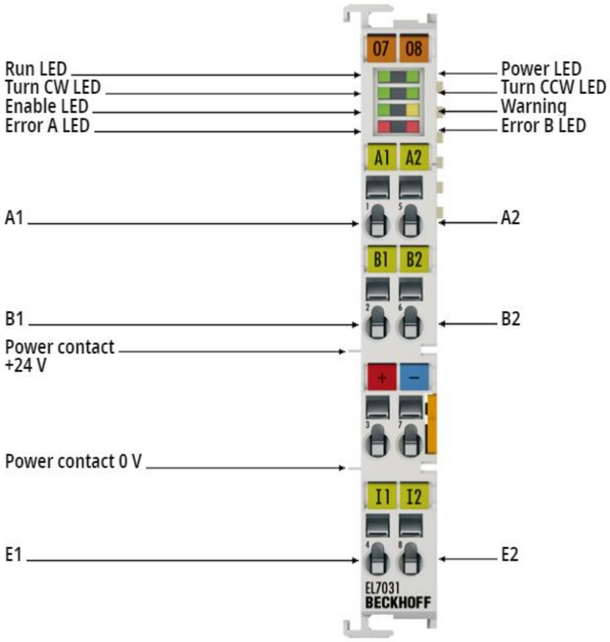

Figure 17 - EL7031 [21]

Table 11 - EL7031 Technical Data[21, 22, p. 18]

Technical Data	EL7031
Technology	Compact Drive Technology
Connection Method	Direct Motor Connection
Nº of Inputs	2 x End Position
Load type	2-phase stepper motor (uni/bipolar)
Nº of Channels	1
Nº of Outputs	1 x stepper motor
Supply Voltage Electronics	24 V DC (Via power Contacts)
Supply Voltage Power	24 V DC (internally via power contacts)
Output Current	Max 1.5 A
Step Frequency	Up to 8000 full steps/s, configurable
Step Pattern	64-fold micro stepping

EtherCAT EK1110

This component (Figure 18) is called an EtherCAT EK1110 [23, 24], designed to be an extension placed at the end of an Embedded PC from the CX series or from a line of components connected using the bus terminal communication, or an EtherCAT Terminal, offering the option of extending the EtherCAT network in the form of a line topology.

Converting the information from the Bus Terminal System into an ethernet signal, it allows the system to be expanded making use of ethernet cables. In this case, this component was used to allow the communication of the system with the servo drive.

In Table 12 it's possible to observe the main specifications of this component:

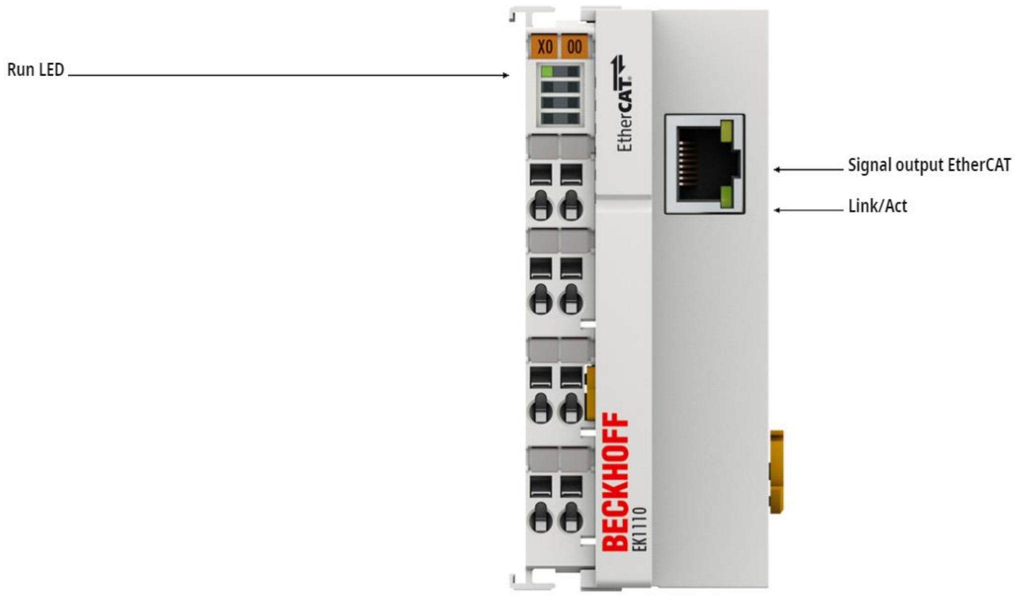

Figure 18 – EtherCAT EK1110 [23]

Table 12 – EK1110 Technical Data [23]

Technical Data	EK 1110
Data transfer medium	Ethernet or EtherCAT cable (min. Cat.5), shielded
Max distance between stations	100 m (100BASE-TX)
Protocol	Any EtherCAT Protocol
Delay	Approximately 1 μs
Data transfer rates	100 Mbit/s
Configuration	Not Required

Servo Driver AX5103

The AX5103 [25-27] (Figure 19) is the drive for the servomotor present in the workstation.

As part of the series AX5000, it has most of the required systems already integrated into its casing, such as power supply unit, EMC filter and DC link capacitors, offering a high deal of flexibility into the system, while keeping the solution as compact as possible. While the series itself has versions which allow multiple channels, this version is a 1-channel drive.

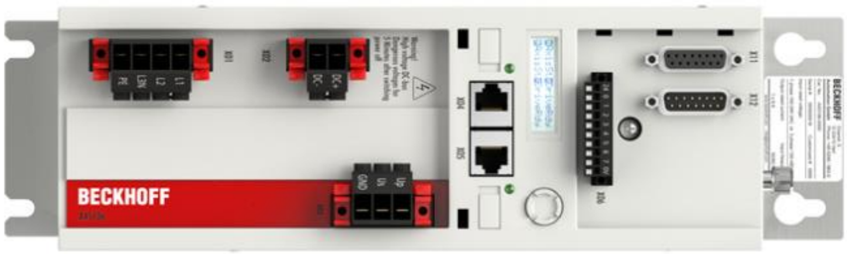

Figure 19 – Servo Driver AX5103[25]

With the AX-Bridge quick connection system, it’s simple to connect multiple AX5000 series devices, allowing for a quick creation of a multi-axis system.

The drive itself can recognise most of the Beckhoff motors, including different types such as synchronous, linear, torque, and asynchronous motors. With this system in place, the configuration of the motors is simplified, not only due to the automatic recognition of motors, but also due to the compatibility with other management software offered by Beckhoff. Other motors from other manufacturers are also possible to be used, with the correct connections, requiring the user to configure the motor parameters, as the drive is not able to recognise the motor.

This drive can be powered by a 3-phase or 1-phase AC current. Currently, it’s being used 1-phase AC 230 V.

Further specifications can be seen in Table 13.

Table 13 – AX5103 Technical Data [26, p. 33]

Technical Data	AX5103
Function	Servo drive
Channel	1
Rated Output Current	3 A
Minimum parameterizable channel peak current at full current resolution	1 A
Peak Output Current	7,5 A
Rated Supply Voltage	1 x 100-10% - 240+10% V AC
Rated apparent power S1 operation – 230 V	1.2 kVA
Max. Braking Power (Internal brake resistor)	14kW

Stepper Motor AS1030

Belonging to the AS1000 stepper motors series, the AS1030 [28, 29] (Figure 20) is a motor suited for auxiliary axis and positioning drives. It's characterised by its robustness and holding torque. The use of an integrated micro-step drive allows the motor to, according to Beckhoff [28], "position very well even without a feedback system and require only a motion terminal for power electronics". Being a hybrid stepper motor, this motor was projected to be used mostly on open loop systems, though it's able to be ordered with an integrated encoder. The model present on the station, however, does not possess an encoder.

Figure 20 - Stepper Motor AS1030 [28]

When it comes to the specifications of the motor itself, it presents a step of 1.8º, the equivalent of 200 steps for a full rotation. Including the micro-step, equivalent to 64 micro-steps per full step, this motor is capable of 12800 micro-steps per full rotation. Further specifications can be seen in Table 14.

In Figure 21, it is displayed the characteristic curve of the stepper motor. Due to a limitation of the drive currently available, EL7031, it is only possible to use this stepper motor at a voltage of 24 V DC.

Table 14 - AS1030 Technical Data [29, p. 42]

Technical Data	AS1030
Rated supply Voltage	24-50 V DC
Rated Current	1.5 A
Rated Power	19.5 W
Standstill Torque	0,6 Nm
Rotor moment of Inertia	0,21 J $[kg * cm^2]$
Resolution	1.8º /200 full steps

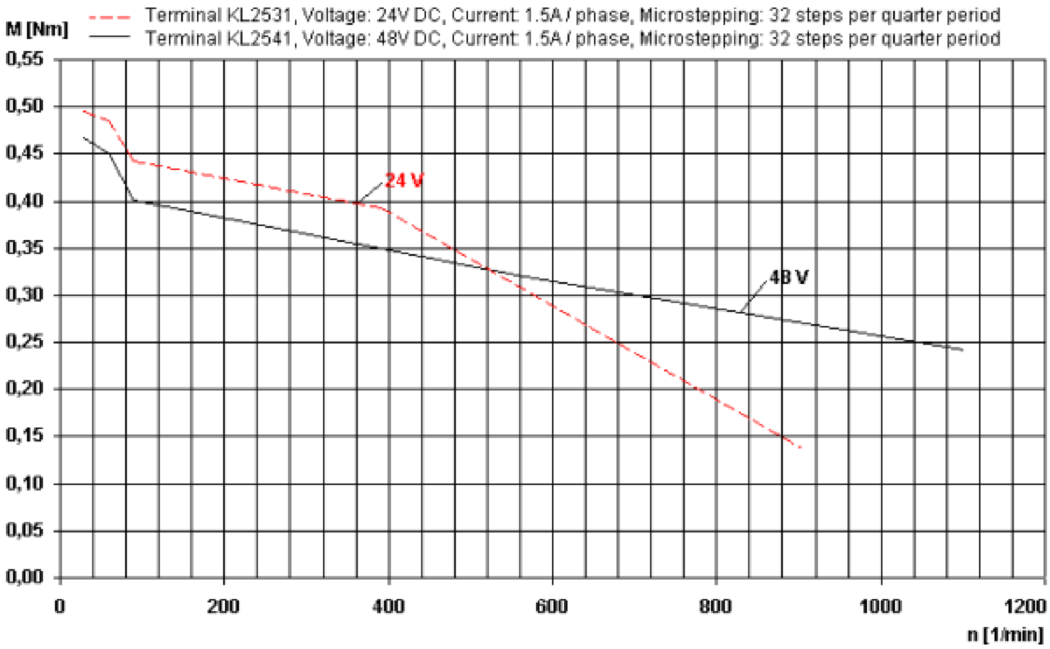

Figure 21 – Characteristic Curve Diagram of the AS1030 [29, p. 43]

Servomotor AM8021

The available servomotor, AM8021-1D11-0000 (Figure 22), belongs to the AM8000 series of synchronous servomotors of the manufacturer Beckhoff [30, 31]. It is a permanent magnet syncronous 3-phase brushless motor.

Figure 22 – AM8021 Servomotor [30]

It's a standard servomotor suitable for drive solutions with high demand on dynamics and performances in the voltage range of 100…480 V AC. The standstill torque of this module reaches the 0.50 Nm, and the model itself comes with an integrated OCT (One Cable

Technology) for “power and feedback: feedback transmission via motor cable, no feedback cable necessary, electronic identification plate, single-turn, absolute position within one revolution, 18 bit resolution” [30].

In Figure 23 it’s presented the characteristic curve of the motor and, in Table 15, it is presented the specifications of the given motor for the current power supply being used in the system (monophasic AC current, 230 V).

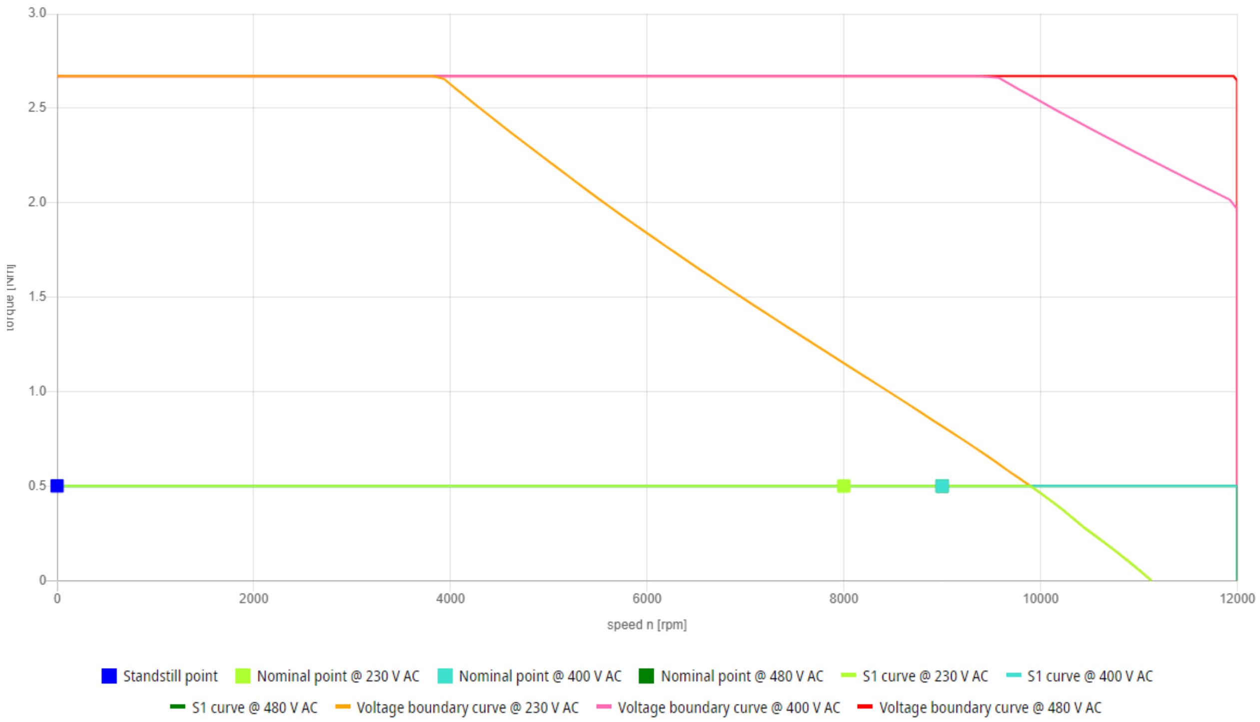

Figure 23 – AM8021 Characteristic curve Diagram[30] . Nominal points @400 V and 480 V AC are the same

Table 15 – AM8021 Technical Data [31, p. 33-34]

Technical Data	AM8021
Standstill Torque	0.5 Nm
Standstill Current	1.6 A
Peak Current	8.6 A
Peak Torque	2.67 Nm
Torque Constant	0.31 Nm/A
Nominal Speed (At 230V)	8000 Nm
Rated Torque (At 230 V)	0.5 NM
Rated Output (At 230 V)	0.42 kW
Rotor moment of inertia	0.14 J $[kg * cm^2]$
Rotor moment of inertia with brake	0.21 J $[kg * cm^2]$

CKK-110 Linear Axis

For the servomotor, it was provided a linear axis from Bosch Rexroth, the CKK-110 [32, 33] (Figure 24). This model was being stored in the warehouse, being an older version of this model.

Figure 24 - CKK-110 Linear Axis

The CKK-110 is a compact linear axis, spanning 110 mm in width, driven by a ball screw assembly. It presents a repeatability of up to 0.005 mm, a course of 900 mm and a pitch of 10 mm.

In Annex A, it is possible to verify more in-depth information related to this model.

Mechanical Switches

Two mechanical switches were provided, the Z-15GM2-B (Figure 25), produced by OMRON [34, 35]. These switches are reverse hinge roller levers, with the possibility of working as a normally open contact or a normally closed contact, depending on the connection.

It presents a standard operating force of 2.35 N maximum, with a release force of 0.55 N minimum.

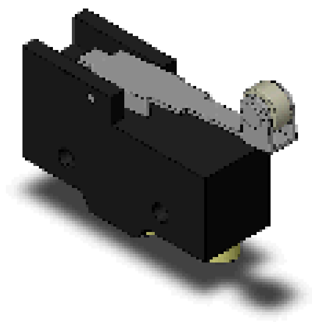

Figure 25 – 3D CAD of the Z-15GM2-B Mechanical Switch [34]

When it comes to operating position (OP), its standard value is of 29.4 to 31 mm, with a free position (FP) of 35mm at its maximum. In Figure 26, it’s possible to verify a drawing representing these two positions.

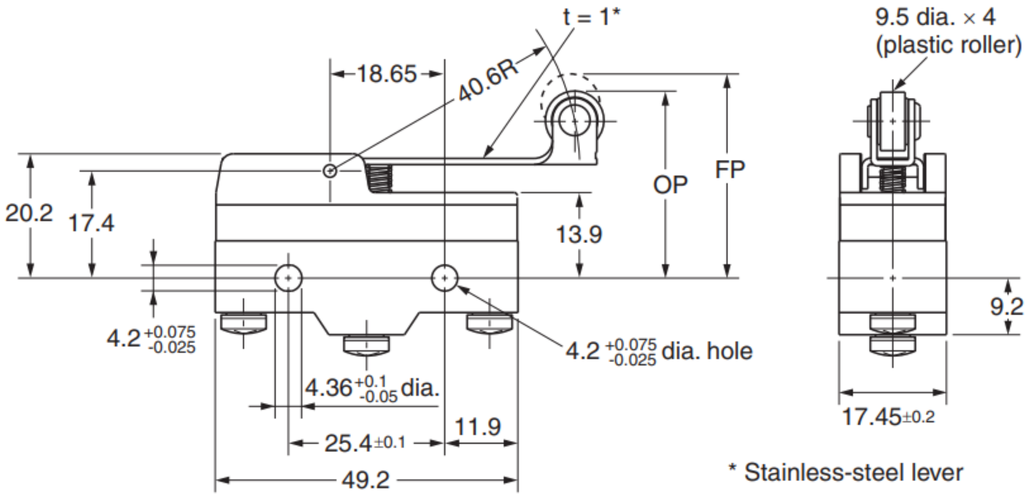

Figure 26 - Mechanical Drawing of Z-15GM2-B (Dimensions in mm) [35]

Proximity Sensor

Alongside the mechanical sensors, it was provided an Inductive Proximity Sensor produced by Carlo Gavazzi, the EI1805PPOSL [36] (Figure 27). Being an inductive sensor, it detects metal in close proximity. It's a normally open sensor, meaning that it only sends a signal to the system when it detects metal in its proximity.

Figure 27 - Inductive Proximity Sensor EI1805PPOSL [37]

3.2 Servomotor

Due to the axis not being chosen for the application, and instead being supplied, it was necessary to make some verifications on the compatibility between the axis and the servomotor. But before those verifications can be done, it is necessary to choose a coupling for the system, as this influences the calculations ahead.

Coupling

For this set of servomotor and linear axis, one of the main concerns when choosing a coupling ends up being the rated torque. In this case, it was verified, and it's visible in Table 15 and Figure 23 that the maximum torque the servomotor can supply is 2.67 Nm. As such, it is necessary, for safety reasons, that the rated torque that the coupling can withstand to be higher than that value.

Another point of concern when choosing couplings is the internal diameter. Considering that both the servomotor and the linear axis present mechanical shafts of different diameter (9 mm and 11 mm, respectively) it was necessary to choose and option that allowed the coupling between different diameters.

For these two reasons, it was chosen the coupling BKL 4.5 (Figure 28), by R+W, with a length of 40 mm, as a suitable option. Not only does it allow for different diameters, as it was required, but it is also a coupling that presents misalignment compensation, allowing for a more stable transfer of momentum. Due to ordering limitations, it was ordered a coupling with diameter of 9 mm on both sides, and it was increased the diameter of one of the sides by using a drilling machine available in the workshop.

More technical data can be seen in Table 16.

Figure 28 – BKL, Metal Bellows Coupling Economy Class with clamping hub [38]

Table 16 – BKL 4.5 Technical Data [39, 40]

Variable	Value	Units
Rated Torque	4.5	Nm
Overall length	40	mm
Inside Diameter D1	6-16	mm
Inside Diameter D2	6-16	mm
Outside diameter	32	mm
Moment of inertia	0.007	$10^{-3}\ \mathrm{kg} * \mathrm{m}^2$
Speed	Up to 10000	rpm

Compatibility

Some calculations were made to verify the compatibility between the motor and the linear axis.

It was required to identify some specific parameters from both manufacturers, values that can be seen in Table 17 and Table 18.

Table 17 - AM8021 Technical Data for Compatibility Verification [31, p. 33-34]

Servomotor AM8021		
Variable	Value	Units
Nominal Voltage	100 to 480	V AC
Standstill Torque	0,5	Nm
Rated Torque	0,5	Nm
Peak Torque	2,67	Nm
Rated Speed	9000	min^{-1}
Rated Power	0,47	kw
Standstill Current	1,6	A
Peak Current	8,6	A
Torque Constant	0,31	Nm/A
Rotor Moment of Inertia	0,139	$kg * cm^2$
Rotor Moment of Inertia with Brake	0,21	$kg * cm^2$

Table 18 - CKK-110 Technical Data for Compatibility Verification [33]

CKK-110 Linear Axis		
Variable	Value	Units
Frictional Torque (Mr)	0,47	Nm
k1	6,076	____
k2	0,029	____
k3	2,533	____
L	900	mm
P	10	mm
v (max)	45	m/min
maximum permissible drive torque	9	Nm

After the verification, it was verified that the frictional torque represented 94% of the value of the standstill torque of the servomotor, and that the linear axis limited the speed of the motor to only 4500rpm. It is concluded, then, that the servomotor has lower torque capacity than the linear axis, i.e., just above the indicated frictional torque. Nevertheless, it was decided to continue with this solution, due to reduced investment costs.

Motor Connector Flange

For the motor connector flange two solutions were considered.

The first solution is based on the acquisition of a custom-made flange/coupling system, manufactured by Bosch Rexroth. Bosch offers the possibility of the user verifying compatibilites before hand by using their configuration system, present within their website. Through it, it was verified that, for the CKK-110, a flange/coupling solution existed.

The second solution comes with the design and manufacturing of the motor connector flange in the university workshops and the acquisition of the coupling.

The motor connector flange needs to be able to accommodate the length of both shafts, from the linear axis and the motor, while also presenting a diameter capable of allowing the accommodation of the coupling. Another point of design has to do with the type of coupling used. Being that the shafts get attached to the coupling via a clamping hub, it exists the need of having two access holes, so that it is possible to tighten the clamp without having to disassemble the components.

The motor connector flange uses four C-Bore holes that allow the screws to go through the component, as opposed to these screws being attached on the outside, providing secure connections between the components.

Figure 29 presents the final design. A technical drawing of this component can be seen in Annex B.

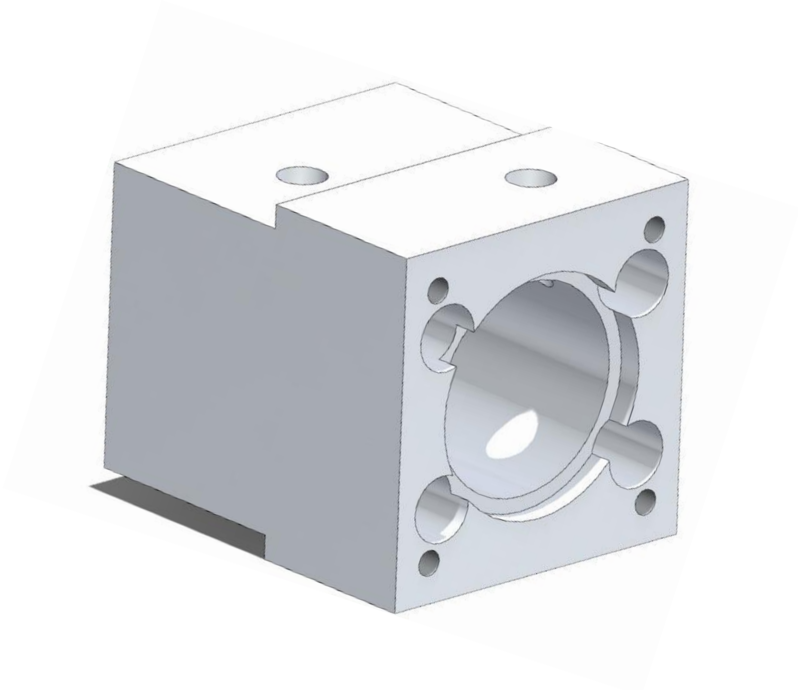

Figure 29 - CAD Model of the Motor Connector Flange

Finite elements simulation within Solidworks was conducted to evaluate the design. The focus is to judge the material based on the critical zones found within the component, and based on the values of stress, strain and deformation found within the critical zones of the component.

First step is to define the mesh being used. For this case, it was used a triangle mesh, with elements with a maximum size of 8 mm, minimum of 0.5mm and 16 Jacobian Points, as to generate a high-quality mesh, as seen in Figure 30.

It is then chosen the possible materials to be used. For this component, it was selected two aluminium alloy, and a steel alloy. Table 19 presents their most important properties.

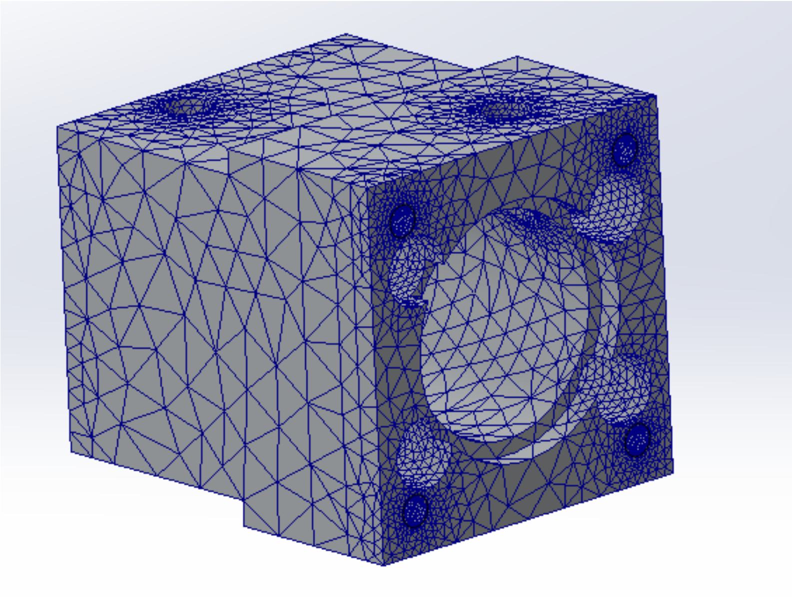

Figure 30 - Mesh used on the simulation of the Motor Connector Flange

Table 19 - Materials and their Properties

Properties	Materials			
	Aluminium Alloy 7075-T6(SN)	Aluminium Alloy 5052-H38	Steel AISI 1045, cold drawn	Units
Elastic Modulus	$7{,}2 * 10^{10}$	$7 * 10^{10}$	$2{,}05 * 10^{11}$	N/m^2
Poisson's Ratio	0,33	0,33	0,29	---------
Shear Modulus	$2{,}69 * 10^{10}$	$2{,}59 * 10^{10}$	$8 * 10^{10}$	N/m^2
Mass Density	2810	2680	7850	kg/m^3
Tensile Strength	$5{,}7 * 10^8$	$2{,}9 * 10^8$	$6{,}25 * 10^8$	N/m^2
Yield Strength	$5{,}05 * 10^8$	$2{,}55 * 10^8$	$5{,}3 * 10^8$	N/m^2

Once the material and mesh have been chosen, it is applied the forces on the face of the component. In this case, it is applied a force, based on the motor's weight, and a momentum, due to the distance between the face of the component and the centre of gravity of the motor, leading to an applied force of 15 N, with a safety coefficient of 1.5, and an applied torque of 0.9 Nm, with the same safety coefficient. In Figure 31, it is possible to see the direction of the forces applied in the face of the component that is connected to the servomotor.

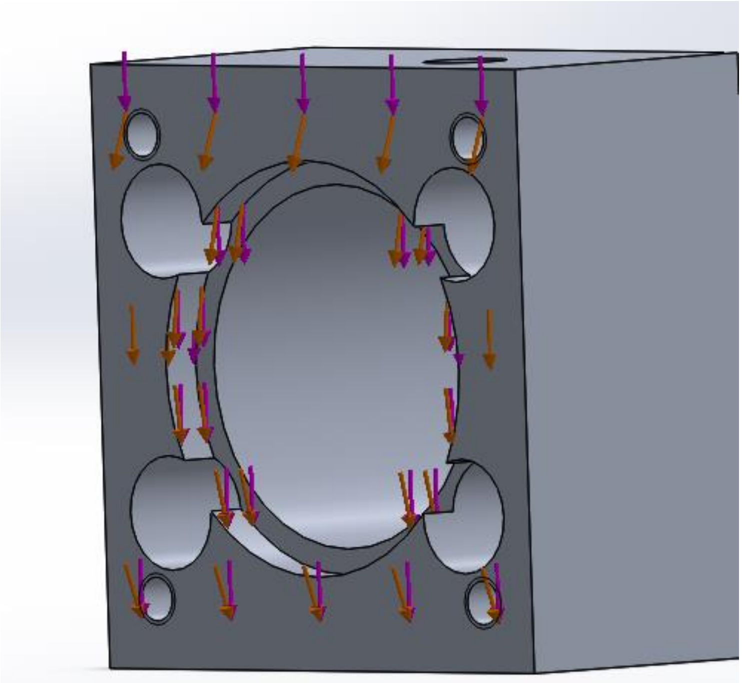

Figure 31 - Applied forces and Torque on the motor connector flange (Purple – Force; Brown – Momentum/Torque)

Based on these conditions, it was verified that all three chosen materials were able to withstand the working conditions required for this system, based on the Solidworks simulations. As such, when it came to choose the material, it was chosen the Aluminium Alloy 7075-T6(SN). For more information on the obtained values of the simulation, it is recommended to observe Annex B, which showcases all the tests made for the three chosen materials.

Figure 32 showcases the assembly of the coupling/flange system.

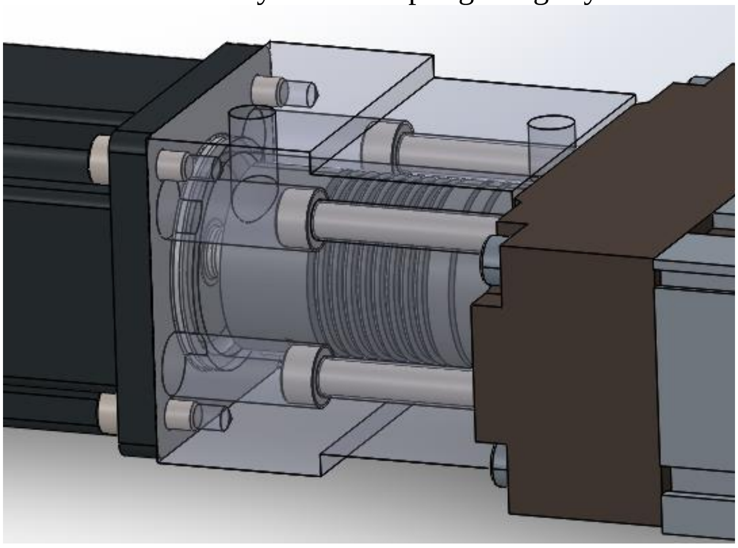

Figure 32 - Coupling/Flange System

Final Iteration

Since an axis is involved, it is necessary to design some extra components for it, with the objective of supporting sensors. These are used for control and safety of the system.

For this, the following items are used:

- Two supports for the mechanical switches.
- One support for the inductive sensor.
- Carriage for the axis.
- Two sets of physical barriers.

For the sensors, it is required that they have a specific and stable position within the system, as to delimit the axis travel and keep the zero-reference point of the system consistent with every homing done by the user. It is also required that the distance between them and the carriage of the axis to be constant, to allow the sensors to always have proper working conditions.

As for the physical barriers, the objective is to stop the carriage before it goes out of the designed travel limits, in case of a malfunction. The barriers themselves include some holes, with the possibility of including soft materials as to make sure that, on an eventual physical contact between the barrier and the carriage, permanent damage does not occur on the components.

For these set of components, and after some iterations for each of the components, the following assembly was defined, as seen in Figure 33.

For each of the components, everything was kept to the bare minimums, as to keep the cost down, while not increasing the complexity of each component for easy manufacturing. In the carriage's case, it was necessary to create a side slope. This side slop allows a smooth activation of the mechanical switches at the ends of the axis travel length.

Each of the components final drawings are presented in Annex C.

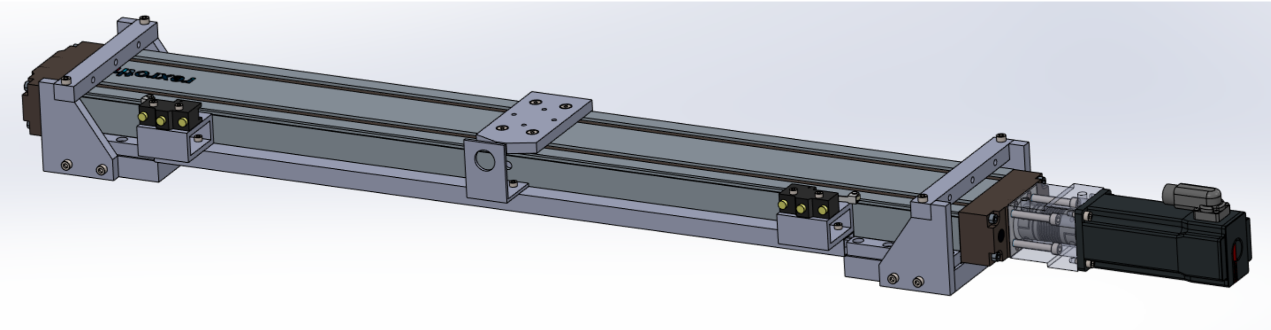

Figure 33 - Linear Axis, full assembly with sensors and motor

3.3 Stepper Motor

It was mentioned in the objectives the need to design and build a solution for the stepper motor.

It was decided to go for a linear axis. It would allow the comparison between the work of a servomotor and of a stepper motor, while also allowing the possibility of creating a two-axis system using the current stepper motor and servomotor, or even by acquiring a second servomotor or stepper motor to create such system.

Considering the linear axis, and after some market search, it was decided to choose a solution from Igus, to verify the available linear axes that could work with the stepper motor.

It was verified two possible axes for the stepper motor, the SAW-1040 (Figure 34) and the SHT-12 (Figure 35). Table 20 presents a general comparison between these axes. The costs for these axes can be seen in Table 21, including the flange/coupling for each of the axis.

Figure 34 - SAW Linear Module [41]

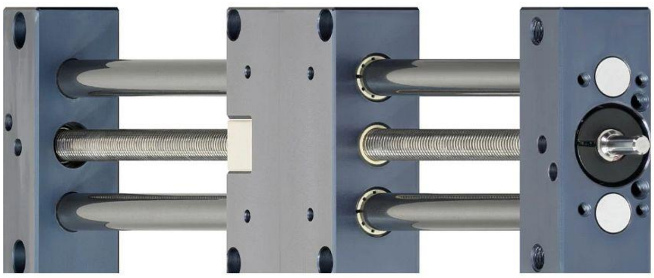

Figure 35 - SHT-12 Linear Module [42]

Table 20 - SAW and SHT-12 Linear Axis Properties [41, 42]

Properties	Axis		
	SAW-1040	SHT-12	Units
Maximum Course	500	500	mm
Maximum Velocity	1500	1500	rpm
Max Static Axial Load	500	700	N
Max Static Radial Load	2000	2800	N

Table 21 - Stepper Motor Budget

Item	Quantity	Cost per unit	Total Cost
Linear Axis SAW-1040-F2AT1-D0A0B-AA0H1AA-300	1	EUR 434,98	EUR 434,98
Linear Axis SHT-12-C1AT1-A0A0B-AA0H1AA-300	1	EUR 387,14	EUR 387,14
CouplingCOU-AR-K-063-100-32-32-B-AAAA	2	EUR 48,23	EUR 96,46
Motor conector flange MF-2040-NEMA23-S	2	EUR 96,58	EUR 193,16

For the time being the existing solution was modified in order to allow the mounting of a magnetic brake. For this purpose, a metal disk was connected to the axis of the motor (Figure 36), together with another disk used for visualising the angular position of the shaft.

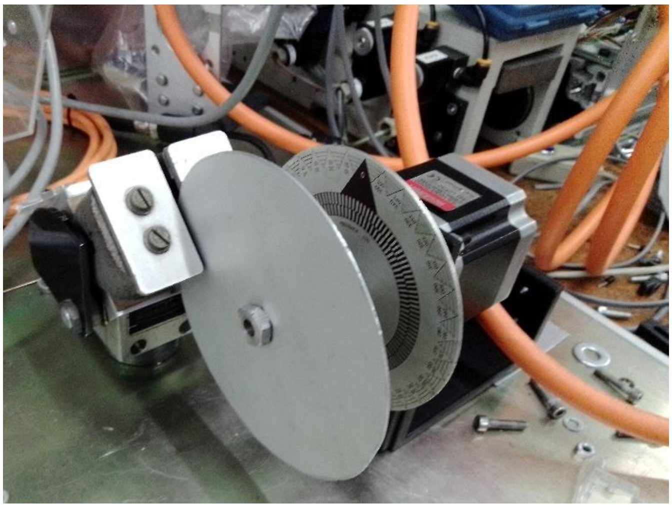

Figure 36 - Current Stepper Motor Set Up

4 Software and Control Program

This chapter focus on the software and the development of the control program.

The software, acquired from Beckhoff, offers the best compatibility with the system, as the majority of the components that are used are manufactured and supplied by them.

4.1 TwinCAT 3

The TwinCAT 3 (The Windows Control and Automation Technology 3) is a programming software based on the open-source software CoDeSys.

This software is a work environment developed by Beckhoff, capable of turning most real time computers and Industrial Computers into control systems, capable of handling and controlling multiple instances of PLC, NC, CNC, and robotics runtime systems. Figure 37 presents the TwinCAT general structure, while Figure 38 presents the device concept.

The software supports multiple connections to other programs, like MATLAB®/Simulink® and presents integration to Visual Studio [43, 44]. It supports the use of all the programming languages mentioned in the IEC 61131-3 norm, while also allowing other language types to work within its environment, such as C/C++ [44].

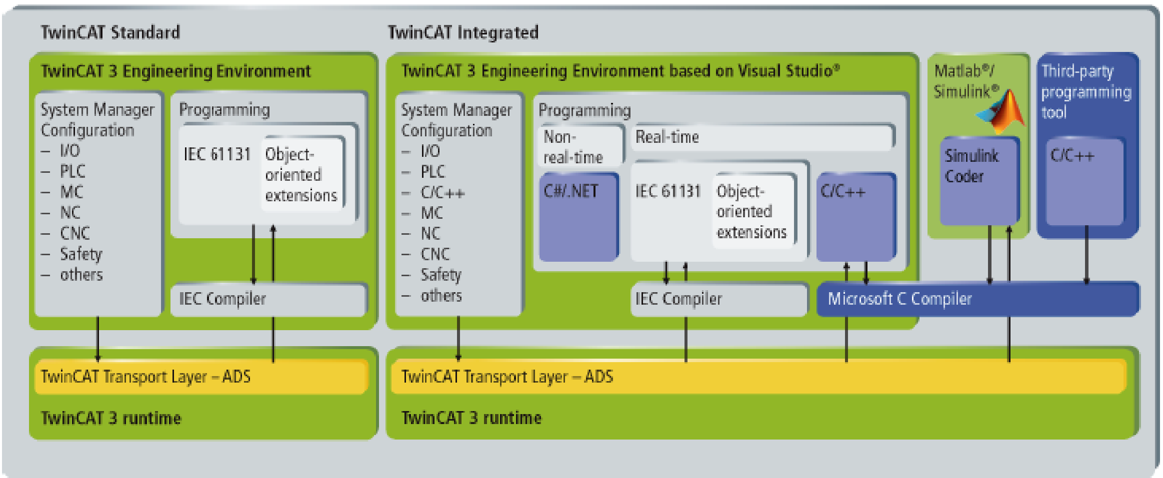

Figure 37 - TwinCAT 3 Structure [43]

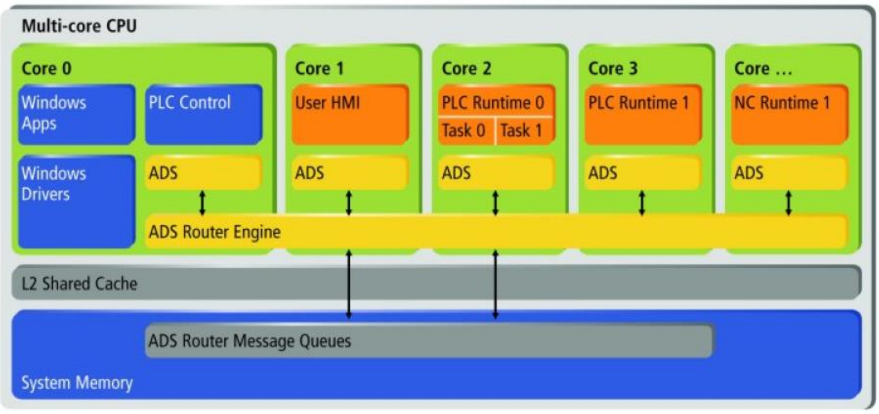

Figure 38 - TwinCAT device concept [45]

To use certain functions and modules of this software, it is required the acquisition of a license. Figure 39 presents some of the hardware categories available. There is also a 7-day trial available for all licenses. This last option exists for didactic purposes, allowing users to fully test the functionalities.

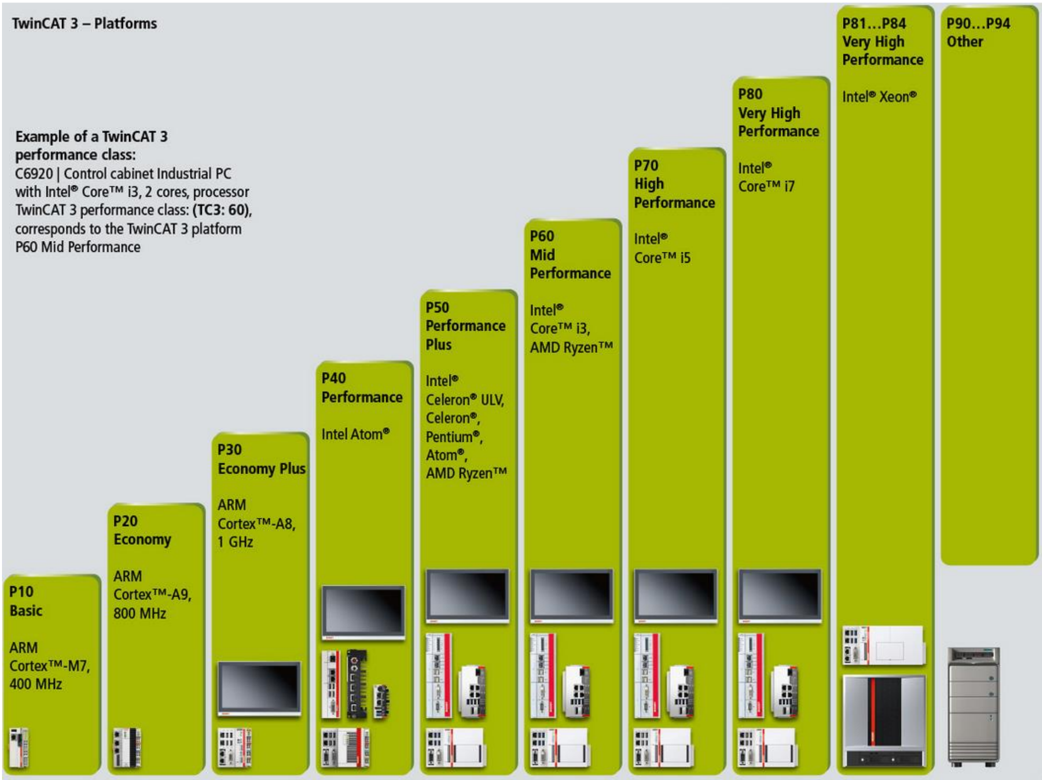

Figure 39 - Beckhoff Hardware Categories [43]

Drive Manager 2

Drive Manager 2 [46], with the T5950 license code, is a module for the configuration of the drive and servomotors, while displaying information about them.

The configuration of these devices can be done automatically by providing information of the process, like the axis pitch, load, and coupling or, alternatively, it can be done manually.

Drive Manager contains information on all the compatible Beckhoff motors, to automatically configure the operating parameters. Other motors require the manual configuration of the parameters.

It is possible to configure multiple parameters of the drive, like the power supply. A sample of the possible configurations for this section can be seen in Figure 40.

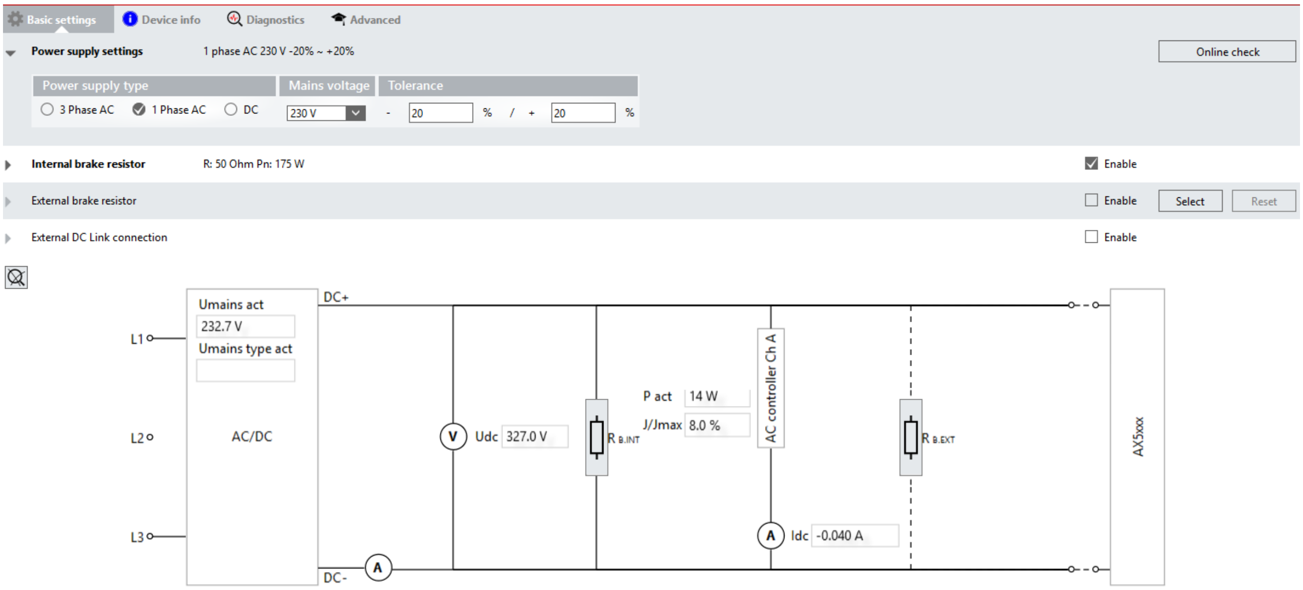

Figure 40 - Drive Manager 2 - Drive Configuration

It is possible to fully configure the motor and limit some other parameters, such as maximum velocity, acceleration, and jerk. Digital inputs at the drive can be configured for a specific task. Figure 41 presents an example of motor parameters and Figure 42 presents an example of the controller.

Drive Manager 2 allows for the manual test of the motor and allows the user to visualise its performance with the integrated Scope View functions (Figure 43).

Parameter	Online value	IsSelected	Current value	Current unit	New value	New unit
Scale factor numerator	10	✓	10		10	
Scale factor denominator	1048576	✓	1048576		1048576	
Encoder mask	4294967295	✓	4294967295		4294967295	
Encoder sub mask	1048575	✓	1048575		1048575	
Invert encoder counting direction	False	✓	False			
Encoder reference system	INCREMENTAL	✓	INCREMENTAL		INCREMENTAL	
Encoder position offset	0	✓	0		0	
Enable encoder soft minimum limit monitoring	False	✓	False		False	
Soft minimum limit	-500	✓	-500		0	
Enable encoder soft maximum limit monitoring	False	✓	False		False	
Soft maximum limit	500	✓	500		0	
Invert motor polarity	False	✓	False			
Output velocity scaling factor	1.02400649589962	✓	1.02400649589962		1.02400649589962	
Unit		✓	mm		mm	
Reference velocity: 110% of max motor speed	1581.5976	✓	1581.5976	mm/s	1581.5976	mm/s
Maximum velocity: 100% of max motor speed	1437.82	✓	1437.82	mm/s	1437.816	mm/s
Fast velocity: 100% of max motor speed	1437.816	✓	1437.816	mm/s	1437.816	mm/s
Manual velocity (fast): 30% of max NC jog speed	150	✓	150	mm/s	150	mm/s
Manual velocity (slow): 5% of max NC jog speed	25	✓	25	mm/s	25	mm/s
Calibration velocity (towards plc cam): 1% of max motor speed	14.37816	✓	14.37816	mm/s	14.37816	mm/s
Calibration velocity (off plc cam): 1% of max motor speed	14.37816	✓	14.37816	mm/s	14.37816	mm/s
Acceleration with an acceleration time of 1s	2156.72	✓	2156.72	mm/s²	2156.724	mm/s²
Decceleration with an acceleration time of 1s	2156.72	✓	2156.72	mm/s²	2156.724	mm/s²
Max allowed acceleration	15000	✓	15000	mm/s²	15000	mm/s²
Max allowed decceleration	15000	✓	15000	mm/s²	15000	mm/s²
Jerk with an acceleration time of 1s	6470.17	✓	6470.17	mm/s³	6470.172	mm/s³

/otor maximal speed for NC @ 230 V AC: 8626.899 rpm

Figure 41 - Drive Manager 2 - Motor Parameters

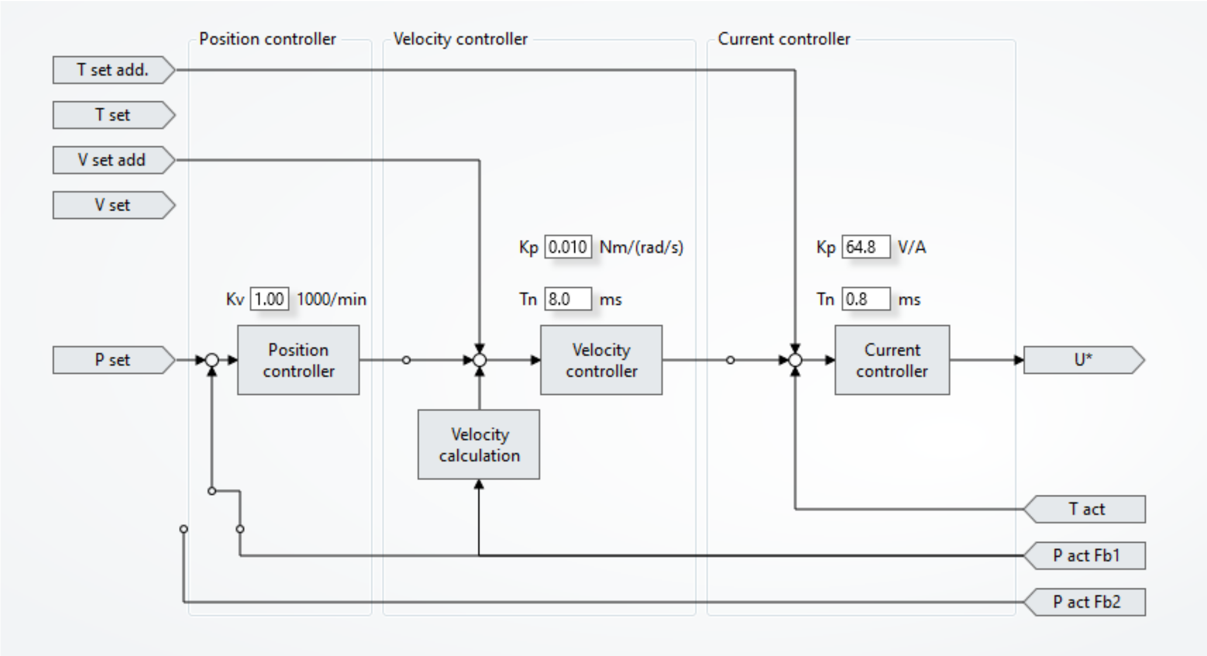

Figure 42 - Drive Manager 2 – Controller

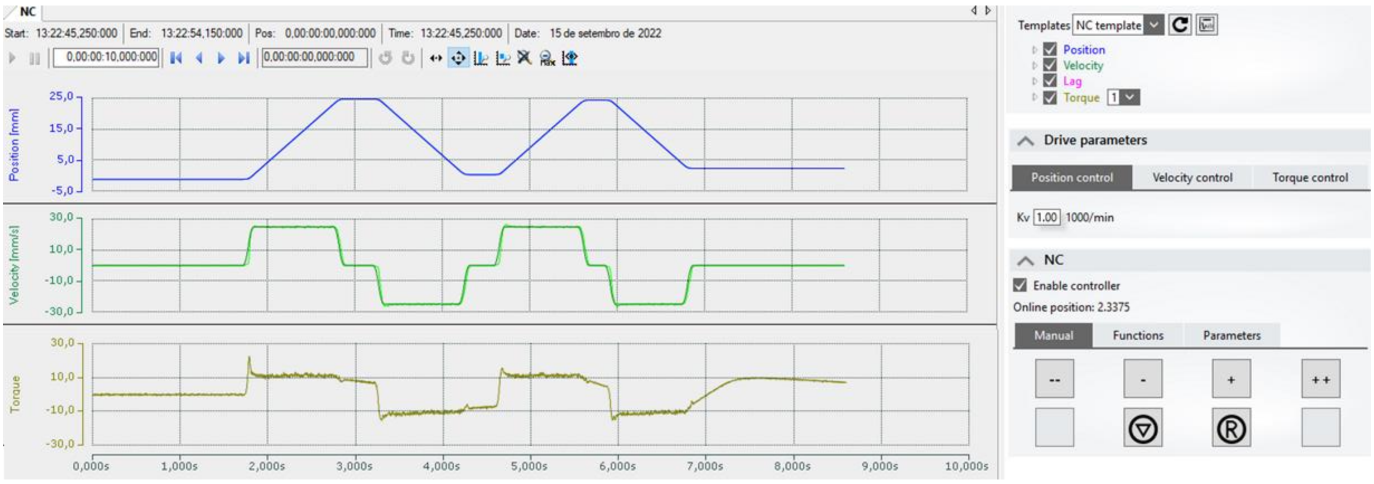

Figure 43 - Drive Manager 2 - Test Run Screen and Scope View Integration, showcasing Position, Velocity, and Torque (% of peak torque)

Motion Control

Motion Control is a module for easy configuration and readiness of motors for motions. The licenses for this module are varied, and range from a single NC 1 axis license, to CNC or Robotic Licenses with unlimited axes [47]. Figure 44 showcases basic information about each type of motion control that Beckhoff supports.

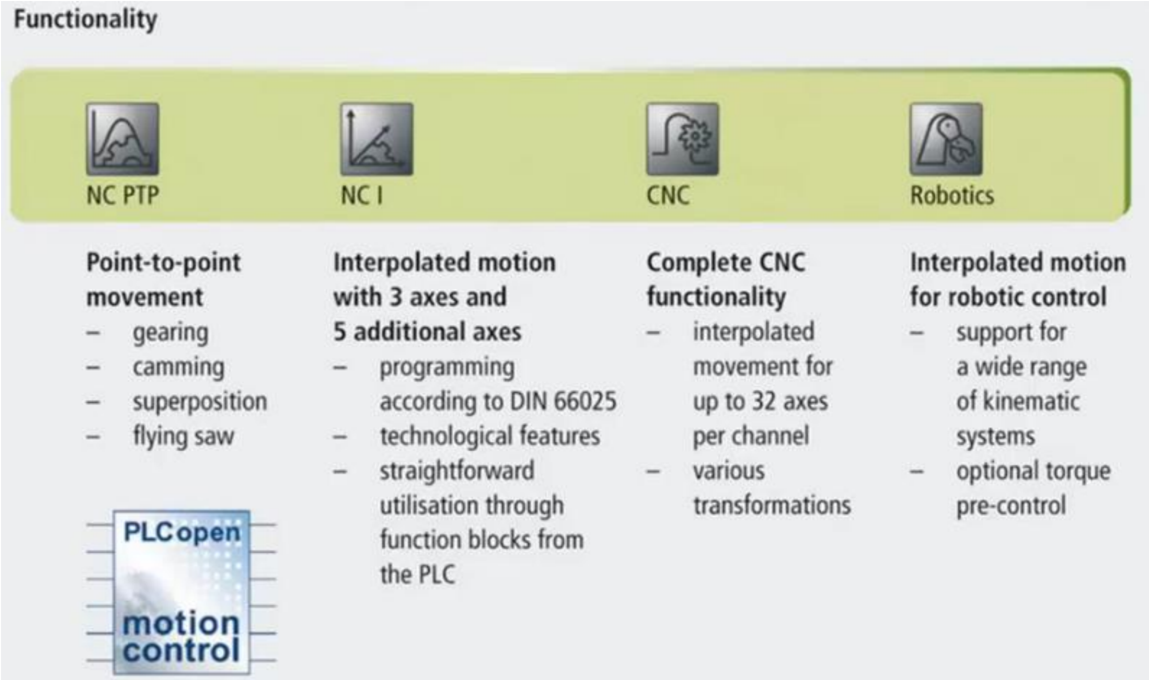

Figure 44 - Motion Control Basic Types and Functionalities[48]

The project uses TF5000, a license for NC Point-to-Point movements, for up to 10 Axes. This license supports the following features [48]:

- Support for electrical and hydraulic servo drives, frequency converter drives, stepper motor drives, DC drives, switched drives (fast/slow axes), simulation axes and encoder axes,
- Support for various fieldbus interfaces.
- Standard axis functions such as start/stop/reset/reference, velocity override, master/slave couplings, electronic gearbox, online distance compensation.
- Programming carried out via PLCopen-compliant IEC 61131-3 function blocks.
- Online monitoring of axis state variables such as actual/setpoint values, releases, control values.
- Configuration of axis parameters and Controller structures.

Scope View

Scope View [49, 50] is a software oscilloscope. Allows the user to represent different signals, variables, and parameters in different chart types, such as YT, XY, bar, digital charts, XYZ charts, and more. It doesn't come with a specific license type, but different licenses can be acquired to increase the functions and tools available. One such example is the Scope View Server, allowing the user to create an automated server within the industrial computer to automatically record data.

4.2 Main Parameters

The control program follows a sectioned tree, with each section dedicated to a specific module or function within the program (Figure 45).

The focus is to present the main parameters used within this control program, from the used licenses to the parameters of the main tasks, motors, and encoders.

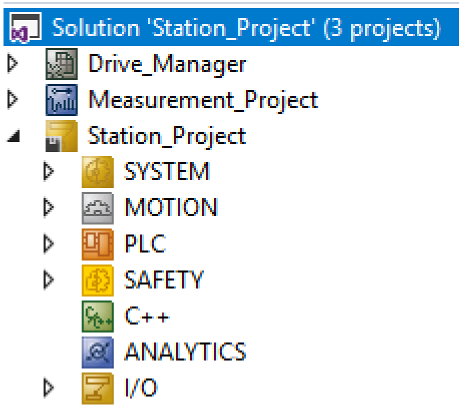

Figure 45 - Control Tree of the Project (TwinCAT 3 Work Environment)

Tasks

When programming, it is necessary to associate each program to a system task. This system task has a level of priority within the runtime, alongside a configurable value of cycle ticks, in milliseconds. In this project, a total of five tasks exists (Figure 46 and Figure 47). Each of these tasks have specific objectives, different levels of priority and cycle ticks.

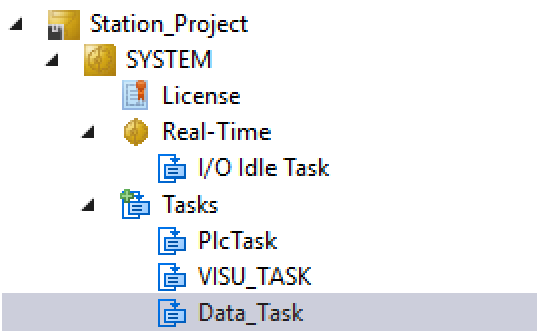

Figure 46 - Control Program Tasks

The first task is I/O Idle Task, related to the inputs and outputs. Presents a cycle tick of 1 mms and a priority of 11.

The second task, PLCTask, runs the code with a cycle tick of 10 ms and a priority level of 20.

VISU_TASK is related to the HMI. It updates the interface based on the cycle ticks of the system, currently set to 200 ms. Presents a task priority level of 30.

Data_Task runs the acquisition of data in the system. This data is used in the interface, with the objective of giving the user a basic view on the behaviour of the motor and system during its execution. It presents a cycle tick of 100ms and a priority of 40.

NC-Task, within the motion control module, is related to the transmission of information between the axes and the plc. This task has a cycle time of 10 ms and a priority level of 8.

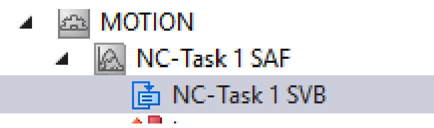

Figure 47 - Motion Control Task

Licenses

Licenses dictate, in TwinCAT 3, what can and not be used within the software. As mentioned before, it is possible to use a 7-days trial for all licenses, allowing the user to use those licences for didactic purposes.

Table 22 presents the licenses in use within this project.

Table 22 - Licenses in Use

License	Order No
TC3 PLC	TC1200
TC3 PLC-HMI	TF1800
TC3 PLC-HMI Web	TF1810
TC3 HMI Scope	TF2300
TC3 NC PTP	TF5000

Servomotor Parameters

Most of the servomotor parameters were configured automatically, using the Drive Manager 2. This process consists in the parameterization of the information about the axis pitch, gear ratio, speed, and torque limitations on the motor (Figure 48). After an automatic tuning process, new parameters are provided to the controller (Figure 49).

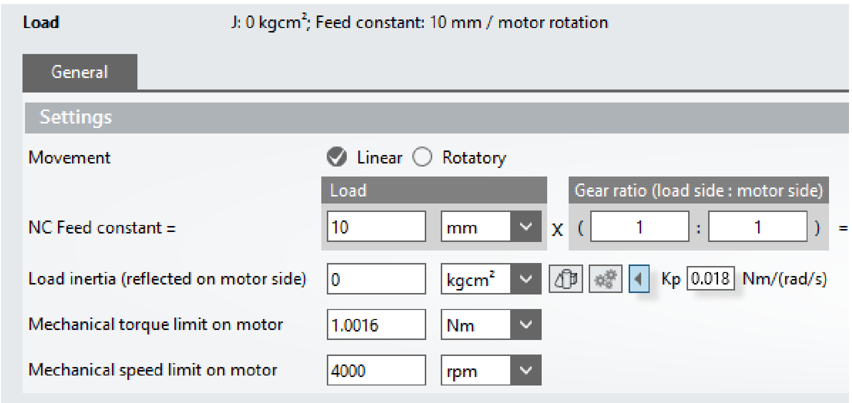

Figure 48 - Axis configuration in Drive Manager 2

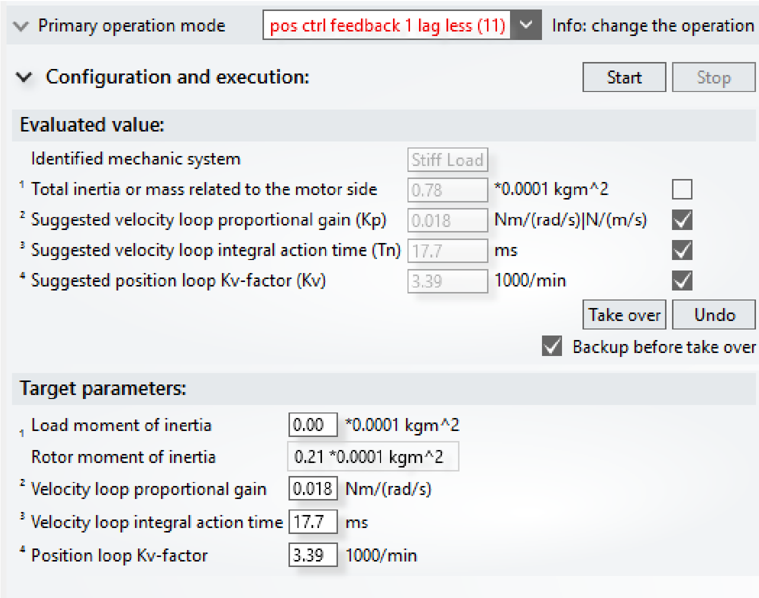

Figure 49 - Automatic Tuning in Drive Manager 2

Not all parameters from the motor are configured using this method like the virtual limits. Virtual limits are a drive related feature, in which the drive keeps track of the position of the axis and stops the movement once it reaches a certain threshold. However, it depends in online information from the encoder, which can lead to errors when the axis is not homed on and, as such, cannot be used as a security measure.

Virtual limits can be configured in both the drive manager 2 and the Motion control. For this project, the virtual limits were placed in -300 and 300 mm (Figure 50).

The full list of parameters can be seen in Annex D, and Figure 51 displays the controller values.

-	Limit Switches:	
	Soft Position Limit Minimum Monitoring	TRUE
	Minimum Position	-300.0
	Soft Position Limit Maximum Monitoring	TRUE
	Maximum Position	300.0

Figure 50 - Virtual Limits in Motion Control

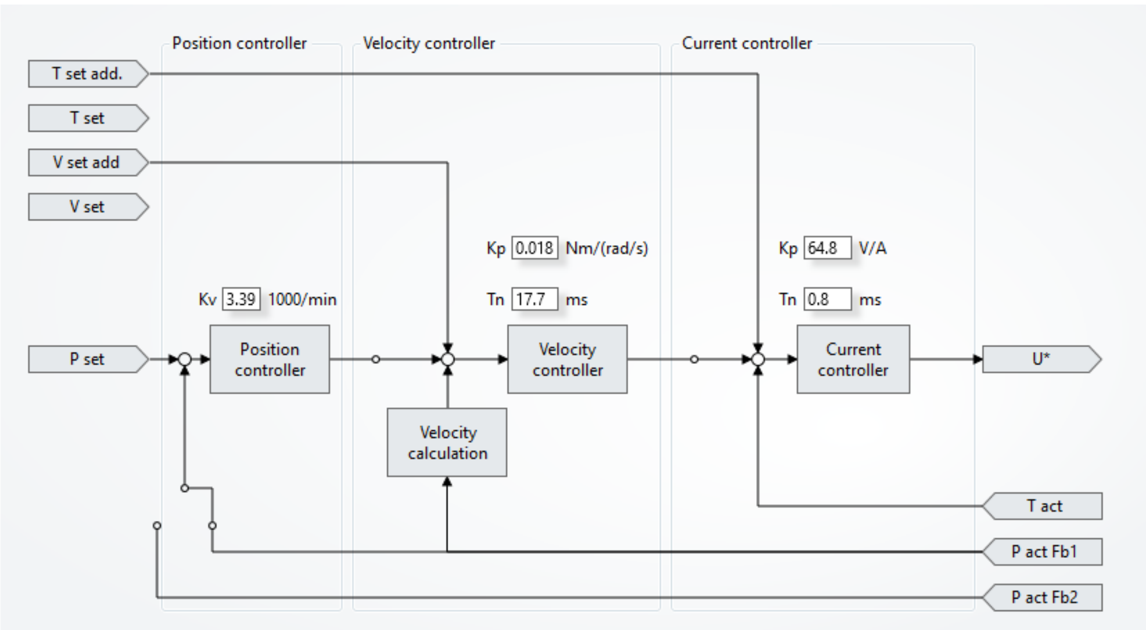

Figure 51 - Servomotor Controller Values

Following the configuration of these parameters, it is necessary to associate the motor to a variable within the program. Figure 52 displays the interface to configure the variable.

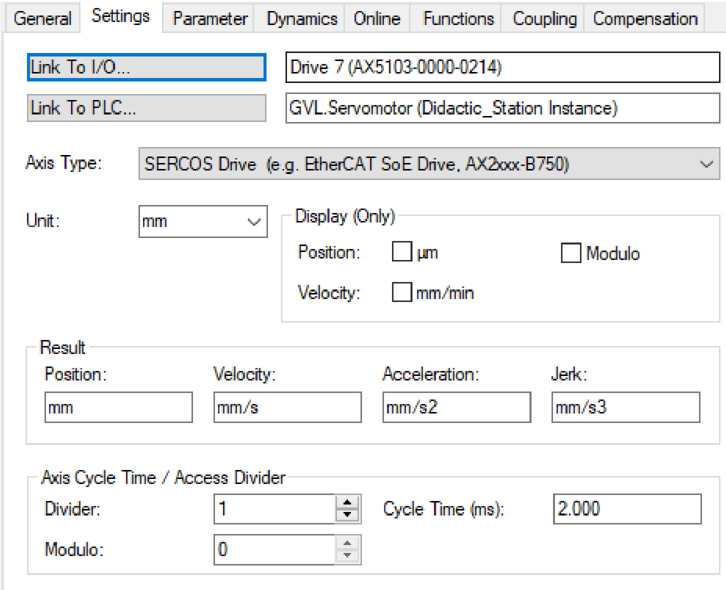

Figure 52 - Motion Control - Servomotor Settings and PLC Variable Link

Stepper Motor Parameters

For the stepper motor, it is followed the procedure described in [12]. One of the parameters configured was the scaling factor. This factor is based on the type of movement that the stepper motor does. Due to limitations, the stepper motor drive only allows for micro-steps. As such, the scaling factor is based on this type of step.

The stepper motor does a total of 64 steps per full revolution, while the drive allows the control by micro-steps, with a total of 200 micro-steps per full step that the stepper motor could do. This converts to a total of 12800 micro-steps per full 360º that the motor does.

To calculate the scaling factor, it is used the following equation:

$$\frac{D}{N} = Sf$$

Where:

- D is the distance per full revolution, in degrees.
- N is the number of steps per full revolution of the motor.
- Sf is the scaling factor, in degrees per revolution.

Using the previous equation and values, it is obtained a value for the scaling factor of 0.028125, as seen in Figure 53.

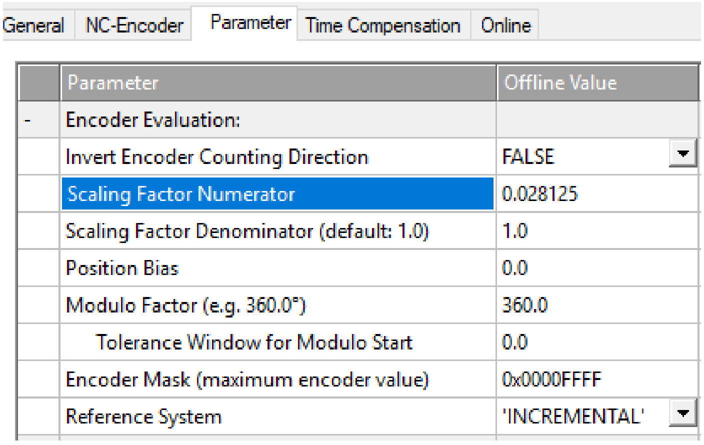

Figure 53 - Stepper Motor Scaling Factor

Another parameter required to set up is the frequency at which the motor works. The frequency influences the max velocity the motor is able to produce, with values seen in Table 23. As a base for this work, the frequency was set to be 1000, leading to a maximum velocity of 1800 °/s.

Table 23 - Frequency Configurations for the AS1030 Stepper Motor [29]

Drive Frequency [Full steps/s]	Maximum Velocity
1000	300 rpm
2000	600 rpm
4000	1200 rpm
8000	2400 rpm

The last parameters to be configured in the acceleration of the motor. Figure 54 presents the parameters used for this work.

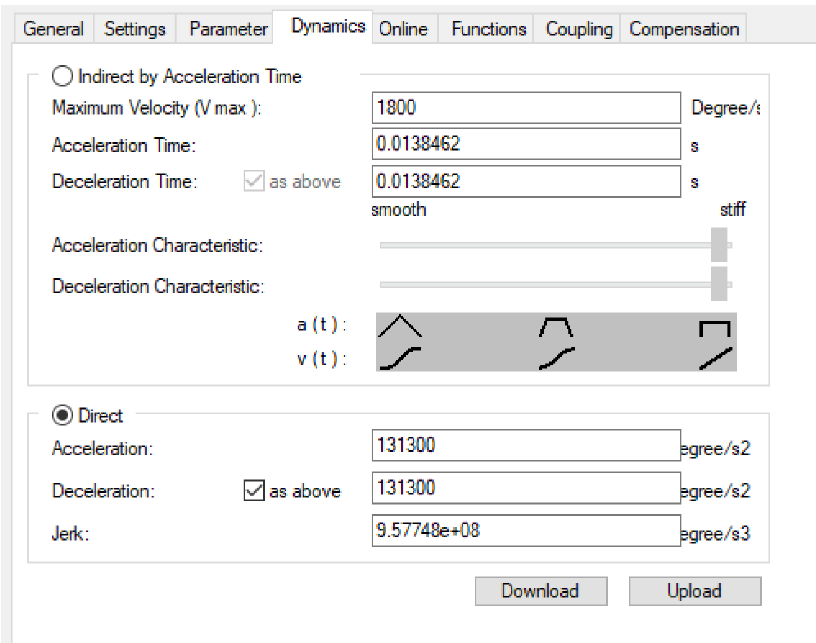

Figure 54 - Stepper Motor Dynamic Parameters

4.3 Code and Interface

The code and interface are organized in sets of small programs, divided into code, variables, and interface screens (Figure 55). This strategy is implemented to increase the modularity of the system and to allow easy access, modification and creation of new programs and interfaces within the work environment.

The most important programs are in the control folders, containing programs dedicated to the powering, stop, reset, homing and limits of the related motors (Figure 56). An example of the code used to control the power of a motor can be observed in Figure 57.

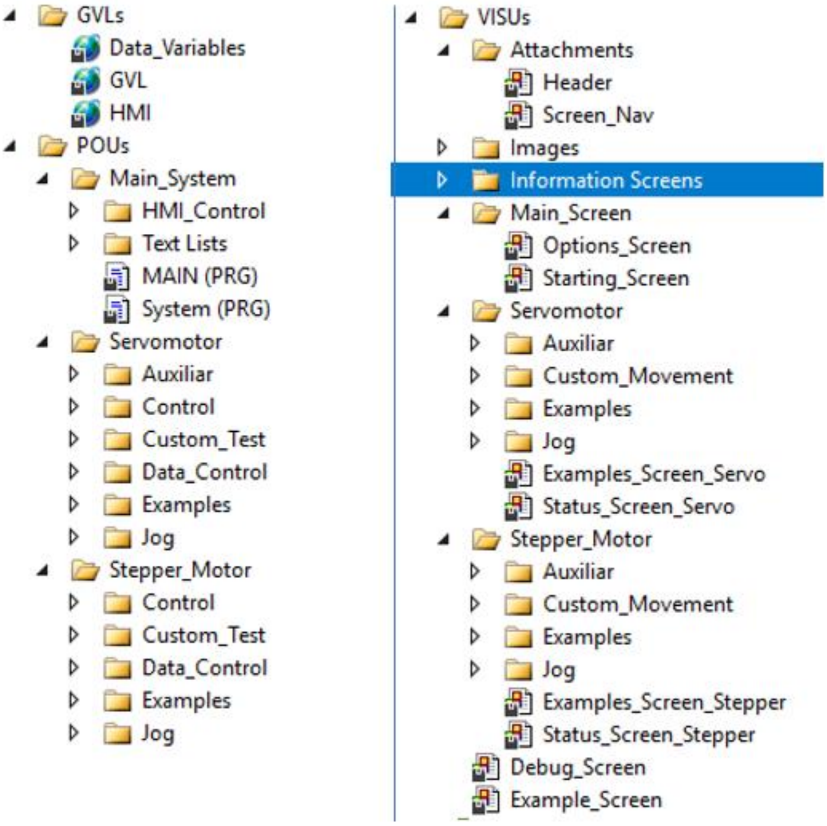

Figure 55 - Structure of the Program - Code and Variables (Left) and Interface (Right)

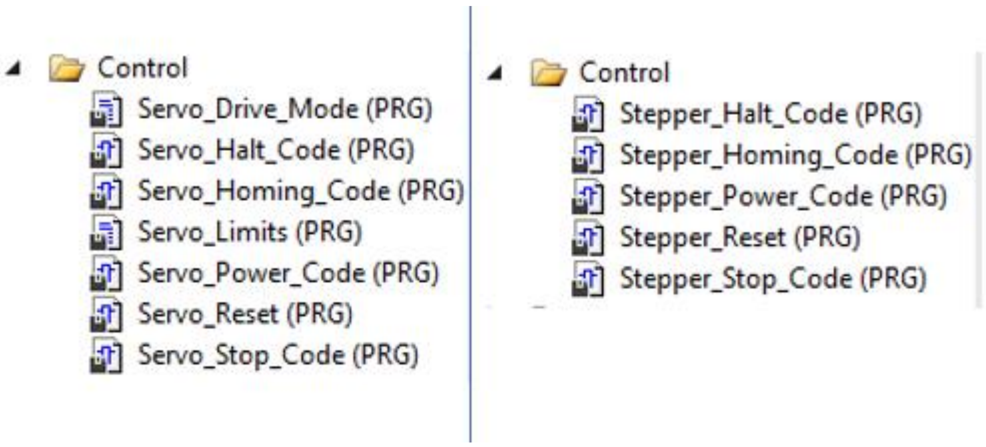

Figure 56 - Control Programs for the servomotor (Left) and Stepper Motor (Right)

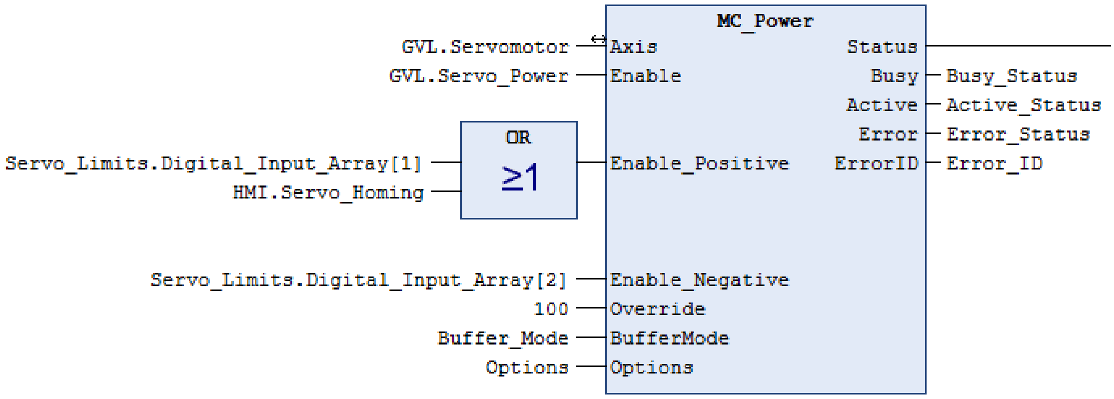

Figure 57 - Power Program for the Servomotor

The structure of the main program is presented in Figure 58.

As verified, both motors have access to two common exercises: Jog and Custom Movement.

Jog consists in allowing the user to move the axes at will or configure simple movements within the program (Figure 59). Custom movement allows it to create a set of movements, tailored by the user, with specific conditions and parameters.

Each of the motors have access to a set of experiments, related to the type of motor and functions available. Both motors have access to two simple examples: Back and Forth, with the objective of allowing the user to test and learn the variables related to the control of the motors, and a repeatability test, to verify the repeatability of the systems.

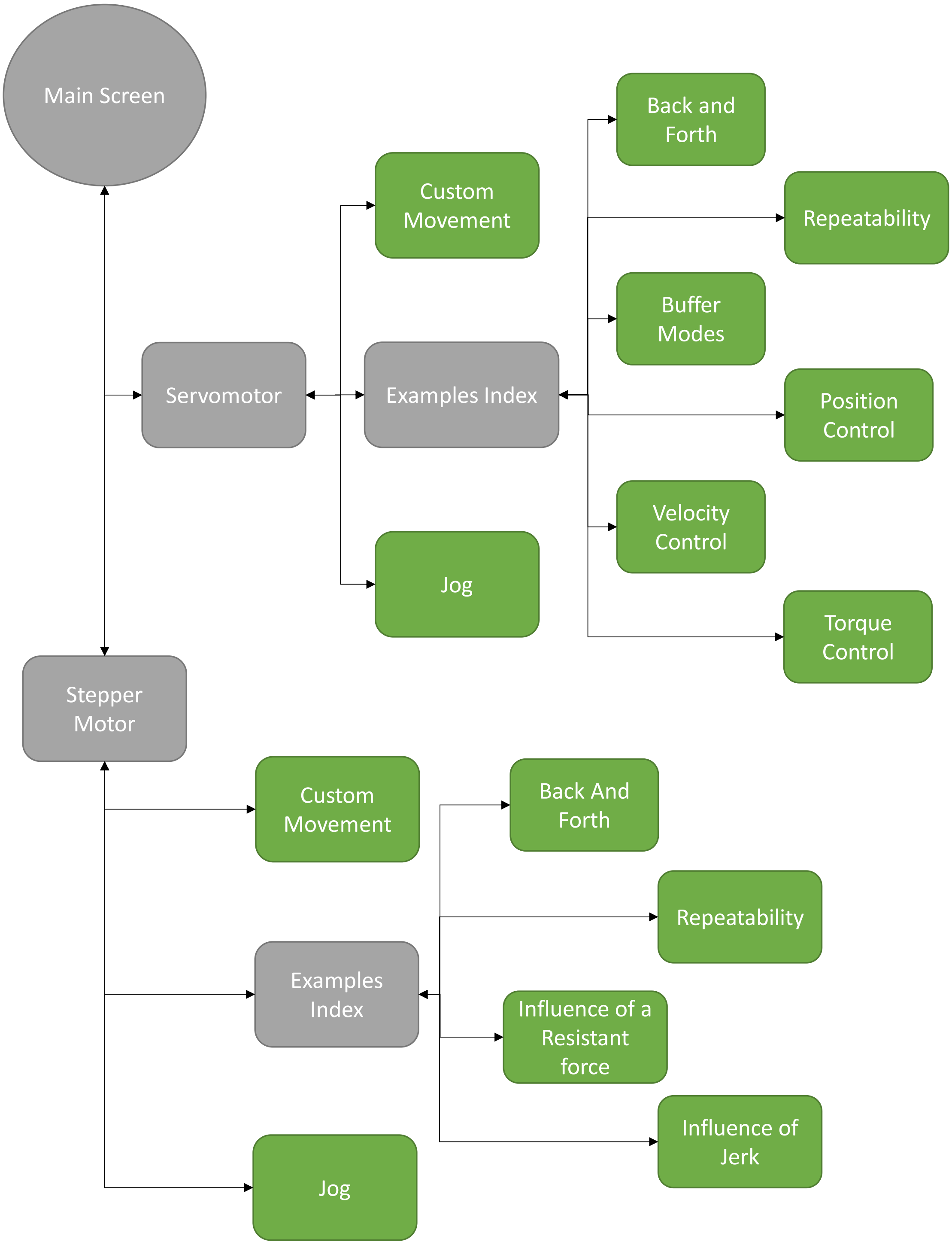

Figure 58 - Structure of the Main Program

```
Step_1000 := NOT HMI.Stepper_Jog_Start;
Step_1001 := HMI.Stepper_Jog_Start;

Jog(
    Axis:= GVL.Stepper_Motor,
    JogForward:= HMI.Stepper_Jog_Forward AND Step_1001,
    JogBackwards:= HMI.Stepper_Jog_Backwards AND Step_1001,
    Mode:= HMI.Stepper_Jog_Mode,
    Position:= HMI.Stepper_Jog_Position,
    Velocity:= HMI.Stepper_Jog_Velocity,
    Acceleration:= HMI.Stepper_Jog_Acceleration,
    Deceleration:= HMI.Stepper_Jog_Deceleration,
    Jerk:= HMI.Stepper_Jog_Jerk,
    Done=> HMI.Stepper_Jog_Status_Done,
    Busy=> HMI.Stepper_Jog_Status_Busy,
    Active=> HMI.Stepper_Jog_Status_Active,
    CommandAborted=> HMI.Stepper_Jog_Status_Abort,
    Error=> HMI.Stepper_Jog_Status_Error,
    ErrorID=> HMI.Stepper_Jog_Status_Error_ID);
```

Figure 59 - Stepper Jog Code

The servomotor has access to examples to test the different types of control and different types of buffer mode for the control blocks of the system. The buffer mode changes how successive movements are connected. For the control, the tests work on control position, velocity, and torque (Figure 60 and Figure 61), with the objective of seeing how the parameters and system behaves.

```
//Example 1, Torque at 10% of the limit Torque, increase of 10% torque per second

    Torque_Control_1(
        Axis:=GVL.Servomotor ,
        Execute:= HMI.Servo_5_1_Start AND Servo_power_Code.Power_Block.Status,
        Relative:= FALSE ,
        Torque:= (0.1/1.0016)*100,
        TorqueRamp:= (0.1/1.0016)*100,
        VelocityLimitHigh:= 150,
        VelocityLimitLow:= -150,
    );

//Example 2, Torque at 10% of the Limit Torque, increase of 50% torque per second

    Torque_Control_2(
        Axis:=GVL.Servomotor ,
        Execute:= HMI.Servo_5_2_Start AND Servo_power_Code.Power_Block.Status,
        Relative:= FALSE ,
        Torque:= (0.1/1.0016)*100,
        TorqueRamp:= (0.5/1.0016)*100,
        VelocityLimitHigh:= 150,
        VelocityLimitLow:= -150,
    );
```

```
//Example 1 Velocity 50 mm/s, Acceleration 50mm/s2, Jerk 20mm/s3
    Velocity_Control_1(
    Axis:= GVL.Servomotor,
    Execute:= HMI.Servo_4_1_Start AND Servo_power_Code.Power_Block.Status,
    Velocity:= 50,
    Acceleration:= 50,
    Deceleration:= 50,
    Jerk:= 20,
    Direction:= MC_Positive_Direction);

//Example 2 Velocity 50 mm/s, Acceleration 50mm/s2, Jerk 200mm/s3
    Velocity_Control_2(
    Axis:= GVL.Servomotor,
    Execute:= HMI.Servo_4_2_Start AND Servo_power_Code.Power_Block.Status,
    Velocity:= 50,
    Acceleration:= 50,
    Deceleration:= 50,
    Jerk:= 200,
    Direction:= MC_Positive_Direction);
```

Figure 60 - Torque Control (Top) and Velocity Control (Bottom) Tests Examples

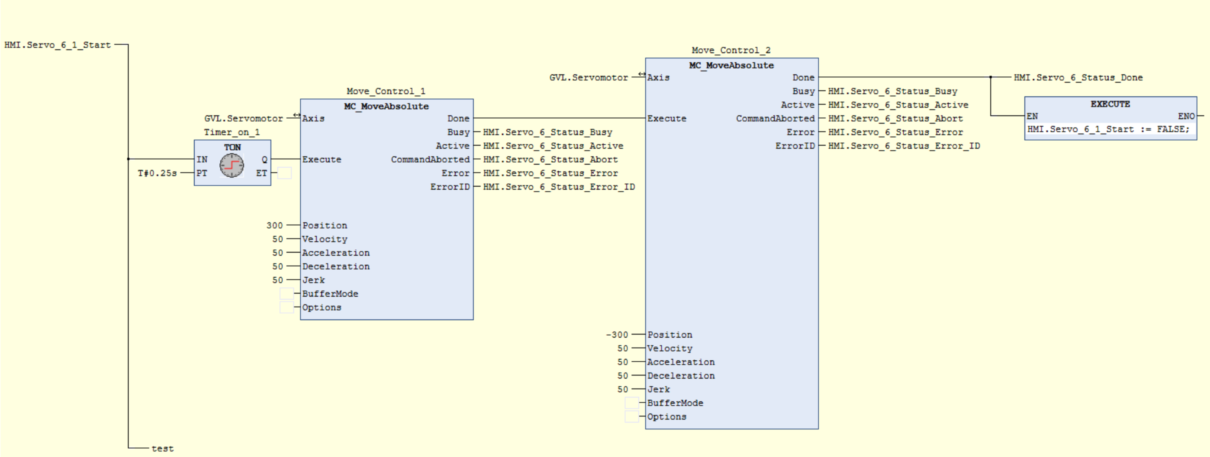

Figure 61 - Position Control Test Example

The stepper motor presents an example related to the loss of steps.

As for the interface, the user is first presented with a starting screen (Figure 62), with the options to navigate to other sections of the program. All the other screens contain the same header and screen navigation, for simplicity. The header allows the user to quickly go back or forward into previously accessed screens and access an options area (Figure 63). The screen navigation allows for quick navigation between the main screens.

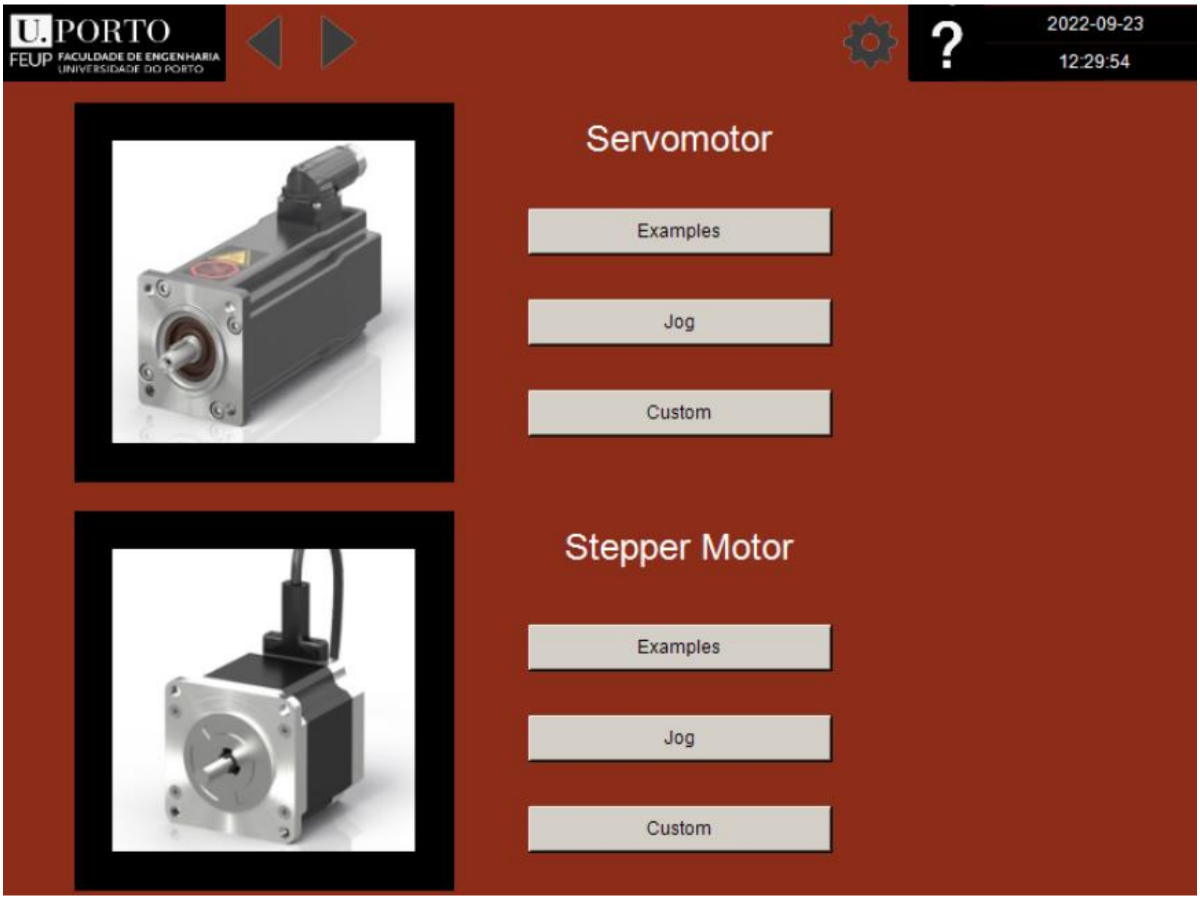

Figure 62 - Starting Screen

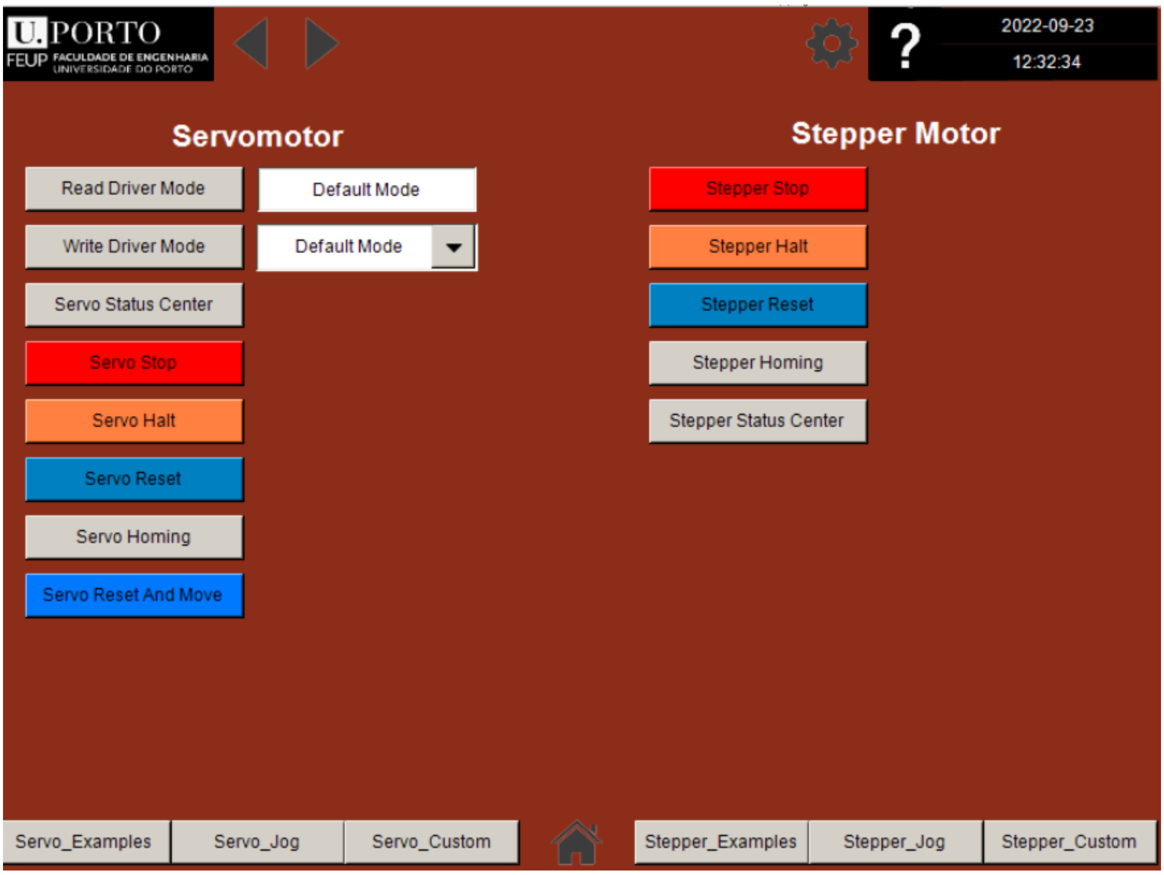

Figure 63 - Options Screen

Each of the exercise interfaces display a simple set of controls and histograms (Figure 64). The histograms showcase specific variables related to that motor, allowing the user to verify certain patterns and movements caused by the parameters. The code keeps them updated, by registering the values into an array. Code example for a histogram can be seen in Figure 65.

Figure 64 - Jog Control Screen

```
//Array Loop for Position
    FOR Loop :=0 TO (GVL.Servo_Data_Control_Array_Max -1) DO
        Data_Array[Loop] := Data_Array[Loop + 1];
    END_FOR

Read_Position(
    Axis:= GVL.Servomotor ,
    Enable:= TRUE ,
);

Data_array[GVL.Servo_Data_Control_Array_Max] := Read_Position.Position;

//Specific Value Display for Position
IF NOT HMI.Servo_Data_Pause THEN

    HMI.Servo_Position := Read_Position.Position;
    FOR Loop :=0 TO GVL.Servo_Data_Control_Array_Max DO
    HMI.Servo_DataArray_Position[Loop] := Data_Array[Loop];
    END_FOR
```

Figure 65 - Histogram Code Example

4.4 Experimental Exercises

The experimental exercises realized focused on four topics: the quality of the data displayed by the histograms, the behaviour of the servomotor during different control types, step responses of the servomotor for position and velocity, and the loss of steps for the stepper motor.

For the data quality, it was compared the graphics produced by the histogram code and by the scope view for the same movement.

For the control types and step response, different parameters were applied, to verify the response of the system in each of the experiments.

For the stepper motor exercise, to verify the loss of steps, it was configured the motor to start up at different speeds.

Data Quality Experiment

The histogram data is acquired from the actual value of position and velocity for both motors. It registers the data every 100ms and builds the graphic based on the acquired values. As such, the objective is to verify how consistent and accurate the displayed information is, and how the resolution fares versus the digital oscilloscope.

To verify, back and forth movements were realized, with the parameters and positions used available in Table 24. For each of the runs, the digital oscilloscope and the histogram code were running, to guarantee that the data was acquired from the same movement and conditions.

Figure 66 to Figure 69 display the obtained results for runs 1 and 5.

Table 24 - Experiments Parameters for the back-and-forth movements

Run	1st Position	2nd Position	Velocity	Acceleration	Jerk
1	200 mm	-200 mm	50 mm/s	25 mm/s^2	500 mm/s^3
2	200 mm	-200 mm	100 mm/s	25 mm/s^2	500 mm/s^3
3	200 mm	-200 mm	50 mm/s	100 mm/s^2	500 mm/s^3
4	200 mm	-200 mm	100 mm/s	100 mm/s^2	500 mm/s^3
5	275 mm	-275 mm	100 mm/s	100 mm/s^2	25 mm/s^3

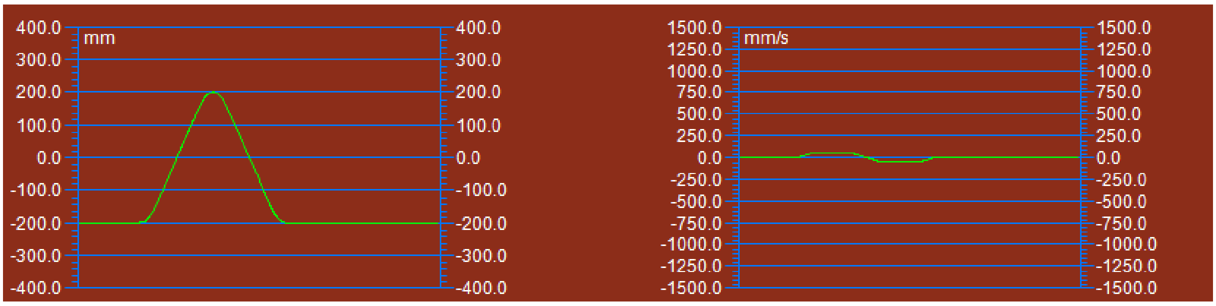

Figure 66 - Results obtained via the Histogram Code for run 1, Position (left) And Velocity (Right)

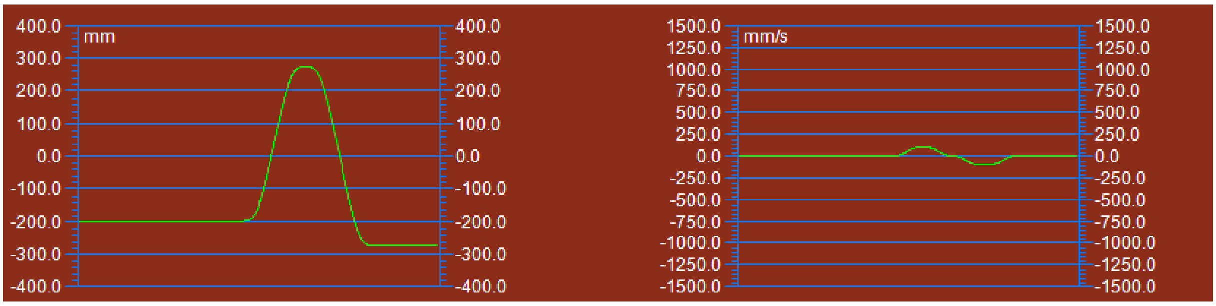

Figure 67 - Results obtained via the Histogram Code for run 5, Position (left) And Velocity (Right)

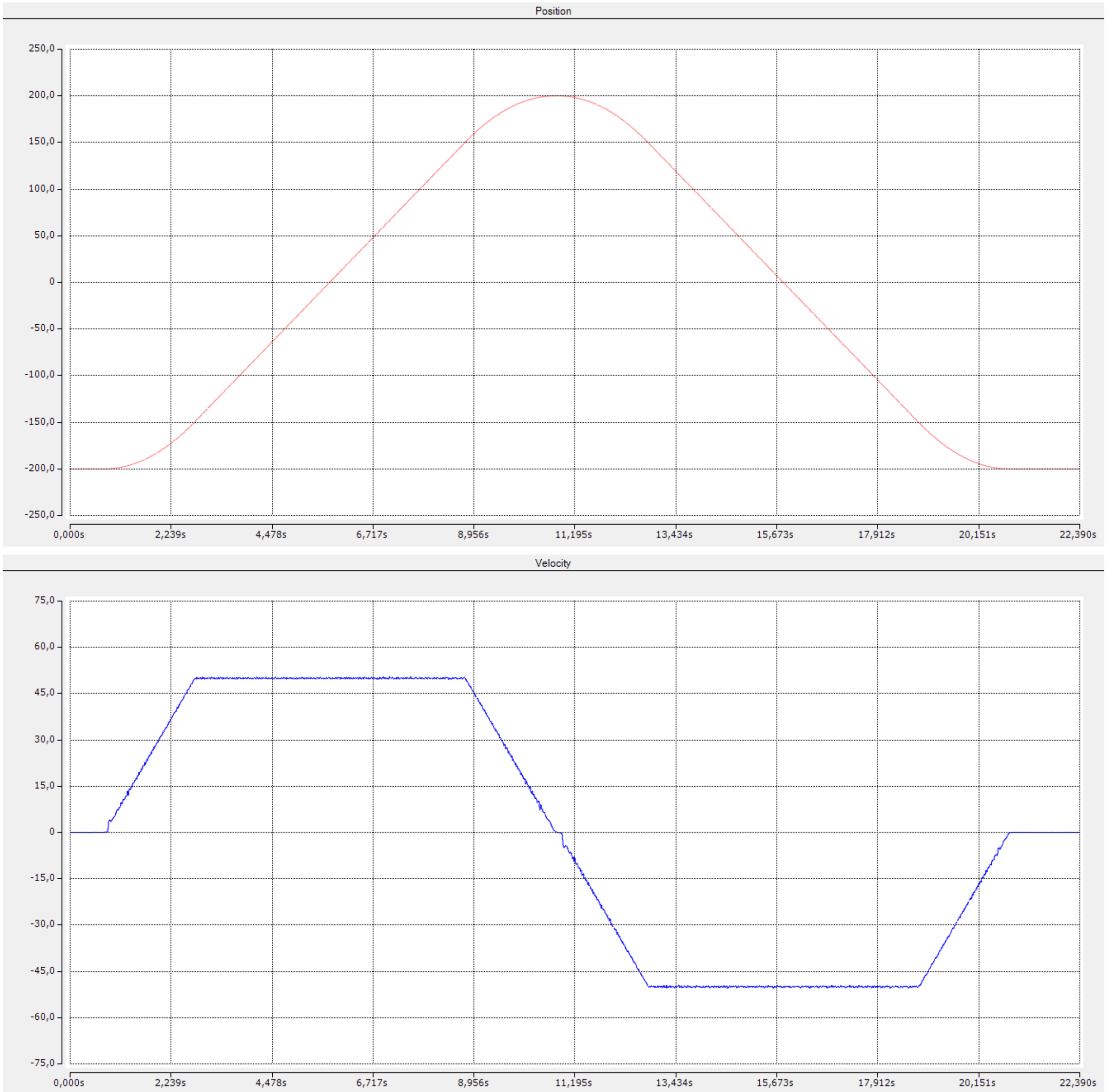

Figure 68 - Results obtained from Scope View for Run 1, Position (mm, Top) and Velocity (mm/s, Bottom)

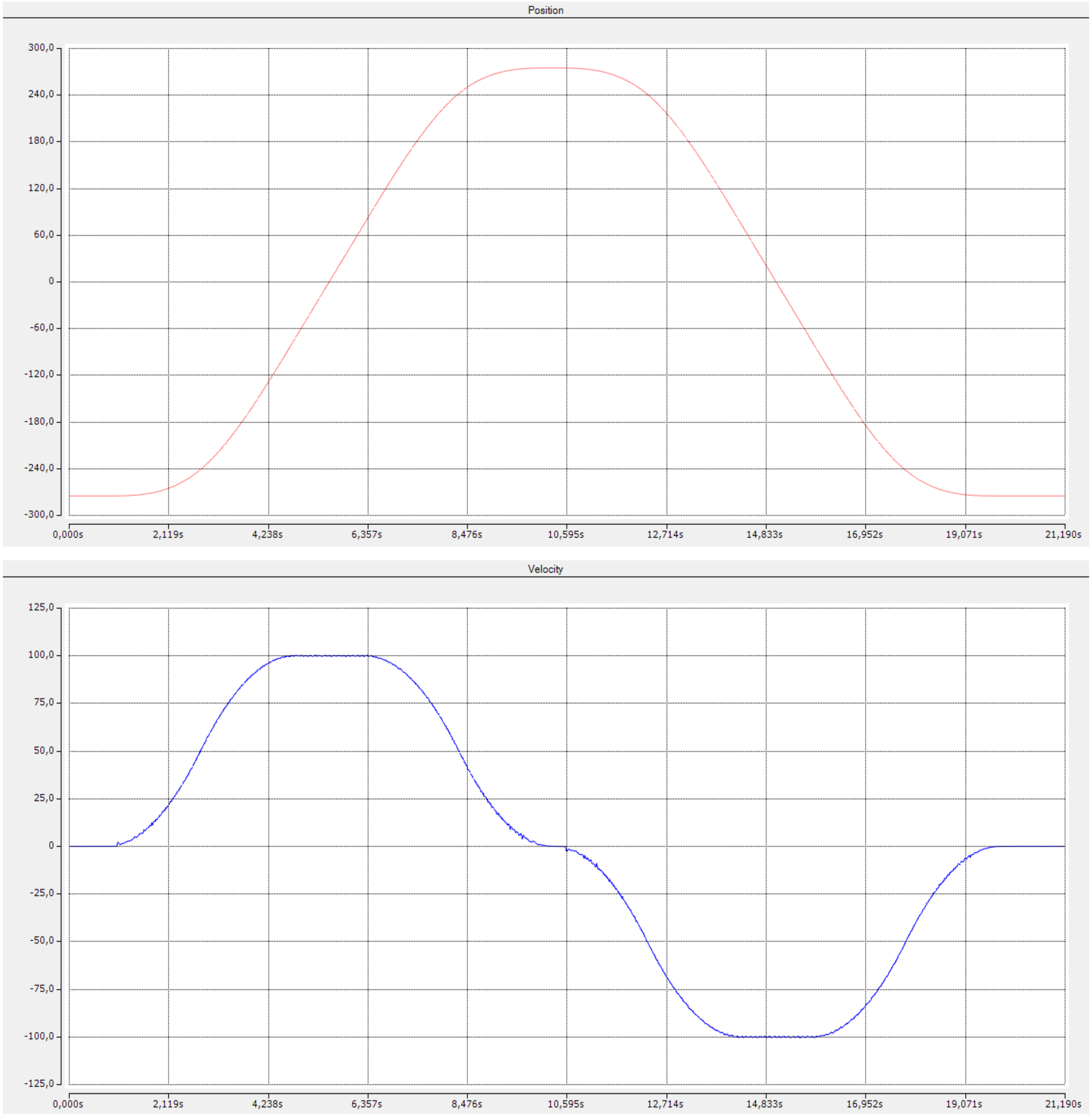

Figure 69 - Results obtained from Scope View for Run 5, Position (mm, Top) and Velocity (mm/s, Bottom)

After the experiments, it’s verified that the histogram possesses a good consistency and accuracy with values displayed. However, it fails in resolution, as it registers few points to draw the graphic. As such, quick spikes on the variables won’t be detected.

The lack of a time scale and analysis of previous values are a negative point in this type of data acquisition as well, as it is not possible to verify previous values, and the graph doesn’t accept a time scale. With that in mind, this can only be used to verify, in real time, a general graphic of these variables to gather a general idea of the behaviour, and doesn’t substitute proper data gathering tools, like Scope View.

Control Type Experiments

The servomotor and its drive offer different control types, such as position, velocity, or torque control. As such, the study of the behaviour of the system for each of these controls proves to be an important point.

To compare and observe each of the control types, four exercises were realized for each control. The next table, Table 25, displays the parameters used for each of the exercises. For this, scope view will be used to gather information on variables like position, velocity, and torque.

Table 25 - Parameters used in the Control Type Experiments

Control Type	Run	Velocity	Acceleration	Jerk
Position Control	**1**	250 mm/s	50 mm/s^2	50 mm/s^3
	2	250 mm/s	250 mm/s^2	50 mm/s^3
	3	250 mm/s	50 mm/s^2	500 mm/s^3
	4	250 mm/s	250 mm/s^2	500 mm/s^3
Velocity Control	**1**	50 mm/s	50 mm/s^2	200 mm/s^3
	2	50 mm/s	150 mm/s^2	200 mm/s^3
	3	150 mm/s	50 mm/s^2	200 mm/s^3
	4	150 mm/s	150 mm/s^2	200 mm/s^3
Torque Control	Run	Torque	Torque Ramp	
	1	0.267 Nm	0.267 Nm/s	
	2	0.534 Nm	0.267 Nm/s	
	3	0.801 Nm	0.267 Nm/s	
	4	1.068 Nm	0.267 Nm/s	

For the position control, it was verified the expected. The system uses the programmed parameters, limited by the user, like velocity, acceleration, and jerk, to achieve the position. With the information of the other variables, the control creates a specific movement to slow down before reaching the specified location. The results verify this situation (Figure 70 and Figure 71).

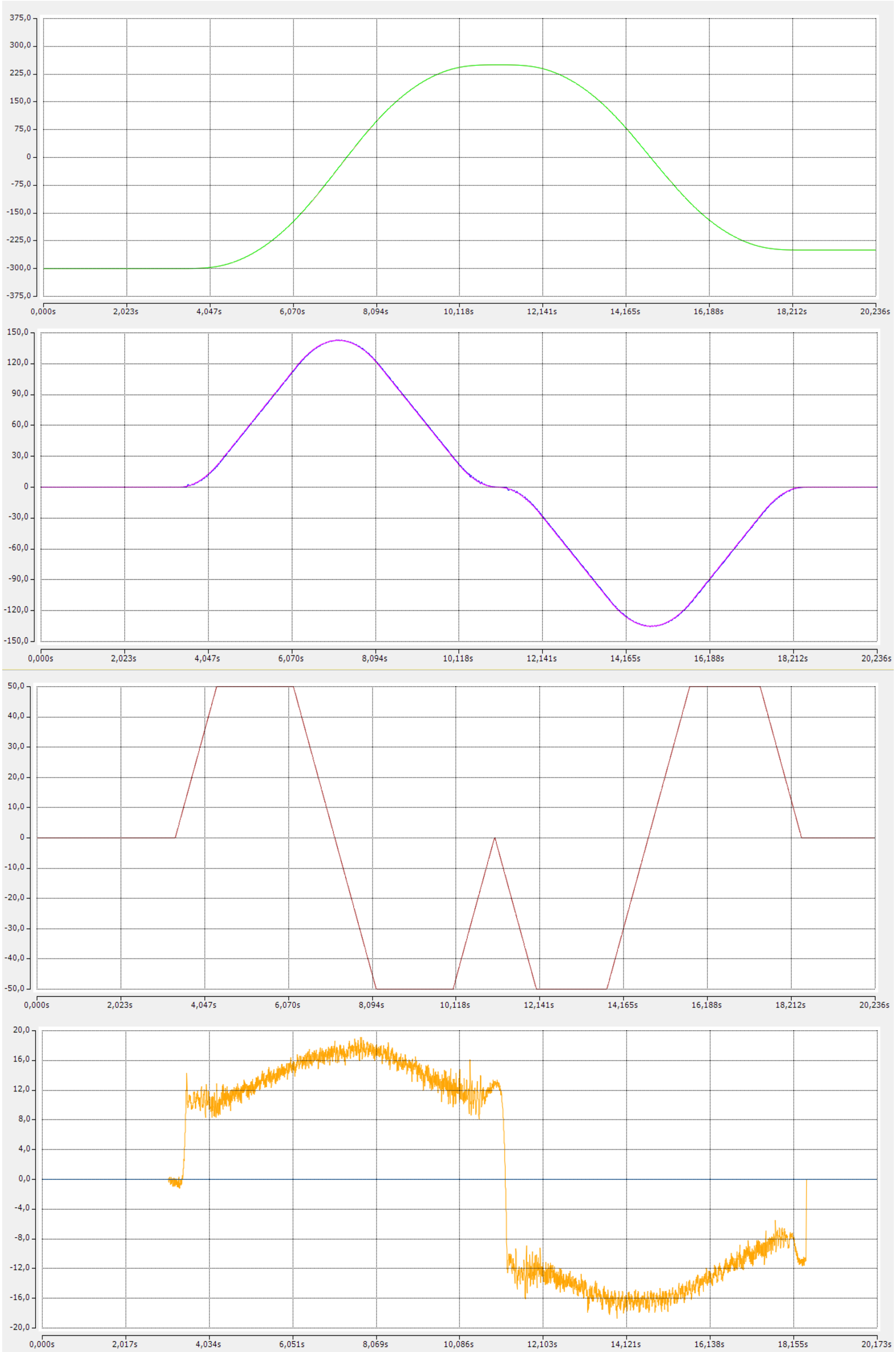

Figure 70 - Results of Run 1 for the Position Control. From top to bottom Position (mm), Velocity (mm/s), Acceleration (mm/s2), Torque (% Peak Torque)

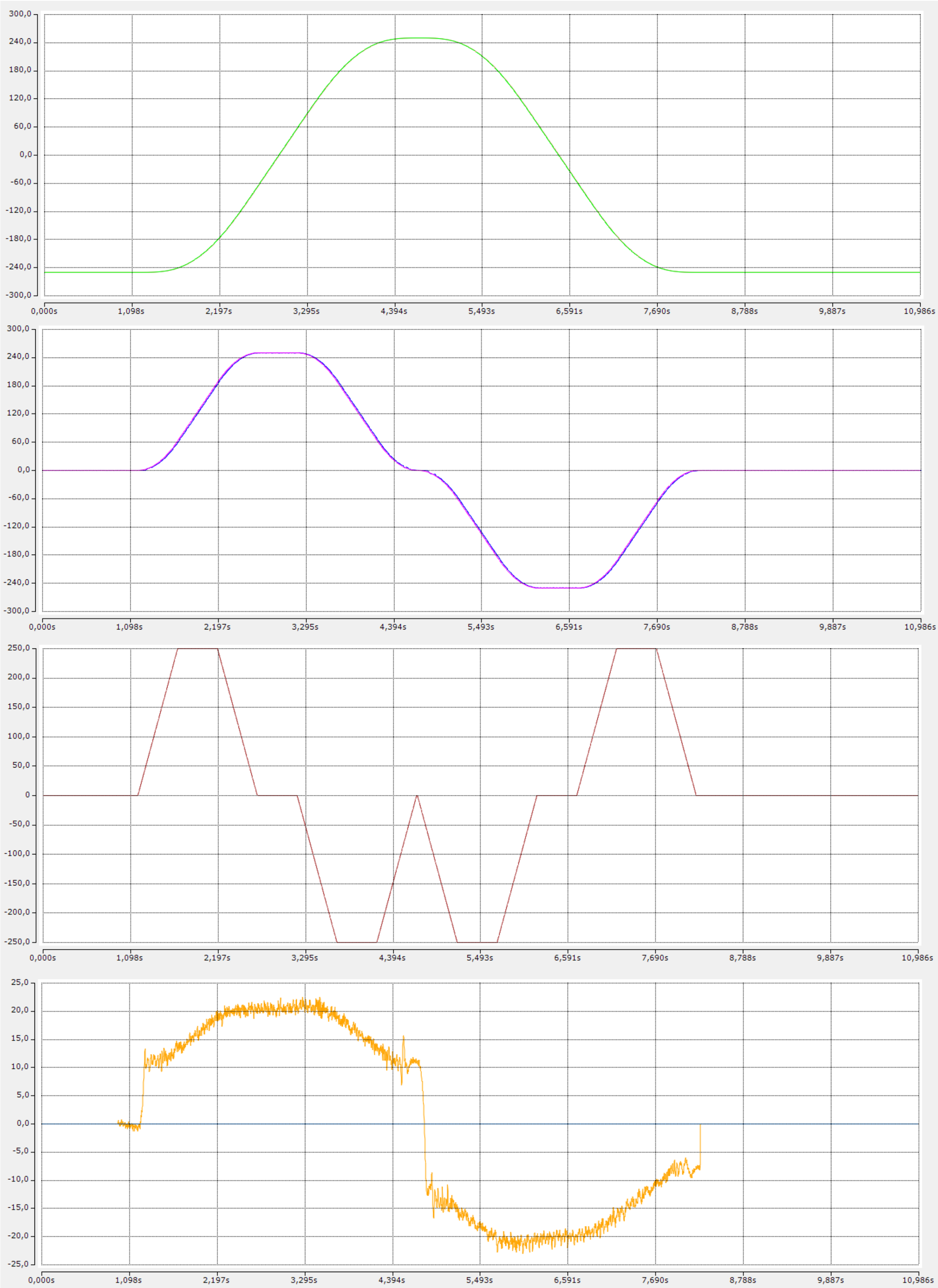

Figure 71 - Results of Run 4 for the Position Control. From top to bottom Position (mm), Velocity (mm/s), Acceleration (mm/s2), Torque (% Peak Torque)

The results from the velocity control tests were found to be like the position control. Both modules tend to increase their velocity while within parameters defined by the user.

The velocity oscillates around the defined value, leading to overshoot of the velocity by a small margin (Figure 72). Main difference between this control and the position control is how the movement stops. Velocity control tries keeps the velocity stable until the user or the system stop the movement, leading to high spikes of deceleration and torque on those moments, which is verified in Figure 73.

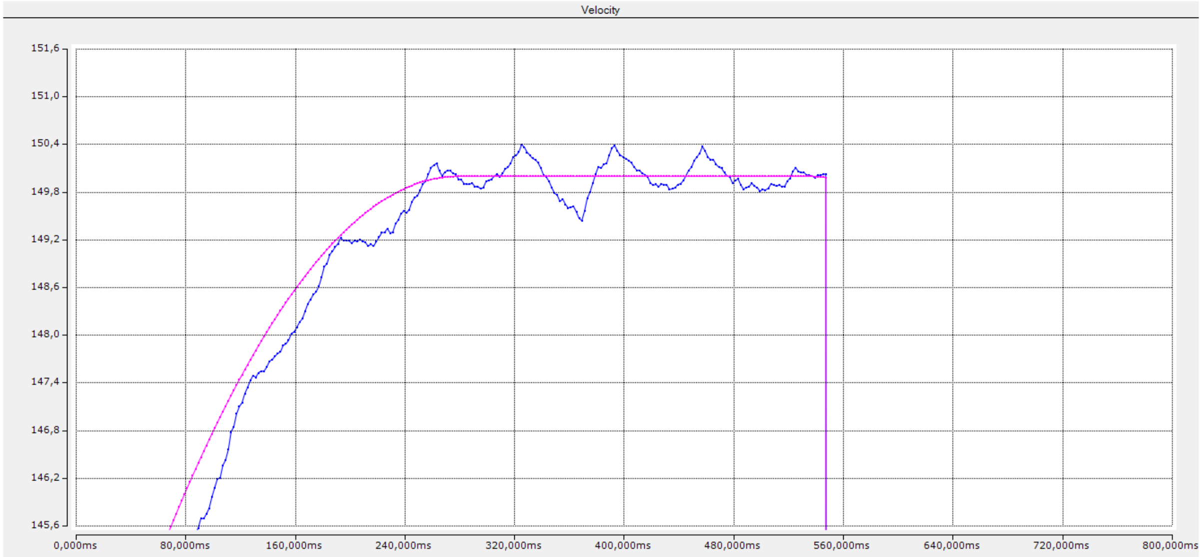

Figure 72 - Velocity Overshoot: Reference Velocity (Purple) and Actual Velocity (Blue)

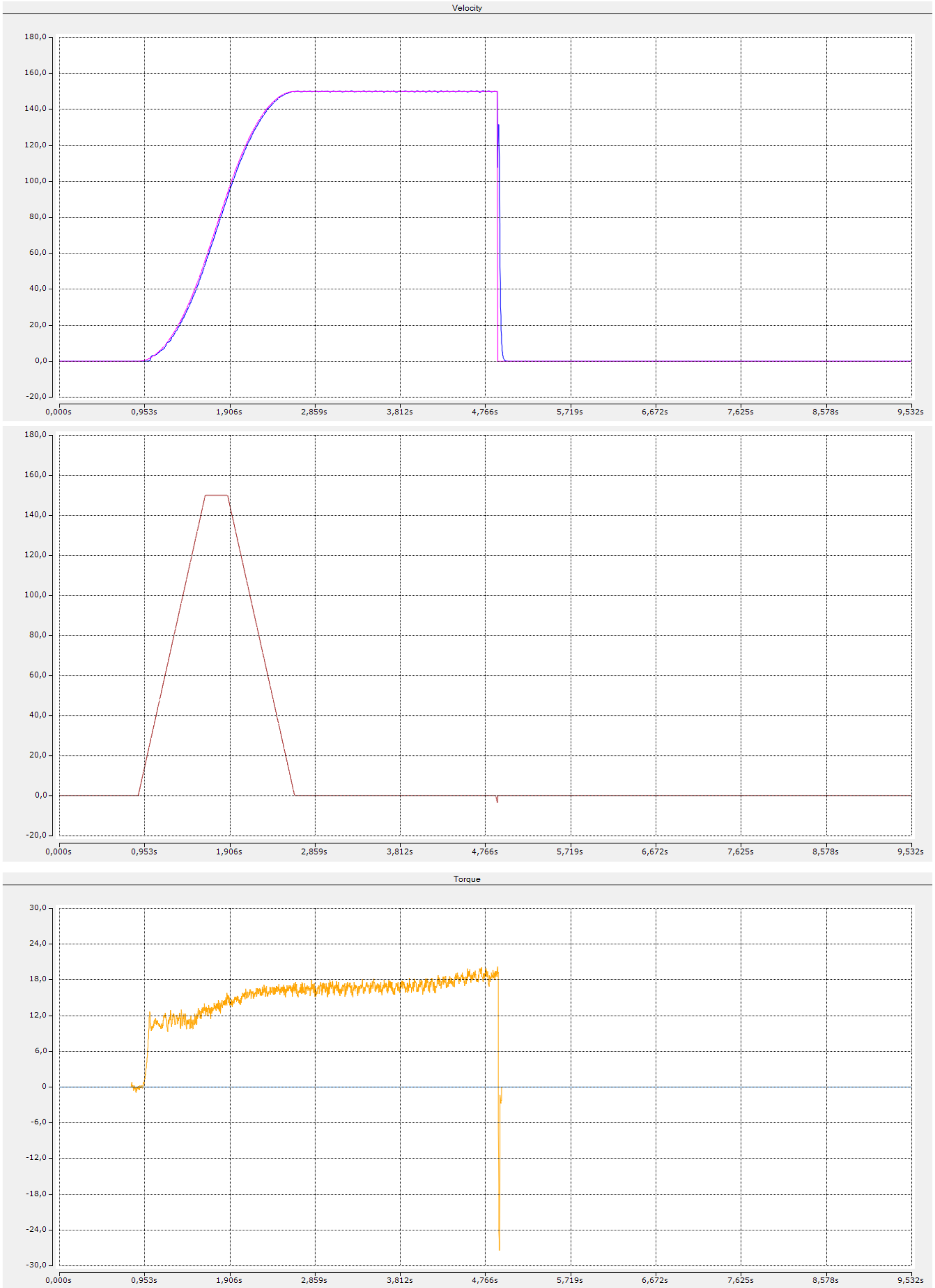

Figure 73 - Results of Run 4 for the Velocity Control. From top to bottom Velocity (mm/s), Acceleration (mm/s2), Torque (% Peak Torque)

For the Torque Control, it was verified that, unlike the previous data, the motor was able to surpass the resistant torque offered by the axis with a torque value located between 0.2 and 0.4 Nm, unlike the maximum value of 0.47 Nm, according to the catalogue for the axis. In the case of 0.2 Nm, the motor was only able to move micrometres, and was regarded as a torque that led to no relevant movement, in this case.

On this control type, it was expected and verified that torque would keep constant after reaching the desired value, even if such conditions lead to no movement of the motor, as seen in Run 1. Figure 74 displays a comparison between two runs.

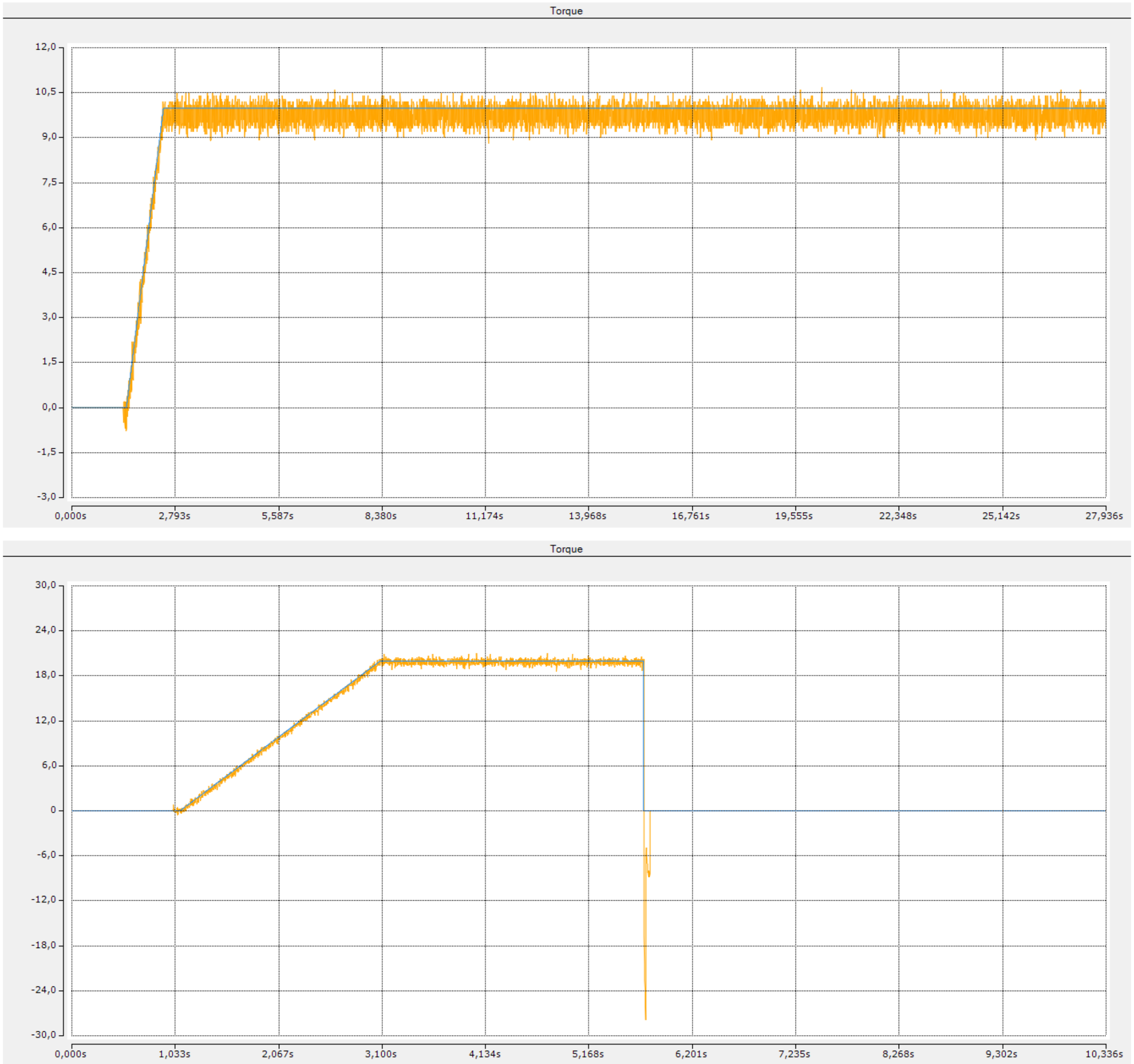

Figure 74 - Results for Torque (% Peak Torque, in orange) and theoretical Torque (% Peak Torque, in blue) from Run 1 (Top) and Run 2 (Bottom) for Torque Control

Step Response for the servomotor

Staring with the step position response, it was used a step of 100 mm to verify the response of the system, with different parameters. The first test, presented in Figure 75, consisted in a movement from negative 100 mm to 0 mm, with a velocity of 600 mm/s and an acceleration of 15000 mm/s^2. The second test (Figure 76) was done within the positions -100 mm and 0 mm, with a velocity of 100 mm/s and an acceleration of 15000 mm/s^2. The last test (Figure 77) was done with the same position limits, a velocity of 600 mm/s and an acceleration of 1500 mm/s^2.

In all these cases, it was verified no overshoot.

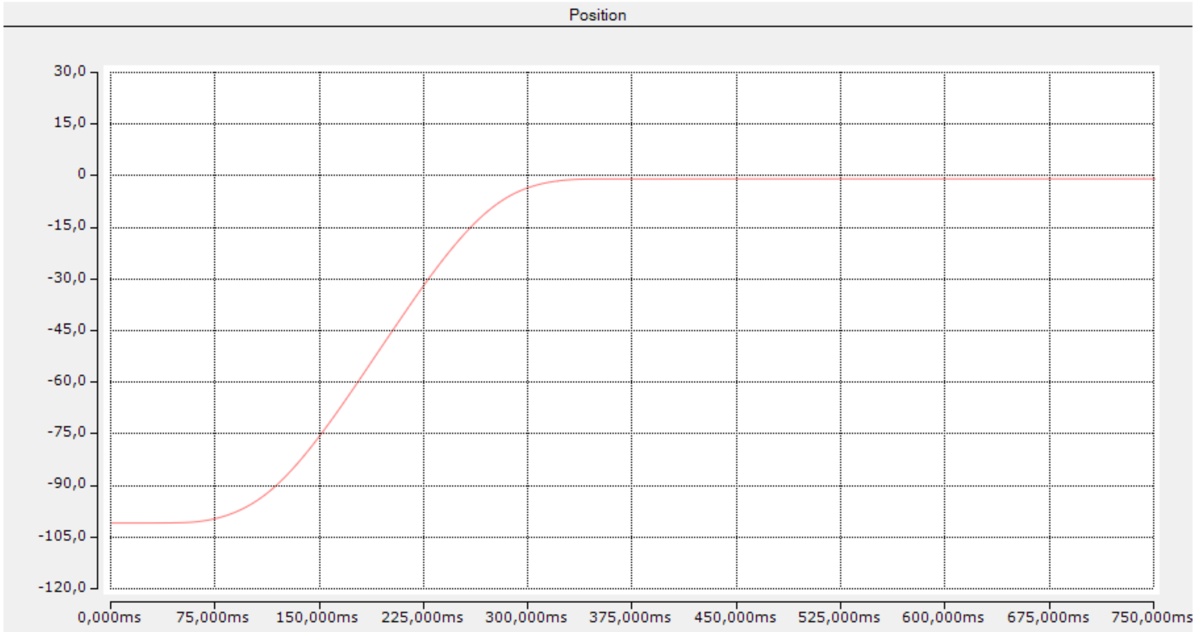

Figure 75 - Position (mm) Step Response. Position from -100 mm to 0 mm, velocity of 600 mm/s, acceleration of 15000 mm/s2

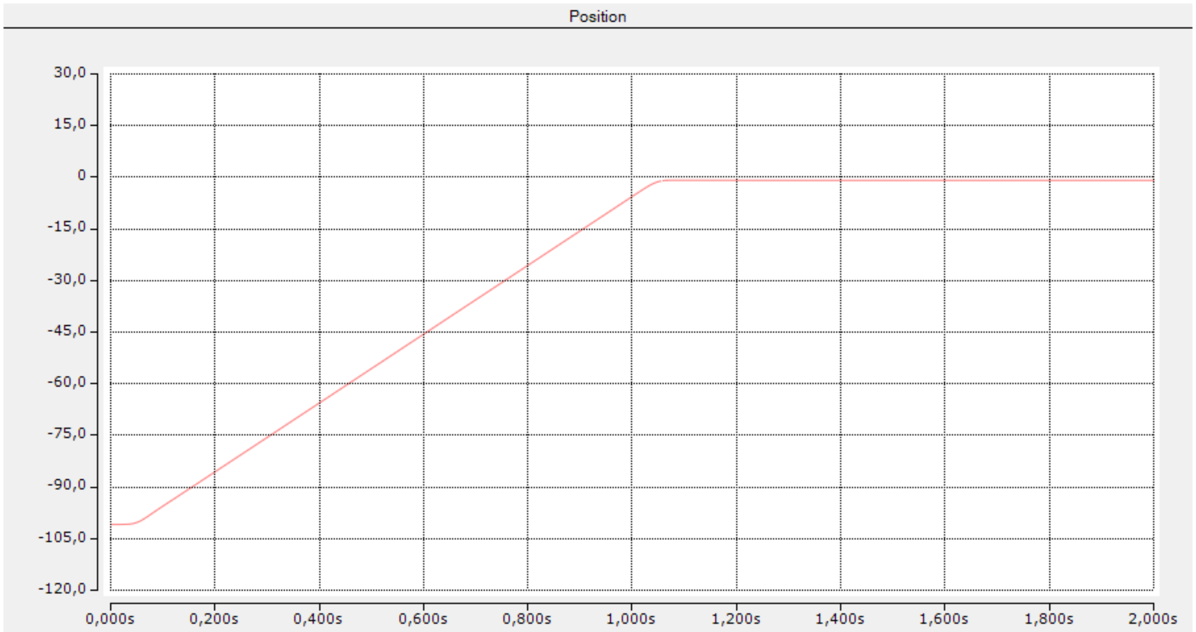

Figure 76 - Position (mm) Step Response. Position from -100 mm to 0 mm, velocity of 100 mm/s, acceleration of 15000 mm/s2

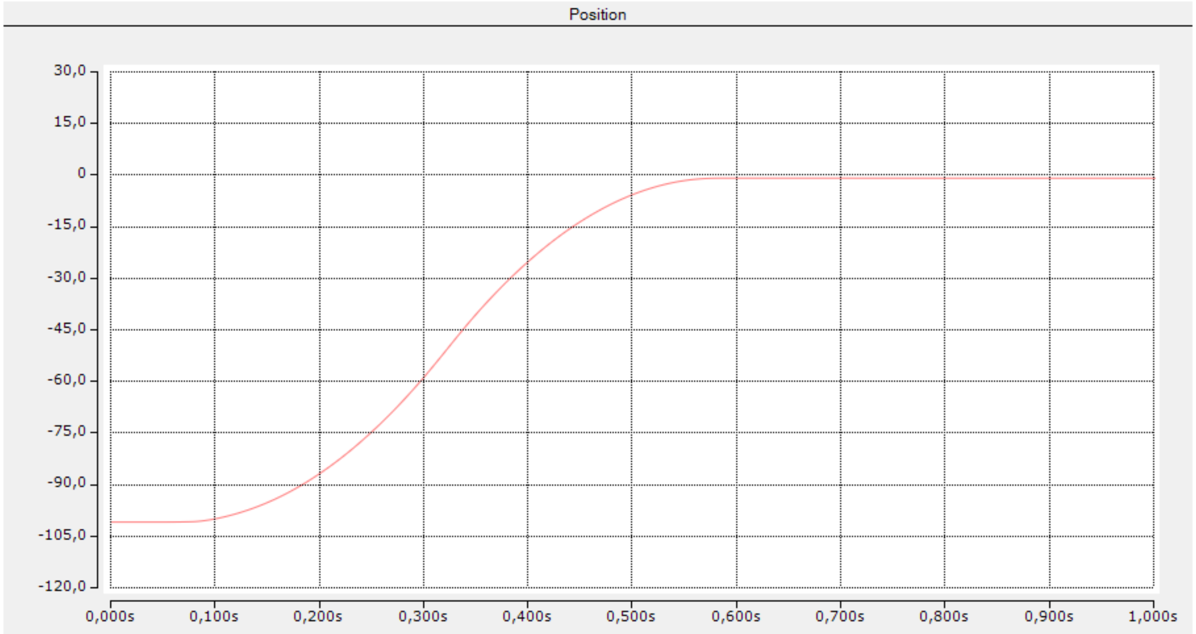

Figure 77 - Position (mm) Step Response. Position from -100 mm to 0 mm, velocity of 600 mm/s, acceleration of 1500 mm/s2

For step velocity response, different values were used. In the first test (Figure 78), the velocity was set to 100 mm/s, while on the second (Figure 79), the velocity was 10 mm/s. The last test, in Figure 80, had a velocity of 50 mm/s.

In these cases, it was verified the existence of overshoot when the velocity was 10 mm/s and 50 mm/s.

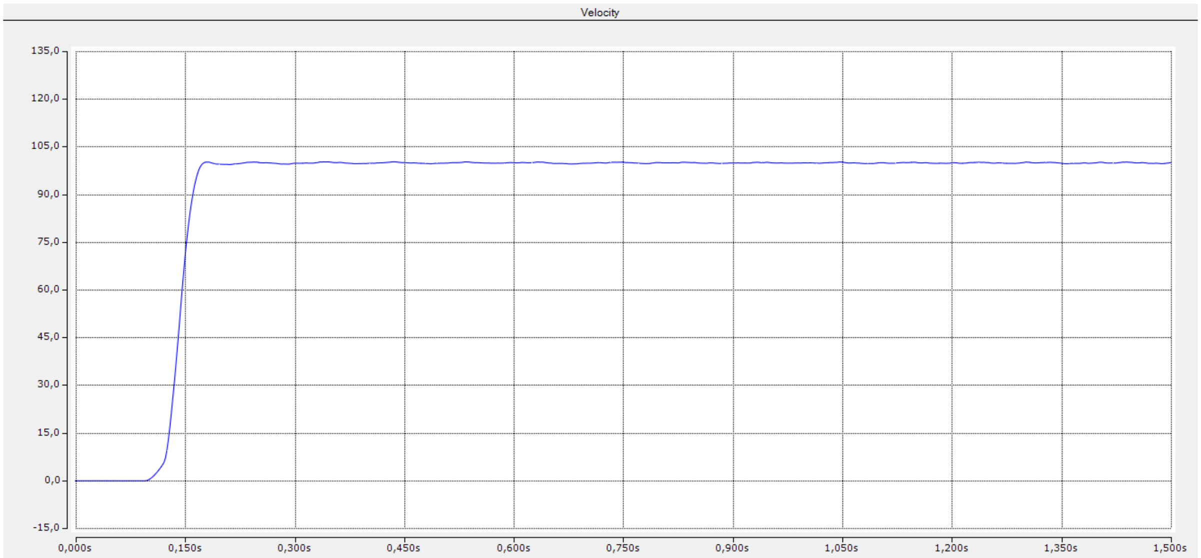

Figure 78 - Velocity Step Response, with a velocity of 100 mm/s

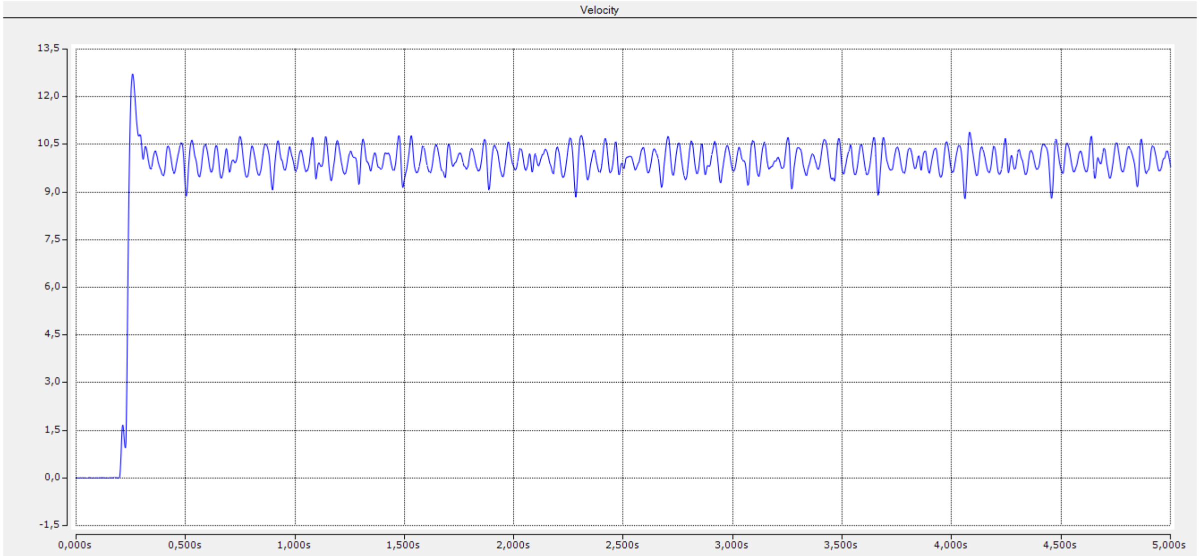

Figure 79 - Velocity Step Response, with a velocity of 10 mm/s

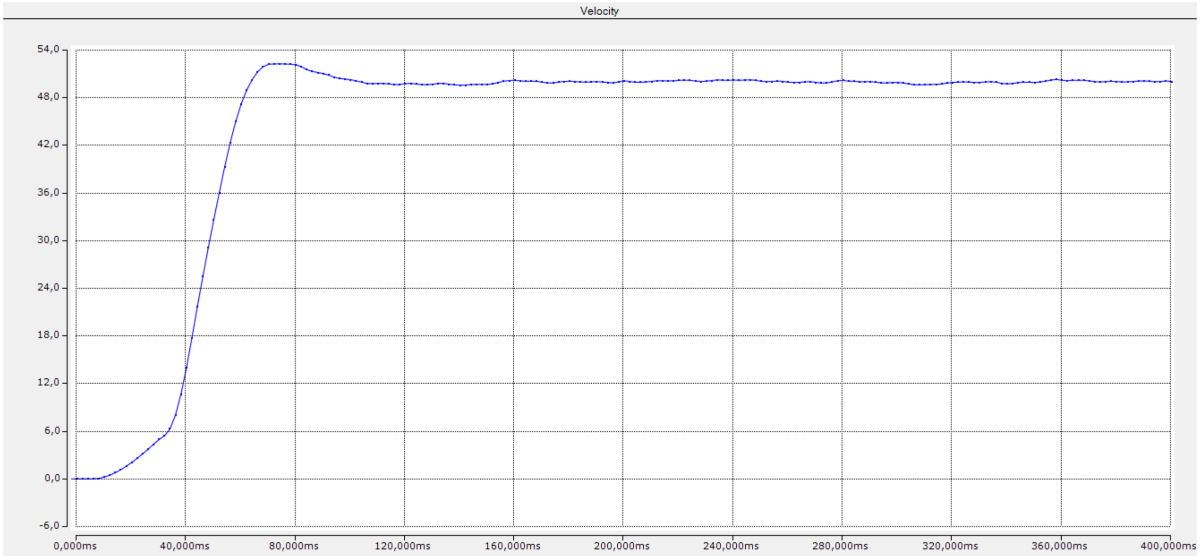

Figure 80 - Velocity Step Response, with a velocity of 50 mm/s

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Loss of steps in the stepper motor due to velocity

Due to working in an open loop configuration, there's a possibility that the stepper motor loses steps, either due to high velocity or accelerations, or due to an external force against the movement. In these tests, the objective is to condition the motor to different start speeds, and verify its behaviour, doing a full rotation (360º). For these tests, the frequency of the drive was changed to allow up to 8000 full steps per sec.

It was verified that, after a velocity of 500 º/s, the system started losing steps. At 700 º/s and 800 º/s, it was verified the movement in the opposite direction of the axis. After that, it was verified that velocities above would lead to the axis of the motor not moving. Information gathered from the test can be seen in Table 26.

Table 26 - Results from the loss of steps experiment

Velocity	Information		
	Reached target velocity?	Lost Steps?	Value of Lost Steps (Degrees)
100 °/s	Yes	No	0°
200 °/s	Yes	No	0°
300 °/s	Yes	No	0°
400 °/s	Yes	No	0°
500 °/s	Yes	No	0°
600 °/s	Yes	Yes	65°
700 °/s	No	Axis moved in the opposite direction.	
800 °/s	No	Axis moved in the opposite direction.	
900 °/s	No	Yes	360°

5 Conclusion and Future Works

Conclusion

The main objective of this thesis was the assembly of a linear axis driven by a servomotor, with the design, manufacturing, and acquisition of additional systems for the axis, such as the flange/coupling and the mechanical limits. A secondary objective was deemed to be the design of a linear axis solution for the stepper motor. Both objectives were completed.

It was verified, during the research, the existence of multiple high-quality didactic workstations in the market, offering a variety of subjects and modules for motors and other systems, capable of showcasing the main features. Most allowed for expansion with other modules or custom components, offering a substantial basis for learning and experiencing these subjects.

The available components, previously acquired from the industrial supplier Beckhoff, showcased a high degree of modularity, easing the construction of industrial systems, and allowing for multiple and easy upgrades for current ones.

It was necessary the design and manufacturing of a motor connector flange. With resource to Solidworks and the available tools, this objective was accomplished.

For this work, it was necessary the creation of a program and interface, configured with the new components in mind. The program had several in-built control blocks, dedicated to the operation and control of the available motors. The interface was sectioned and modular, with the objective of avoiding clutter within the HMI, and to allow the user to have quick and easy access to information related to the work at hand. For these, the work environment used, called TwinCAT 3, provided a great set of available functions and modules.

It was also created a set of experiments and tools for the users. For both motors, it was created the ability to jog or create sets of movements, each with their own parameters and conditions. As for the experiments, each focused on general topics, such as repeatability of a motor/axis, or specific subjects, such as the different control types or cases where the stepper motor loses steps.

While it wasn't possible to integrate a digital oscilloscope, Scope View, into the interface, this tool was prepared within the work environment to allow users an easy way of obtaining graphics and information, with high precision.

Future Works

After this work, it was verified a great number of avenues through which it is possible to upgrade the system.

Currently, the system does not have a proper safety, lacking not only emergency buttons, but also the programming of such buttons and other emergency tools. While the system was programmed with limits in both velocity, torque and position, these limits cannot be considered security options, and are mere tools for the program.

It is verified that the current station requires a redesign, increasing the modules and tools available, like the acquisition of modules for analogue and digital inputs, and acquisition of an axis for the stepper motor. Other components to help the study of repeatability of the motors and new ways of applying forces to the axes or motors would increase the amount of information gathered from exercises, and even the creation of a 2-axis CNC within the station would prove beneficial.

The integration into the system of a Scope View server would provide access to a digital oscilloscope, without the need of having to connect the system to a local computer to access this tool. However, it would require an upgrade to the industrial computer currently present in the system.

Another point for a possible upgrade is the integration of a physical HMI, and/or the connection of the system to the local network, for easy access. In the last case, it would be recommended the insertion of cameras in the station to observe the behaviour of the system, without requiring the presence in the laboratory.

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ANNEX A: CKK-110 Linear Axis Technical Data

This annex contains an excerpt from “Star – Compact Modules” catalogue, providing in-depth information on the CKK-110 linear axis.

STAR – Compact Modules CKK
Technical Data

General technical data

Load capacities and moments

Compact Module	No. of carriages	Ball screw	Dynamic load capacity C			Dynamic moments		Planar moment of inertia		Maximum length	Moved mass
		$d_0 \times P$	Guideway (N)	Ball screw (N)	Fixed bearing (N)	M_t (Nm)	M_L (Nm)	I_x (cm⁴)	I_y (cm⁴)	L_{max} (mm)	m_b (kg)
CKK 12-90	1	12 x 5 12 x 10	4 620	3 800 2 500	6 900	125	16	14.32	124.4	750	0.36
	2 (l_m = 65 mm)	12 x 5 12 x 10	7 500	3 800 2 500	6 900	200	240	14.32	124.4	750	0.59
CKK 15-110	1	16 x 5 16 x 10 16 x 16	15 600	12 300 9 600 6 300	13 400	515	80	37.74	318.7	1 500	0.52
	2 (l_m = 85 mm)	16 x 5 16 x 10 16 x 16	25 340	12 300 9 600 6 300	13 400	835	1 075	37.74	318.7	1 500	0.86
CKK 20-145	1	20 x 5 20 x 20 25 x 10	37 600	14 300 9 100 15 700	17 000	1 650	255	114.10	986.4	1 800	1.21
	2 (l_m = 100 mm)	20 x 5 20 x 20 25 x 10	61 080	14 300 9 100 15 700	17 000	2 685	3 050	114.10	986.4	1 800	2.06

l_m = center-to-center distance between carriages.

Maximum permissible loads

Compact Module	No. of carriages	Maximum permissible forces			Maximum permissible moments	
		F_{y1} (N)	F_{y2} (N)	F_x (N)	M_t (Nm)	M_L (Nm)
CKK 12-90	1	4 620	4 620	2 490	125	16
	2	7 500	7 500	4 050	203	244
CKK 15-110	1	12 000	6 000	3 480	198	31
	2	19 490	9 740	5 650	322	414
CKK 20-145	1	29 000	14 500	8 410	638	100
	2	47 110	23 550	13 660	1 030	1 180

Modulus of elasticity E

$E = 70\,000\ N/mm^2$

Mass

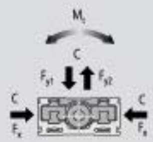
Mass calculation does not include motor or switches.

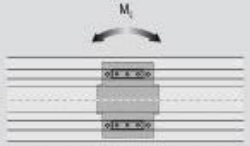
Mass formula:

Mass (kg/mm) · length L (mm) + mass of all parts of fixed length (carriage, end blocks, etc.) (kg)

Compact Module	Ball screw	No. of carriages	Mass (kg)
CKK 12-90	with	1	0.0055 · L + 0.9
		2	0.0055 · L + 1.2
CKK 15-110	with	1	0.0092 · L + 1.6
		2	0.0092 · L + 2.0
CKK 20-145	with	1	0.0178 · L + 3.0
		2	0.0178 · L + 3.9

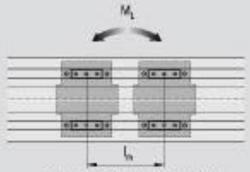
14 RE 82 601/04.99





Compact Module with one carriage

l_m = center-to-center distance between carriages



Compact Module with two carriages

Notes on dynamic load capacities and moments

The dynamic load capacities and moments are based on 100 000 m travel.

However, a travel of just 50 000 m is often taken as a basis.

If this is the case, for comparison purposes:

Multiply value **C**, **M_t** and **M_L** from the STAR table by 1.26.

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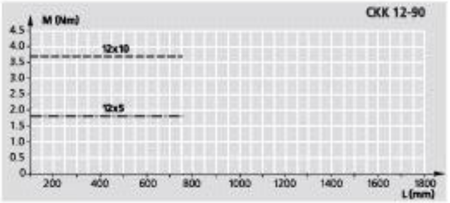
STAR – Compact Modules CKK
Technical Data

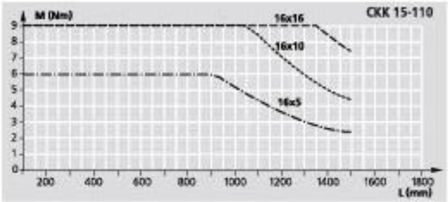
Maximum permissible drive torque M_{per}

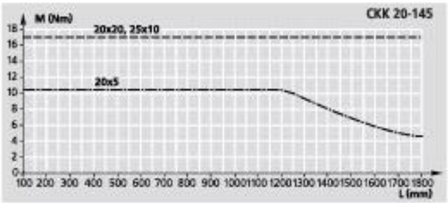
The M_{per} values shown apply in the following conditions:

- horizontal operation
- ball screw journal without keyway
- no radial load on ball screw journal

Observe the rated torque of coupling used!







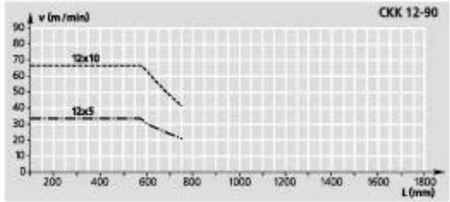
Ball screw journal with keyway

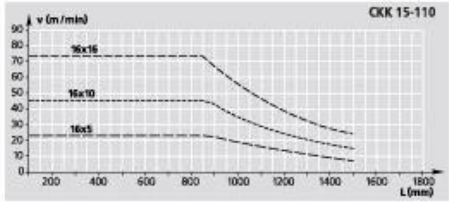
Due to the notch effect and the reduction of the effective diameter, observe the following maximum values for the drive torque!

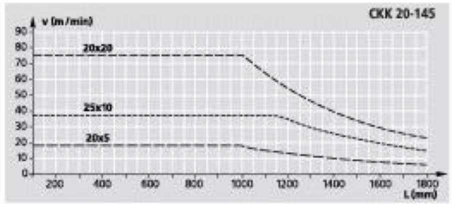
Compact Module	M_{per} (Nm)
CKK 12-90	–
CKK 15-110	5.0
CKK 20-145	11.5

Maximum velocity v

Observe the motor speed!







STAR – Compact Modules CKK
Technical Data

Data for side drive with timing belt, floating bearing side for motor attachment via side drive with timing belt

Motor type		MKD 25B / MMD 042A					MKD 41B / MMD 082A					MDD 71A				
Moment of friction M_{RSv} (Nm)		0.35					0.4					0.45				
		permissible torque for lengths up to L[1] = … for			reduced mass moment of inertia for		permissible torque for lengths up to L[1] = … for			reduced mass moment of inertia for		permissible torque for lengths up to L[1] = … for			reduced mass moment of inertia for	
gear ratio i = …			i = 1	i = 1.5	i = 1	i = 1.5		i = 1	i = 1.5	i = 1	i = 1.5		i = 1	i = 2	i = 1	i = 2
Compact Module	ball screw $d_0 \times P$	L (mm)	M_{Bv} (Nm)	M_{Bv} (Nm)	J_{Bv} (10^{-6} kgm²)	J_{Bv} (10^{-6} kgm²)	L (mm)	M_{Bv} (Nm)	M_{Bv} (Nm)	J_{Bv} (10^{-6} kgm²)	J_{Bv} (10^{-6} kgm²)	L (mm)	M_{Bv} (Nm)	M_{Bv} (Nm)	J_{Bv} (10^{-6} kgm²)	J_{Bv} (10^{-6} kgm²)
CKK 12-90	12 x 5	750	1.8	1.2	38	14										
	12 x 10	750	2.5	1.7												
CKK 15-110	16 x 5	1400	2.5	1.7	41	16	900	6.0	4.0	240	82					
	16 x 10	1500	2.5	1.7			1200	6.9	4.6							
	16 x 16	1500	2.5	1.7			1500	6.9	4.6							
CKK 20-145	20 x 5						1400	7.5	5.0	250	85	1200	10.5	5.2	1310	217
	20 x 20						1800	7.5	5.0			1800	16.0	8.0		
	25 x 10						1800	7.5	5.0			1800	16.0	8.0		

M_{Bv} = permissible torque of system with side drive with timing belt at motor journal (observe max. motor torque of M_{max})
M_{RSv} = moment of friction of side drive with timing belt at motor journal
J_{Bv} = reduced mass moment of inertia of side drive with timing belt
i = gear ratio of side drive with timing belt
[1] permissible torques for other lengths available upon request

AC servo motor data

☞ see "Controllers, Motors, Electrical Accessories" catalog RE 82 701

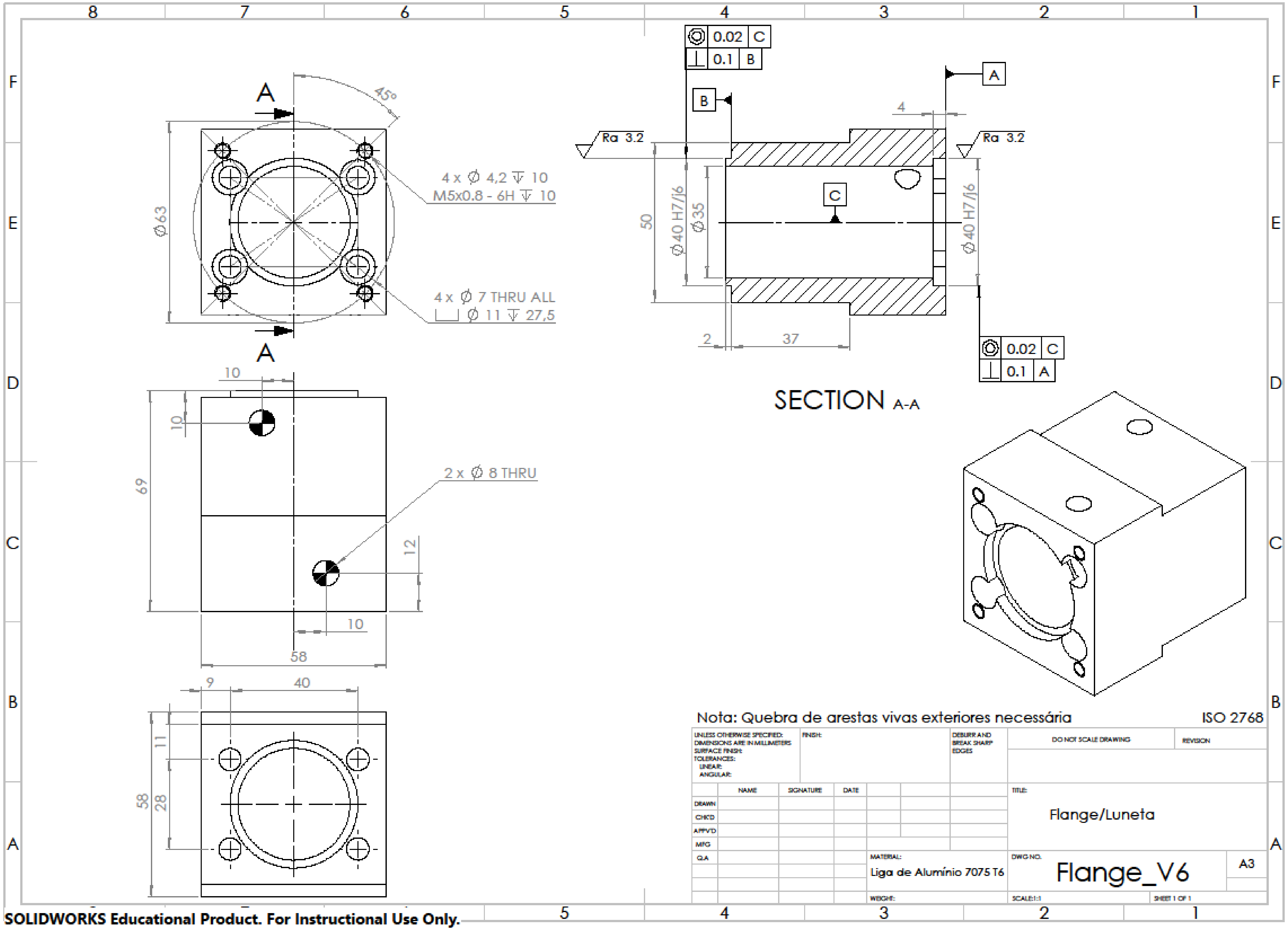
Motor type		MKD 25B-144 KG1	MKD 41B-144 KG1	MDD 71A-N-060-N2S-095 GB1
Maximum effective speed n_{max}	(min⁻¹)	☞	☞	☞
Rated torque M_n	(Nm)	0.9	2.7	2.2
Maximum torque M_{max}	(Nm)	☞	☞	☞
Mass moment of inertia $J_M + J_{Br}$	(10^{-6} kgm²)	30 + 8	170 + 16	440 + 38
Braking torque M_{Br}	(Nm)	1.0	2.2	3
Mass with brake m_{Br}	(kg)	2.25	4.65	6.88

MiniDrive motor data

Motor type		MMD 042A	MMD 082A
Maximum effective speed n_{max}	(min⁻¹)	3000	3000
Rated torque M_n	(Nm)	1.3	2.4
Maximum torque M_{max}	(Nm)	3.36	6.9
Mass moment of inertia $J_M + J_{Br}$	(10^{-6} kgm²)	37 + 3	133 + 8
Braking torque M_{Br}	(Nm)	1.3	2.4
Mass with brake m_{Br}	(kg)	2.0	3.7

ANNEX B: Motor Connector Flange Technical Drawing and Simulation Reports

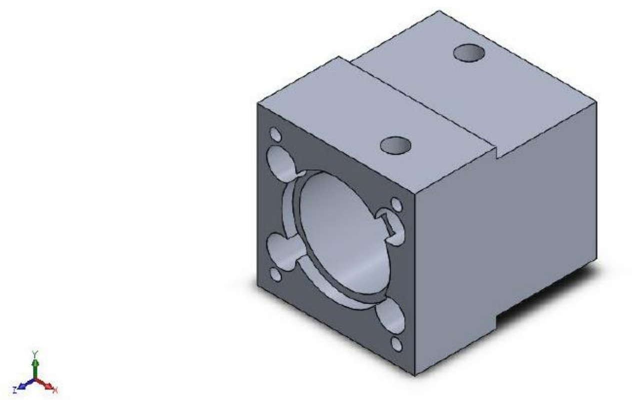
This annex provides the motor connector flange mechanical drawing and all the results from the performed finite elements tests for three materials: Aluminium Alloy 7075-T6, Aluminium Alloy 5052-H38, and AISI 1045 Steel, cold drawn.



A
45°
4 x Ø 4,2 ↧ 10
M5x0.8 - 6H ↧ 10
Ø63
4 x Ø 7 THRU ALL
⌴ Ø 11 ↧ 27,5
10
10
69
2 x Ø 8 THRU
12
10
58
9
40
11
58
28
0.02 C
0.1 B
A
B
4
Ra 3.2
Ra 3.2
C
50
Ø40 H7/j6
Ø35
Ø40 H7/j6
2
37
0.02 C
0.1 A
SECTION A-A
Nota: Quebra de arestas vivas exteriores necessária
ISO 2768
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Flange/Luneta
MATERIAL:
Liga de Alumínio 7075 T6
DWG NO.
Flange_V6
A3
WEIGHT:
SCALE:1:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.

Motor Connector Flange Simulation Report for Aluminium Alloy 7075-T6

Model Information



Model name: Flange_V7
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Ø8.0mm Dowel Hole1 	Solid Body	Mass:0,350788 kg Volume:0,000124836 m^3 Density:2 810 kg/m^3 Weight:3,43772 N	C:\Users\Marcelo\Desktop\Tese\M. Martins\Construção 3D\Versão Atual\Simulação\1ºSim\Flange_V7.SLDPRT May 11 15:54:12 2022

SOLIDWORKS Analyzed with SOLIDWORKS Simulation   Simulation of Flange_V7   2

Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\Marcelo\Desktop\Tese\M. Martins\Construção 3D\Versão Atual\Simulação\1ºSim)

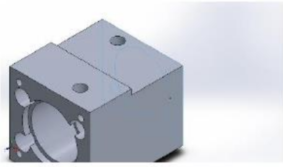
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

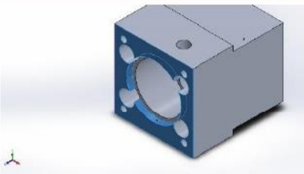
Model Reference	Properties	Components
	**Name:** 7075-T6 (SN) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 5,05e+08 N/m^2 **Tensile strength:** 5,7e+08 N/m^2 **Elastic modulus:** 7,2e+10 N/m^2 **Poisson's ratio:** 0,33 **Mass density:** 2 810 kg/m^3 **Shear modulus:** 2,69e+10 N/m^2 **Thermal expansion coefficient:** 2,36e-05 /Kelvin	SolidBody 1(Ø8.0mm Dowel Hole1)(Flange_V6)
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 1 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-4,23184e-05	27,4539	0,00345731	27,4539
Reaction Moment(N.m)	0	0	0	0

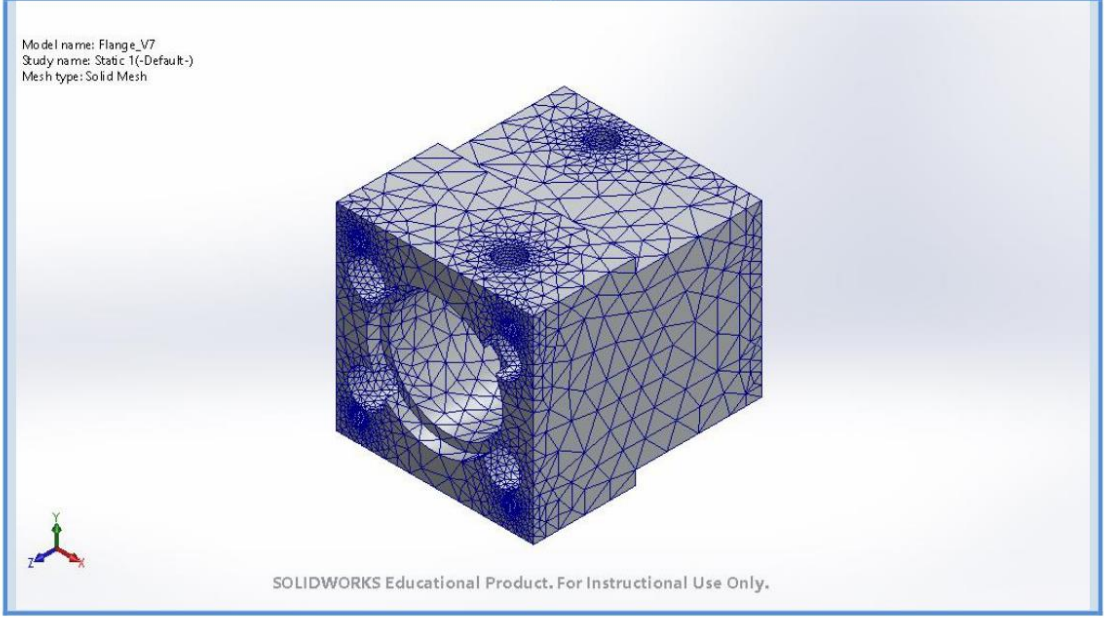
Load name	Load Image	Load Details
Force-1		**Entities:** 5 face(s) **Reference:** Edge< 1 > **Type:** Apply force **Values:** ---; ---; 15 N
Torque-1		**Entities:** 5 face(s) **Reference:** Axis1 **Type:** Apply torque **Value:** 0,9 N.m

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	8 mm
Minimum element size	0,5 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	107973
Total Elements	67300
Maximum Aspect Ratio	8,3689
% of elements with Aspect Ratio < 3	94,6
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:08
Computer name:	MININT-2RLQ54R



Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-4,23184e-05	27,4539	0,00345731	27,4539

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

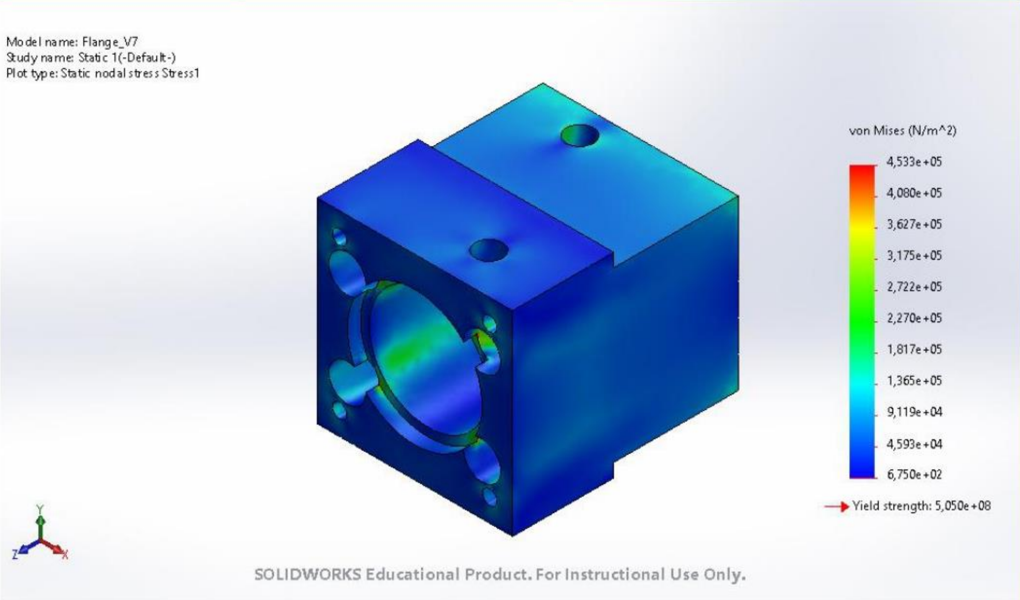
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0,00354576	0,00358633	-0,00121259	0,00518696

Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

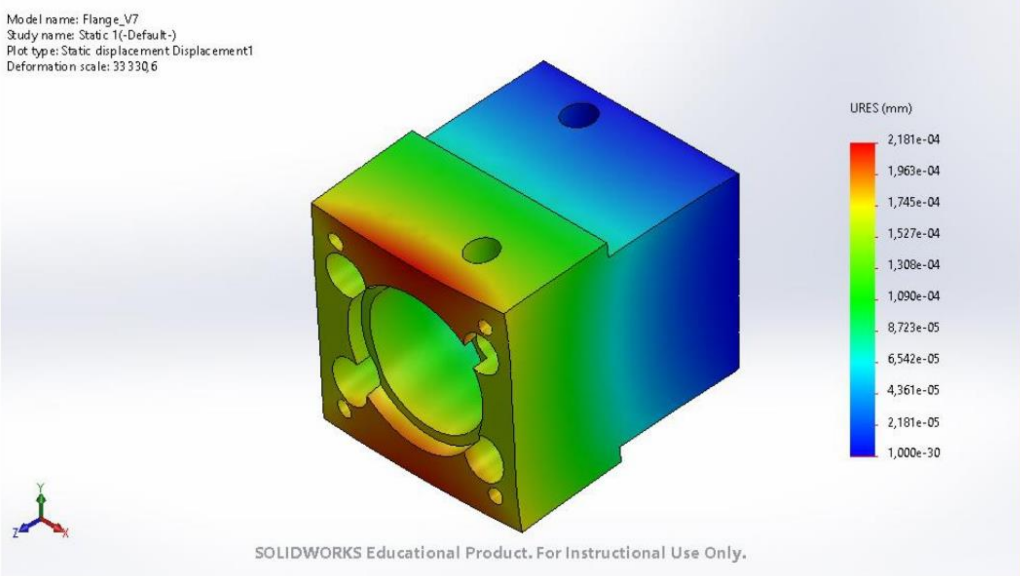
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	6,750e+02N/m^2 Node: 383	4,533e+05N/m^2 Node: 15837



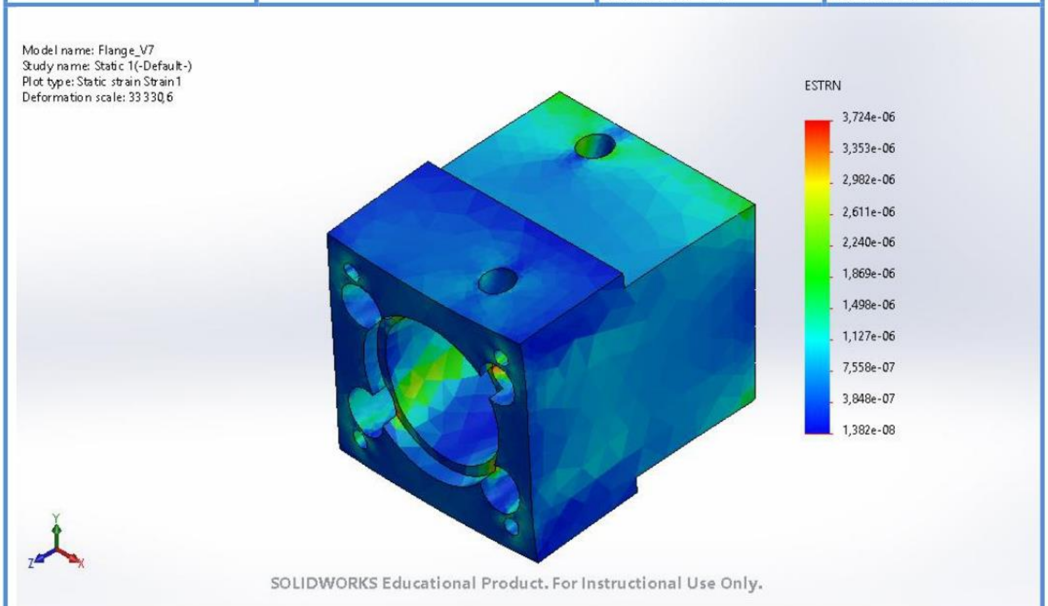
Flange_V7-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0,000e+00mm Node: 5	2,181e-04mm Node: 16099



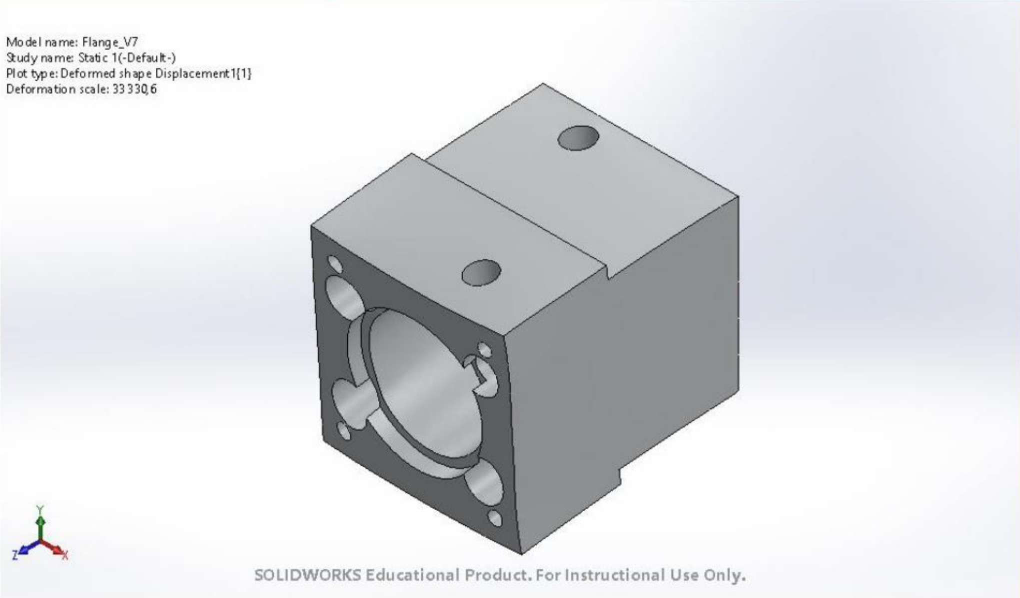
Flange_V7-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1,382e-08 Element: 7493	3,724e-06 Element: 51364



Flange_V7-Static 1-Strain-Strain1

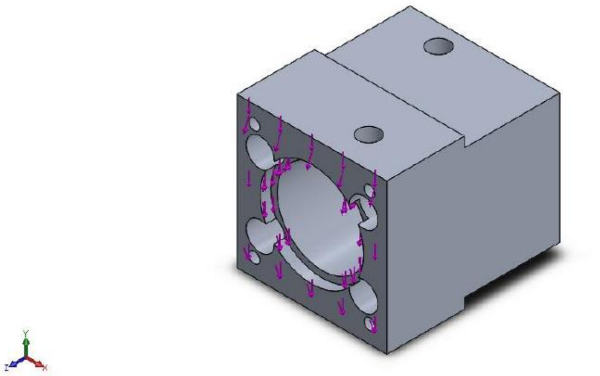
Name	Type
Displacement1{1}	Deformed shape



Flange_V7-Static 1-Displacement-Displacement1{1}

Motor connector Flange Simulation Report for Aluminium Alloy 5052-H38

Model Information



Model name: Flange_V7
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Ø8.0mm Dowel Hole1 	Solid Body	Mass:0,334559 kg Volume:0,000124836 m^3 Density:2 680 kg/m^3 Weight:3,27868 N	C:\Users\Marcelo\Desktop\Tese\M. Martins\Construção 3D\Versão Atual\Simulação\2ºSim\Flange_V7.SLDPRT May 2 14:50:48 2022

Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\Marcelo\Desktop\Tese\M. Martins\Construção 3D\Versão Atual\Simulação\2°Sim)

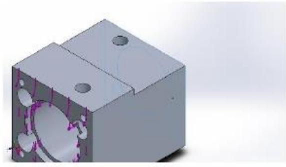
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

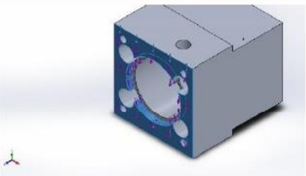
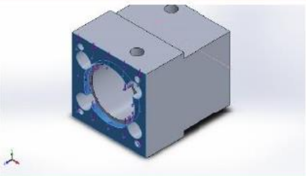
Model Reference	Properties	Components
	**Name:** 5052-H38 **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 2,55e+08 N/m^2 **Tensile strength:** 2,9e+08 N/m^2 **Elastic modulus:** 7e+10 N/m^2 **Poisson's ratio:** 0,33 **Mass density:** 2 680 kg/m^3 **Shear modulus:** 2,59e+10 N/m^2 **Thermal expansion coefficient:** 2,38e-05 /Kelvin	SolidBody 1(Ø8.0mm Dowel Hole1)(Flange_V6)
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 1 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	0,0014559	27,4538	0,000228196	27,4538
Reaction Moment(N.m)	0	0	0	0

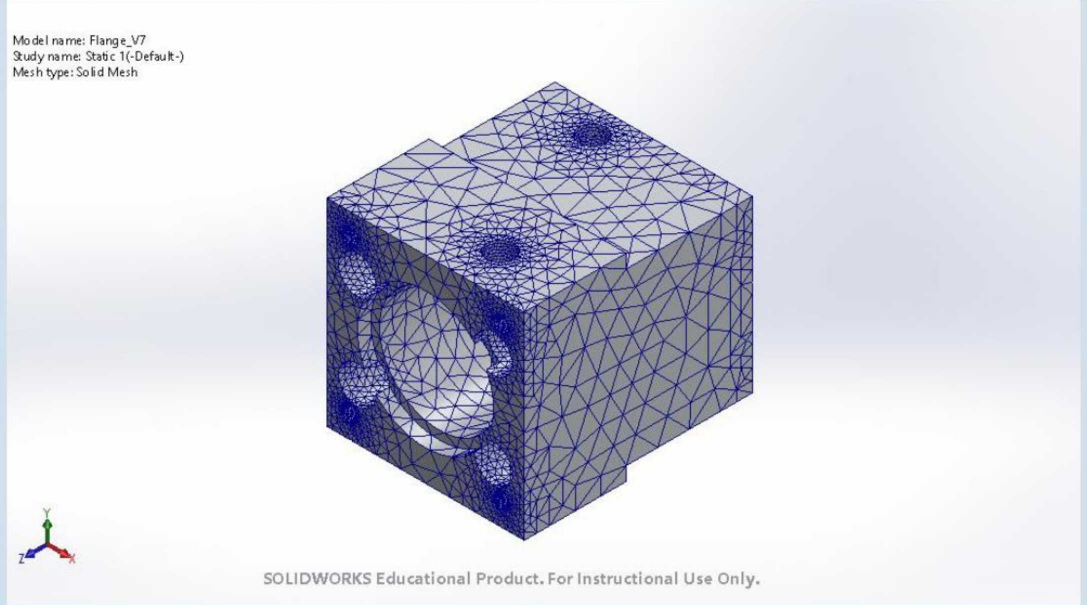
Load name	Load Image	Load Details
Force-1		**Entities:** 5 face(s) **Reference:** Edge< 1 > **Type:** Apply force **Values:** ---; ---; 15 N
Torque-1		**Entities:** 5 face(s) **Reference:** Axis1 **Type:** Apply torque **Value:** 0,9 N.m

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	8 mm
Minimum element size	0,5 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	107973
Total Elements	67300
Maximum Aspect Ratio	8,3689
% of elements with Aspect Ratio < 3	94,6
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:08
Computer name:	MININT-2RLQ54R



Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0,0014559	27,4538	0,000228196	27,4538

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

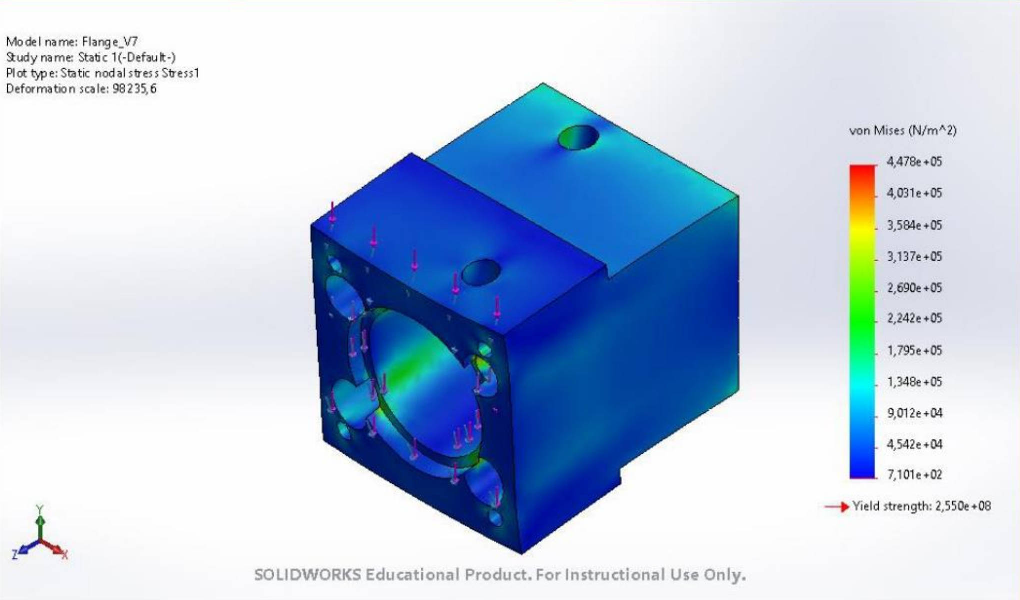
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0,0260385	-0,0152336	7,62945e-05	0,0301674

Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

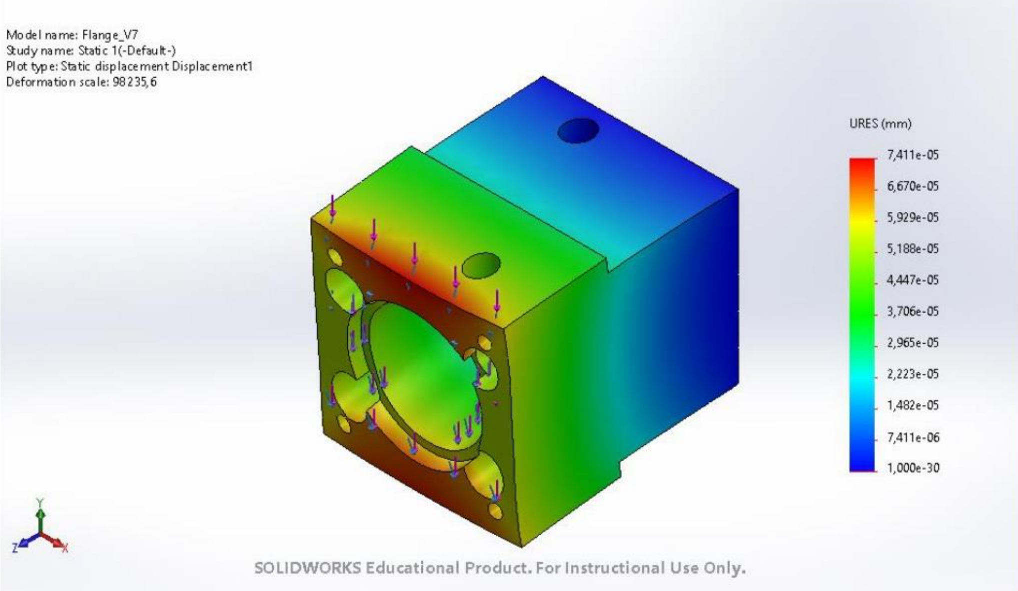
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	7,101e+02N/m^2 Node: 383	4,478e+05N/m^2 Node: 15837



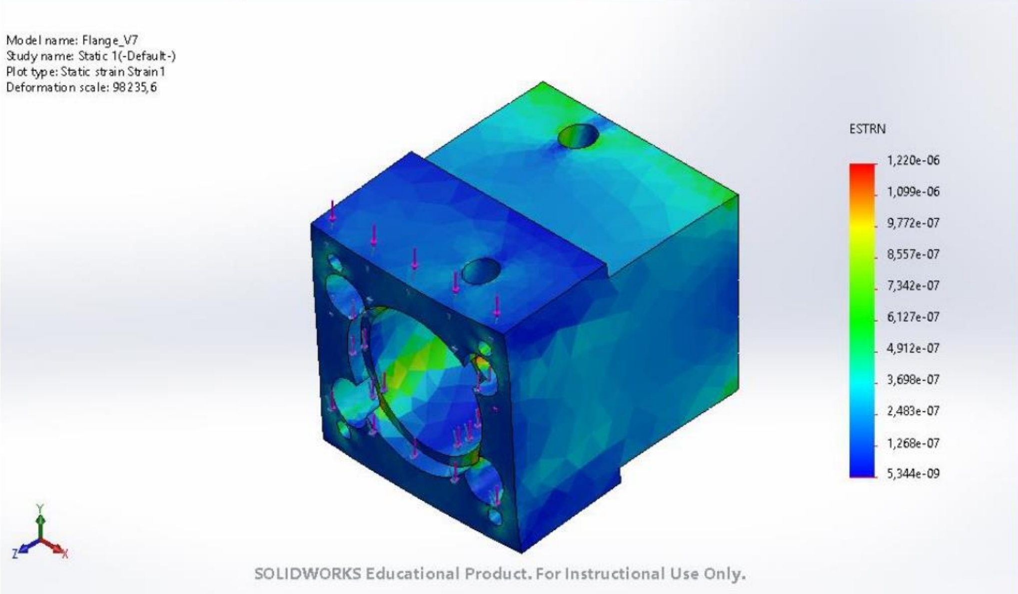
Flange_V7-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0,000e+00mm Node: 5	7,411e-05mm Node: 16099



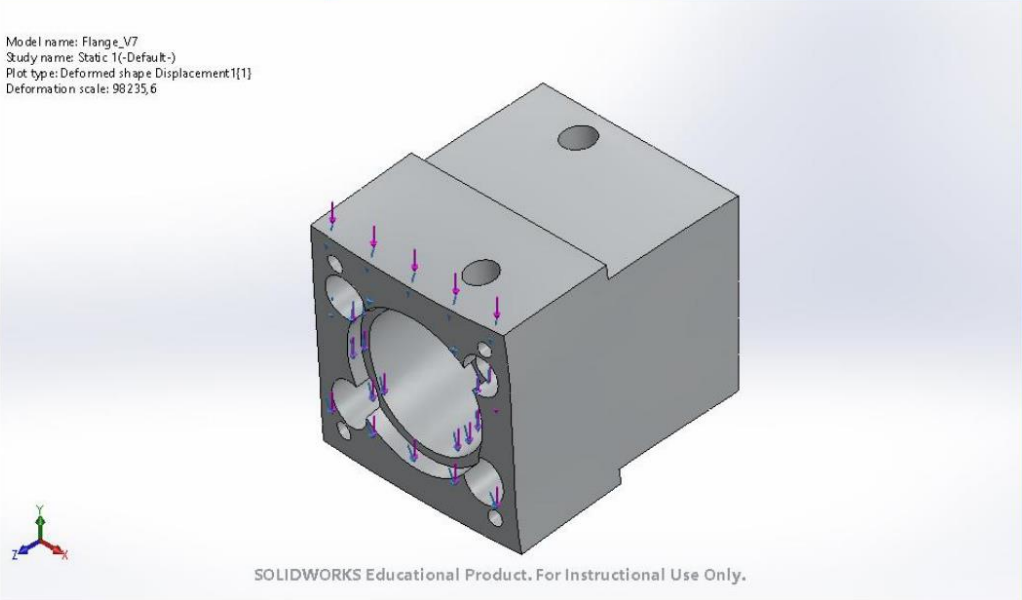
Flange_V7-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	5,344e-09 Element: 8688	1,220e-06 Element: 51364



Flange_V7-Static 1-Strain-Strain1

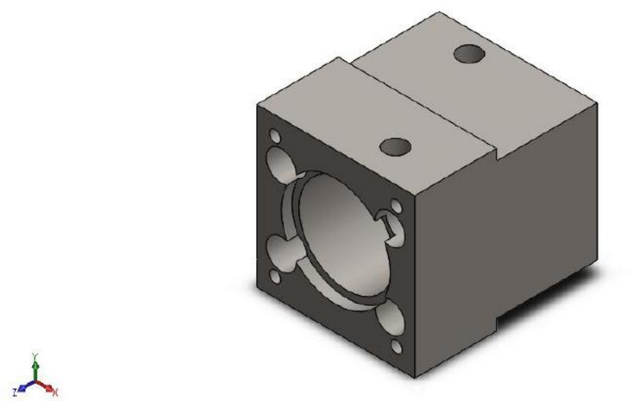
Name	Type
Displacement1{1}	Deformed shape



Flange_V7-Static 1-Displacement-Displacement1{1}

Motor Connector Flange Simulation Report for AISI 1045 Steel, cold drawn

Model Information



Model name: Flange_V7
Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Ø8.0mm Dowel Hole1 	Solid Body	Mass:0,979959 kg Volume:0,000124836 m^3 Density:7 850 kg/m^3 Weight:9,6036 N	C:\Users\Marcelo\Desktop\Tese\M. Martins\Construção 3D\Versão Atual\Simulação\3ºSim\Flange_V7.SLDPRT May 2 15:09:50 2022

Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\Marcelo\Desktop\Tese\M. Martins\Construção 3D\Versão Atual\Simulação\3ºSim)

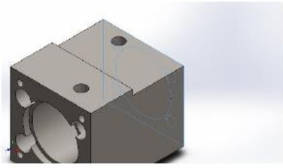
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

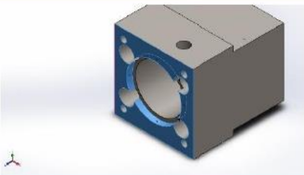
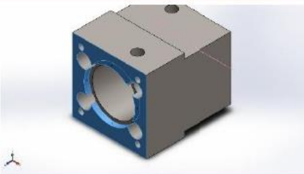
Model Reference	Properties	Components
	**Name:** AISI 1045 Steel, cold drawn **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 5,3e+08 N/m^2 **Tensile strength:** 6,25e+08 N/m^2 **Elastic modulus:** 2,05e+11 N/m^2 **Poisson's ratio:** 0,29 **Mass density:** 7 850 kg/m^3 **Shear modulus:** 8e+10 N/m^2 **Thermal expansion coefficient:** 1,15e-05 /Kelvin	SolidBody 1(Ø8.0mm Dowel Hole1)(Flange_V6)
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 1 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	0,0014559	27,4538	0,000228196	27,4538
Reaction Moment(N.m)	0	0	0	0

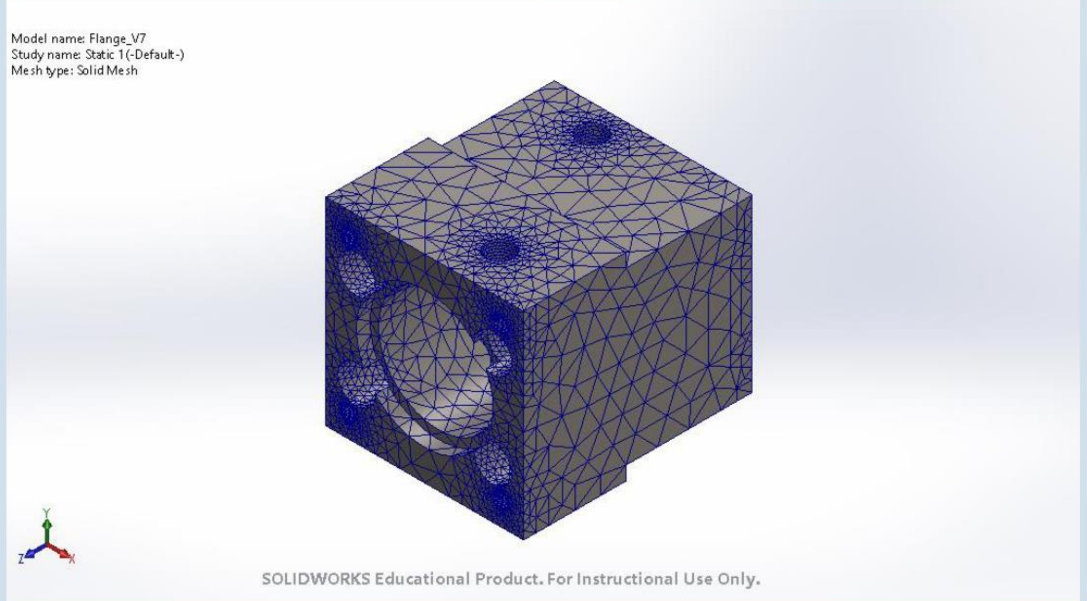
Load name	Load Image	Load Details
Force-1		**Entities:** 5 face(s) **Reference:** Edge< 1 > **Type:** Apply force **Values:** ---; ---; 15 N
Torque-1		**Entities:** 5 face(s) **Reference:** Axis1 **Type:** Apply torque **Value:** 0,9 N.m

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	8 mm
Minimum element size	0,5 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	107973
Total Elements	67300
Maximum Aspect Ratio	8,3689
% of elements with Aspect Ratio < 3	94,6
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:08
Computer name:	MININT-2RLQ54R



Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0,0014559	27,4538	0,000228196	27,4538

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

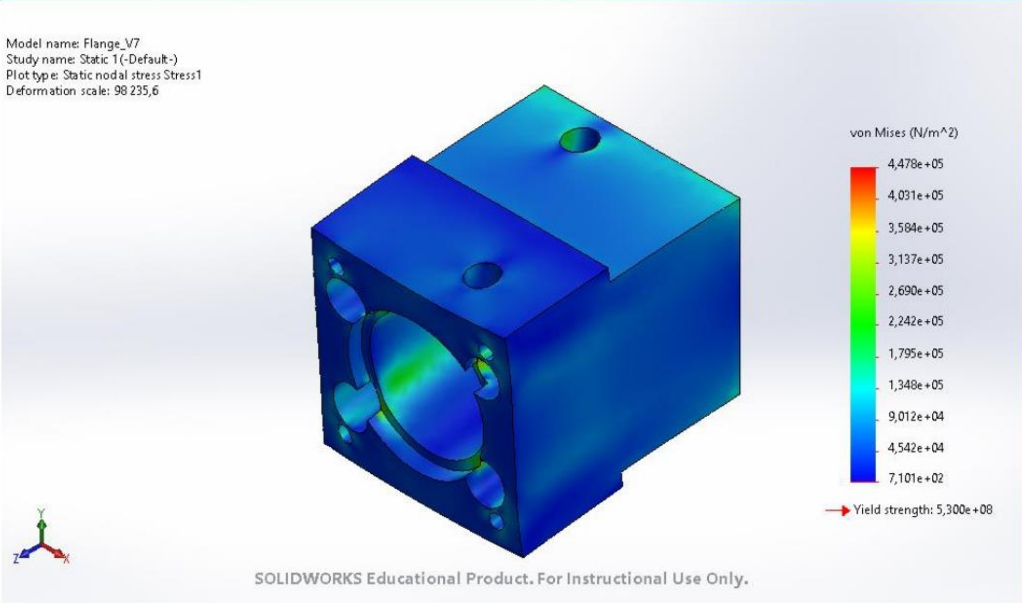
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0,0260385	-0,0152336	7,62945e-05	0,0301674

Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

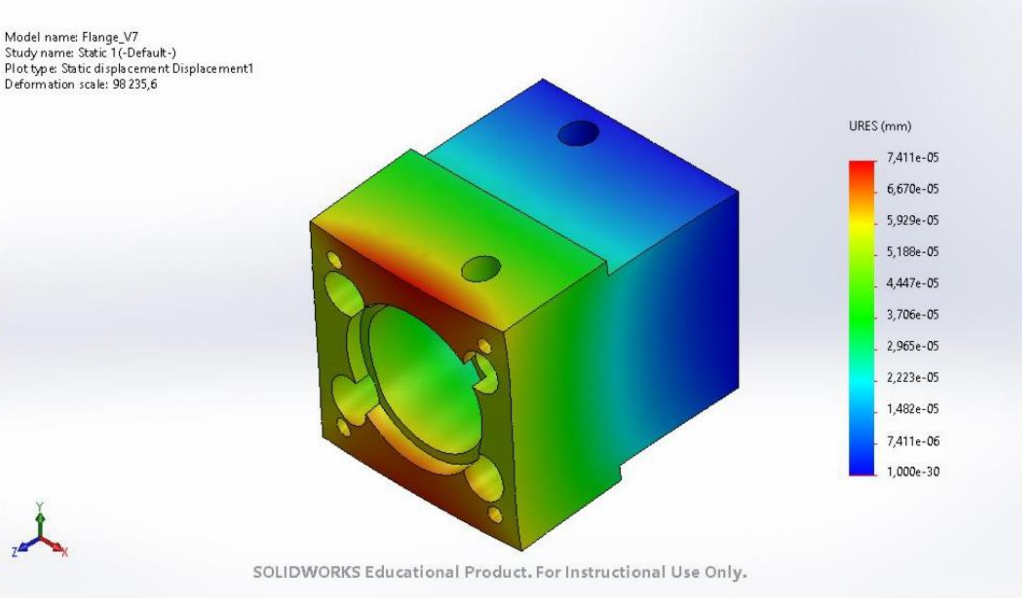
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	7,101e+02N/m^2 Node: 383	4,478e+05N/m^2 Node: 15837



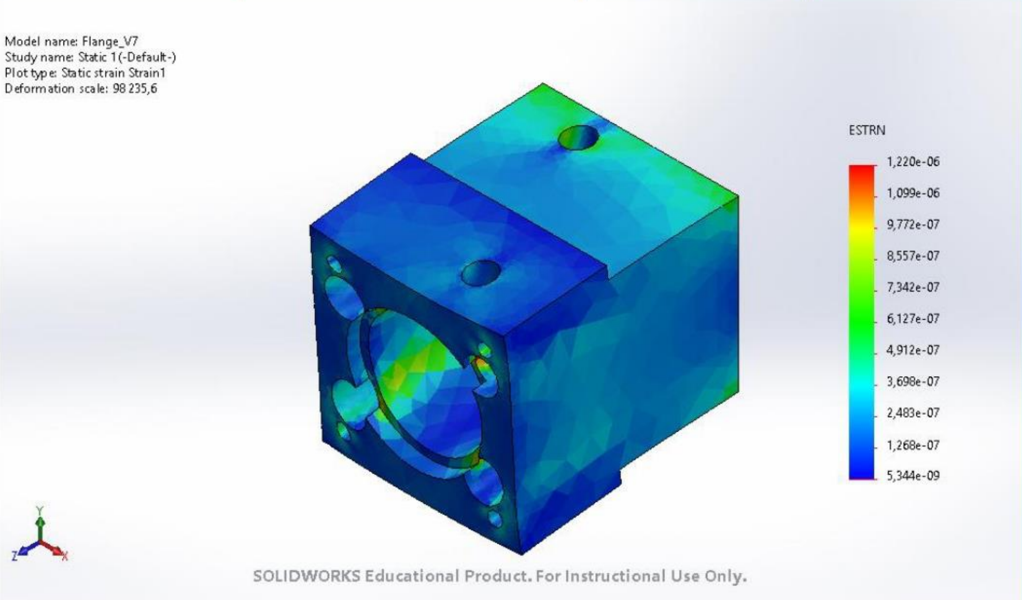
Flange_V7-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0,000e+00mm Node: 5	7,411e-05mm Node: 16099



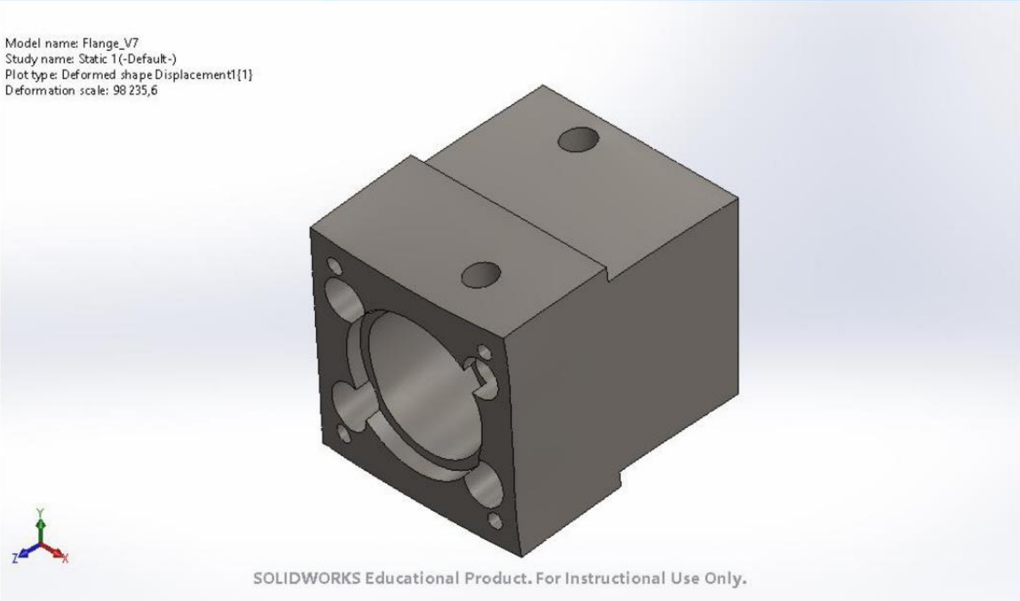
Flange_V7-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	5,344e-09 Element: 8688	1,220e-06 Element: 51364



Flange_V7-Static 1-Strain-Strain1

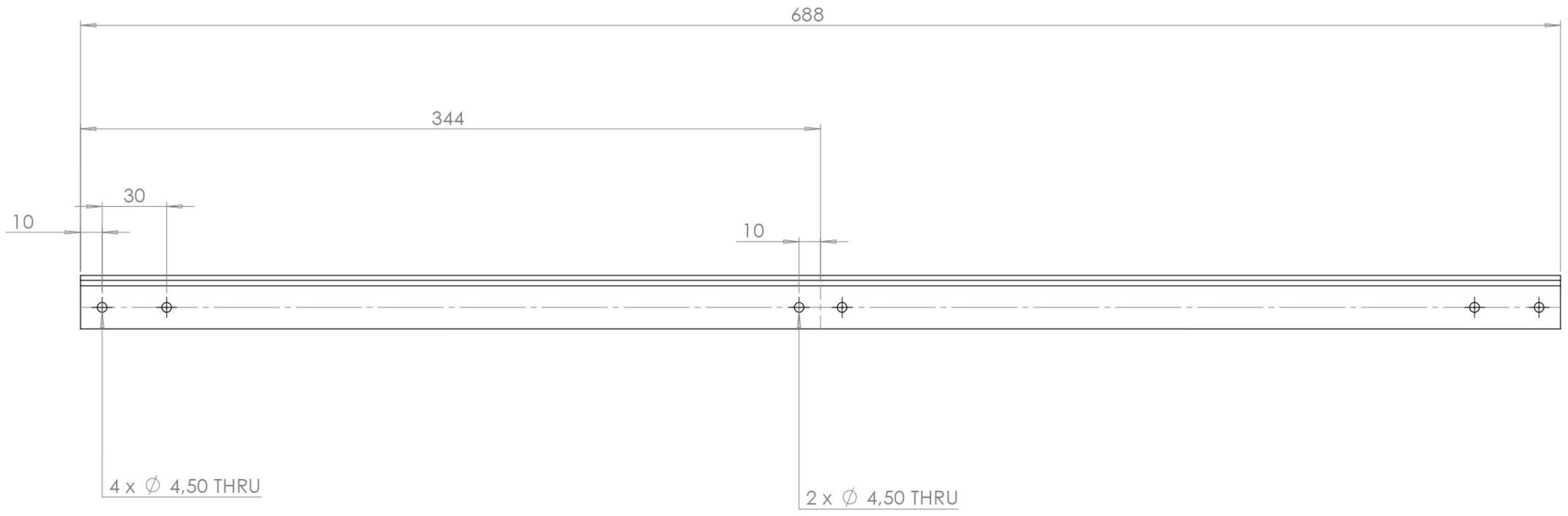
Name	Type
Displacement1{1}	Deformed shape



Flange_V7-Static 1-Displacement-Displacement1{1}

ANNEX C: Extra Components – Technical Drawings

This Annex provides the technical drawings for all the extra components designed to support and aid the CKK-110 linear axis. Includes supports for sensors, physical barriers, an axis carriage, and additional support components.



Nota:
Apenas executar furos nas posições referidas e corte de comprimento da peça em questão.

ISO 2768

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

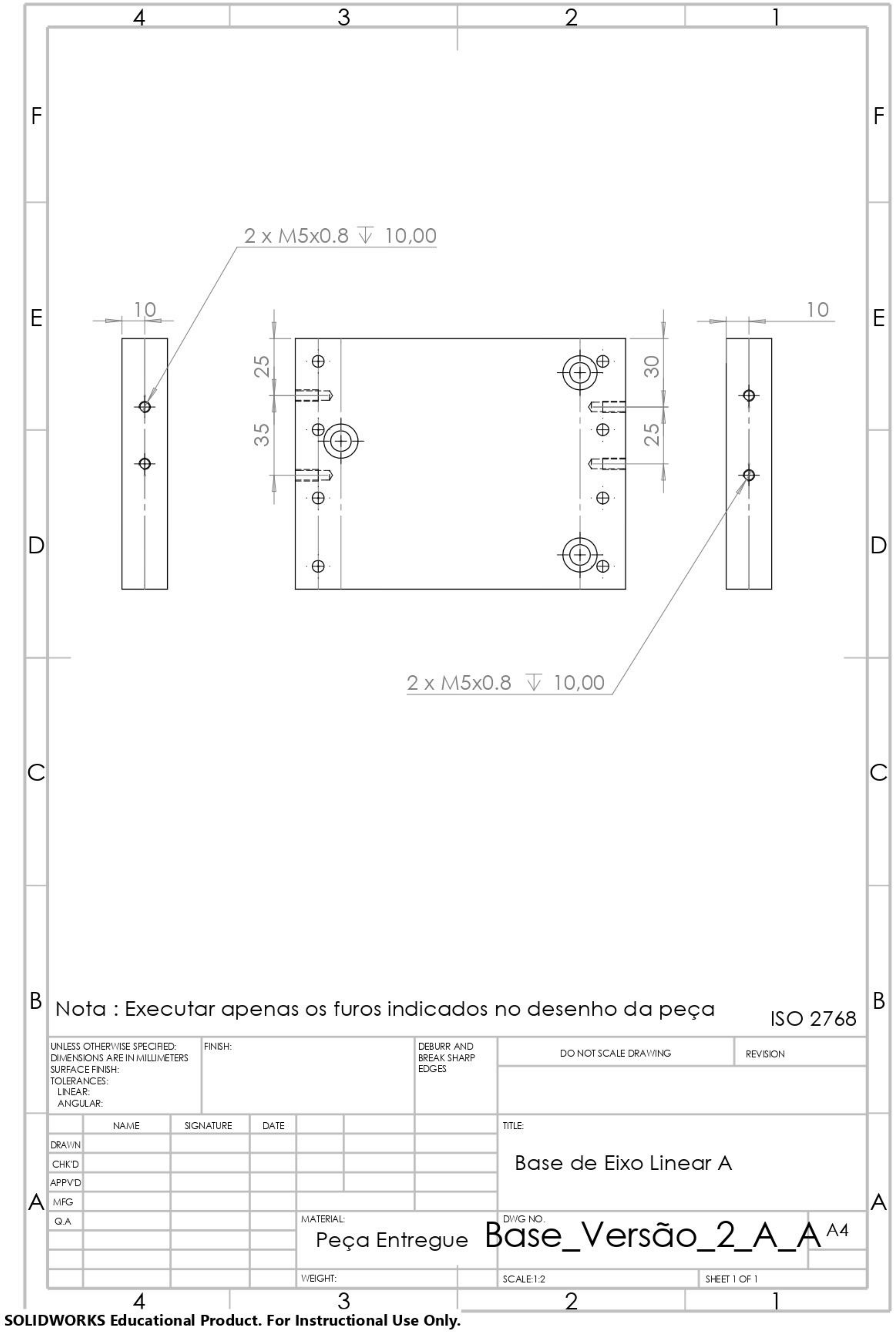
TITLE: Acoplamento Lateral

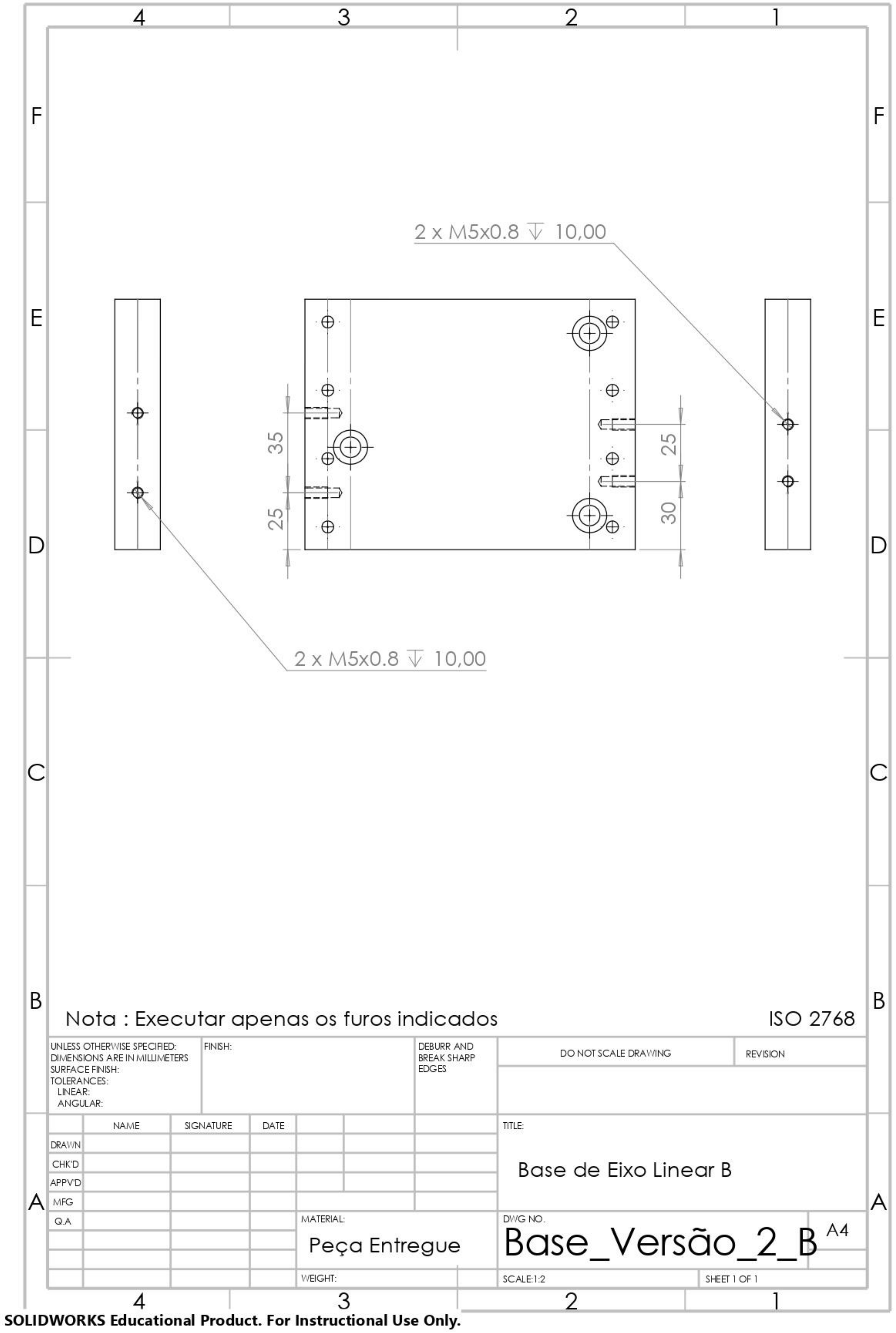
MATERIAL: Peça Entregue

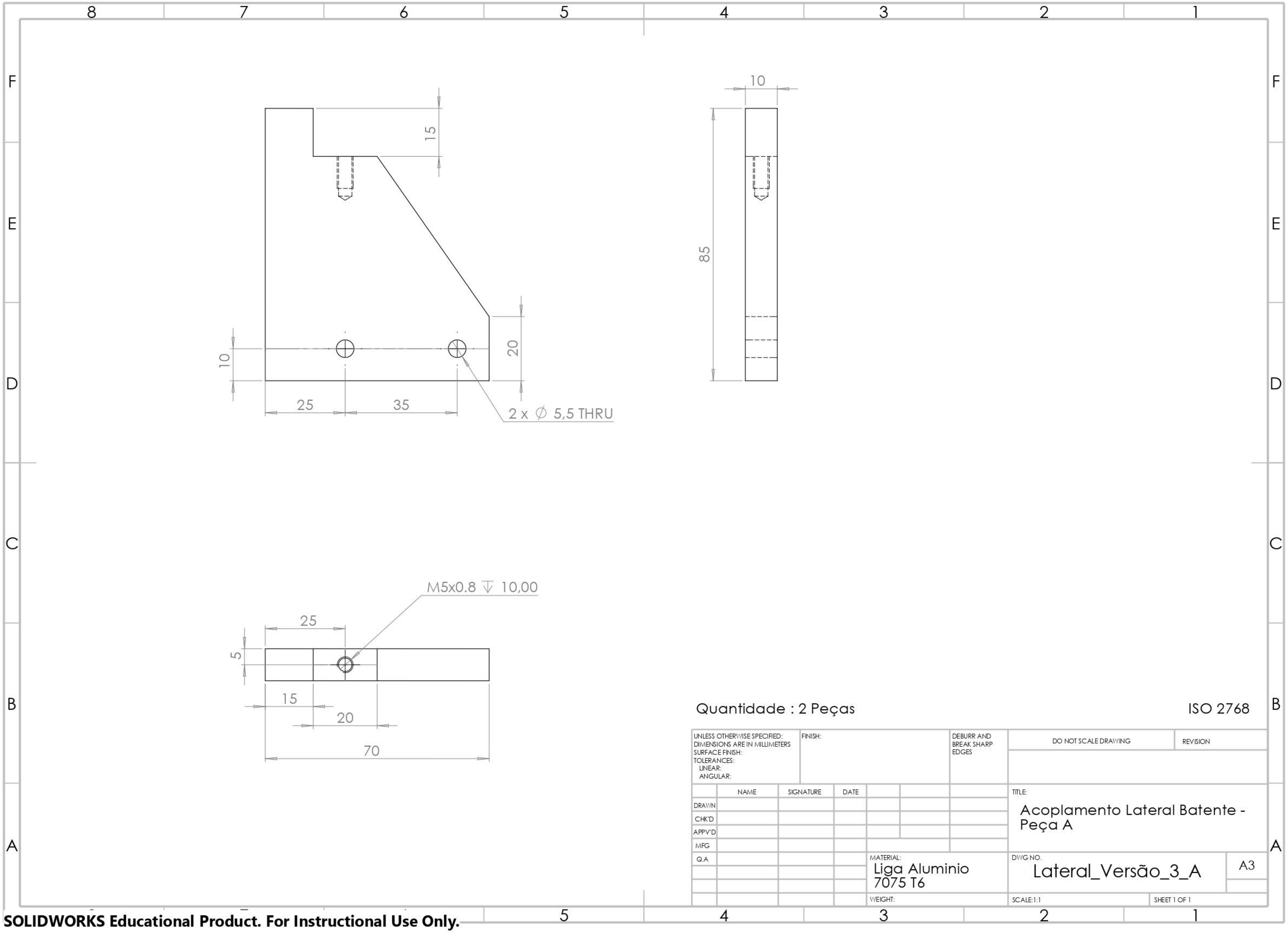
DWG NO. Acoplamento_Versão_2 — A3

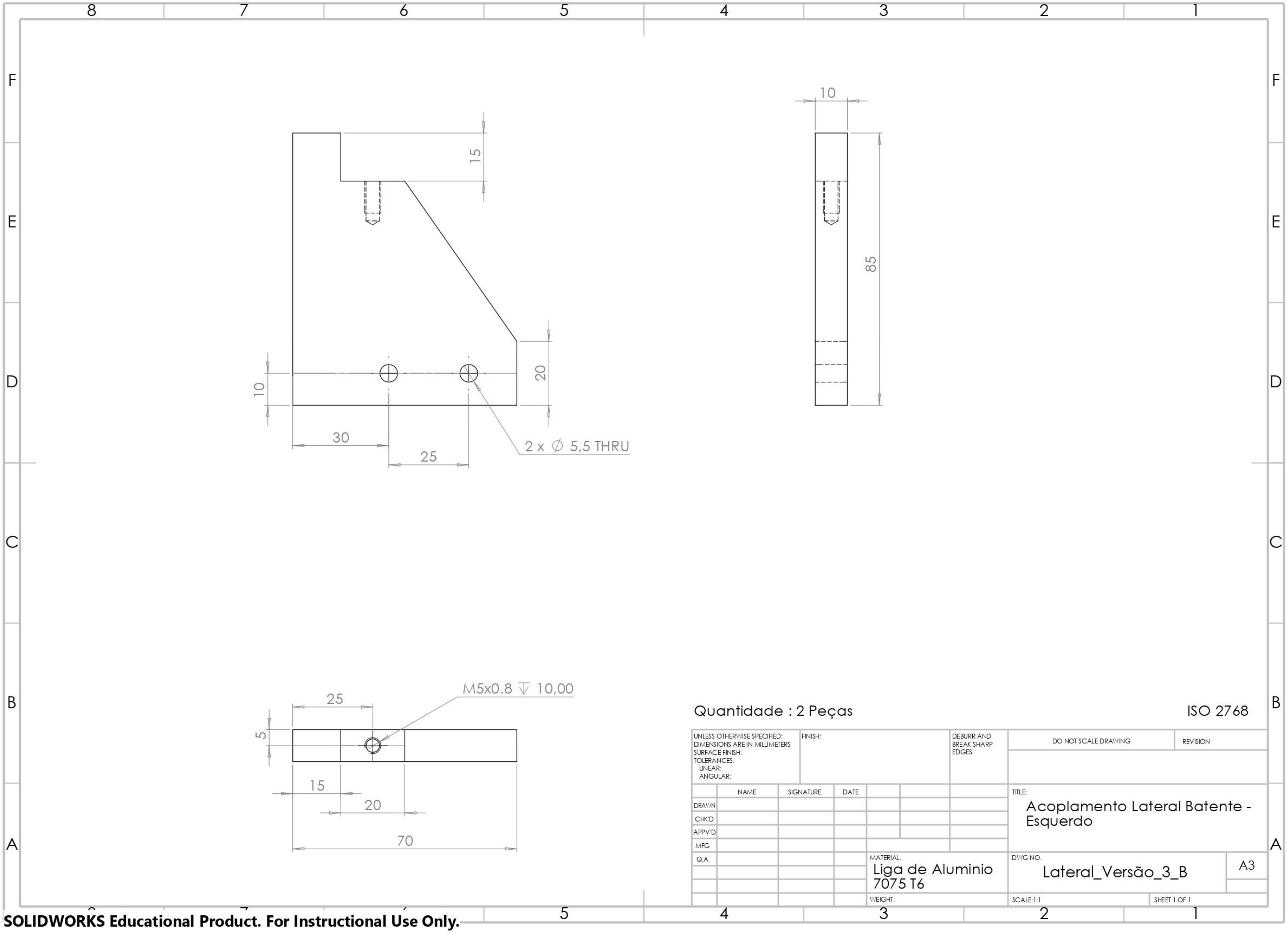
WEIGHT:

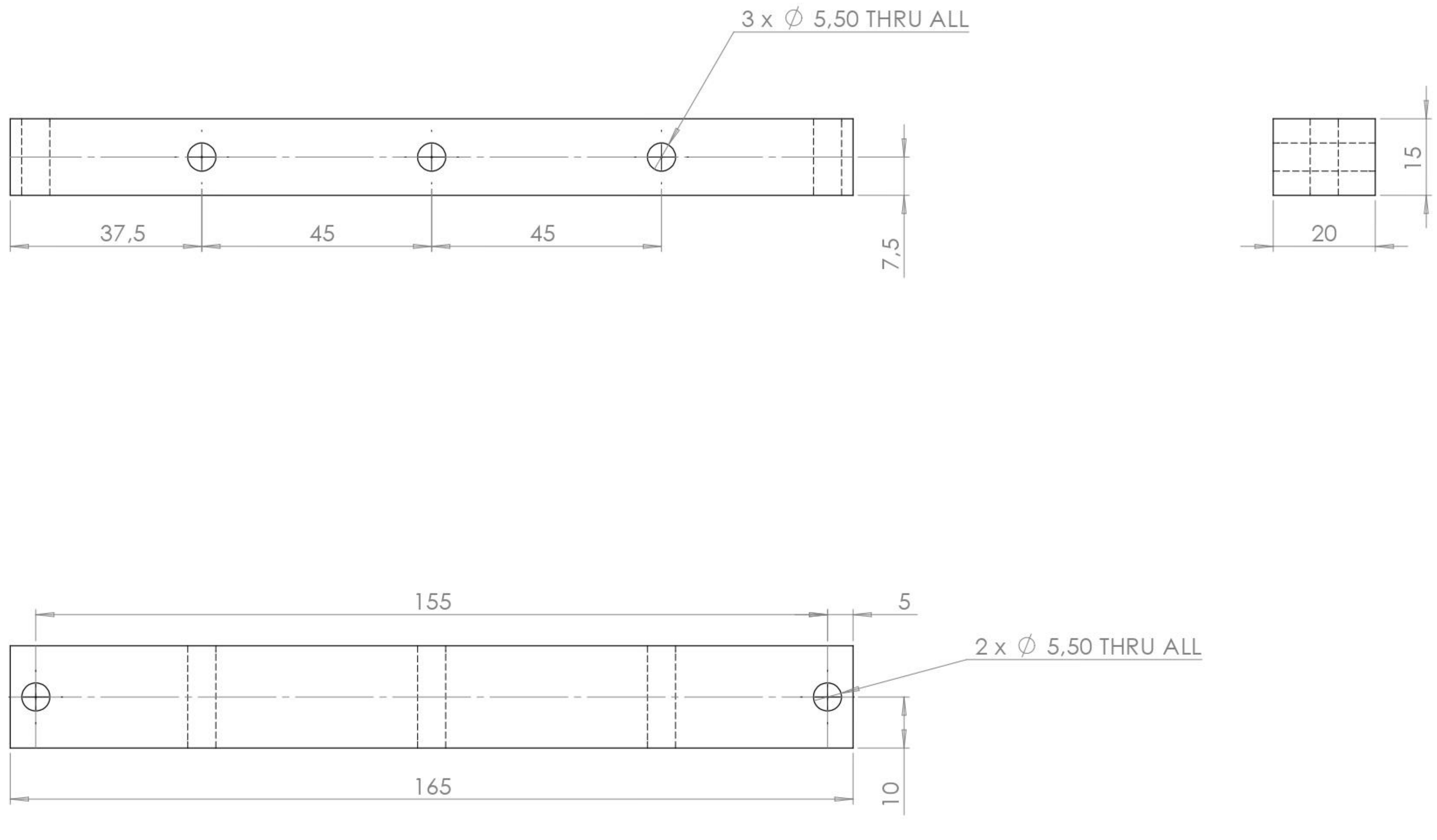
SCALE:1:2 — SHEET 1 OF 1


2 x M5x0.8 ↧ 10,00
10
25
35
30
25
10
2 x M5x0.8 ↧ 10,00
Nota : Executar apenas os furos indicados no desenho da peça
ISO 2768
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Base de Eixo Linear A
MATERIAL:
Peça Entregue
DWG NO.
Base_Versão_2_A_A
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.


2 x M5x0.8 ↧ 10,00
35
25
25
30
2 x M5x0.8 ↧ 10,00
Nota : Executar apenas os furos indicados
ISO 2768
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Base de Eixo Linear B
MATERIAL:
Peça Entregue
DWG NO.
Base_Versão_2_B
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.


10
15
85
10
20
25
35
2 x ∅ 5,5 THRU
M5x0.8 ↧ 10,00
25
5
15
20
70
Quantidade : 2 Peças
ISO 2768
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Acoplamento Lateral Batente - Peça A
MATERIAL:
Liga Aluminio 7075 T6
DWG NO.
Lateral_Versão_3_A
A3
WEIGHT:
SCALE:1:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.


15
20
10
30
25
2 x ∅ 5,5 THRU
10
85
M5x0.8 ↧ 10,00
25
5
15
20
70
Quantidade : 2 Peças
ISO 2768
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Acoplamento Lateral Batente - Esquerdo
MATERIAL:
Liga de Aluminio 7075 T6
DWG NO.
Lateral_Versão_3_B
A3
WEIGHT:
SCALE:1:1
SHEET 1 OF 1



Quantidade : 2 Peças

ISO 2768

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Batente

MATERIAL: Liga de Aluminio 7075 T6

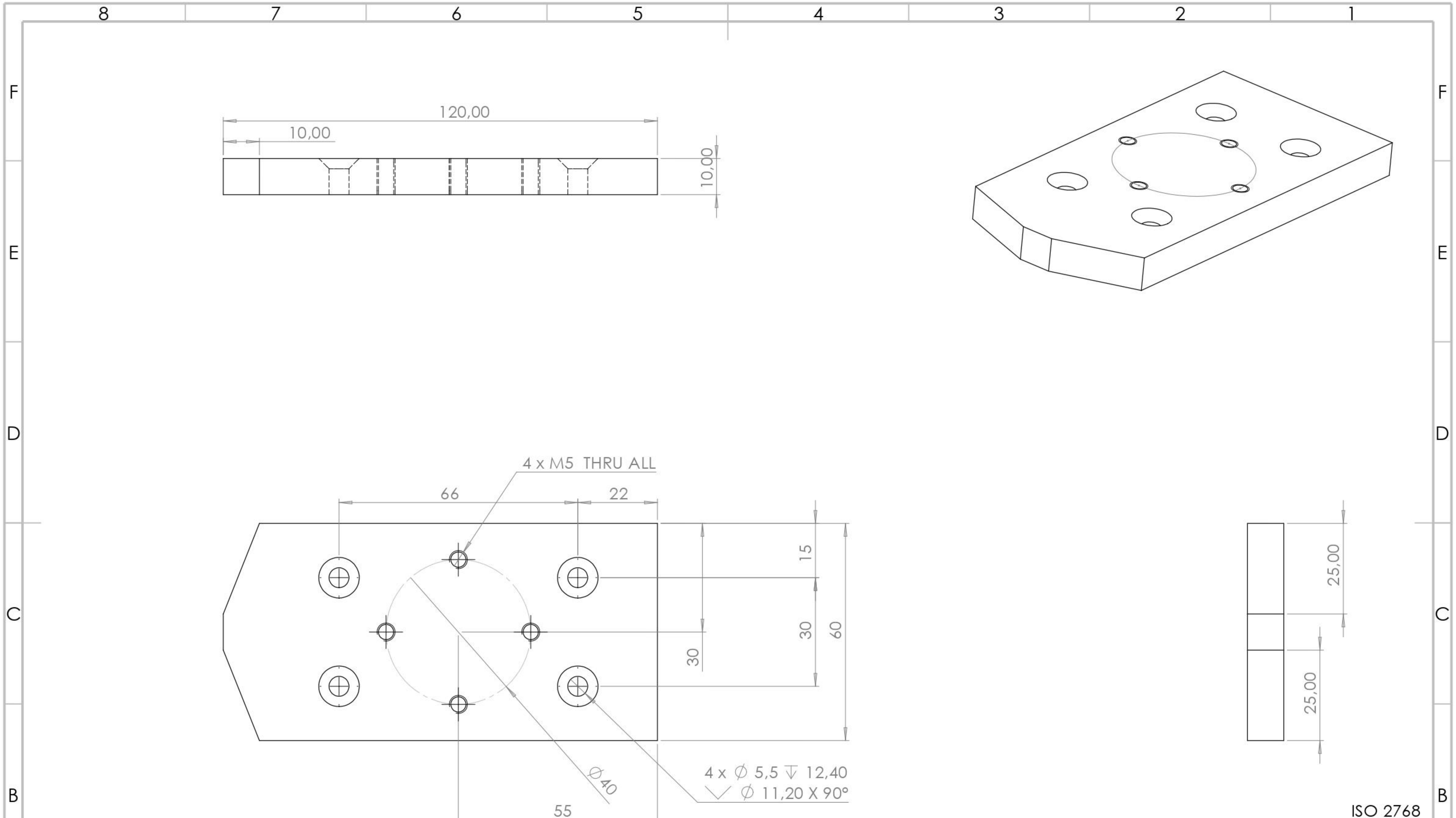
DWG NO. Batente_Versão_2

A3

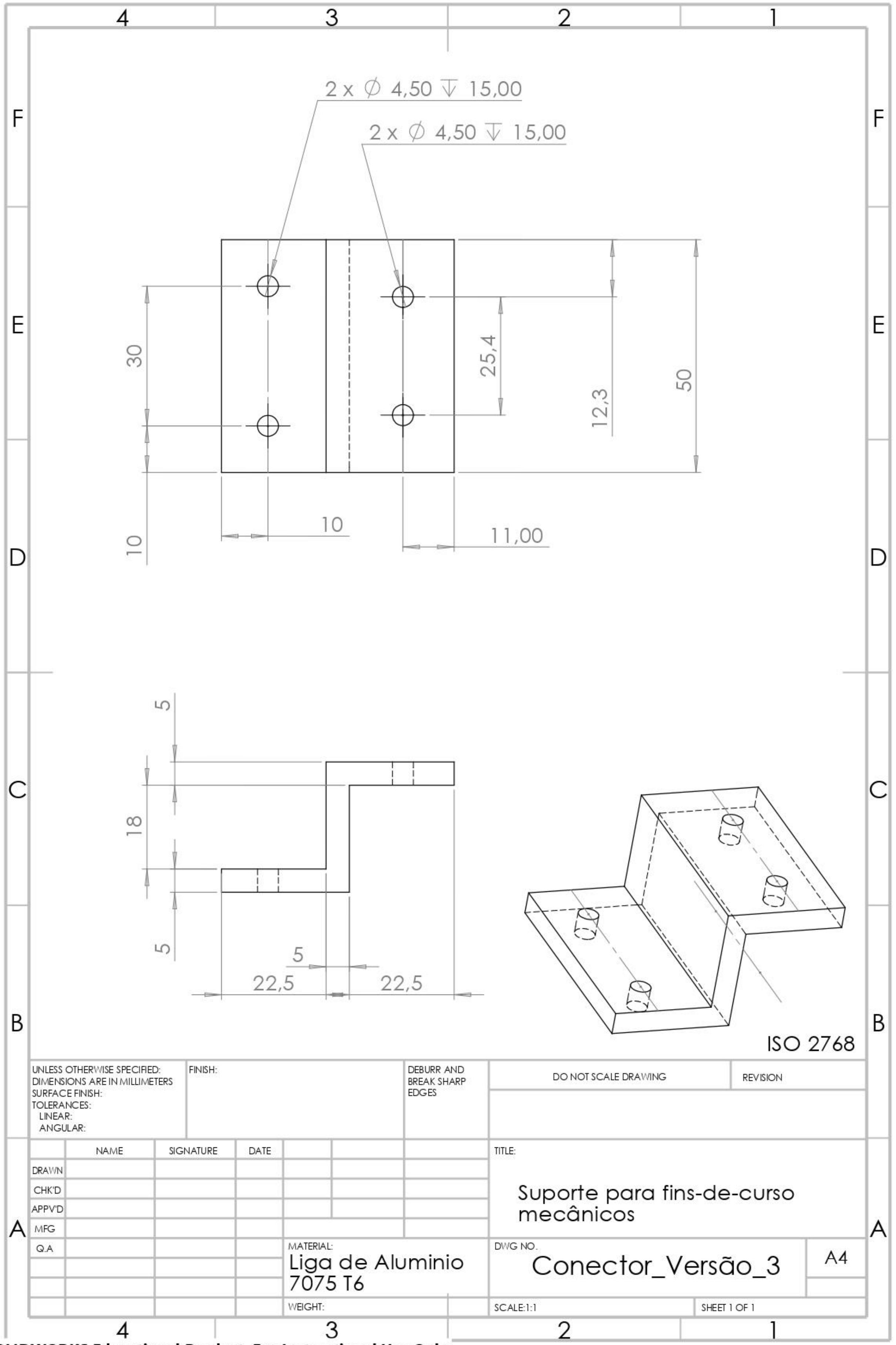
WEIGHT:

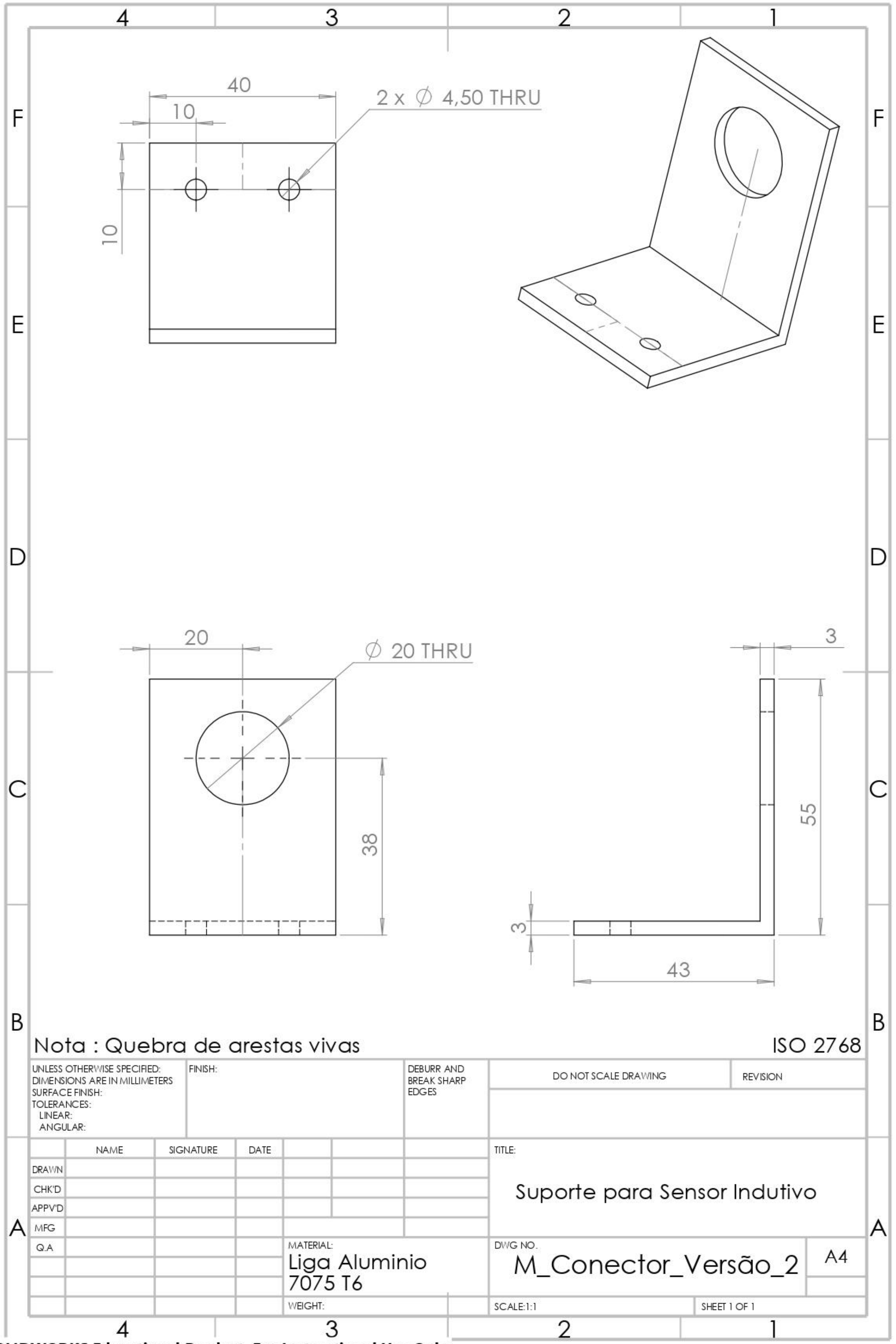
SCALE:1:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE	TITLE: Carro de Eixo Linear		
DRAWN						
CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL: Liga Aluminio 7075 T6	DWG NO. carro_versão_2		A3
			WEIGHT:	SCALE:1:1	SHEET 1 OF 1	


2 x ∅ 4,50 ↧ 15,00
2 x ∅ 4,50 ↧ 15,00
30
25,4
12,3
50
10
10
11,00
5
18
5
5
22,5
22,5
ISO 2768
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Suporte para fins-de-curso mecânicos
MATERIAL:
Liga de Aluminio 7075 T6
DWG NO.
Conector_Versão_3
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1


40
10
2 x ∅ 4,50 THRU
10
20
∅ 20 THRU
38
3
55
3
43
Nota : Quebra de arestas vivas
ISO 2768
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Suporte para Sensor Indutivo
MATERIAL:
Liga Aluminio 7075 T6
DWG NO.
M_Conector_Versão_2
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1

ANNEX D: Servomotor Parameters

This Annex provides all the main servomotor parameters acquired from the automatic process to configure the servomotor.

Parameter	*Value*	*Unit*
Scale factor numerator	10	
Scale factor denominator	1048576	
Encoder mask	4294967295	
Encoder mask	4294967295	
Encoder sub mask	1048575	
Invert encoder counting direction	False	
Encoder reference system	INCREMENTAL	
Encoder position offset	0	
Enable encoder soft minimum limit monitoring	True	
Soft minimum limit	-300	
Enable encoder soft maximum limit monitoring	True	
Soft maximum limit	30	
Invert motor polarity	False	
Output velocity scaling factor	1.02400649589962	
Unit	mm	
Reference velocity: 110% of max motor speed	1581.5976	mm/s
Maximum velocity: 100% of max motor speed	1437.82	mm/s
Fast velocity: 100% of max motor speed	1437.816	mm/s
Manual velocity (fast): 30% of max NC jog speed	225	mm/s
Manual velocity (slow): 5% of max NC jog speed	37.5	mm/s
Calibration velocity (towards plc cam): 1% of max motor speed	14.37816	mm/s
Calibration velocity (off plc cam): 1% of max motor speed	14.37816	mm/s
Acceleration with an acceleration time of 1s	2156.72	mm/s^2
Deceleration with an acceleration time of 1s	2156.72	mm/s^2
Max allowed acceleration	15000	mm/s^2
Max allowed deceleration	15000	mm/s^2
Jerk with an acceleration time of 1s	6470.17	mm/s^3