The Capstone Team Project

MECT/MENG 411

Name of Project: *Design and Development of a Smart Factory*

Group Name: *TEAM MECHANIZERS*

Group Members:

17700450	*ZEYAD SHEHATA*
17700557	*HISHAM AFASH*
17700158	*AL AMIR SHAHEEN*
16700725	*HABIB UR REHMAN*
17700358	*AHMED ABDEL RAOUF*

Supervisor: *Assoc. Prof. Dr. Qassim Zeeshan*

Semester: *Spring 2020-2021*
Submission Date: *07th of June 2021*

Eastern Mediterranean University

Department of Mechanical Engineering

ABSTRACT

Nowadays, Development of technology is necessary because it relates to human needs and both are rapidly increasing. The goal is to make life easier every day. As for industries, the development of Industry 4.0 introduced a brand-new way of organizing the means of production, and that introduced a new era of technology use in industrial sectors.

One of the most important applicants of Industry 4.0 is the smart factory model. A Smart Factory is a concept for indicating the ultimate goal of digitization in manufacturing. A smart factory model applies the means of the 4th industry through different aspects including new technologies such as cloud computing. It combines the physical production process with digital technology.

Our smart factory model mainly consists of a robotic arm and two conveyor belts. All assembled and manufactured using 3D printing and different workshop processes. In order for our project to meet the objectives, cost, performance, availability, and environment will be all taken into consideration. It basically combines mechatronics with mechanical skills to introduce a modern mimic of how smart factories can be represented. With the use of sensors and Arduino board which will make the process flexible and efficient we will be able to detect the process of the factory and sense any error that might occur. Applying all these aspects the results expected is to have a full-modern smart factory that applies the visions of the 4th industry.

Table of Contents

List of Figures

List of Tables

LIST OF SYMBOLS and ABBREVIATIONS

3D: Three-Dimensional.

PLA: Polylactic-acid

Θ_i: Theta angle of X-axis.

d_i: Distance between Z-axis to another.

α_i: Alpha angle of Z-axis.

a: distance between X-axis and another.

CHAPTER 1 - INTRODUCTION

1.1 Detailed definition of the project

The smart factory is defined as a factory where physical production processes and operations are combined with digital technology, smart computing, and big data to create a more opportunistic system for companies that focus on manufacturing and supply chain management. The smart factory is an aspect of Industry 4.0, a new phase in the Industrial Revolution that focuses heavily on real-time data, embedded sensors, connectivity, automation, and machine learning.[1]

Figure 1 Outline of Smart Factory

Extensive use of IoT sensors and devices connects machines and enables visibility into their condition as well as into factory processes, creating an industrial internet of things (IoT) [2]. Increasingly sophisticated analytics and applications based on AI and machine learning handle many of the routine tasks, freeing up people to focus on handling exceptions and making higher-level decisions. Robots are expected to populate smart factories for routine work, working alongside people. Smart factories rely on smart manufacturing, which connects the plant to other entities in the digital supply network, enabling more effective supply chain management. They also rely on digital manufacturing, which uses a Digital twin to connect a product digitally at all stages in its lifecycle. [3]

Given that one of the most fundamental characteristics of a smart factory is its connectedness, sensors are critical to linking devices, machines, and systems to provide data needed to make real-time decisions. In a similar way that smart home devices accomplish routine actions like dimming lights at a certain time or triggering alerts when something is amiss, the ideal smart factory runs itself on a much larger scale, self-correcting where appropriate and alerting for human intervention where needed. In addition, the extensive amount of data provides real-time insight to supply chain stakeholders, both inside the factory and to the business and partners. In this way, agility can increase exponentially, and issues can be addressed proactively. Already, IoT technologies have helped to monitor industrial operations, provide supply chain visibility, and predict equipment downtime.

1.2 Significance of the project

The smart factory model acts for a breakthrough from more traditional automation to a completely associated and workable system. Making a smart factory is not easy, it needs a high level of accuracy and engineering skills from different majors so it can serve the fourth revolution of industry successfully. However, this project seeks to achieve the basics of Industry 4.0 through different mechanical and mechatronics processes.

This model of smart factory can be used perfectly as a mimic to represent how factories in the modern era should work. The project perfectly applies mechatronics skills by having a modern robotic arm that takes the product from a process to another and it is essential to have since the adoption of robots in industries worldwide is on the high rise. The robotic arm provides working with high quality and accuracy in less time.

Smart factory model should provide high engineering skills. With two conveyor belts aside to the robotic arm this model serves classic mechanical work with high efficiency and modern perspective. All the parts of the model are associated through a conveyor belt and controlled by a programmable Arduino that will make the process flexible and efficient.

1.3 Detailed project objectives

The main objective of the project is to design and manufacture a smart factory model which can evaluate the idea of a smart factory that contains a robotic arm using Arduino. Detailed project objectives are illustrated below.

1.3.1 Design for safety

The factory model is being implemented for several reasons, first of which is that it can ease the process of sorting and moving heavy materials. Usually this is carried using manpower, which can cause lifetime injuries if done repeatedly daily. Add to that the factory model helps work to be done in extreme organization and precision as by identifying each object by its color and moved automatically it will know where the material should be headed to.

1.3.2 Design for cost

Design for cost is the conscious use of engineering processing technology to reduce the design cost. This is achieved using suitable low-cost materials and manufacturing processes. For example, the part of the robotic arm platform was manufactured using a 3D printing system and then assembled using mechanical fasteners. As for the other parts of the model they are all manufactured by wood material which is not as expensive as metals. As for the rods and threaded rods they were made of stainless-steel and lead respectively.

1.3.3 Design for assembly

The main assembly of the robotic arm was involved two sub-assemblies which is the arm and the conveyor system. The 3D construction of the robotic arm is done by using Solidworks. The arm assembly was done using screws and nuts, while the conveyor system was done by wood-carving and joinery then followed by screws and nuts.

1.3.4 Design for environment

The material used in the smart factory are used to be environmentally friendly. Polylactic acid (PLA) is used for the robotic arm, this material is known to consist of renewable raw materials. Wood material is chosen to design the conveyor belts, this type of material was chosen since it is known to require less energy in manufacturing processes other than materials which makes it environmentally friendly.

1.3.5 Design for performance

Design for performance is one of the main project objectives which is achieved by making a factory model that with connectedness and sensors, can take input data and perform real-time decision leading to a factory that can run itself and self-correcting and giving alerts for human intervention when needed.

1.4 Detailed project constraints

Cost: The manufacturing and assembly cost of the model parts doesn’t exceed the available budget as most of the parts are 3D printed using Polylactic Acid (PLA).

Availability: The model is designed using materials and components available in the international market.

Reliability: System uses Arduino board which allows devices to communicate and interact with each other through a programmable code and data exchange of devices. Thus, stochastic events, errors and failures can be minimized, thus wastes, total costs and lead times can be reduced. [4]

Efficiency: the system has high resource utilization, due to self-organizing, self-regulating, and self-adapting operation. So sustainable production can be provided in the long term due to more efficient resource utilization.

Maintainability: This system is of a predictive maintenance type which means that all things are connected via an Arduino board and they are able to communicate and alert each other and if an error or failure is detected the system stops, the machines and parts are set to repair quickly.

Economic: The smart factory design will add up to the economy by enabling factories to produce more while lowering costs and industries may almost double their operating profit in the long run.

1.5 Report Organization

The following report consists of seven chapters in total, each chapter is divided into different subsections. The first chapter is Introduction, which entails five sections which are, Detailed Definition of Smart Factory, Significance of The Smart Factory Model, Detailed Project Objectives which been divided into five sections, detailed project constraints and finally Report Organization which explains the structure of the report.

The second chapter, Literature Review explains the smart factory model and the advantages of it, the other sections consist of the concurrent solutions, the comparisons of these concurrent solutions and finally the engineering standard used.

The third chapter, Design and Analysis consists of the proposed or selected design, which states the various reasons of choosing the specified material and design. The other sections include the engineering standards used, design calculations and last of all the cost analysis (BOM).

The fourth chapter is Manufacturing Plan. It has two sections which are Manufacturing Processes Selection where all the types of manufacturing processes are mentioned. The other section is the Detailed Manufacturing Processes which gives full detailed information about the manufacturing process of the project.

The fifth chapter is Product Testing Plan. It entails the verification plan of the objectives of the project as well as the Verification plan of the applied engineering standards.

The sixth chapter is Results and Discussions, this chapter discusses the overall procedure and the final results, and it discusses the standards that were used in this project and the constraints the team faced meanwhile working on it.

The seventh chapter is Conclusion, this chapter sums up the whole procedure briefly and illustrates the future works of the model and how it can be implemented in a better operation.

CHAPTER 2 - LITERATURE REVIEW

2.1. Background Information

The term ' smart factory ' is recent to the science world, however, the concept has been talked about in various different forms for the couple of years. Many tech companies in recent times, have been creating smart factories for some of the world's leading manufactures in different industries such as automotive and discrete industries for more than a decade now.

At first, smart factories were originally designed to specifically help vehicle assembly and manufacturing to tackle the challenges of managing ever increasing level of complexity in assembly lines brought by huge changes and demand in customization. The development in smart industries sector delivered real- time operational awareness and data insights that enabled smart and effective decisions for optimal process execution, eliminating the cost and burden of manual processes. This reduced the risk of errors and rework which lead to increase in productivity and savings which ensured the manufactures about safe future of smart factories.

Around 4 percent of the world’s cars are now built in a factory installed with Ubisense’s Smart Factory but while automotive manufacturers have been the early adopters of location-driven Smart Factory solutions, other sectors such as agricultural and military have seen an increase in demand from manufactures. [5]

2.2. Concurrent Solutions

The smart factory is characterized as a factory where digital technology, smart computing and big data combine physical production processes and operations to create a more opportunistic system for companies that concentrate on manufacturing and supply chain management. Industry 4.0, a new stage in the Industrial Revolution that focuses heavily on real-time data, embedded sensors, networking, automation, and machine learning, is an aspect of the smart factory.

The smart factory brings the fourth industrial revolution to bear by driving more intelligent manufacturing. Some ways this can play out include:

- Using machine learning to automatically analyze data collected on equipment by sensors and monitoring devices and find opportunities for gains in performance. From there, the program will adjust the parameters that machines use to run, automatically enforcing process changes.
- Using robotics solutions to deal with routine activities that previously needed human interaction at a deeper level.

2.2.1. Deloitte Smart Factory

Deloitte Smart Factory is a pre-configured suite of cloud-based IoT software designed to accelerate smart applications for manufacturing transitions for businesses with manufacturing activities. Driven by AWS IoT, Deloitte developed and created a suite of cloud software and integrated services to bring smart factory capabilities to industrial companies. Smart Factory Fabric suite of services helps businesses boost their operating efficiency and reduce costs by increasing visibility, improving production, improving quality, and minimizing unplanned downtime associated with running a smart factory. [6]

The Smart Factory Fabric solution, built on Amazon web services (AWS), connects the physical and digital world, leveraging a powerful technology stack:

- At the plant level, the solution can read and offer two-way communication with a multitude of edge devices, reducing latency and getting information real-time.
- The pertinent information can be ported to the cloud layer, allowing for rich data analysis, modeling, and cognitive processes to create insights.
- A set of applications have been designed to proactively interact with the data insights, offering alerts, ability to transact, and most importantly, a rich user experience.

Once integrated with your IT landscape and combined with AWS methodology, the cloud-enabled smart manufacturing technology can activate and transform the factory to adjust manufacturing behaviors and achieve the anticipated ROI. [7]

Deloitte's Smart Factory model offers a global design, versatile enough to handle numerous installations as shown in Figure (2). When completely scaled, it will provide indicators for various aspects of the company and an integrated view of the operations required to uncover opportunities for change and make decisions across the sector. [8]

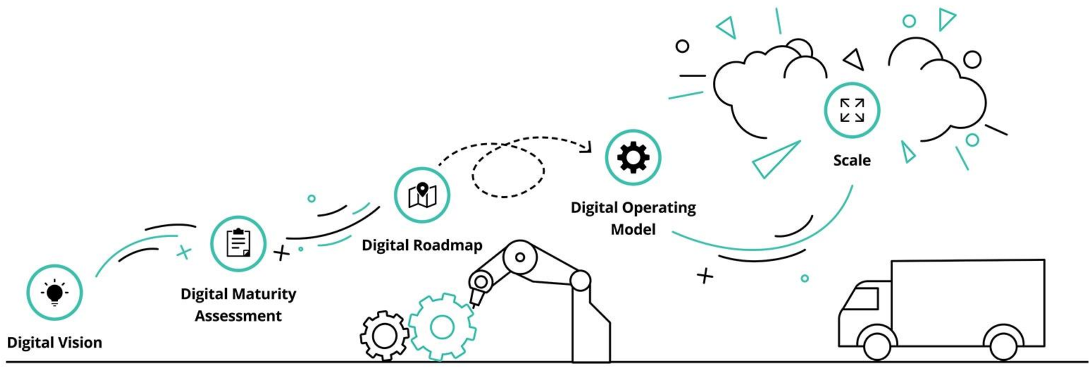


Figure 2 Deloitte smart factory digital journey.

2.2.2 Toyota Smart Manufacturing and Connectivity

As a leading material handling manufacturer, Toyota has proven its dominance in the field time and time again. With more than 130,000 trucks connected on a global scale, they were the earliest and most confident adopters of these Industry 4.0 solutions and promise further innovation as time and technologies progress. [9]

Preventative maintenance is the ultimate goal for Toyota when it comes to connectivity, and equipping their smart trucks with digital solutions serve as a major step towards that goal. To begin receiving direct insights and data from their trucks, customers need only activate an account; Toyota encourages companies to embrace these offerings by showing how simple and painless it is. The simpler things are for everyone involved, the easier it is for Toyota to build value-adding and long-term relationships with its customers. [10]

To further add value to its customers, Toyota uses the same smart trucks within its own operations. This allows them to learn from their own needs and apply their first-hand experience when supporting customers. Toyota strives to always be learning and developing, sharing best practice across as many industries as possible and serving as an inspiration for other companies considering the implementation of Industry 4.0 solutions. [11]

Figure 3 Toyota smart production factory

2.2.3 ABB’s Smart Factory

ABB’s factory of the future at the Hanover Messe features industry-leading digital twin technology, which makes it possible to amend and optimize manufacturing without interrupting the production process. [12] As welding automotive parts has become more complex in recent years, designing production around the optimal robotics path is critical to boost weld quality and productivity. The Dassault System solution will integrate a digital twin that complements ABB’s Robot Studio software to simulate the application and illustrate how it can augment production by outlining the best possible robot path.

A key feature of the factory of the future is the sensor, which collects and feeds information about the production process into the industrial internet. ABB has developed a compact ABB Ability™ Smart Sensor that can be easily attached to the frame of a low-voltage induction motor, mounted bearings and pumps to measure key parameters, such as vibration and temperature. Using on-board algorithms, based on ABB’s decades of expertise in electric motors, the ABB Ability™ Smart Sensor gathers information about the equipment’s condition and sends the data via a wireless Bluetooth connection to a secure server, from which it can be accessed through a Smartphone or tablet.

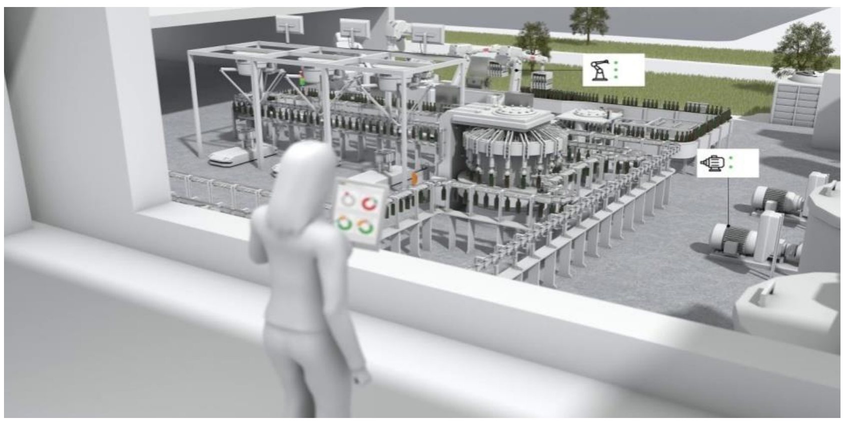


Figure 4 Digital twin in ABB's smart factory

2.3 Comparisons of the Concurrent Solutions

Table 1 : Comparison of Concurrent Solutions

	Deloitte smart factory	Toyota smart manufacturing and productivity	ABB's smart factory
Software	Cloud-based and IoT software	Smart application	Smart sensor relays
Connectivity	Amazon web services	Smart trucks	Bluetooth and internet
Smart parts/materials	Cloud computing	Tracking and tracing	Smart sensors

Based on concurrent solutions mentioned above in Table 1, comparisons are made to choose the one most suitable for our project. Our smart factory model design uses the sensors to identify different colored products which can also prove to be beneficial while differentiating between working and defective products, similar to the features found in the ABB's smart factory which uses smart sensors in the process of manufacturing. Also, to use the sensor's ability to the fullest, on-board algorithms are used to gather information about the equipment’s condition and send the data to the server for better maintenance and production.

2.4 Engineering Standards of the Concurrent Solutions

Standards are present in every industry. They are used to have a uniform design, methods, processes, etc. across the world. Each industry has certain standard they follow and adhere there product according to it.

2.4.1 ISO 10303

ISO 10303, commonly known as STEP, is an international standard designed to exchange product data between CAD systems with a neutral data structure. The purpose of this international standard is to provide a framework capable of representing product data during the life cycle of a product, independent of any specific method. The design of this definition makes it appropriate not only for neutral file exchange, but also as a basis for the implementation and sharing of product databases and archiving. [13]

2.4.2 IEC 62832

A standard for digital representation and identification of assets in the factory. Today each department inside the enterprise describes its products and production systems according to its own data management schemes, often using different terms and structures, with no seamless information exchange can be found between all the actors involved in the product and production system lifecycle due to this lack of interoperability in the information systems. This standard aims to establish guidelines for communicating the descriptions of the objects and the exchange of information among different systems in the organization. [14]

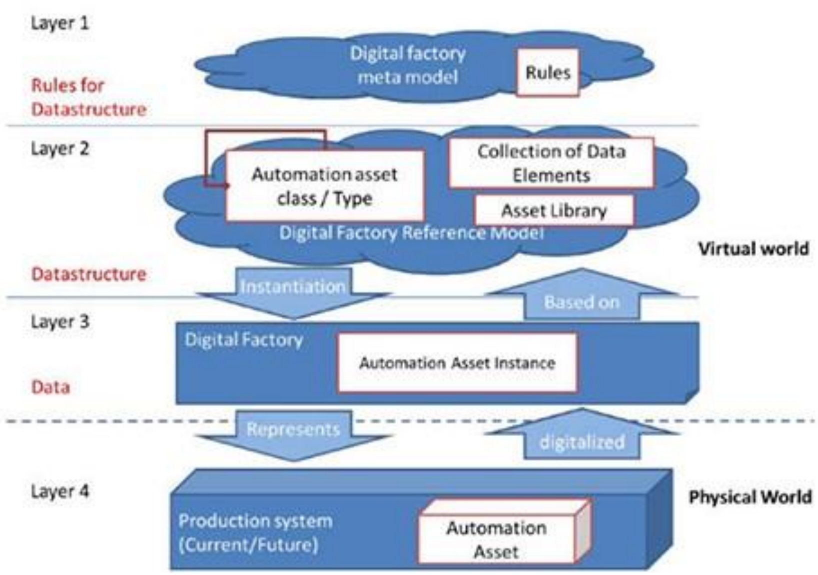


Figure 5 Conceptual layers of the Digital Factory Framework.

2.4.3 DIS 22400

DIS 22400 specifies key performance measures (KPIs) used in the management of manufacturing operations. DIS 22400-2:2014 defines the number of KPIs chosen for current practice. The KPIs are presented using their formula and corresponding components, their time behavior, their unit/dimension and other characteristics. DIS 22400-2:2014 also specifies the user category to which the KPIs are used and the development methodology to which they relate. Some of the measures defined include the following:

- Raw materials inventory, Consumables inventory), Finished goods inventory, Work in process inventory, Consumed material.
- Order quantity, Scrap quantity, Good quantity, Rework quantity, Produced quantity
- Equipment production capacity, Worker efficiency, Throughput Rate, Utilization efficiency, Overall equipment effectiveness, Availability, Effectiveness, Quality Ratio, Technical efficiency, First pass yield, Scrap ratio, Rework ratio
- Process capability index, Inventory turns, Finished goods ratio
- Mean Operating time between failures, Time to failure, Corrective maintenance time. [15]

2.4.4 IEEE P1872.1

This standard describes an ontology that allows the representation, reasoning and communication of task information in the field of robotics and automation. This ontology includes main terms as well as their descriptions, attributes, types, structures, properties, shortcomings and relationships. It will address the way in which hierarchical planners represent the information of the task, which will allow them to interact better between the levels of the ontology hierarchy. [16]

CHAPTER 3 -DESIGN and ANALYSIS

3.1 Proposed/Selected Design

The selected model design shown in Figure (6) consists of a Scara-robotic arm which is printed using 3D-printer using Polylactic Acid (PLA) material which is eco-friendliest option for 3D-printers operation. This Arduino controlled smart factory model consists of a part of a factory where a 4-Degrees of freedom with 5-Axial directions robotic arm is used to sort out products. IR infrared sensors and color sensors are used to run the sorting process, detect errors and malfunction. The design and assembling of each part are going to be listed in the following sections.

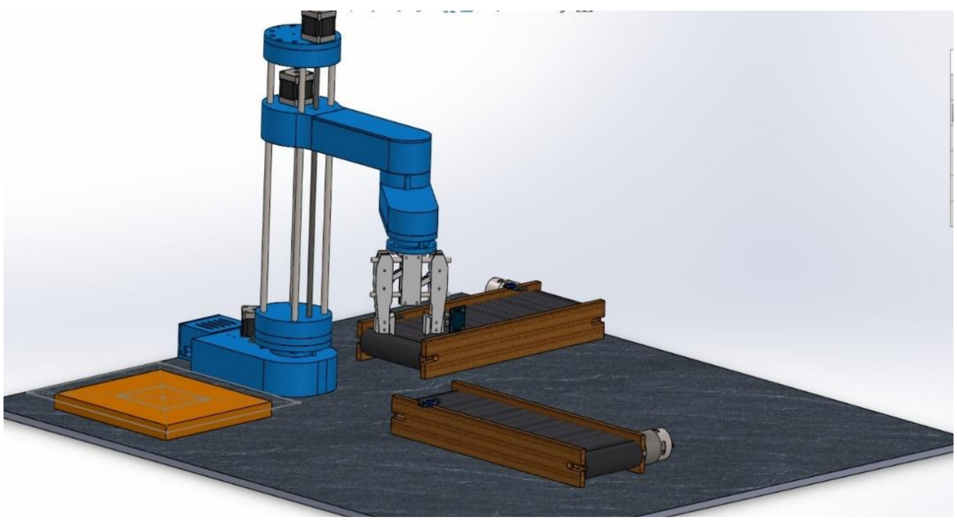


Figure 6 The selected design for the model.

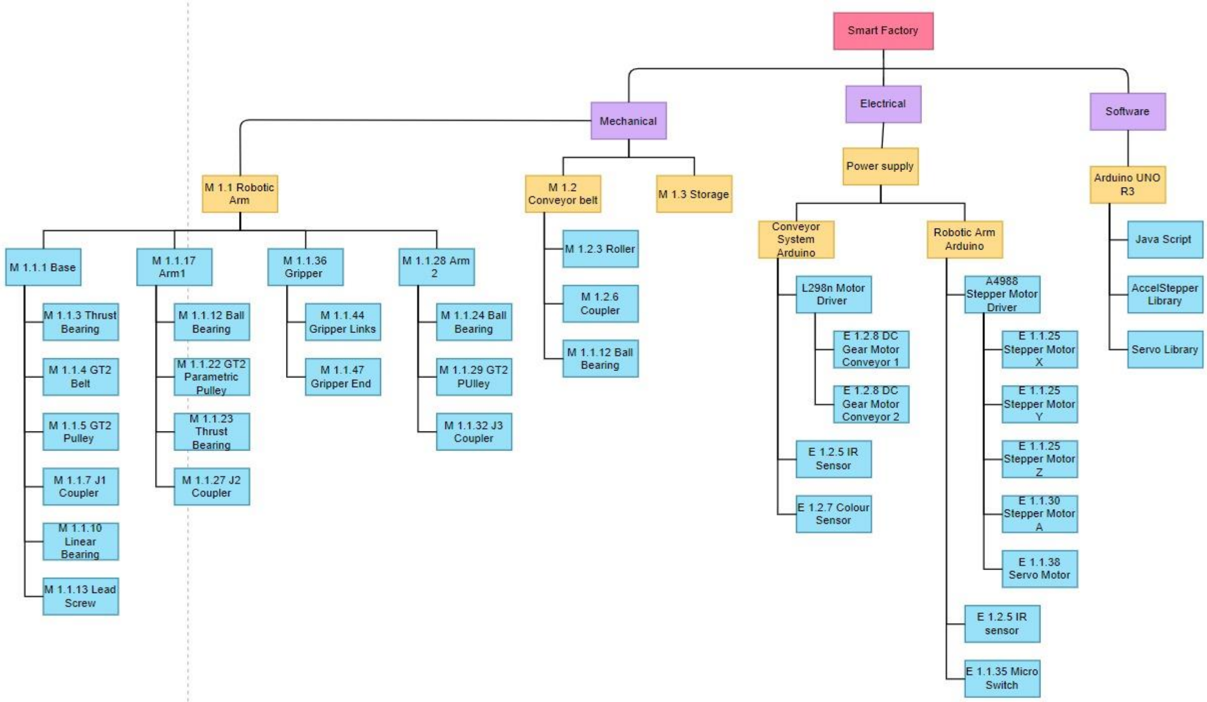


Figure 7 Breakdown structure.

3.1.1 Mechanical Components

Each model should have mechanical and electrical parts, both of mechanical and electrical parts depends on each other to do the required task. As we see here in Table 2 is a table that shows the mechanical components of the project and the benefit of it.

Table 2: The Mechanical Components

Mechanical Components	Usage
Scara robotic arm	The application of this robotic arm is pick and place for objects for the drilling and stamping production line.
Conveyor belt	The conveyor belt is used for transporting the material from one place to another without the human interference.
Storages	This storage acts as a temporary store for processed parts before they are transported along the production line.

3.1.2 Electrical Components

Electrical components to all intense and purposes are the most important tools that should be available in the project, because the project cannot operate without them. All the information, program codes, and user command are installed and being saved in the Arduino which can operate and take control over the model to do the required tasks and detect errors without the human interference.

Here is a table that shows all the electrical components involved in this project and the use of them. To get better understanding while reviewing the upcoming information.

Table 3 : The Electrical Components

Electrical Components	Usage
DC 12V 100 rpm gear Motor	This motor is used to rotate the wheel of the Convey belt and provide them with motion.
17HS1910 Stepper Motor	A stepper motor used to provide the Scara robot with motion along the axis.
MG996R servo motor	A servo motor which is used to control the Scara gripper motion.
Arduino UNO R3 board	The Arduino is used to control the motors and sensors circuit by which the model works by getting date from the inputs, running a code full of statements and condition and based of different conditions sends a signal to the outputs of the circuit.
IR infrared sensor	These sensors are used to detect infrared radiation in its surrounding environment. It's used to detect objects.

A4988 stepper driver	The A4988 is a micro stepping driver used for controlling bipolar stepper motor.
Arduino CNC shield	CNC shield is plugged onto the Arduino and on top of it is the A4988n drivers and is used as a driver expansion board.
L298n motor driver	L298n motor driver is used for driving DC and stepper motor.
Limit switches	Limit switches are used to detect the presence or absence of an objects and used to limit the travel of an object.
Color sensor	Photoelectric sensor which emits light from a transmitter, and then detects the light reflected back from the detection object with a receiver.

The stepper, servo and DC gear motor play a big rule in this project, they convert the electrical power from the battery source to a mechanical power which provides motion to the conveyer belt, robotic arm. The Arduino UNO R3 acts as a control unit of the model where all the controlling information are installed and saved. While one Arduino board contains all the programming commands to be executed by the robotic arm and the second Arduino control the conveyor system. Both Arduino then share information and work together via serial communication. Finally, sensors are used to detect errors in the production line.

3.1.3 Circuit Diagrams Design

A circuit is a closed loop that electrons can travel in. A source of electricity such as a battery, which provides energy in the circuit. Unless the circuit is complete, that is, making a full circle back to the electrical source. No electrons will move. Circuits are so important; they can define how the project could work and operate and it acts like a map which shows how everything must be connected to run the project successfully. In this project there are many electrical components needs to be connected between each other.

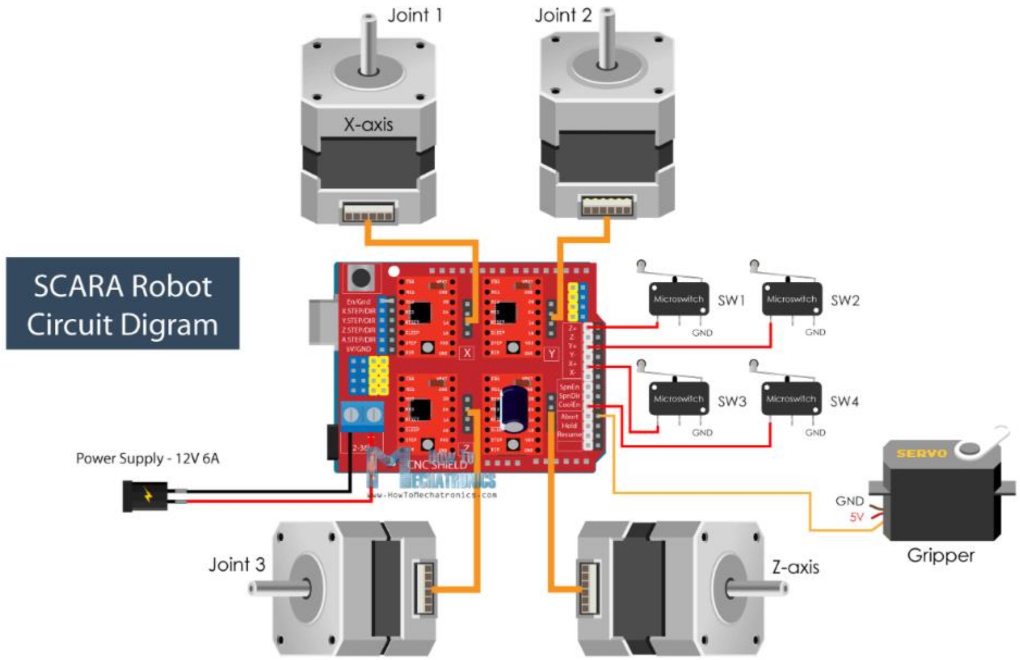


Figure 8 Circuit diagram of the scara robotic arm

As shown Figure (8), the Scara-robotic arm circuit consists of 4 NEMA 17 stepper motor and 1 servo for the control of the joints and end effector respectively. For the controlling of the stepper motor, each stepper motor was controlled using an A4988 motor driver connected to the top of a CNC shield paired with an Arduino UNO board which is the brain of the Scara-robotic arm. Limit switches were connected to each axis of the robotic arm to limit the travel motion of each joint and to define the home position. Finally, a 12V and 4amps power supply was used to power the circuit and jumper cables were placed on each enable pins for each axis to enable the motors.

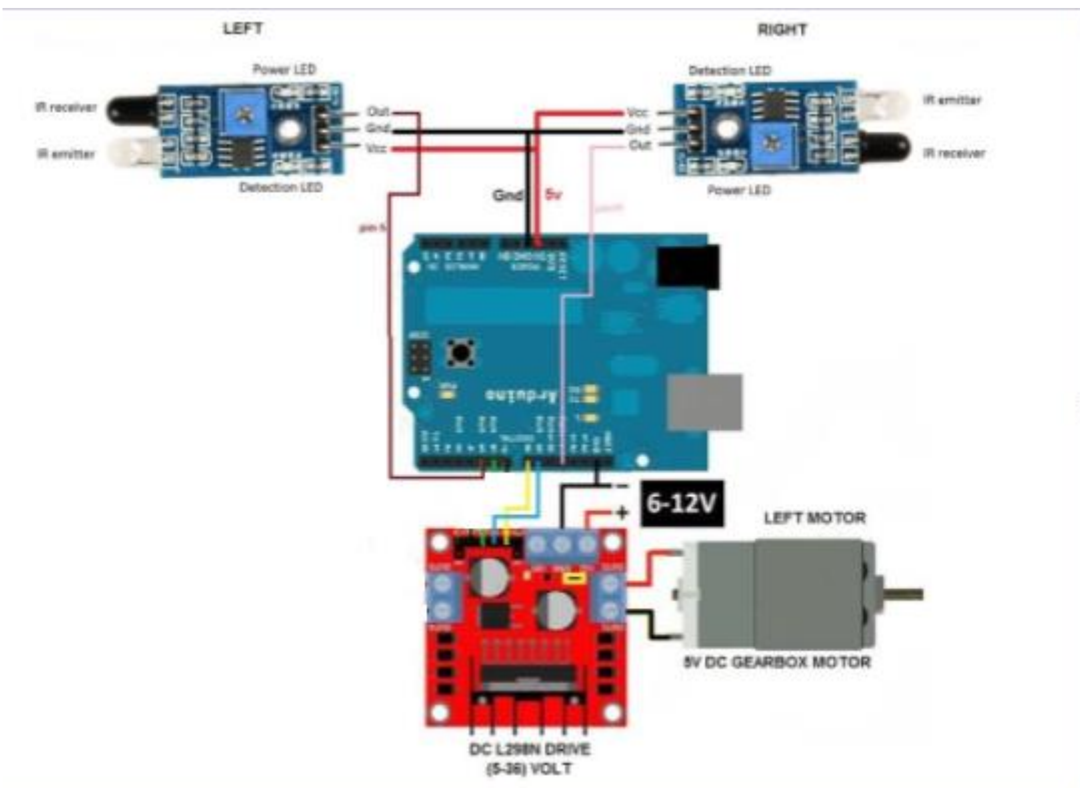


Figure 9: Circuit diagram for the conveyor belt system

As illustrated in Figure (9), the conveyor belt system consists of DC gear motor and 2 IR infrared sensors. The gear motor used is a 12v and 100 rpm gear motor and it is connected to a L298N motor driver which is responsible for the enable/disable, direction of rotation and rotation speed of the motor by communicating with the Arduino UNO board and based on the values or status of the color and IR sensors connected to the Arduino signals are sent to L298N motor driver for the controlling of the motor.

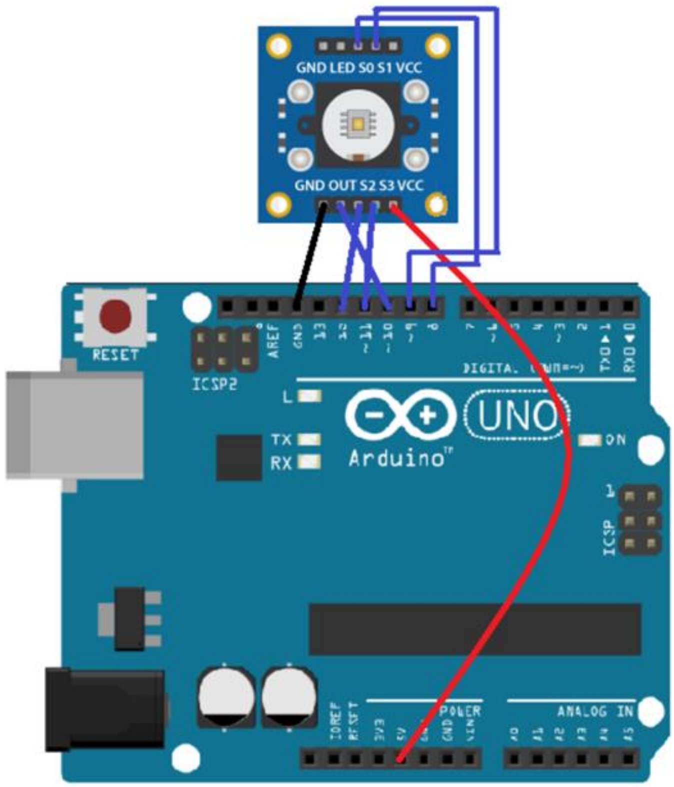


Figure 10 Color sensor simple connection.

As shown in figure (10), the TCS230 color sensor connection consist of S0, S1, S2, S3, OUT, GND and VCC while VCC and GND are connected to 5v and ground respectively. While S0, S1 are for setting frequency and S2, S3 are for reading the color value and finally the OUT pin gives the output to the Arduino in the form of square waves. To start with, frequency was set to 20% for detecting color values. And after testing the color and taking reading from the sensor for coding purpose the color Green required the photodiode values to be ($30<R<85$ & $25<G<80$) while for blue values where required to be ($35<B<95$ & $75<G<150$) which was the condition used in coding to differentiate between colors.

Finally this color sensor was connected via serial communication between 2 Arduino UNO R3 controlling the robotic arm and conveyor system respectively to give data to both of them for color sorting purposes.

3.1.4 Controlling System

Control system is one of the most important components in the whole project. Any electrical or mechanical machine have a method to be controlled by. Either manual or automatic. In this project the controller circuit plays a very big rule because it receives the data from the sensors and pass it to the other components making it possible to control the system using Arduino with Java script programing without user interference.

In this project, the smart factory model is controlled via an Arduino connected to a computer for the programming purpose. Using Java script programming language, we are able to control the sensors that is responsible to detect any movement in the production line so that is can send signals which is then translated by the program and enables it to control the status of the motors which control the conveyor belts so that machines on the production line can proceed with their functions continuously without any human interference.

The Arduino UNO R3 is programmed in a way that allows all the electrical components to connect between each other. In other words, the controller is the place where all the electrical cables are joined to control all the components in the project. The control program is designed in a method to avoid any error or problems might face the operation process.

This is possible with an Arduino because it continuously monitors the state of the input devices and make the decisions based upon the commands stated in a program to control the state of the output devices. This operation takes place by energizing the output pins of the DC gear motor when sensors conditions are met while in the robotic arm case stepper motors energize for a specific number of steps by which the desired position can be reached and finally in the case of the servo motor when condition is met, it rotates by a given angle.

3.1.5 Operation Mechanism

The smart factory can be viewed as a closed loop system, by which a sequence of machine movements is controlled by an Arduino. The smart factory model consists of two conveyor belts and a robotic arm placed in the middle for product sorting purpose. The work piece is heading toward the robotic arm from the first conveyor belt, the moment it reaches the robotic arm, the IR infrared sensor and the color sensor detect the work piece, and the conveyor belt stops so that the arm pick and place operation can take place. Depending on the color of the work piece it proceeds to either the storage or the next conveyor belt via the robotic arm. If the object color is blue, the robotic arm will transport the work piece to the storage. Otherwise, if the work piece is green. The robotic arm transports the work piece to the next conveyor belt.

3.2 Engineering Standards

Standards for the design are as follows:

- ISO 20140-5 Automation systems and integration -- Evaluating energy efficiency and other factors of manufacturing systems that influence the environment.
- ISO 13849 Safety of machinery -- Safety-related parts of control systems.
- ISO 8373:2012 -- Robots and robotic devices. [18]
- ISO 9283:1998 Manipulating industrial robots -- Performance criteria and related test methods.
- IEC 61131 Programmable controllers -- Programming languages.
- ISO/TS 15066:2016 Robots and robotic devices -- Collaborative robots.
- IEC 62443 Industrial communication networks -- Network and system security - Terminology, concepts, and models
- IEC 62061 Functional safety of electrical, electronic, and programmable electronic control systems. [19]

3.3 Design Calculations

In this section, mathematical methods are used to obtain the operating analysis and calculations for the project. Calculations are to be carried out for determining the following:

1. Robot arm torque calculations.
2. Physical measurement properties of the robotic arm.
3. Robotic arm forward kinematics calculations.

3.3.1 Robot Arm Torque Calculations

The robot torque arm calculations is intended to help choosing the right motor for each joint of the used robotic arm. The torque (T) required at each joint is calculated as a worst-case scenario (lifting weight at 90 degrees). The units used for calculations is in SI units (cm, kg).

L: length from pivot to pivot.

M: link mass.

A: Stepper or servo motor mass.

T: Torque Calculated

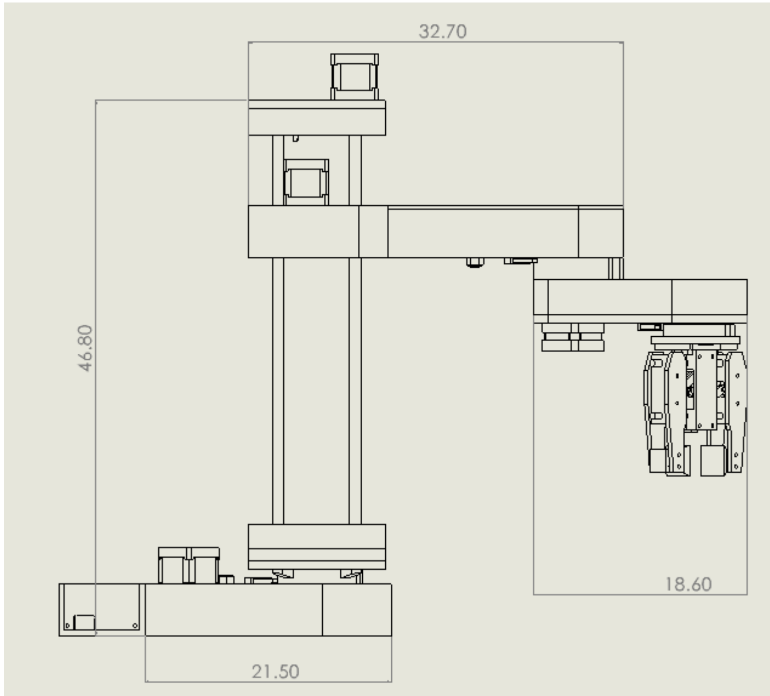


Figure 11: Explanation of the units and measurements used to calculate the torque

Table 4 : Torque calculations for the robotic arm .

L : [CM]	M : [KG]	A : [KG]	T : [KG CM]
L1: 21.50	1.2	0.245	23.176
L2: 46.80	1.1	0.245	32.986
L3: 32.70	0.9	0.245	28.081
L4: 18.60	0.9	0.230	24.388

As shown in Table (4), these are the torque calculations for each joint of the robotic arm which are three joints. Calculating torque for the robotic arm is important to know. Torque is used to measure the maximum performance level of the arm and to know which and what type of motors to choose during the manufacturing process of the project. While the process torque is little higher than the maximum torque that the motor can generate, gears are added in each links to increase the torque produced by the motor. The arm is in the safe site and could operate perfectly with less amount of error. But if the process torque exceeds the maximum amount of torque generated by the motor, failure will occur to the system.

3.3.2 A4988 Motor Current Tuning

The A4988 stepper driver will interrupt the current to the stepper motor, it is an important thing to set up the current when using these drivers as the motor current limit especially when you're using a higher input voltage than what the motor is rated for. Using a higher voltage generally enables you to get more torque and a faster step speed, but limiting the amount of current flowing through the motor coils so the coil does not get damaged.

The adjustment was done by calculating the current reaching to the 2 models of the stepper motor used and then adjusting the reference voltage on the driver.

Current limit = $V_{ref} * 2$

My stepper = 1.6 A

$1.6 = V_{ref} * 2$

$V_{ref} = 1.6/2$

$V_{ref} = 0.8V$

Therefore, adjusting the voltage reaching the A4988 stepper driver connected to the 42mm stepper motor model to 0.8 as shown in the Figure 13. [20]

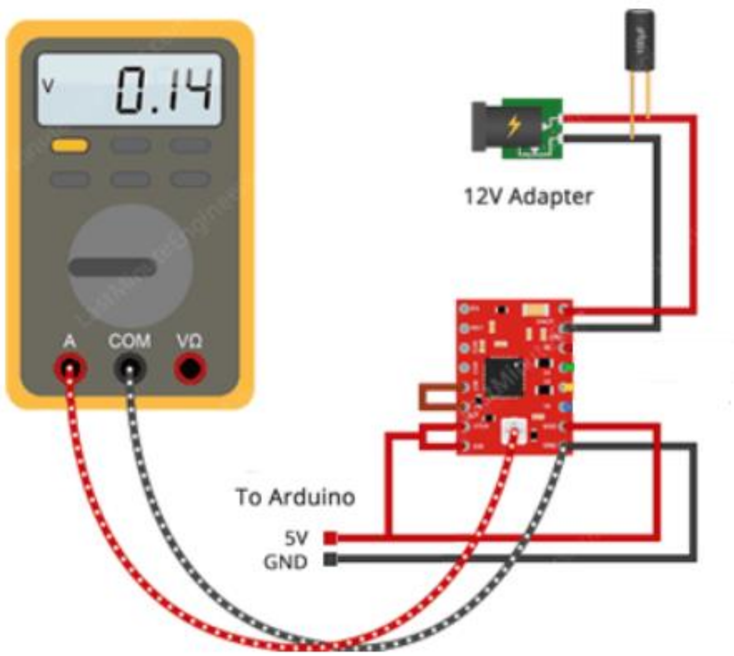


Figure 12 Adjusting the voltage passing to the A4988 stepper driver.

While for the 28mm stepper motor model adjusting the voltage reaching the A4988 stepper driver to 0.6 V as stated in the calculations below.

Current limit = $V_{ref} * 2$

My stepper = 1.2 A

$1.6 = V_{ref} * 2$

$V_{ref} = 1.6/2$

$V_{ref} = 0.6$ V

3.3.3 Robotic Arm Forward Kinematics Calculation

In this section, the forward kinematics of the robotic arm is going to be explained. Forward kinematics refers to the use of the kinematic equation of a robot to compute the position of the end-effectors from a specified value for the joint parameters.

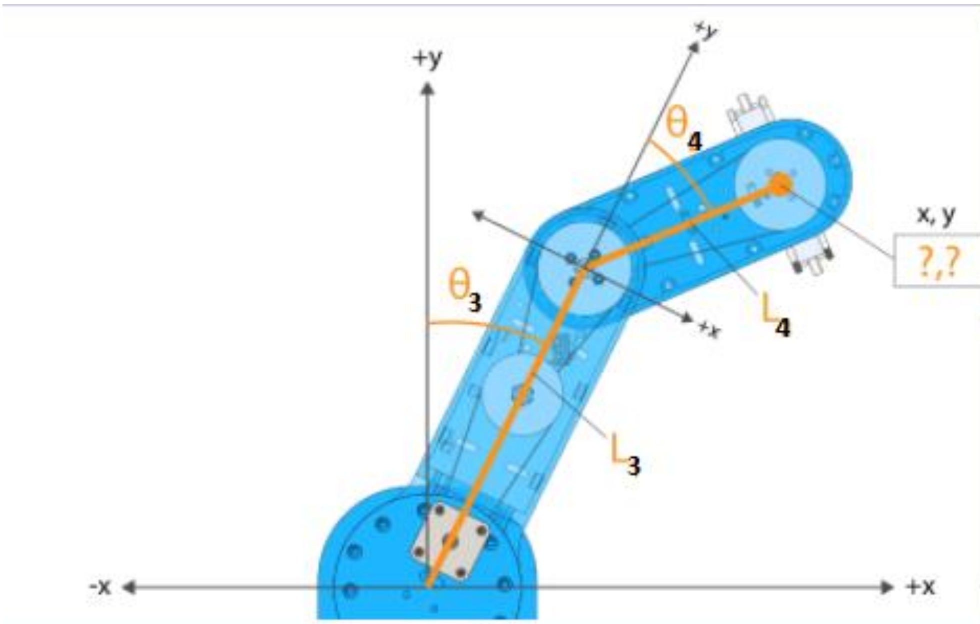


Figure 13 Top view

TOP view gives us:

- θ3: rotational angle of link 1, can be any value between 0° and 180°.
- L3: horizontail length of link 1.
- L4: horizontal length of link 2.
- Θ4: rotational angle of link 1, can be any value between 0° and 360°.

SIDE view gives us:

- Θ1, θ2 and θ3: The first, second and third angles, determine the angle of each arm from the home position.

- .L1, L2: The length of the arms.
- .d1: The distance between the base of the robot and the top end of the robot.
- d2: the distance from fourth joint and the end effector

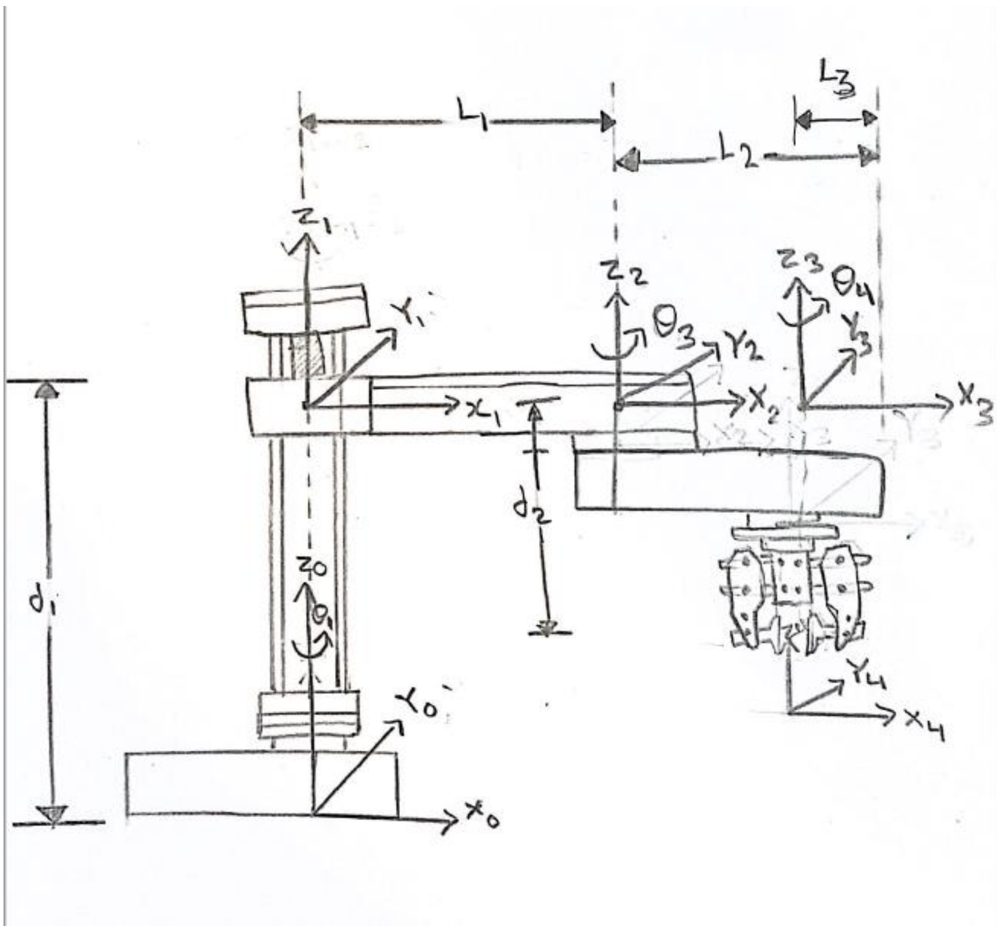


Figure 14 Side View

Table 5 DH Parameters Table

#	**θ_i**	**d_i**	**a_i**	**α_i**
1	θ_1	d_1	0	0
2	θ_3	0	L_1	0
3	θ_4	0	L_2-L_3	0
4	0	d_2	0	0

$$A1 = \begin{bmatrix} cos\theta 1 & -sin\theta 2 & 0 & 0 \\ \sin\theta 1 & cos\theta 1 & 0 & 0 \\ 0 & 0 & 1 & d1 \\ 0 & 0 & 0 & 1 \end{bmatrix} A2 = \begin{bmatrix} cos\theta 3 & -sin\theta 3 & 0 & L1cos\theta 3 \\ \sin\theta 3 & cos\theta 3 & 0 & L1sin\theta 3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A3 = \begin{bmatrix} cos\theta 4 & -sin\theta 4 & 0 & (L2 - L3)cos\theta 4 \\ \sin\theta 4 & cos\theta 4 & 0 & (L2 - L3)sin\theta 4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} A4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

T1 = A1*A2*A3*A4

$$x = L_1 \times \sin(\theta_1) + L_2 \times \sin(\theta_1 + \theta_2)$$

$$y = L_1 \times \cos(\theta_1) + L_2 \times \cos(\theta_1 + \theta_2)$$

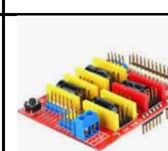
3.4 Cost Analysis

Table 6 Capital investment

	Quantity	Unit price	Total
Screw drivers set	1	$3.27	$3.27
Multimeter	1	$9.53	$9.53
Soldiering gun	1	$8.17	$8.17

Table 7 Cost analysis

ITEM	QUANTITY	NAME	SOURCE	COST	PICTURE
1	2	King Lan Electric Motor 12V DC Geared Motor High Torque Gear Reducer Motor – 125RPM	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	20.2$/ Piece	
2	1	MG996R servo motor	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	9.53$/ Piece	

3*	8	A4988 Stepper Motor Driver	Banggood LLPC Location: China Tel:+00852-35903678 Email:Cservice@banggood.com	2.72$/ Piece	
4	4	Arduino UNO R3	eBay inc Location: USA - California Tel:1-866-540-3229 Email:custumerservice@ebay.com	10.89$/ Piece	
5	1	TCS3200 Color Sensor Color Recognition	Banggood LLPC Location: China Tel:+00852-35903678 Email:Cservice@banggood.com	8.17$/ Piece	
6*	2	Arduino CNC shield v3	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	5.45$/ Piece	

7	4	Nema17 Stepper Motor 42mm 1.68A	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	14.97$/ Piece	
8*	2	L298n motor driver	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	5.00$/ Piece	
9*	2	12V 4amp power supply	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	9.80$/ Piece	
10	10	Micro limit switches	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	0.85$/ Piece	

11	6	Geekcreit® IR Infrared Obstacle Avoidance Sensor	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	2.72$/ Piece	
12	12	Radial ball bearing 8x22x7mm	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	1.40$/ Piece	
13	4	Linear bearings 10mm	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	5.44$/ Piece	
14	2	Thrust ball bearing 40x60x13mm	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	5.44$/ Piece	

15	4	Thrust ball bearing 35x52x12mm	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	5.00$/ Piece	
16	1	Lead screw – 8mm 400mm	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	10.89$/ Piece	
17	4	Smooth rod shaft – 10mm 400mm	Amazon.com Location: Washington, United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	7.00$/ Piece	
18	1	Stepper motor coupler 5mm to 8mm	Amazon.com Location: Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	5.44$/ Piece	

19	5	GT2 Idler Pulley 20 Teeth Aluminum 5mm Bore 6mm Width Timing Belt Pulley Wheel	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	2.60$ /Piece	
18	1	Hybrid Ceramic Bearing 35*47*7 mm	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	5.44$/ Piece	
19	2	Hybrid Ceramic Bearing 30*45*7 mm	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	5.44$/ Piece	
20	2	GT2 Closed Loop Timing Belt Rubber 6mm 400 mm Synchronous Belt	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	3.90$ /Piece	

21	2	GT2 Closed Loop Timing Belt Rubber 6mm 300 mm Synchronous Belt	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	3.80$ /Piece	
22	1	GT2 Closed Loop Timing Belt Rubber 6mm 200 mm Synchronous Belt	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	2.18$/ Piece	
23*	1	Various lengths M3, M4 and M5 bolts and nuts	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	20.00$/ Piece	
24*	2	Mounted bracket for motor	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	5.45$/ Piece	

25	2	Motor coupler 4mm	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	4.90$/ Piece	
26	1	Leather sheet 100*70cm	Amazon.com Location:Washington,United States Tel: 1-888-280-4331 Email:ecr-replies@amazon.com	10.89$/ Piece	
			Total price	460.88$	

(*); Not included in the drawings.

CHAPTER 4 – MANUFACTURING PLAN

4.1 Manufacturing Process Selection

The project collaborative Smart Factory Model was mainly produced with the aid of 3D printing machine and other simple assembly processes. 3D printing is a method of manufacturing known as ‘Additive manufacturing’, since instead of removing material to create a part the process, it adds material in successive patterns to create the desired shape.

The uses of 3D printing in the model are:

- The links of the robotic arm.
- Couplers and gears for each joint of the robotic arm.
- The attached gripper of the robotic arm.
- Coupler connection for the conveyor belts.

CAD programs such as Solidworks, and coding language like G-Coding were used to slice the 3D part into layers, each layer has a thickness of 1mm with a filling of 30%, then it will be traced onto the build plate by the printer and once the pattern is completed the build plate is lowered and the next layer is added on top of the previous one.

Typical manufacturing techniques are known as ‘Subtractive Manufacturing’ because it is a process by which 3D objects are constructed by successively cutting material away from a solid block of material. Milling and cutting are also subtractive manufacturing techniques. Subtractive Manufacturing process creates a lot of waste since; the material that is cut off generally cannot be used for anything else and is simply sent out as scrap. 3D Printing eliminates such waste since the material is placed in the location that it is needed only, the rest will be left out as empty space.

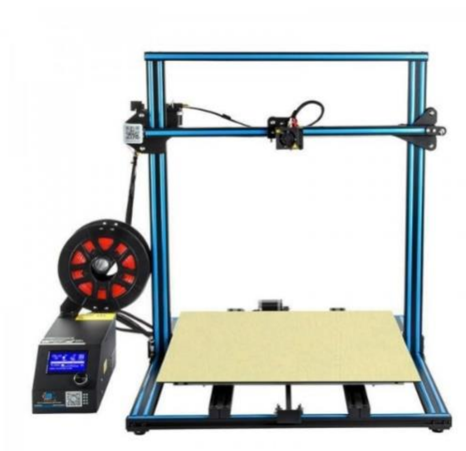


Figure 15 Creality 3D CR-10 S5 3D Printer

The machine used was Creality 3D CR-10 S5 3D Printer. Such printer was selected due to many features in it, it features large printing size, filament detector which avoids any printing interrupts, and double motor screw which increases the printing accuracy. The Creality CR-10 S5 is a 3D-printer manufactured by Lux watts shown in Figure (15). [21] The machine uses the material various materials such as PLA, ABS, PETG, and PVA and has a maximum resolution of 0.1mm. The printer uses the fused deposition modeling (FDM) single extruder, and a Bowden drive.

The printing is controlled via the program Simplify3D, which prepares the parts for production after it has been exported from Solid Work as STL File, and then converted into G-Code. This can be done by using the default settings or by editing the parameters to achieve a desired result. Through the program used we may edit the resolution which directly effects our product quality which is as well proportional to time consumption. This will be done for the production of the robotic arm parts and will be assembled using screws as this allows dismantling if a small part of the arm gets damaged. By 3D printing, the design objectives can be met.

The tensile strength of the given materials is:

- PLA: 37 MPa
- ABS: 27 MPa
- PETG: 35.7 MPa
- PVA: 10 MPa
- The melting point of the given materials is:
- PLA: 180º - 220º C
- ABS: 105º C
- PETG: 160º C
- PVA: 200º C

The water absorption of the given materials after 24 hours is:

- PLA: 23%
- ABS: 30%
- PETG: slight
- PVA: very high

The cost of the given materials is:

- PLA: 0.63 $/Kg
- ABS: 0.65 $/Kg
- PETG: 0.56 $/Kg
- PVA: 0.37 $/Kg

Table 8 Manufacturing process selection

10 → highest 1 → lowest	Polylactic Acid (PLA)	Acrylonitrile Butadiene Styrene (ABS)	Polyethylene terephthalate glycol-modified (PETG)	Poly(vinyl alcohol) (PVA)
Strength	10	6	8	2
Cost	5	6	7	9
Heat resistance	9	3	6	7
Water resistance	6	5	9	2
Reliability	8	7	8	6
Safety	9	6	7	4
SUM	47	33	45	30

Other than 3D printing, other processes were carried out to manufacture other parts of the model such as the conveyor built. Such parts were done by wood-crafting process assembled using screws, bearings, and tools in the department workshop.

4.2. Detailed Manufacturing Process

As some of the parts were bought such as bearings, rods, and screws while most of the work was 3D printed and handmade such as conveyor belts and the small storage also bearings will be added to the rollers to perform a smoother movement to the conveyor belts.

As for the robotic arm, the shoulder is put above the base and secured together using bolts and nuts. A turning movement was achieved by adding the gears and attaching them to the motor using belts and couplers. To achieve a smooth movement bearings were placed in between each joint. Smooth and threaded rods were manufactured using milling and turning machine. All linking related to the robotic arm is done by M3, M4, M5, and M8 bolts. By drilling holes and links to the gripper allows its wires and cables to be connected to the motor box and the Arduino board. As for the Z-axis stainless-steel rods were used in order to assure the stability of the arm and to smooth the movement along the Z-axis direction. Stainless-steel rods were manufactured using turning machine in a workshop followed by a grinding machine to achieve a better surface finishing and make the surface of the rods smooth enough while moving along with the bearings.

CHAPTER 5 - PRODUCT TESTING PLAN

This chapter aims to discuss whether the objectives of this project were on point. Moreover, a method of testing will be followed for the objectives to be met will be developed. Lastly, this chapter aims to verify whether applied standards came to expectations throughout this project.

5.1 Verification Plan of the Objectives of the Project

Several tests will be conducted to validate the compatibility of the model to the objectives of the design and ensure that the requirements and user expectations are met. The user has then to decide whether the model can perform a particular task, whether enough information exists to program this factory model.

- The main objective of the smart factory model is to be able to receive an item and be able to carry out the instructions needed by itself and be self-learning. This will be tested by inserting items to the smart factory model. After that we will be able to conserve the movement of the conveyer belts leading to the color sensor followed by an IR sensor right before reaching the robotic arm. This is where half of the real test is. As we will be testing if the sensor can detect faulty objects or not. After that the process would be testing the robotic arm as we will conduct if it can carry the object easily and freely around to move it from one conveyer belt to the other or to the faulty storage depending on the information given by the color sensor on either if the object is faulty and will go to faulty storage or the pickup storage and sent to delivery.

- As for another testing method for the robotic arm, simulation using ROBODK is done. The objective of this simulation was to theoretically test if the robotic arm and color sensor will be able to function as wanted. In this simulation a source is added to add items at random with objects being either faulty or good based on what could happen the test would see if the color sensor will give the robotic arm the correct instructions to place the objects in the correct conveyer depending on their condition. In the simulation shown in Figure (18) the conveyers are used as processors as with the sensor they would allow to give the same output/ doing the same task.

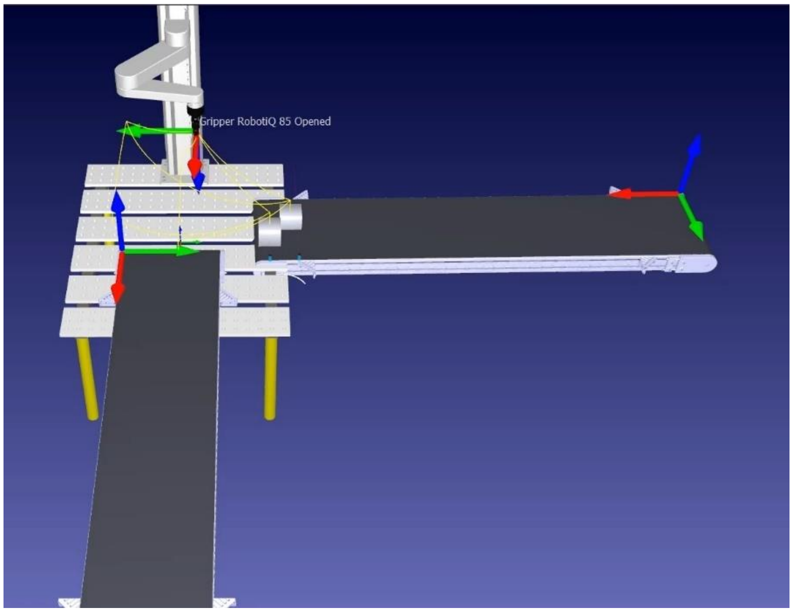


Figure 16 the RoboDK simulation that was used to do the testing.

5.2 Verification Plan of the Applied Engineering Standards

To verify the testing standards for the smart factory, these specific standards were followed:

ISO 20140-5

Automation systems and integration -- Evaluating energy efficiency and other factors of manufacturing systems that influence the environment. [18] This standard was included so that the model can run on low power supply with a good efficiency.

ISO 13849

Safety of machinery -- Safety-related parts of control systems. The model has no human interaction during the process of working, with the material used (PLA) to assure the safety and to avoid any type of pollution. No critical speed was used in the robotic arm and conveyor belts.

ISO 8373:2012

This standard defines the terms used in relation with robots and robotic devices operating in both industrial and non-industrial environments. [18] This standard is followed by the concept of our project as it is reprogrammable and it could have multi-purposes and good work under complete autonomy, which was proven in the model testing.

ISO 9283:1998

It is intended to facilitate understanding between users and manufacturers of robots and robot systems. As our model has the ability to repeat processes in multi-directional pose and distance accuracy (robotic arm movement). The model has exchangeability of moving the object from one conveyor belt to the other.

ISO/TS 15066:2016

It specifies safety requirements for collaborative industrial robot systems and the work environment and supplements the requirements and guidance on collaborative industrial robot operation given in ISO 10218-1 and ISO 10218-2. [18] The model can process on a workshop desk performing with less safety precautions needed doing human-like actions.

IEC 62443

The standard sets forth security capabilities that enable a component to mitigate threats for a given security level without the assistance of compensating countermeasures. [19] In Arduino coding the robotic arm is given limits to its speed and directional movements to its respective joints, as well as for the conveyor belts are given discrete average speed which cannot cause any damage.

IEC 62061

This standard describes the implementation of safety-related electrical control systems on machinery and examines the overall lifecycle from the concept phase through to decommissioning. Arduino board is put in a box in order to prevent any climate change that can damage/affect the Arduino board. As for the robotic arm cables they are connected from the inside, disconnecting any external communication which extends its life expectancy.

CHAPTER 6 - RESULTS AND DISCUSSIONS

6.1. The Results

Starting with the assembly procedure the 3D printed parts were printed successfully except for some holes in the Z-axis were not as accurate as required which caused some noise while moving the arm along the Z-axis. However, sand paper was used in order to increase the holes diameter therefore, the noise was reduced. Other than that bearings, gears, and belts in each joint were connected perfectly resulting an efficient motion. As for the conveyor belts, the couplers required two trials since the first trial resulted an error in the diameters which caused a break in the coupler. However, the second trial the design was changed which gave the coupler a strong withstand torque created by the motor.

The initial plan was to use PLC however, due to limited financial budget PLC was replaced with an Arduino which was more complicated but cheaper cost-wise. Working with Arduino was difficult in the beginning since the first supplier gave a faulty piece of Arduino, however after changing the supplier and connecting the Arduino to the motor controller the procedure went smoothly.

As for the testing method two tests were conducted. Firstly a test was done through simulation software RoboDK. Using the exact robot and degrees of freedom we were able to simulate the movement of the robotic arm when moving a blue or green object from and to conveyor belts and storage. Arm movement simulation code was written in Matlab and the objects that were tested in the simulation had the same size, weight, and properties all in all relative to the real life tested objects.

Second test was to check the flexibility of the whole model together, to do that a timer was set before the object was placed on the conveyor belt to calculate the timing in seconds needed for the blue object to reach the storage and the green to be transported and reach end of the other conveyor belt. Results are as shown in Table (9).

Table 9 flexibility test reults

# Of trials	Object's color	Time in seconds (s)
Trial #1	Green	30
	Blue	22
Trial #2	Green	26
	Blue	18

6.2. The Engineering Standards

As mentioned in the previous sections, NFPA 70E was followed throughout the project to ensure safety while working with electricity and mechanical equipment. Also, isolated gloves and safety goggles were used to satisfy this standard to maximum level. In addition to that, ISO 8373:2012 standard, which defines the manufacturing of a robotic arm was used which completely satisfied the requirements of the standard.

6.3. The Constraints

Throughout the project, several constraints were faced:

- Economic: Due to limited financial budget, different parts of the project were compromised in order to be in the budget range.

- Availability: Due to the on-going pandemic, many parts of the project were hard to find locally. While delivery from aboard faced many huddles due to delay in shipments.

- Politics: Majority of parts of the project were purchased online. However, due to political complications about location of the country, issues were faced during the purchasing which increased the delivery cost since, orders went through customs regulations at Turkey as well.

- Safety : All safety standards and precautions were taken very seriously during the project especially while using mechanical workshop equipment's (i.e. drilling, welding machines)

- Environmental: To ensure safe and clean environment, all waste produced during the project was carefully collected and processed as advised.

CHAPTER 7 - CONCLUSION AND FUTURE WORKS

7.1 Conclusion

In the current industrial age, smart manufacturing systems have played an important and evolving role in the implementation of smart manufacturing technology. The main aim of smart manufacturing technology is to improve the operational efficiency, productivity and has great impact in the global economy. The main objectives of this project was to show reliability and robustness of the system to withstand rough industrial conditions, less error, higher quality and increased speed in production level with taking safety factor in consideration. The objectives was achieved successfully while implementing a smart factory model consisting of a robotic-arm performing a pick-and-place operation through two conveyor belts using a color sorting system.

Additionally, it can be mentioned that the Arduino used in our model is the brain of the control system as it connects the input-output systems together. Arduino is an echo system which allows for rapid development and gives us complete control as the software of the Arduino is well-suited with our operation system.

7.2 Future Works

The Arduino and robotic arm used in this model can be modified and updated to the newer versions. It can also be mentioned that the current model contains conveyor belts made out of wood, the material can be changed to metal to achieve more stability and reliability.

In addition, instead of using only one robotic arm in the model, multiple robotic arms can be used to pick and place the objects which can be helpful in speeding the process and also to, expand the project to even more automated system with further more complexity.

It can also be mentioned that the current Arduino used is an Arduino UNO R3 board which can be replaced with Arduino MEGA that can be used instead of 2 Arduino systems in the project that will add more digital and analog pins which allows us to run the system fully on one Arduino board.

As for the robotic arm some improvements can be implemented, the length of joint 2 and joint 3 links can be shortened since the current length causes a high percentage of shear stress. Smaller motors can be used in order to reduce the weight of the arm, therefore, the moment of the arm will be reduced.

REFERENCES

[1] Admin. (2019, May 9). *What is a Smart Factory and its Role in Manufacturing?* Retrieved from https://abas-erp.com/en/news/smart-factory-manufacturing#:%7E:text=The%20smart%20factory%20is%20defined,manufacturing%20and%20supply%20chain%20management

[2] Admin (n.d). *Smart Manufacturing And Smart Industry in Context*. Retrieved from https://www.i-scoop.eu/industry-4-0/manufacturing-industry/

[3] Margaret Rouse. (2019, April). *Smart Factory*. Techtarget. Retrieved from https://searcherp.techtarget.com/definition/smart-factory

[4] Fei Tao. (2019). *Digital twin and big data*. Science direct. Retrieved from https://www.sciencedirect.com/topics/engineering/smart-manufacturing

[5] Nell Walker. (2017). *Past present and future of smart factories*. Manufacturing Global. Retrieved from https://www.manufacturingglobal.com/technology/past-present-and-future-smart-factories

[6] AWS. (2020, July). *Deloitte Smart Factory Fabric Solution*. Aws Amazon. Retrieved from https://aws.amazon.com/iot/solutions/DeloitteSFF/

[7] Channy Yun. (2020, December 15). *Transform your Business with AWS IoT (1:42)*. Amazon Web Services, Inc. Retrieved from https://aws.amazon.com/iot/?nc=sn&loc=1https://orca.cf.ac.uk/125573/1/Yuqian%20-%20Conference%20-%20Standards%20for%20Smart%20Manufacturing%20-%20A%20review.pdf

[8] Harald Prof. (n.d). The Deloitte Smart Factory experience.

Retrieved from https://www2.deloitte.com/global/en/pages/energy-and-resources/articles/deloitte-smart-factories.html

[9] The Leadership Network®. (2020, July 28). *How Toyota Helps Customers Turn Information into Insights*. Retrieved from https://theleadershipnetwork.com/article/connectivity-at-toyota

[10] *Toyota production system*. (2016). Toyota Forklifts. Retrieved from https://toyota-forklifts.eu/about-toyota/toyota-production-system/

[11] *Toyota Production System*. (2017). Global Toyota. Retrieved from https://global.toyota/en/company/vision-and-philosophy/production-system/

[12] Group article. (2019, April 01). *Smart production meets digital twin in ABB's factory of the future.* Retrieved from https://new.abb.com/news/detail/18462/smart-production-meets-digital-twin-in-abbs-factory-of-the-future

[13] Leiva, C. (2020, November 02). *For Smart Manufacturing – Integration Standards are a must..*. IBASEt. Retrieved from https://www.ibaset.com/blog/smart-manufacturing-integration-standards-opc-ua-step-oagis-isa95/

[14] Admin. (2015, June 21). *Conceptual layers of the Digital Factory Framework.* [Illustration]. Retrieved from https://www.ibaset.com/smart-manufacturing-integration-standards-opc-ua-step-oagis-isa95/

[15] IEEE. (2017, April 01). *Towards Industry 4.0: Gap Analysis between Current Automotive MES and Industry Standards Using Model-Based Requirement Engineering - IEEE Conference Publication*. Ieeexplore. Retrieved from https://ieeexplore.ieee.org/abstract/document/7958432?casa_token=m17RsAMCqZMAAAAA:I2oMJV95dQ9DVEdGz7owrgMHqoJEca6M4XB5MCVkevQrZu87UDVRBC0zRkzLabjuBGg4mLi014M

[16] *IEEE SA Search*. (n.d.). Standards IEEE. Retrieved from https://standards.ieee.org/search-results.html?q=smart%20factory

[17] Dejan. (2020, October 02). *How To Build Your Own Arduino Based Robot*. Retrieved from https://howtomechatronics.com/projects/scara-robot-how-to-build-your-own-arduino-based-robot/

[18] ISO Engineering standards. (n.d). Retrieved from https://www.iso.org/search.html?q=design%20iso&hPP=10&idx=all_en&p=0&hFR%5Bcategory%5D%5B0%5D=standard

[19] IEC (n.d). Retrieved from

https://www.iec.ch/global/search?keyword=IEC%2061131#gsc.tab=0&gsc.q=IEC%2061131

[20] Admin. (2021). *Control Stepper Motor with A4988 Driver Module & Arduino.* Retrieved from https://lastminuteengineers.com/a4988-stepper-motor-driver-arduino-tutorial/

[21] Admin (n.d) *Creality 3D CR-10 S5 3D* Retrieved from

https://creality3d.shop/?gclid=Cj0KCQjwweyFBhDvARIsAA67M70xVLlTMBDDswTZXmYPsNbE-2wTRuv3RjUaQ68-cTJnbvPrPMkTFRYaAgB0EALw_wcB

[22] ISO/ASTM 52921:2013. (2018, July 10). Retrieved from

https://www.iso.org/standard/62794.html

[23] ISO/ASTM 52915:2013. (2016, February 12). Retrieved from

https://www.iso.org/standard/6194-4.html

[24] ISO/TS 15066:2016. (2016, February 04). Retrieved from

https://www.iso.org/standard/629-96.html

[25] ISO 8373:2012. (2017, June 27). Retrieved from

https://www.iso.org/standard/55890.html?-browse=tc

APPENDIX A: Electronic Media

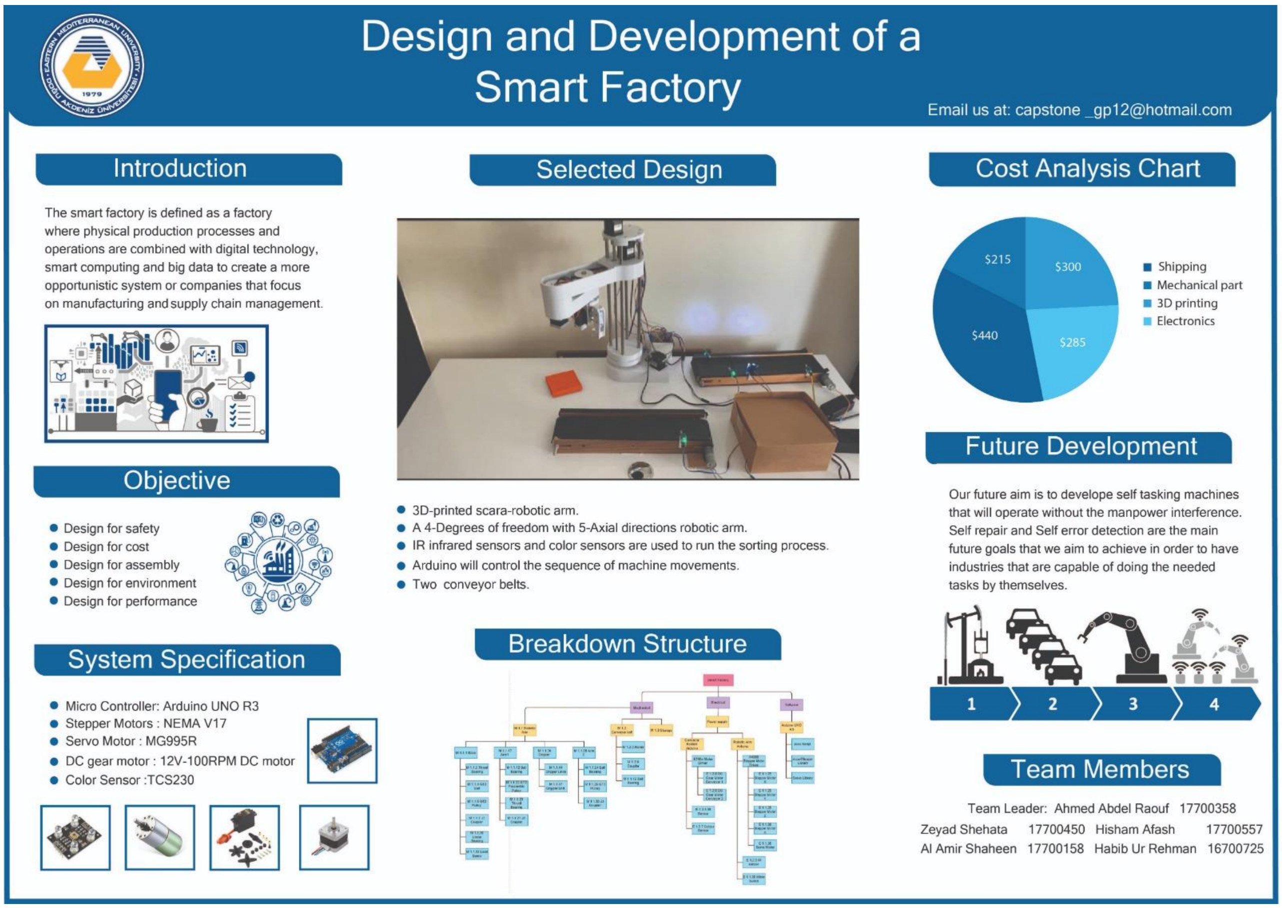


Figure 17 Poster of the project.

APPENDIX B: Constraints

Economic Constraints: The aim is to balance cost budget, time and quality during the design and production of the project. The design is limited by the funding, since the project is carried out by the students', the available funds are truly short and this in return limits the choice of materials and process selection.

Manufacturability: The manufacturing process greatly limits this design, as the only manufacturing processes available are those in the workshop of mechanical engineering department of the university, which creates limited processes only. Some belts were difficult to find in local/international shops since it required a very specific size. Add on that, the process of 3D printing took a large amount of time which was time consuming and some 3D printed parts lacked of accuracy.

Assembly: Some of the wires were difficult to manage which made the process more complex. The size of the screws made the process difficult to assemble since some parts of the 3D printing were unreachable.

APPENDIX C: Standards

ISO/ASTM 52921:2013 includes terms, definitions, nomenclature, and acronyms associated with coordinate systems and testing methodologies for additive manufacturing (AM) technologies in an effort to standardize terminology used by AM users, producers, researchers, educators, press/media, and others, particularly when reporting results from testing of parts made on AM systems. Terms included cover definitions for machines/systems and their coordinate systems plus the location and orientation of parts. [22]

ISO/ASTM 52915:2013 describes a framework for an interchange format to address the current and future needs of additive manufacturing technology. For the last three decades, the STL file format has been the industry standard for transferring information between design programs and additive manufacturing equipment. An STL file contains information only about a surface mesh and has no provisions for representing color, texture, material, substructure, and other properties of the fabricated target object. As additive manufacturing technology is quickly evolving from producing primarily single-material, homogenous shapes to producing multi material geometries in full color with functionally graded materials and microstructures, there is a growing need for a standard interchange file format that can support these features. [23]

ISO/TS 15066:2016 specifies safety requirements for collaborative industrial robot systems and the work environment, and supplements the requirements and guidance on collaborative industrial robot operation given in ISO 10218-1 and ISO 10218-2. [24] It does not apply to non- industrial robots, although the safety principles presented can be useful to other areas of robotics

ISO 8373:2012 defines terms used in relation with robots and robotic devices operating in both industrial and non-industrial environments. [25]

ISO128 – International Technical Drawing Standards

ISO14001 – Environment Management System

IEC61969 – Mechanical Structures for electrical electronic equipment. This standard determines to operate the system of the hydraulic press within safe procedure and techniques used to prevent any damage to machinery and surrounding of the operator. [18]

ISO 286-1 This standard is used for tolerance grades used in the drawings.

APPENDIX D: Project Plan

Table 10 Logbook

Day/Month/Year	Description of the work
05/10/20	Started with research for the project individually.
10/10/20	Meeting with supervisor to discuss about the selected design.
11/10/20	Team meeting to discuss the report and divide the work.
19/11/20	Revision of the proposed design.
01/12/20	Review of chapter 1 and chapter 2. Started work on the initial design.
02/12/20	Meeting with the team members. Chapter 3 finished.
10/12/20	Discussion on parts of the project available in the market. Chapter 4 and 5 started.
14/12/20	Worked on appendixes, table of contents, etc.
16/12/20	Team meeting to discuss the progress and improvements.
22/12/20	Review of the design and calculations.
29/12/20	Improvised chapter 4 and chapter 5.

02/01/21	Corrections of report and checked for plagiarism
04/01/21	Finalizing the report and submission.
10/02/21	Capstone 1 report reviewed and discussion over the design.
20/02/21	Components of the project checked online and 3d printing started.
04/03/21	Panel assembly started.
12/03/21	Mechanical work on the conveyors.
20/03/21	Wiring work started.
01/04/21	Wiring work finished and damaged parts 3d printed again.
10/04/21	Testing of robotic arm.
21/04/21	Testing of sensors and conveyor belts.
02/05/21	Testing of complete system and discussion.
12/05/21	Debugging the problems found in the system.
15/05/21	Discussion on chapter 6 and 7 of the report.
22/05/21	Changes and addition in report.
30/05/21	Final review meeting on the report and discussion on the presentation.
31/05/21	Finalizing the report.

Tasks	PLAN START	PLAN DURATION	PLAN END	Graph START	Graph duration	PERCENT COMPLETE
SMART FACTORY MODEL	5/10/2020	246	7/6/2021			
Literature review				1	4	100%
Research about the project and assigning tasks	10/10/2020		12/10/2020	5	4	100%
Discussion over the proposed design.	22/10/2020	5	26/10/2020	9	4	100%
Discussion about pros and cons of concurrent solution	20/10/2020		21/10/2020		4	100%
Design and Analysis	10/2/2020	8	11/7/2020	13	4	100%
Defining the design and components needed	11/8/2020	40	11/10/2020	17	4	100%
Research about components needed for 3D printing	11/11/2020	5	11/11/2020	21	4	100%
Research and discussion on available parts in market	10/12/2020	4	5/1/2021			100%
Parts selection and update on design	20/02/2021		1/3/2021		4	100%
Mechanical work on conveyors and wiring setup	12/3/2021	10	1/4/2021	25	4	100%
Panel assembly	4/3/2021	5	06/04/202	29	4	100%
3D printing of damaged parts and overall assembly	20/02/2021	5	12/5/2021	33	4	100%
Manufacturing					4	100%
Assembly and trails of the system	05/052021	3	12/29/2021	37	4	100%
Electrical wiring of the project	20/03/2021	6	1/5/2021	41	4	100%
Work on the simulations	8/5/2021		20/05/2021		4	100%
Testing the components of the system	2/5/2021	3	20/5/2021	45	4	100%
PRODUCT TESTING PLAN						100%
Testing the robotic arm	10/4/2021	3	1/6/2021	53	4	100%
Testing of the conveyor belts and sensors	21/04/2021		12/5/2021			100%
Testing o f complete system and discussion	2/5/2021		12/5/2021			100%

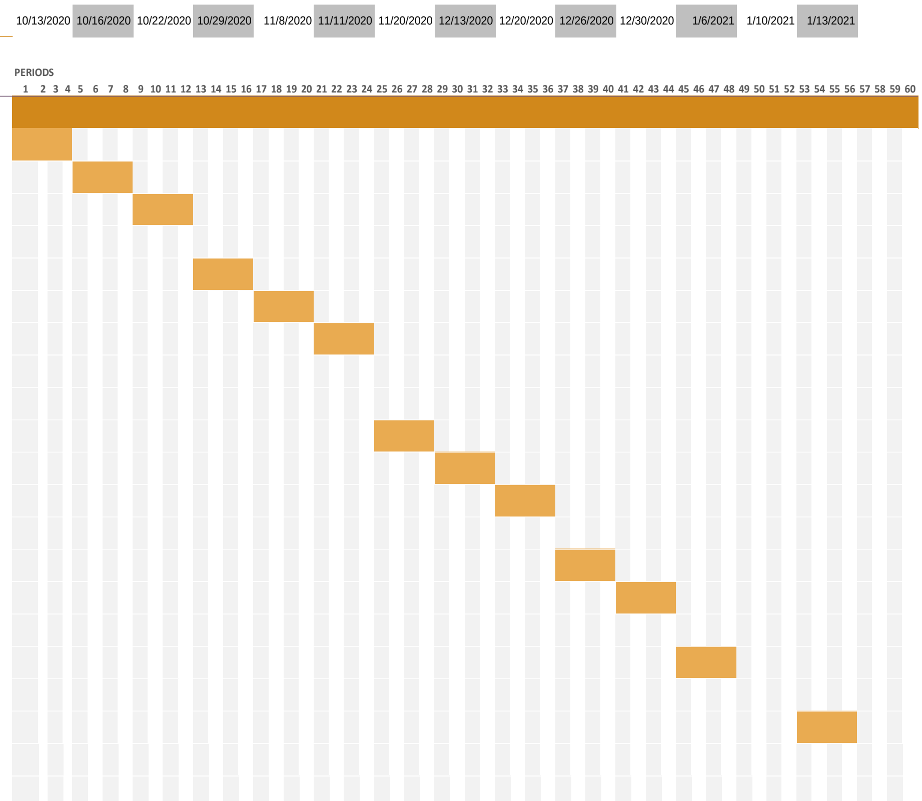
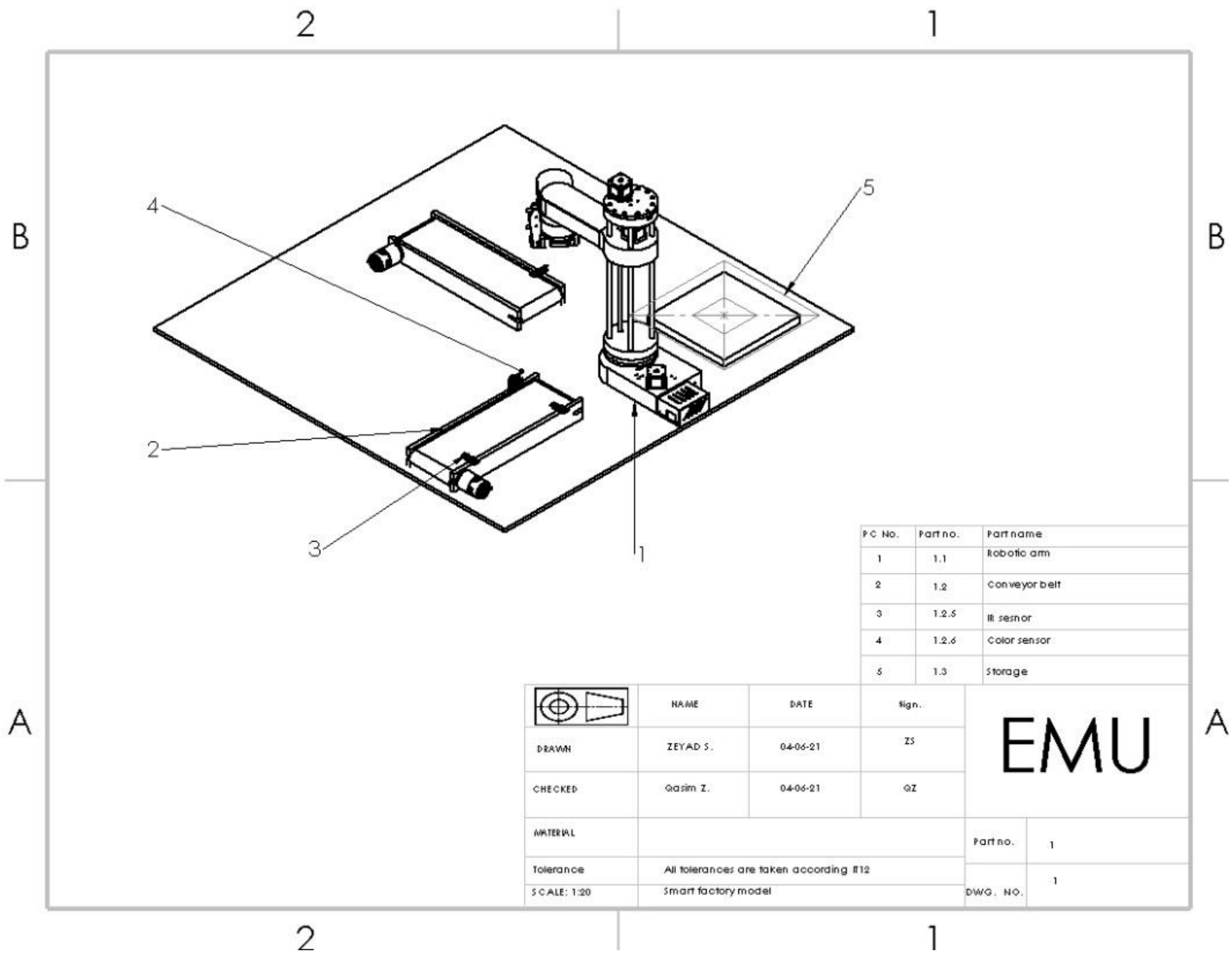
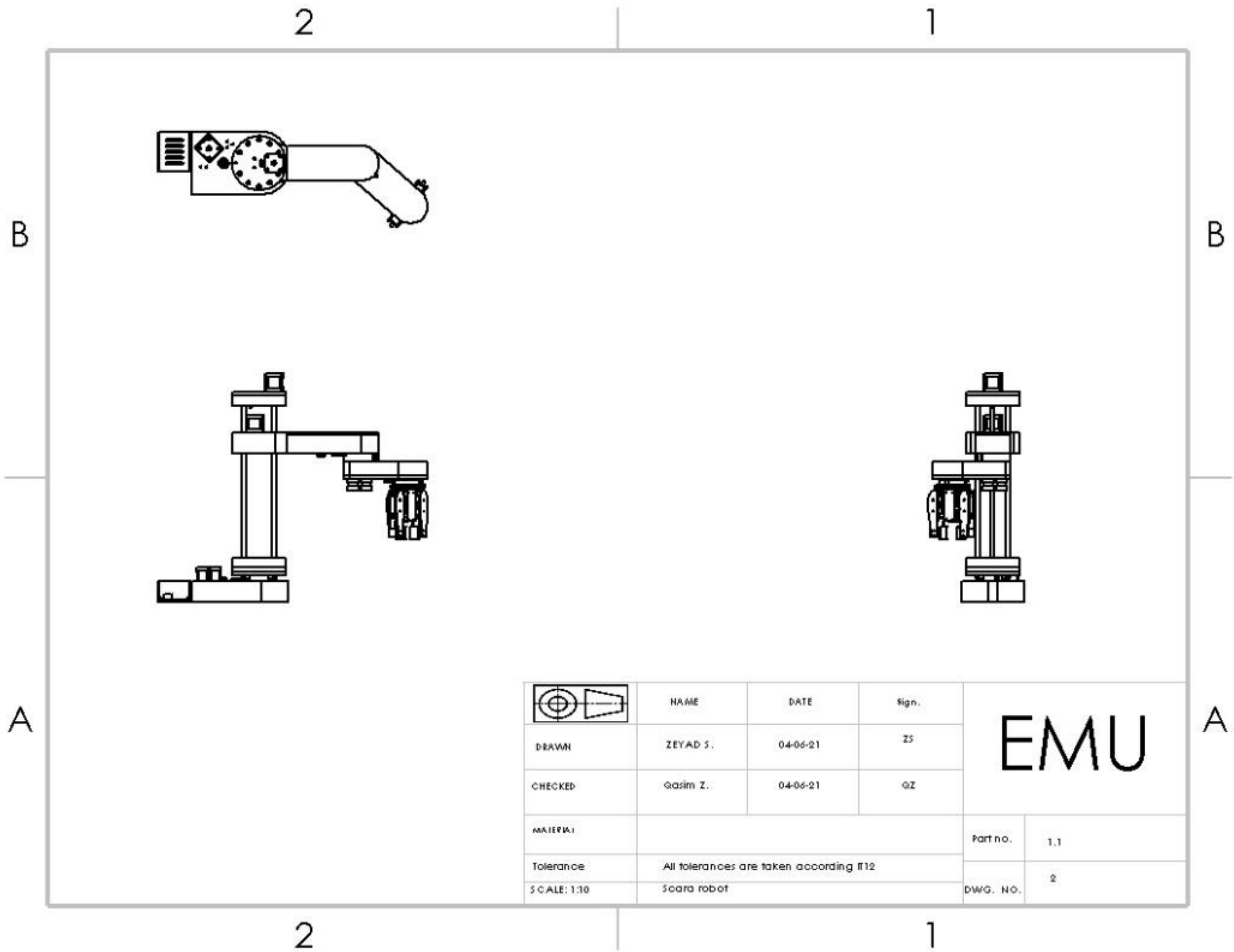
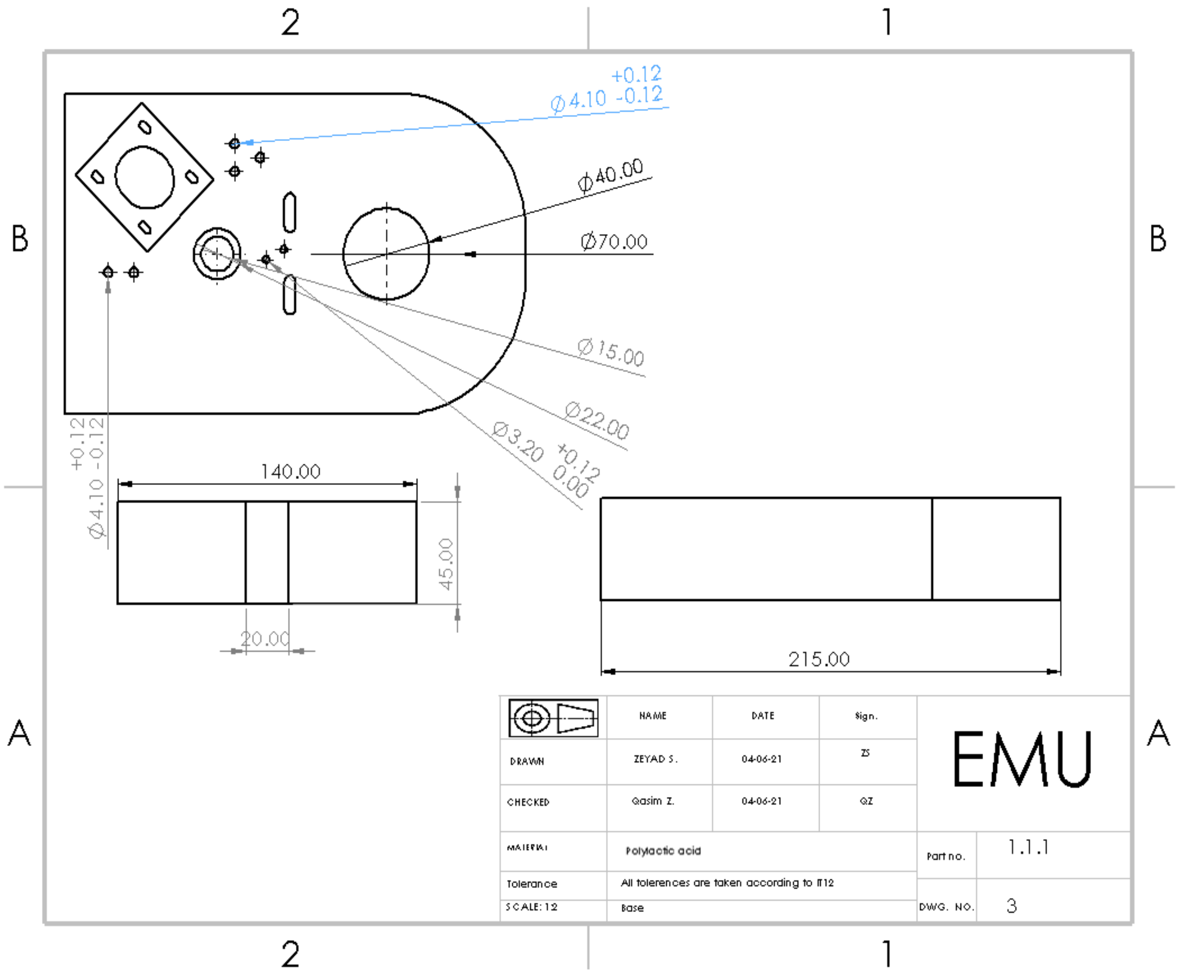


Figure 18 Gantt chart.

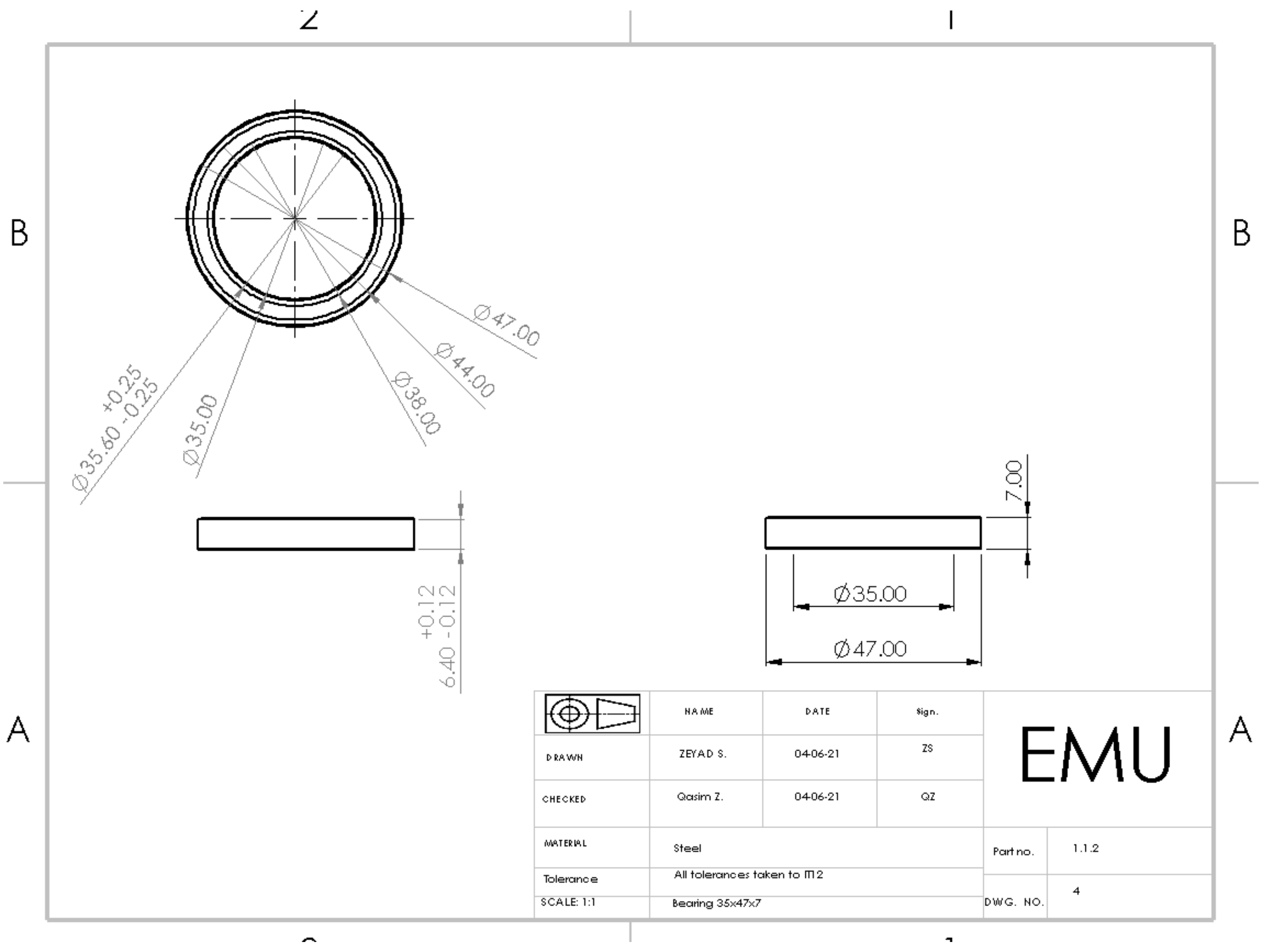
APPENDIX E: ENGINEERING DRAWINGS



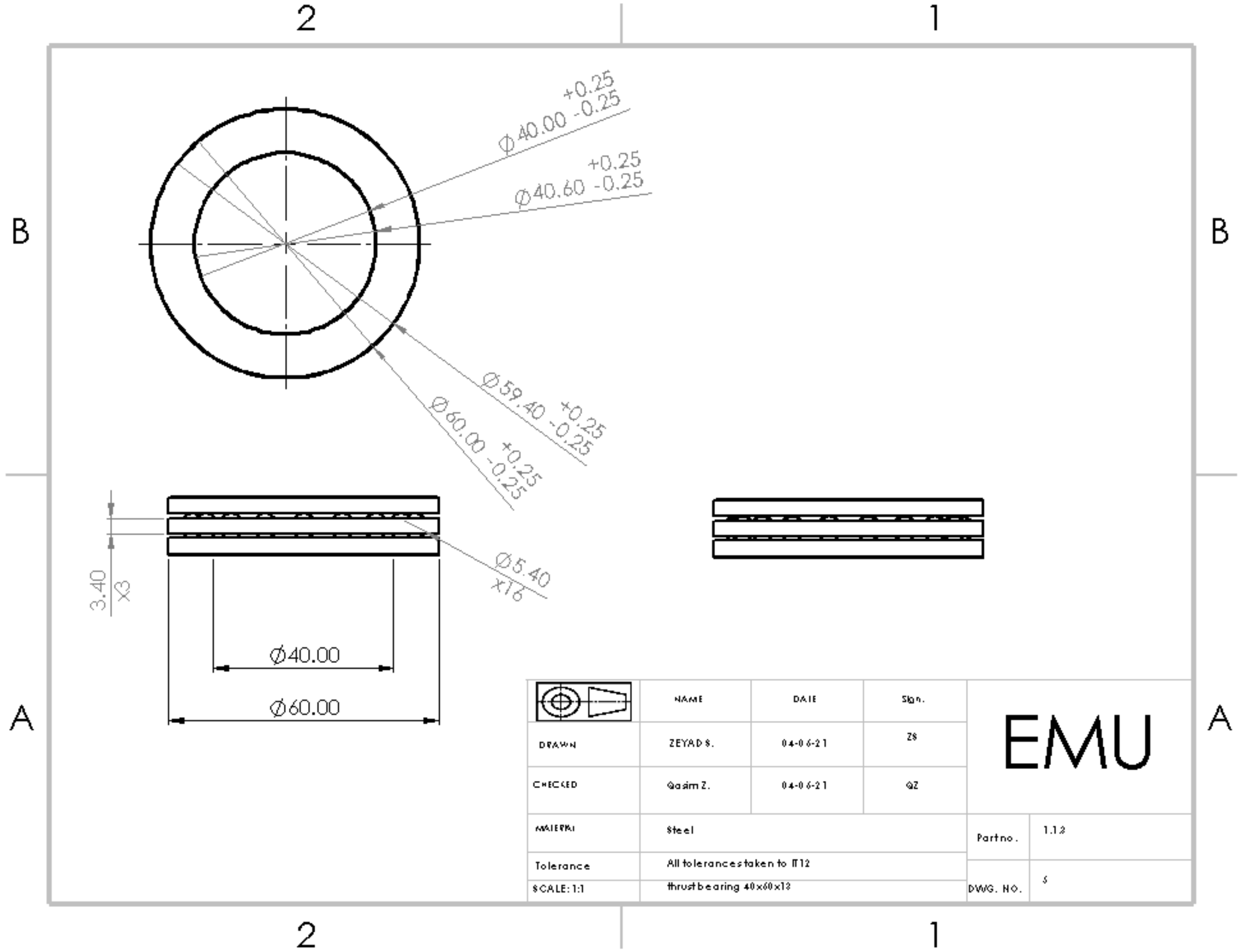

2
1
B
B
A
A
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Part no.
1.1
Tolerance
All tolerances are taken according IT12
2
SCALE: 1:10
Scara robot
DWG. NO.
2
1



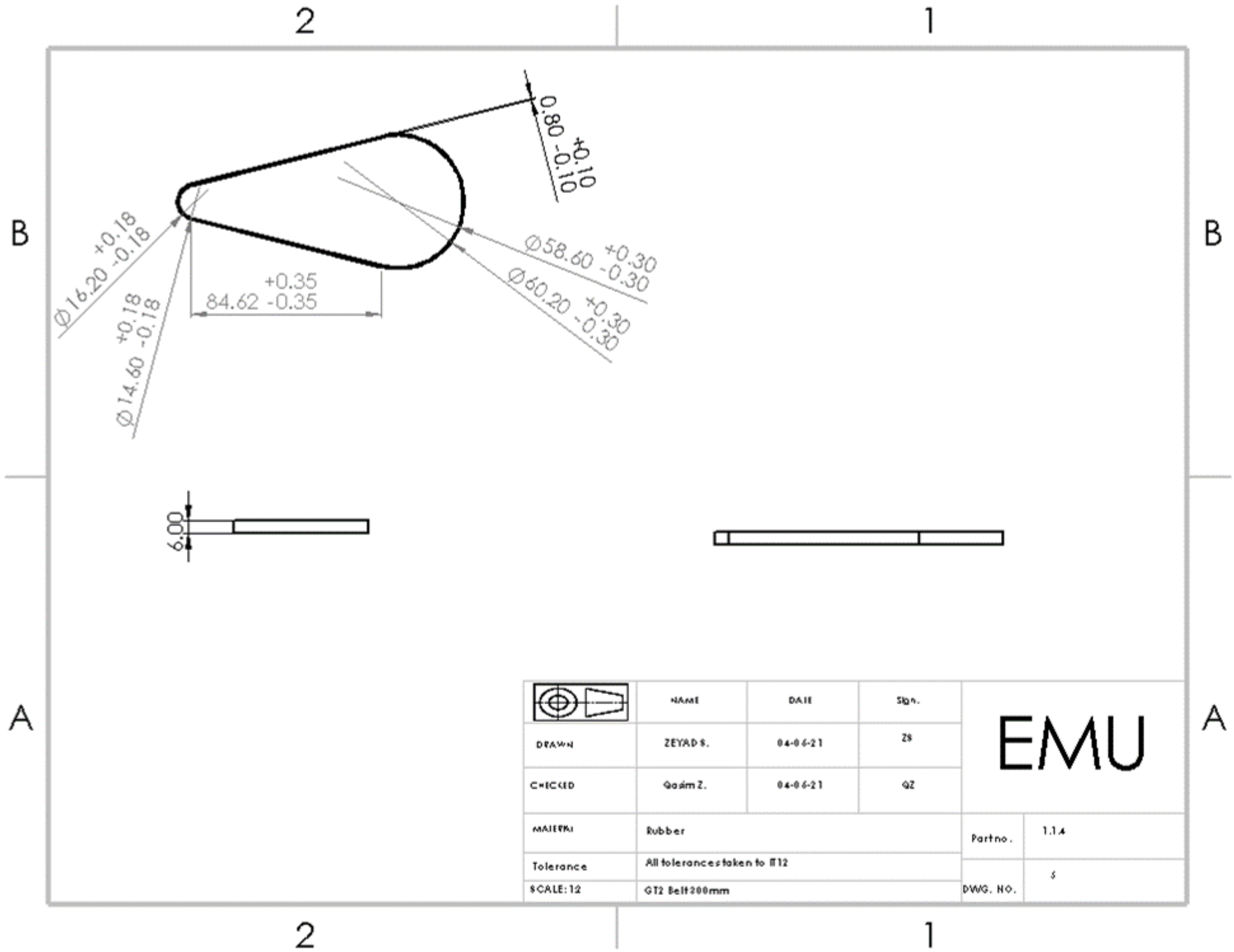
2
1
B
A
+0.12
Ø4.10 -0.12
Ø40.00
Ø70.00
Ø15.00
Ø22.00
Ø3.20 +0.12 0.00
140.00
45.00
20.00
215.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.1
Tolerance
All tolerences are taken according to IT12
SCALE: 1:2
Base
DWG. NO.
3



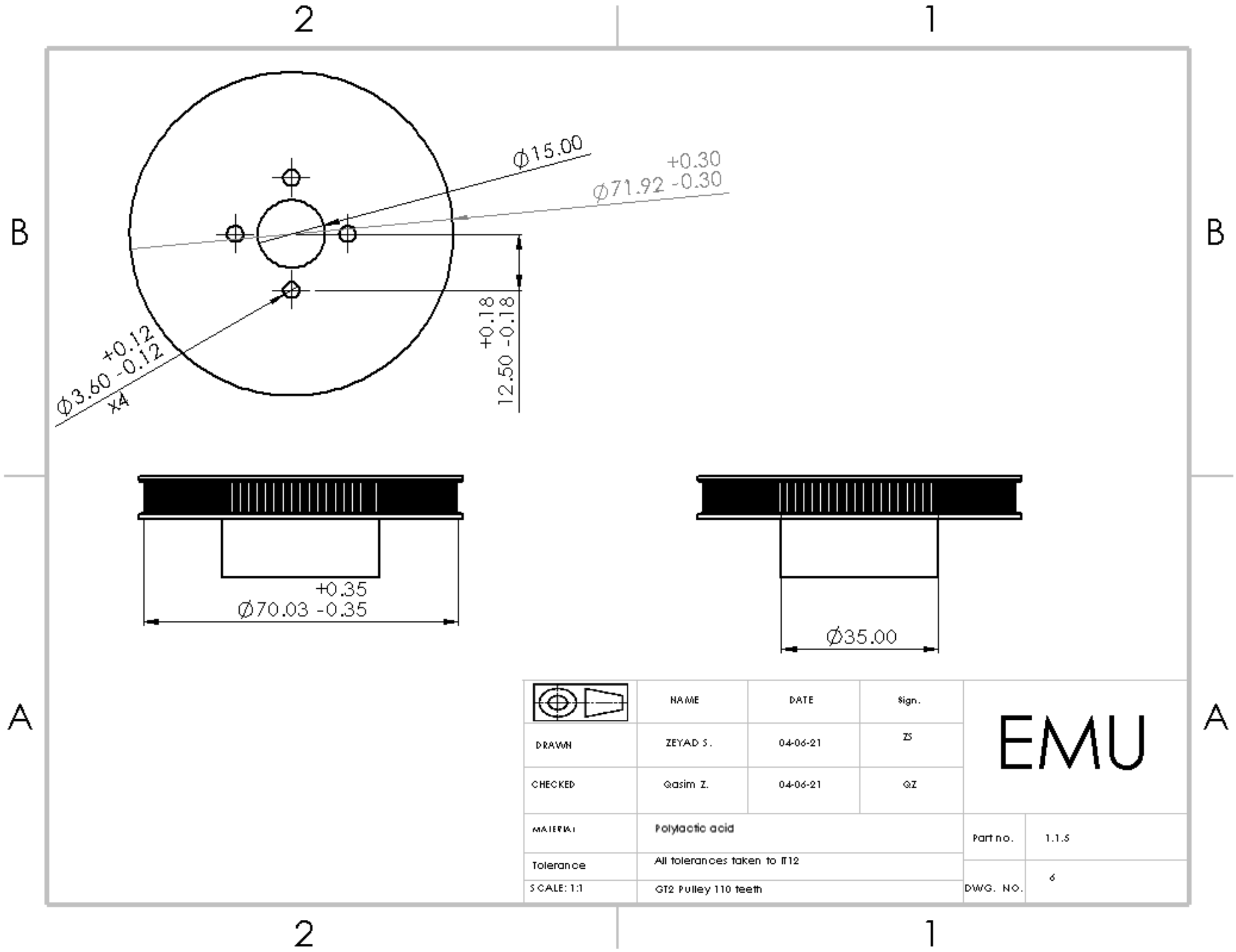
Ø47.00
Ø44.00
Ø38.00
Ø35.00
Ø35.60 +0.25 -0.25
6.40 +0.12 -0.12
7.00
Ø35.00
Ø47.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Steel
Part no.
1.1.2
Tolerance
All tolerances taken to IT12
SCALE: 1:1
Bearing 35x47x7
DWG. NO.
4



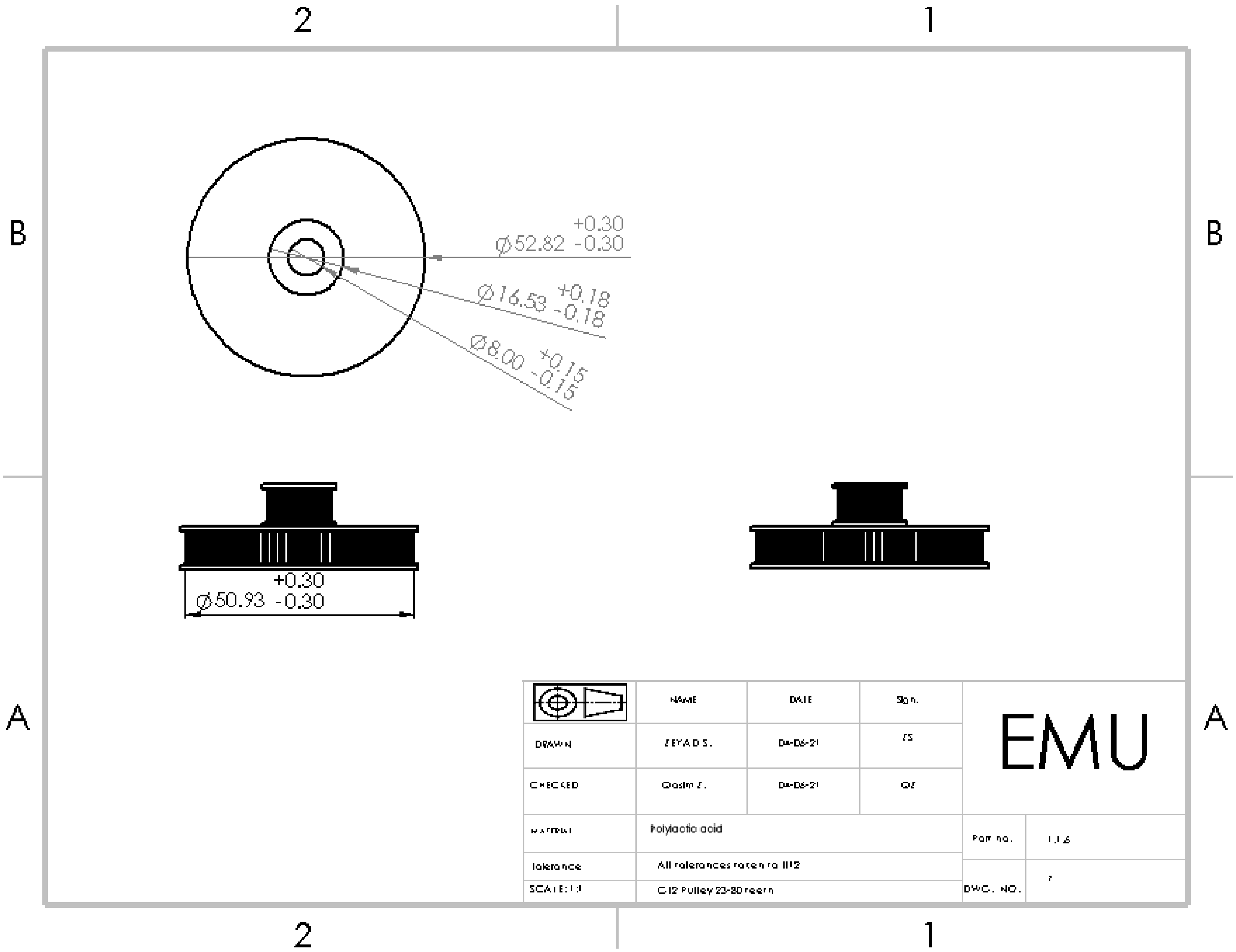
Ø40.00 +0.25 -0.25
Ø40.60 +0.25 -0.25
Ø59.40 +0.25 -0.25
Ø60.00 +0.25 -0.25
3.40 X3
Ø5.40 X16
Ø40.00
Ø60.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Steel
Part no.
1.12
Tolerance
All tolerances taken to IT12
SCALE: 1:1
thrust bearing 40x60x13
DWG. NO.
5



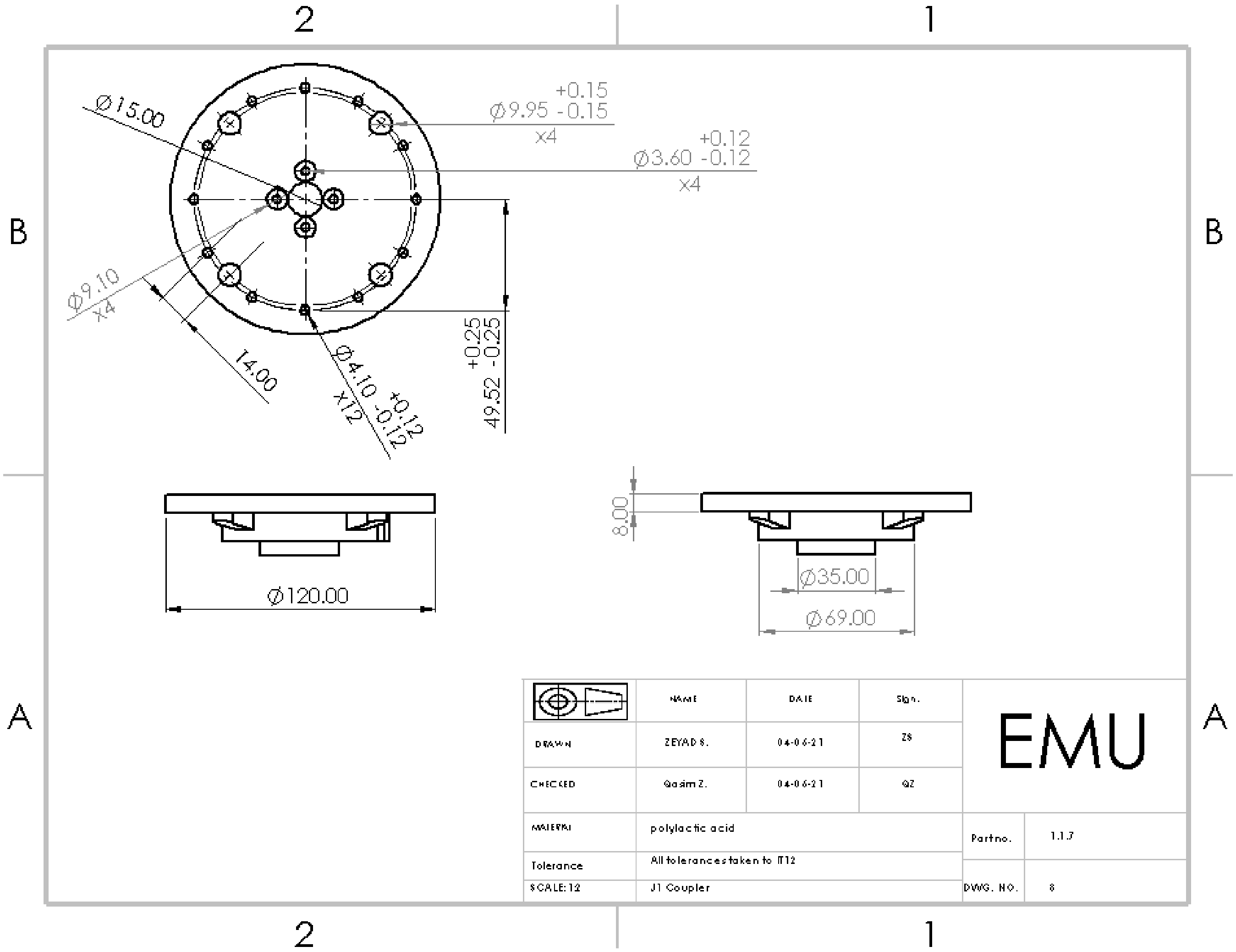
2
1
B
A
+0.10
0.80 -0.10
⌀16.20 +0.18 -0.18
⌀14.60 +0.18 -0.18
84.62 +0.35 -0.35
⌀58.60 +0.30 -0.30
⌀60.20 +0.30 -0.30
6.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Rubber
Part no.
1.1.4
Tolerance
All tolerances taken to IT12
SCALE: 12
GT2 Belt 200mm
DWG. NO.
5



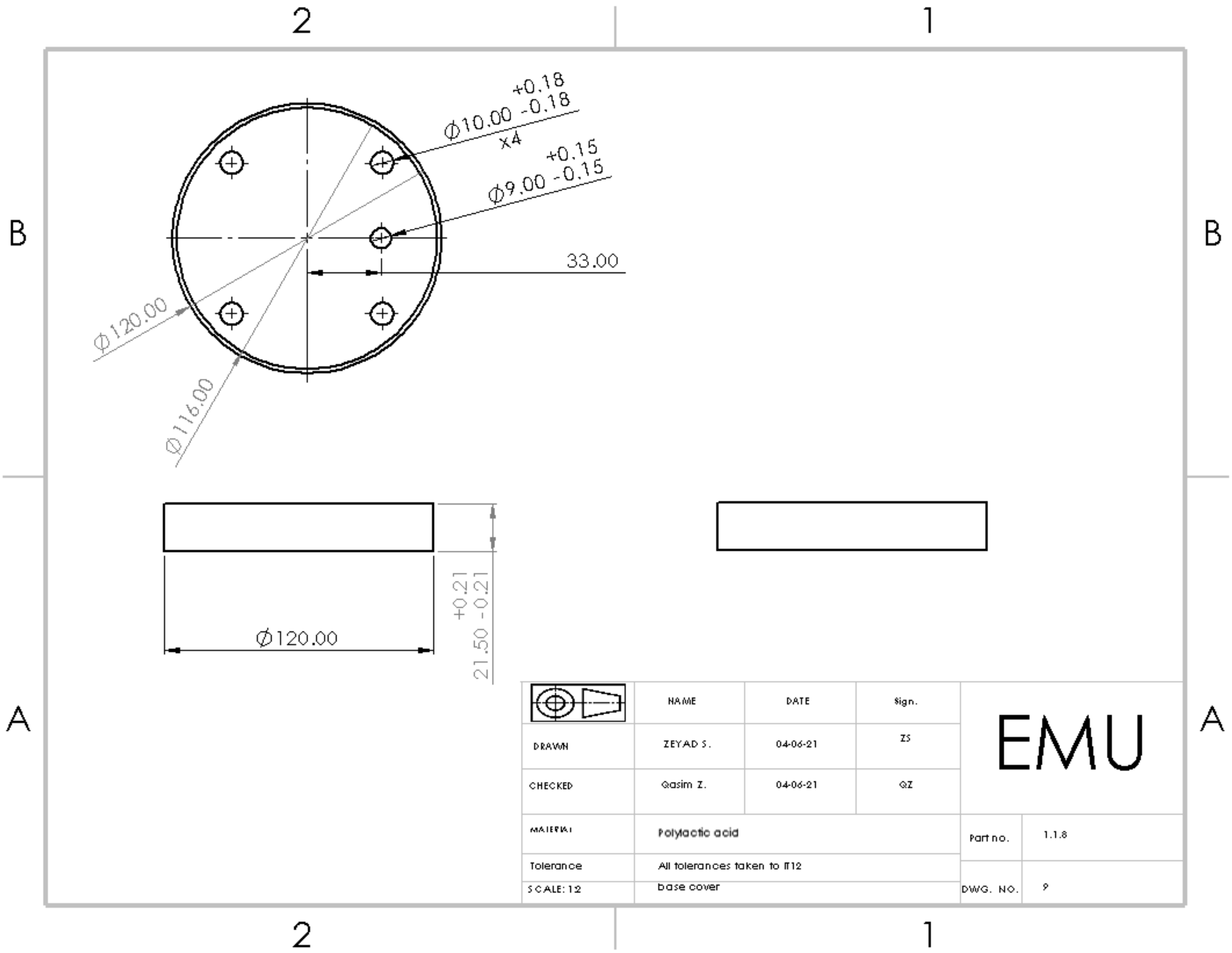
Ø15.00
Ø71.92 +0.30 -0.30
Ø3.60 +0.12 -0.12
x4
12.50 +0.18 -0.18
Ø70.03 +0.35 -0.35
Ø35.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.5
Tolerance
All tolerances taken to IT12
SCALE: 1:1
GT2 Pulley 110 teeth
DWG. NO.
6



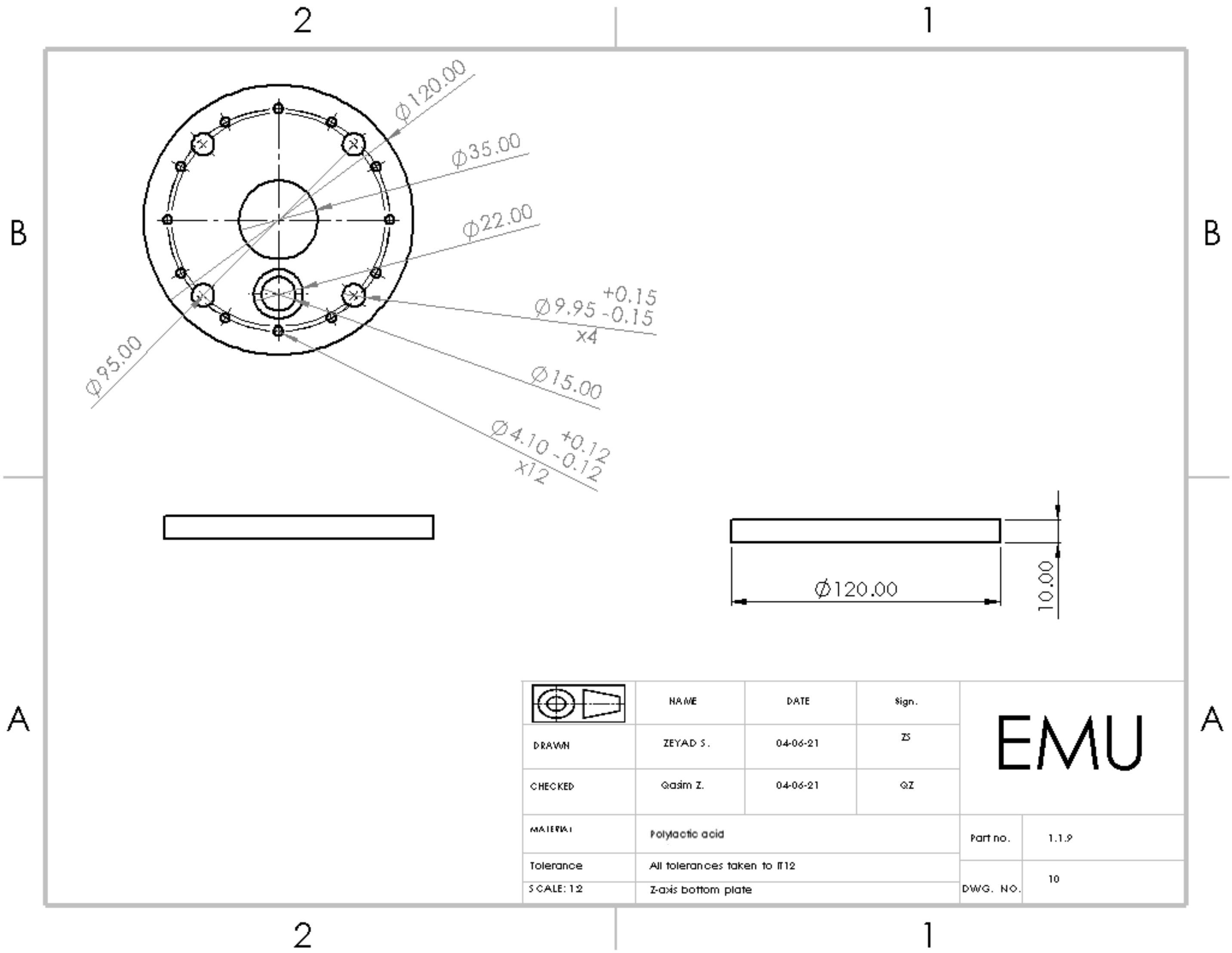
2
1
B
A
+0.30
Ø52.82 -0.30
Ø16.53 +0.18 -0.18
Ø8.00 +0.15 -0.15
+0.30
Ø50.93 -0.30
NAME
DATE
DRAWN
CHECKED
Polylactic acid
EMU
DWG. NO.

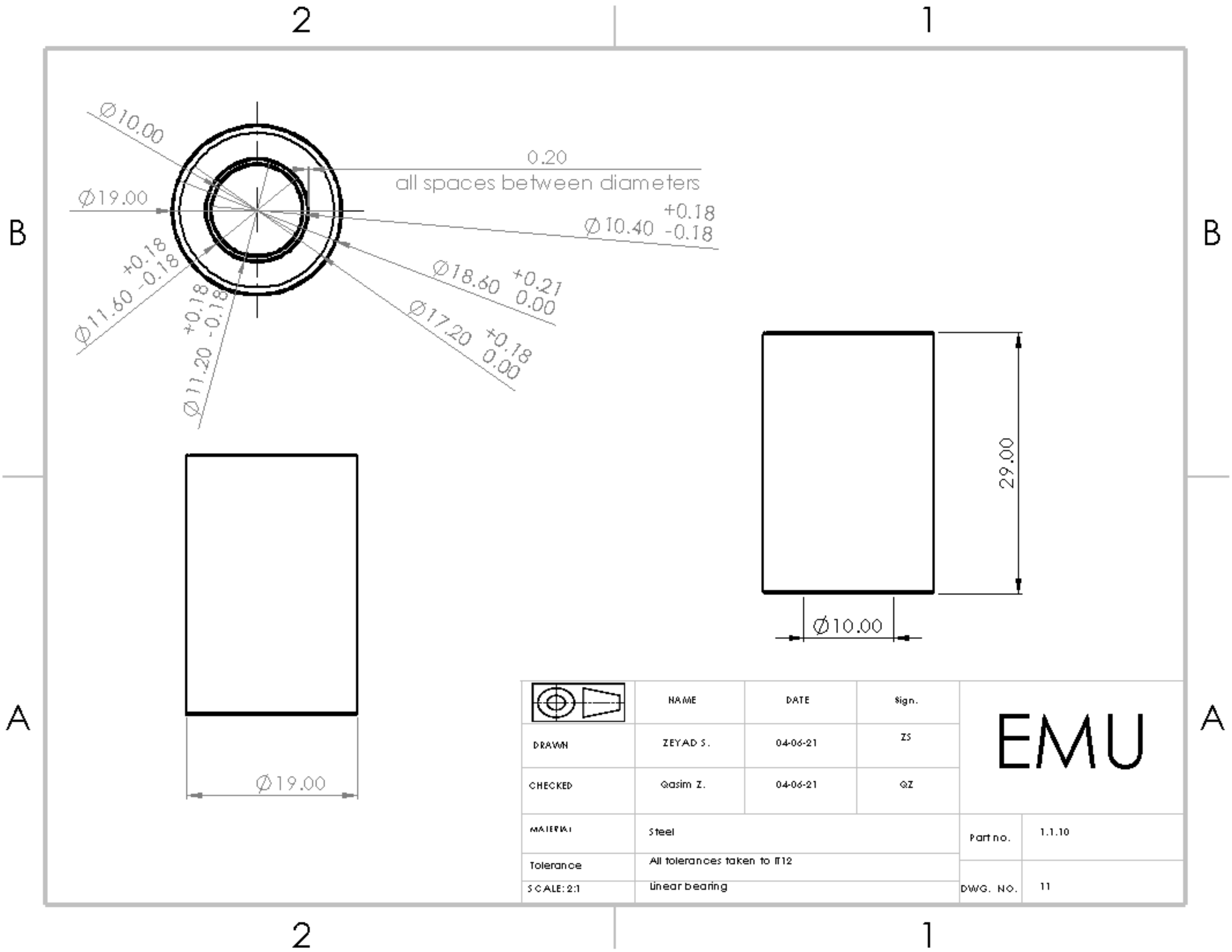


Ø15.00
+0.15
Ø9.95 -0.15
x4
+0.12
Ø3.60 -0.12
x4
Ø9.10
x4
14.00
Ø4.10 +0.12 -0.12
x12
49.52 +0.25 -0.25
Ø120.00
8.00
Ø35.00
Ø69.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
polylactic acid
Part no.
1.1.7
Tolerance
All tolerances taken to IT12
SCALE: 1:2
J1 Coupler
DWG. NO.
8

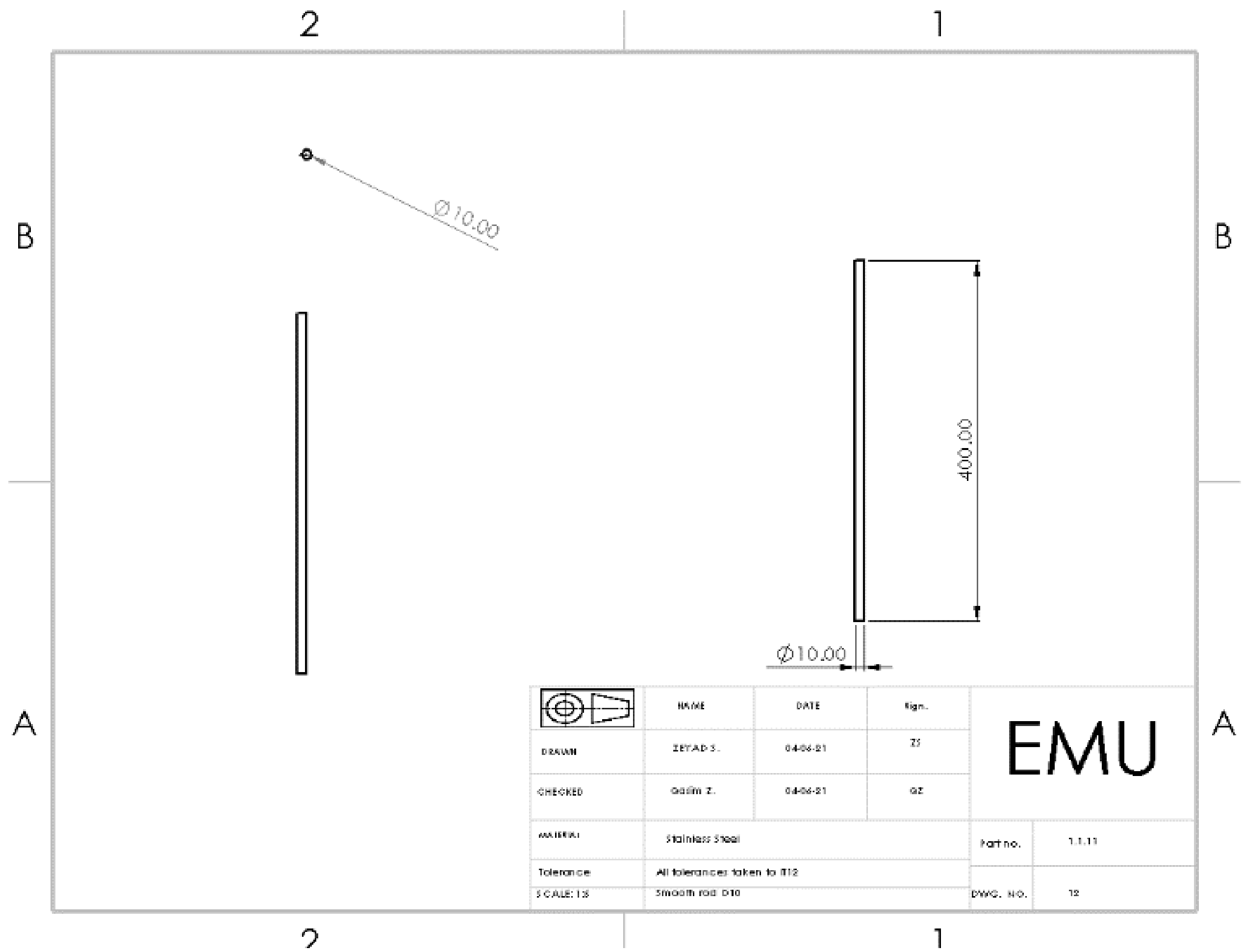


⌀10.00 +0.18 -0.18
x4
⌀9.00 +0.15 -0.15
33.00
⌀120.00
⌀116.00
⌀120.00
21.50 +0.21 -0.21
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.8
Tolerance
All tolerances taken to IT12
SCALE: 1:2
base cover
DWG. NO.
9

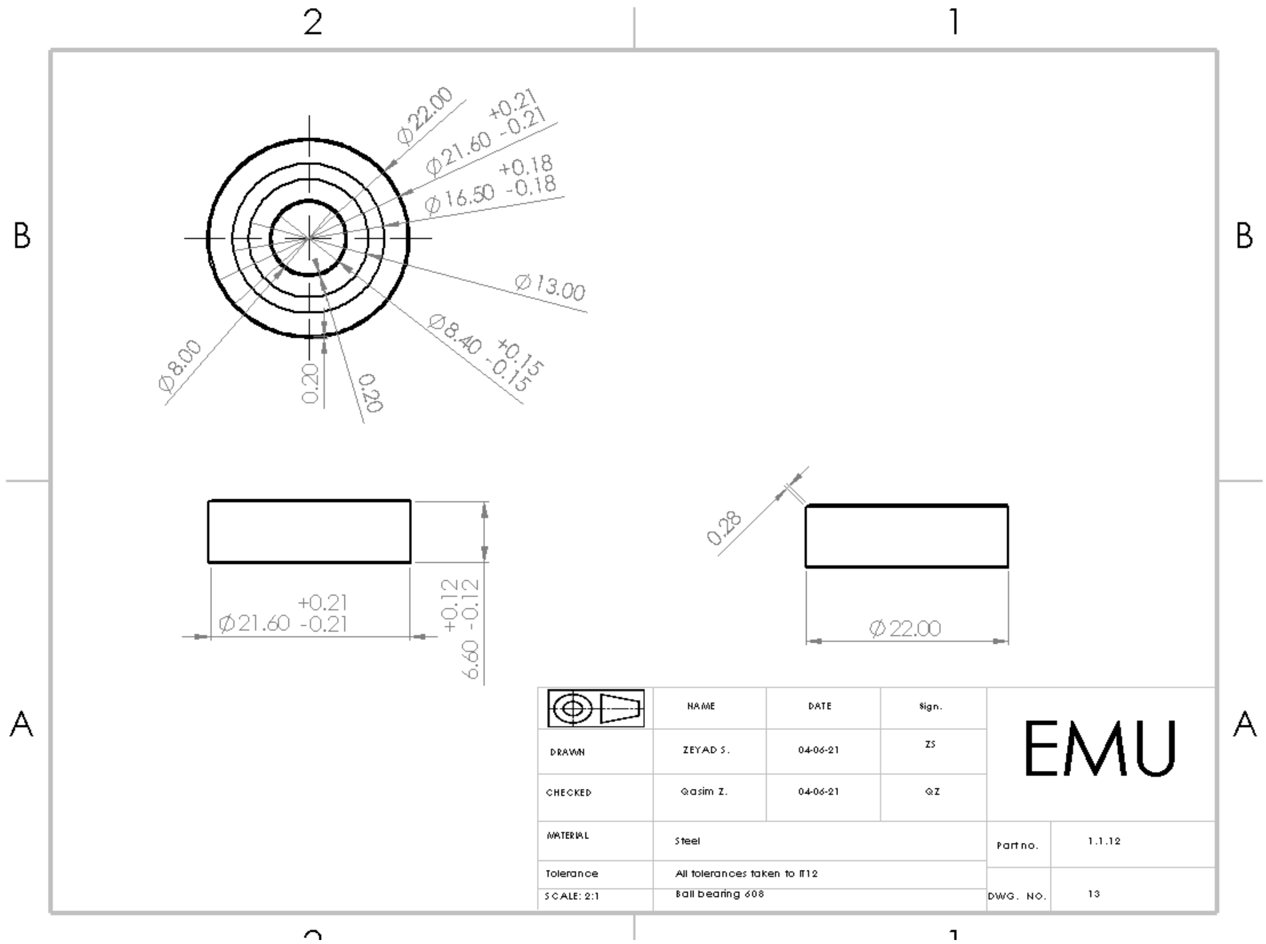

Ø120.00
Ø35.00
Ø22.00
Ø9.95 +0.15 -0.15
x4
Ø15.00
Ø4.10 +0.12 -0.12
x12
Ø95.00
Ø120.00
10.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.9
Tolerance
All tolerances taken to IT12
SCALE: 1:2
Z-axis bottom plate
DWG. NO.
10



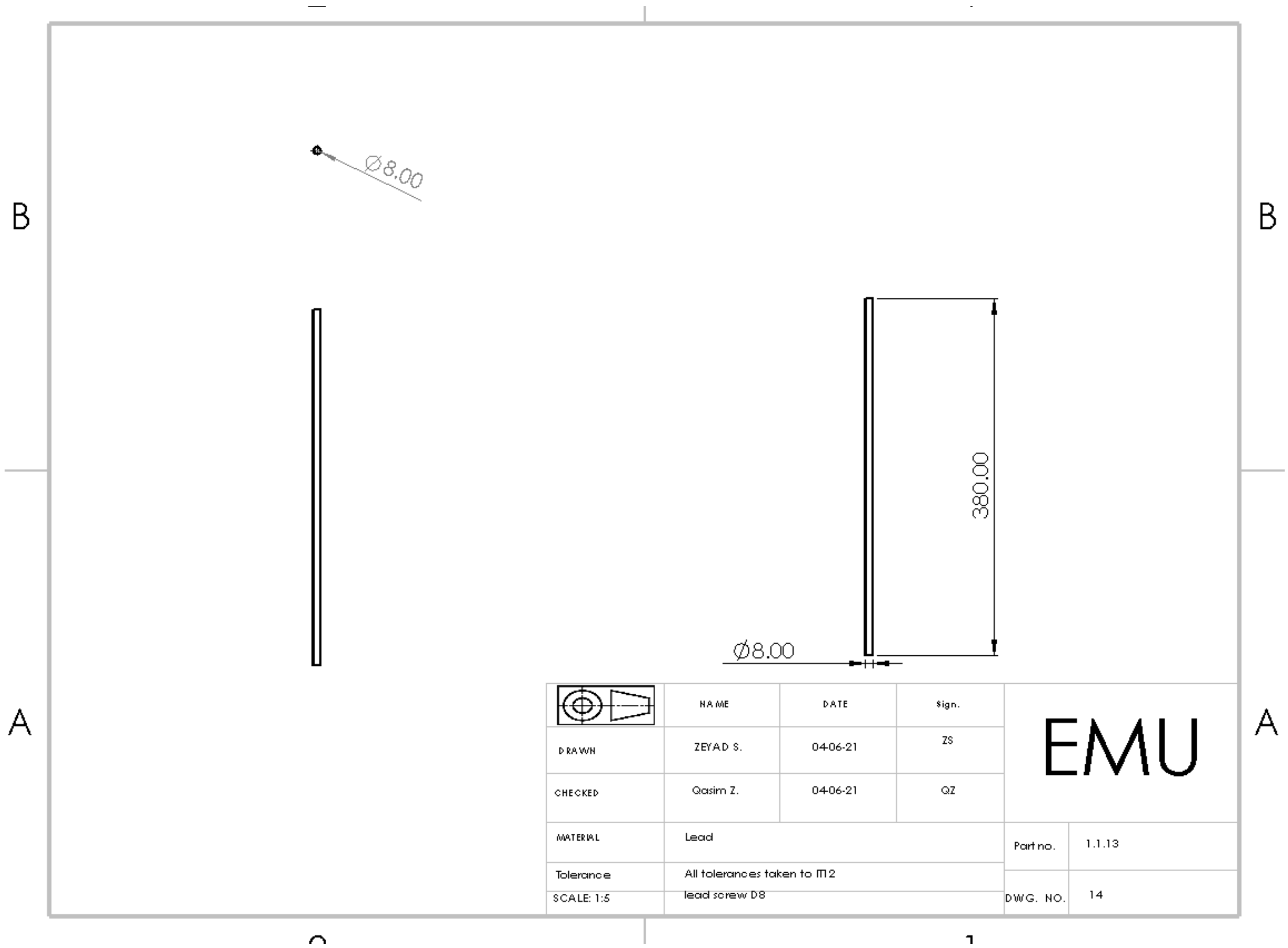
2
1
B
A
Ø10.00
Ø19.00
0.20
all spaces between diameters
Ø10.40 +0.18 -0.18
Ø18.60 +0.21 0.00
Ø17.20 +0.18 0.00
Ø11.60 +0.18 -0.18
Ø11.20 +0.18 -0.18
29.00
Ø10.00
Ø19.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Steel
Part no.
1.1.10
Tolerance
All tolerances taken to IT12
SCALE: 2:1
Linear bearing
DWG. NO.
11



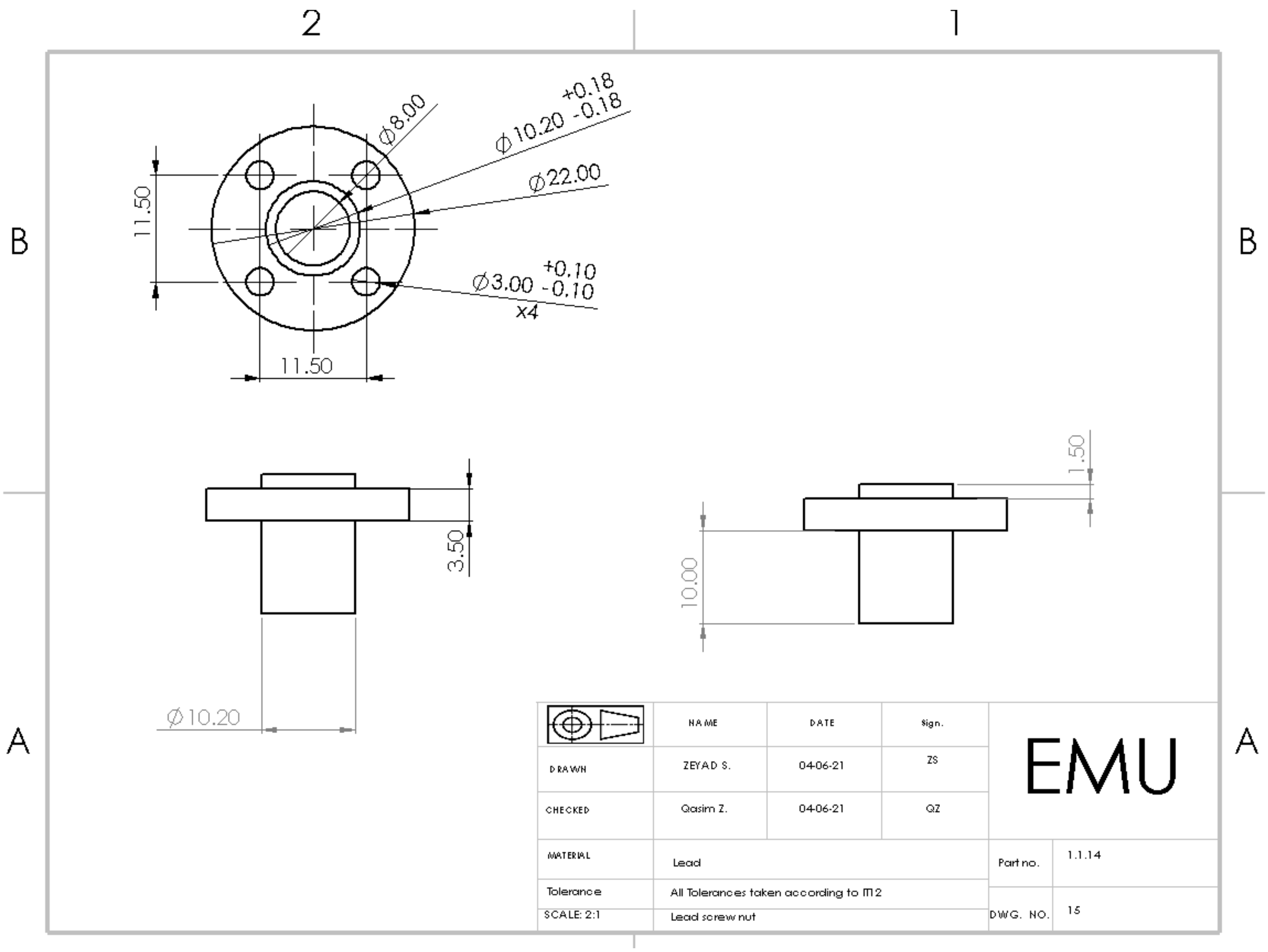
Ø10.00
400.00
Ø10.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Stainless Steel
Part no.
1.1.11
Tolerance
All tolerances taken to IT12
SCALE: 1:5
Smooth rod D10
DWG. NO.
12

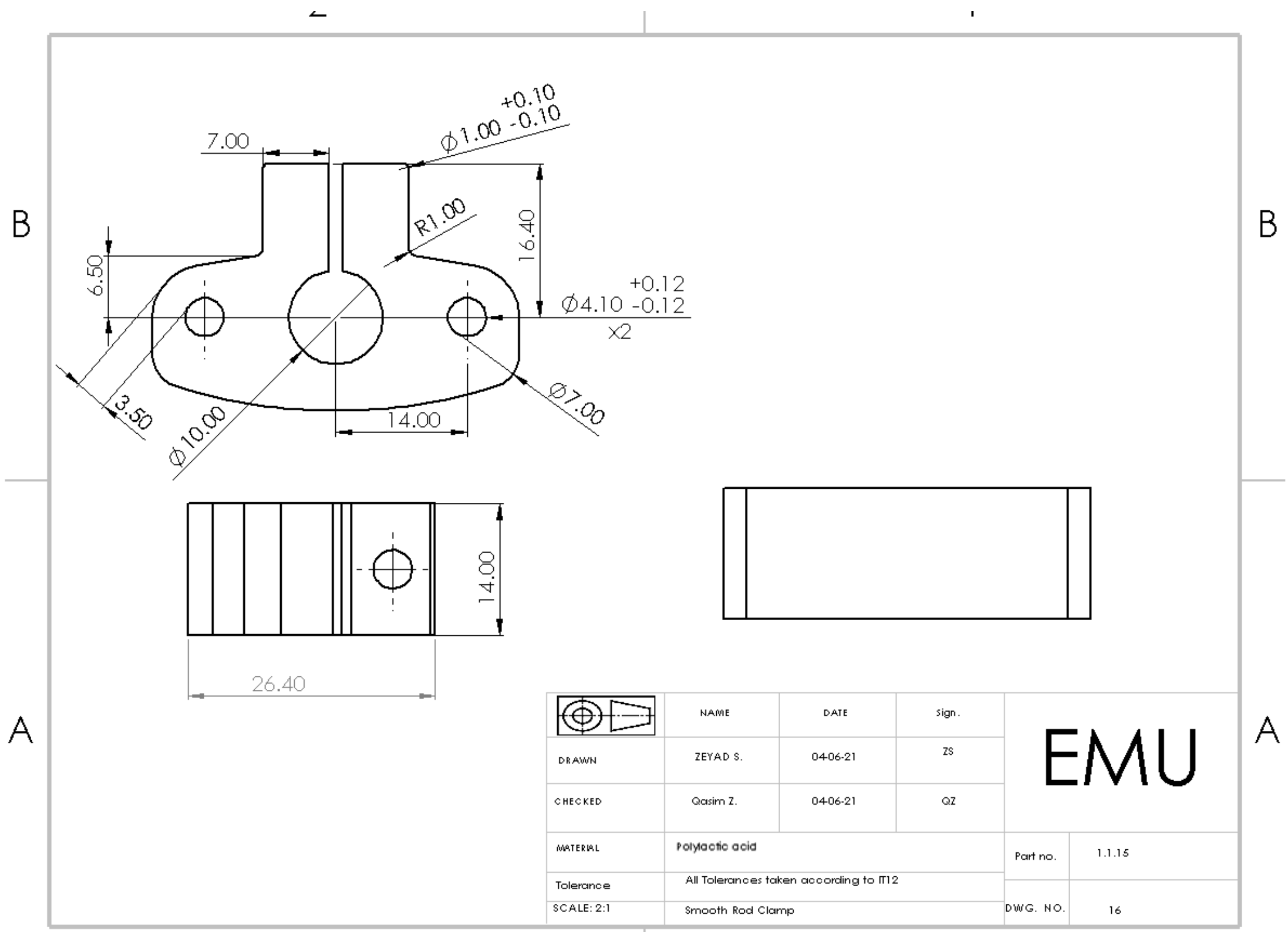


2
1
B
A
Ø22.00
Ø21.60 +0.21 -0.21
Ø16.50 +0.18 -0.18
Ø13.00
Ø8.40 +0.15 -0.15
Ø8.00
0.20
0.20
Ø21.60 +0.21 -0.21
6.60 +0.12 -0.12
0.28
Ø22.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Steel
Part no.
1.1.12
Tolerance
All tolerances taken to IT12
SCALE: 2:1
Ball bearing 608
DWG. NO.
13

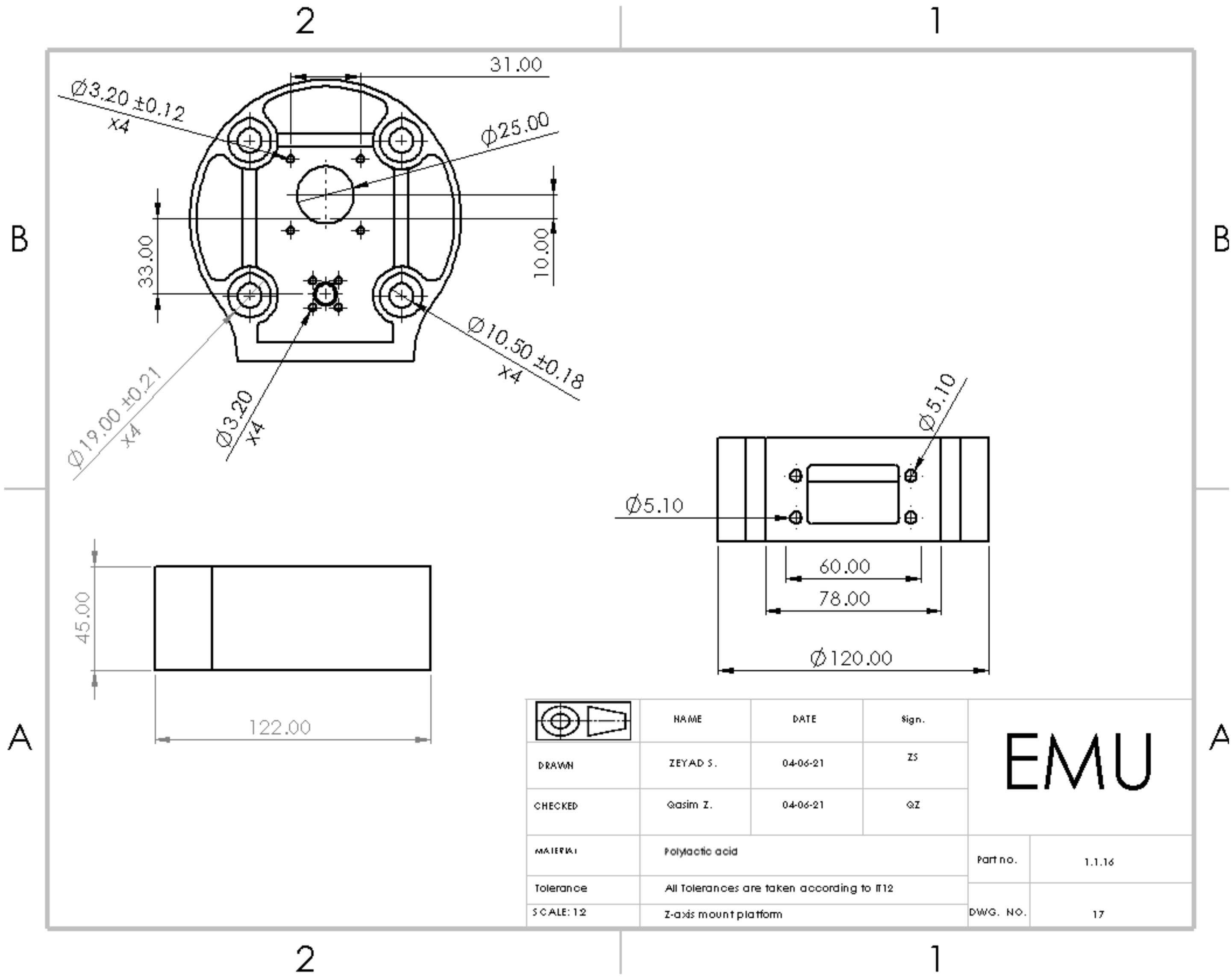


Ø8.00
380.00
Ø8.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Lead
Part no.
1.1.13
Tolerance
All tolerances taken to IT12
SCALE: 1:5
lead screw D8
DWG. NO.
14

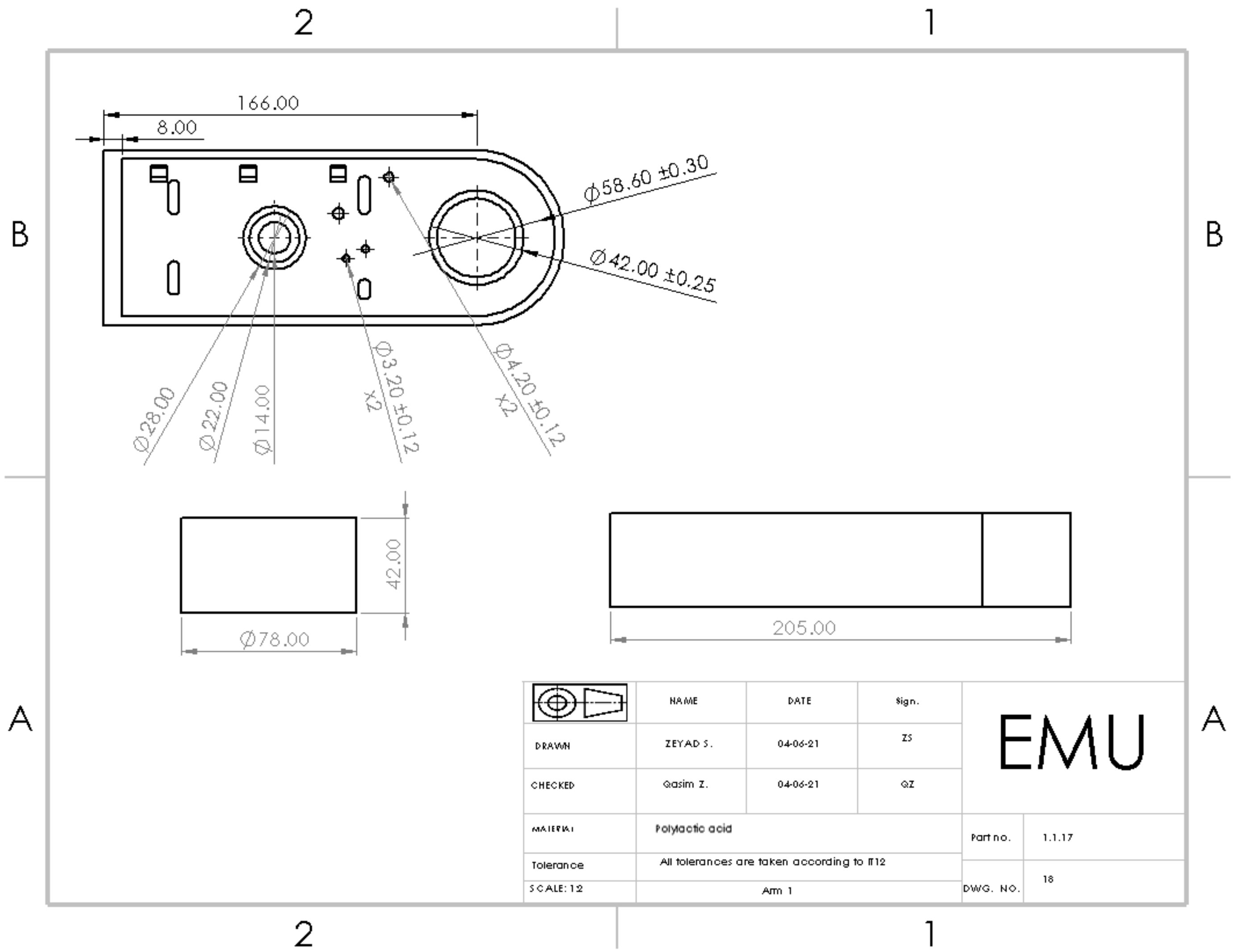

2
1
B
A
⌀8.00
⌀10.20 +0.18 -0.18
⌀22.00
⌀3.00 +0.10 -0.10 x4
11.50
11.50
3.50
1.50
10.00
⌀10.20
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Lead
Part no.
1.1.14
Tolerance
All Tolerances taken according to IT12
SCALE: 2:1
Lead screw nut
DWG. NO.
15

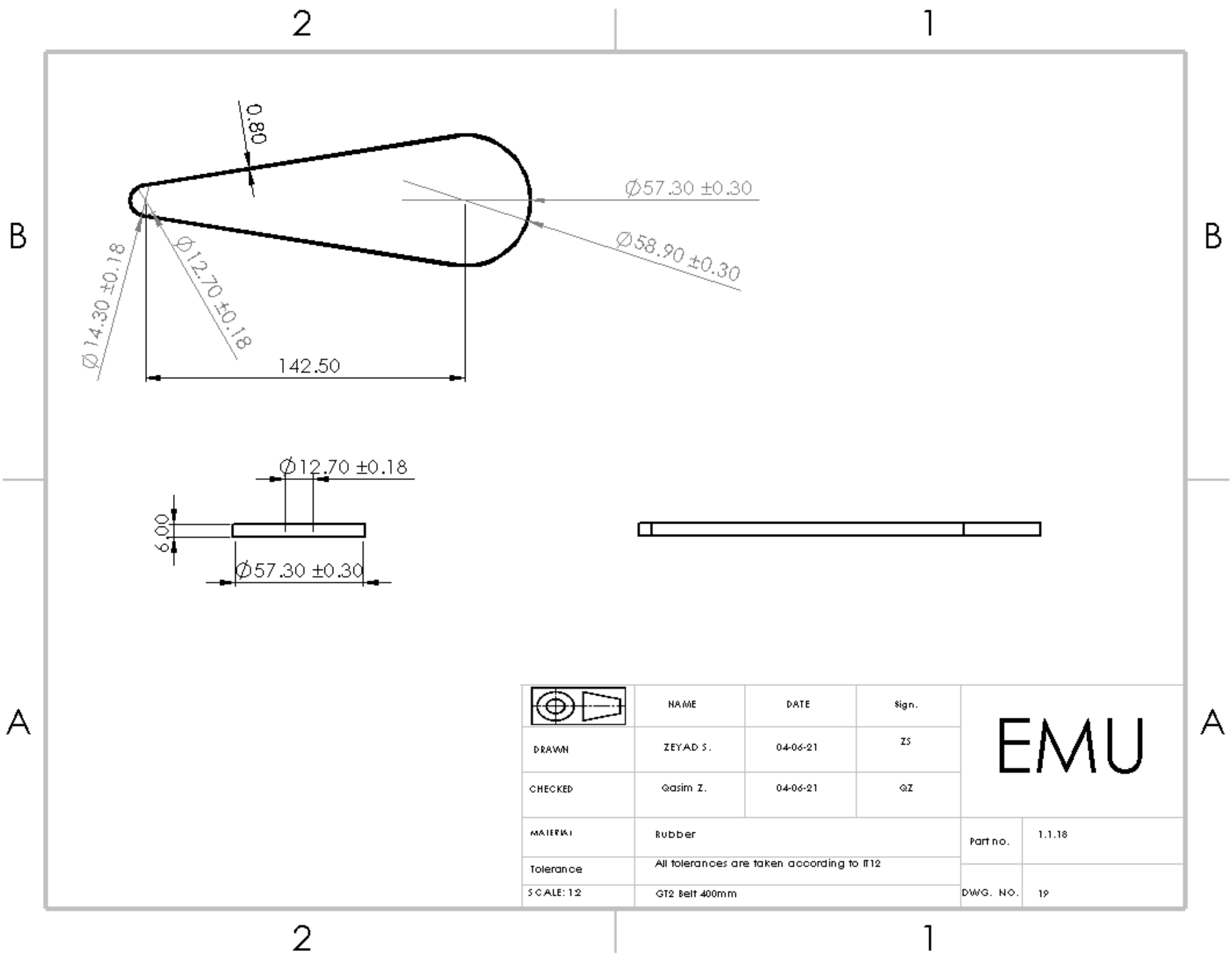


B
B
A
A
7.00
Ø1.00 +0.10 -0.10
R1.00
16.40
6.50
Ø4.10 +0.12 -0.12
×2
3.50
Ø10.00
14.00
Ø7.00
14.00
26.40
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.15
Tolerance
All Tolerances taken according to IT12
SCALE: 2:1
Smooth Rod Clamp
DWG. NO.
16

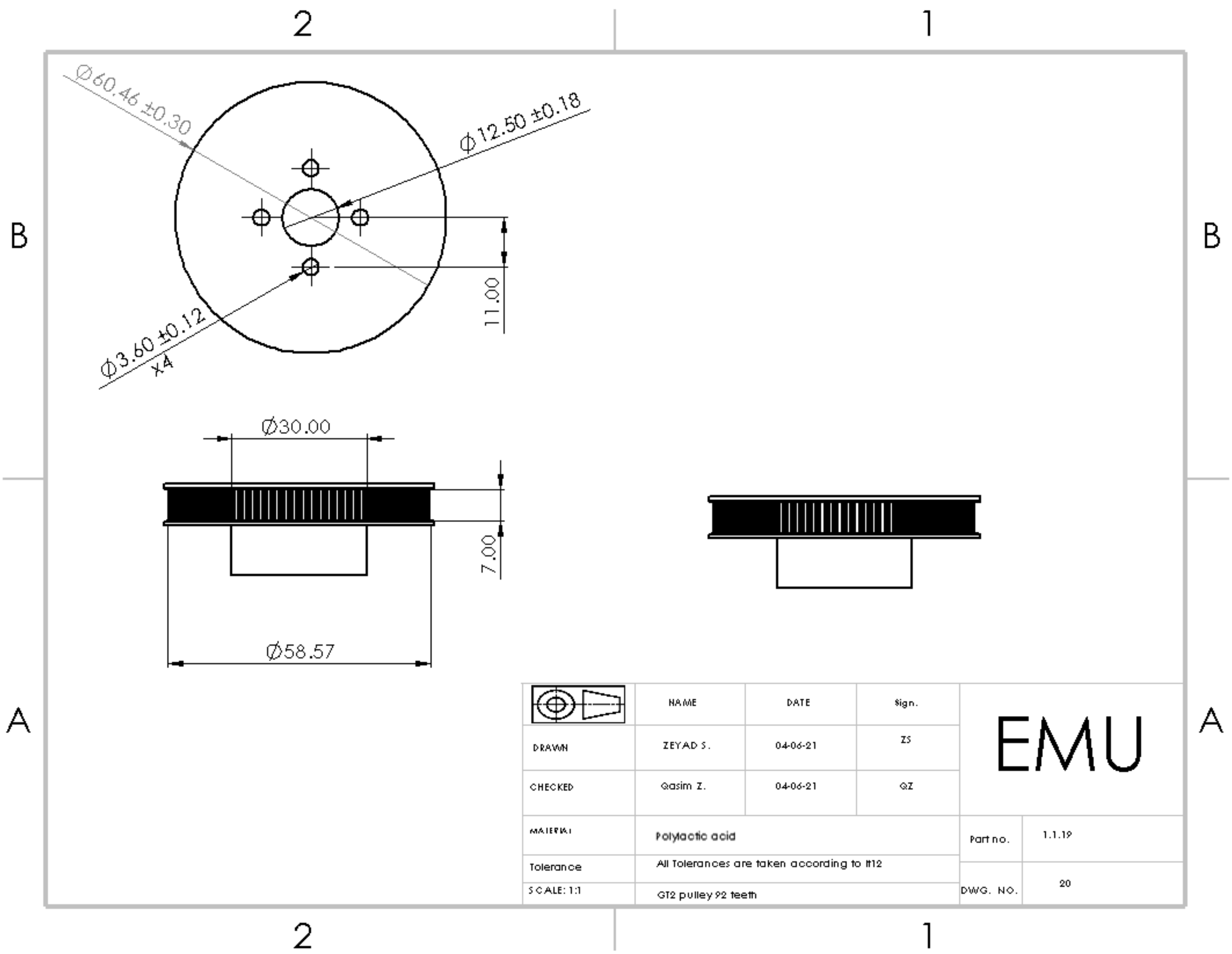


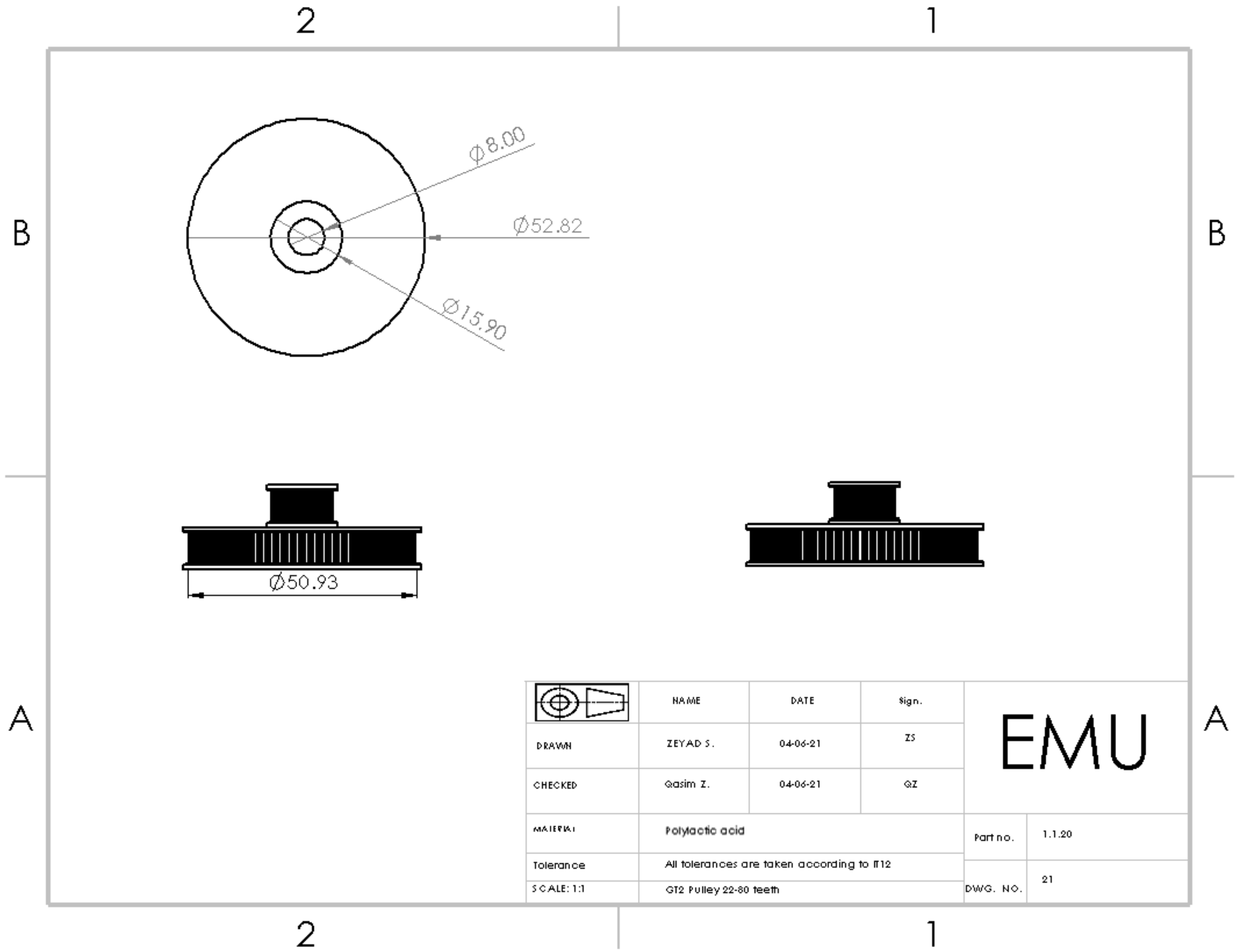
2
1
B
A
31.00
Ø3.20 ±0.12
x4
Ø25.00
33.00
10.00
Ø10.50 ±0.18
x4
Ø19.00 ±0.21
x4
Ø3.20
x4
Ø5.10
Ø5.10
60.00
78.00
Ø120.00
45.00
122.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.16
Tolerance
All Tolerances are taken according to IT12
SCALE: 1:2
Z-axis mount platform
DWG. NO.
17

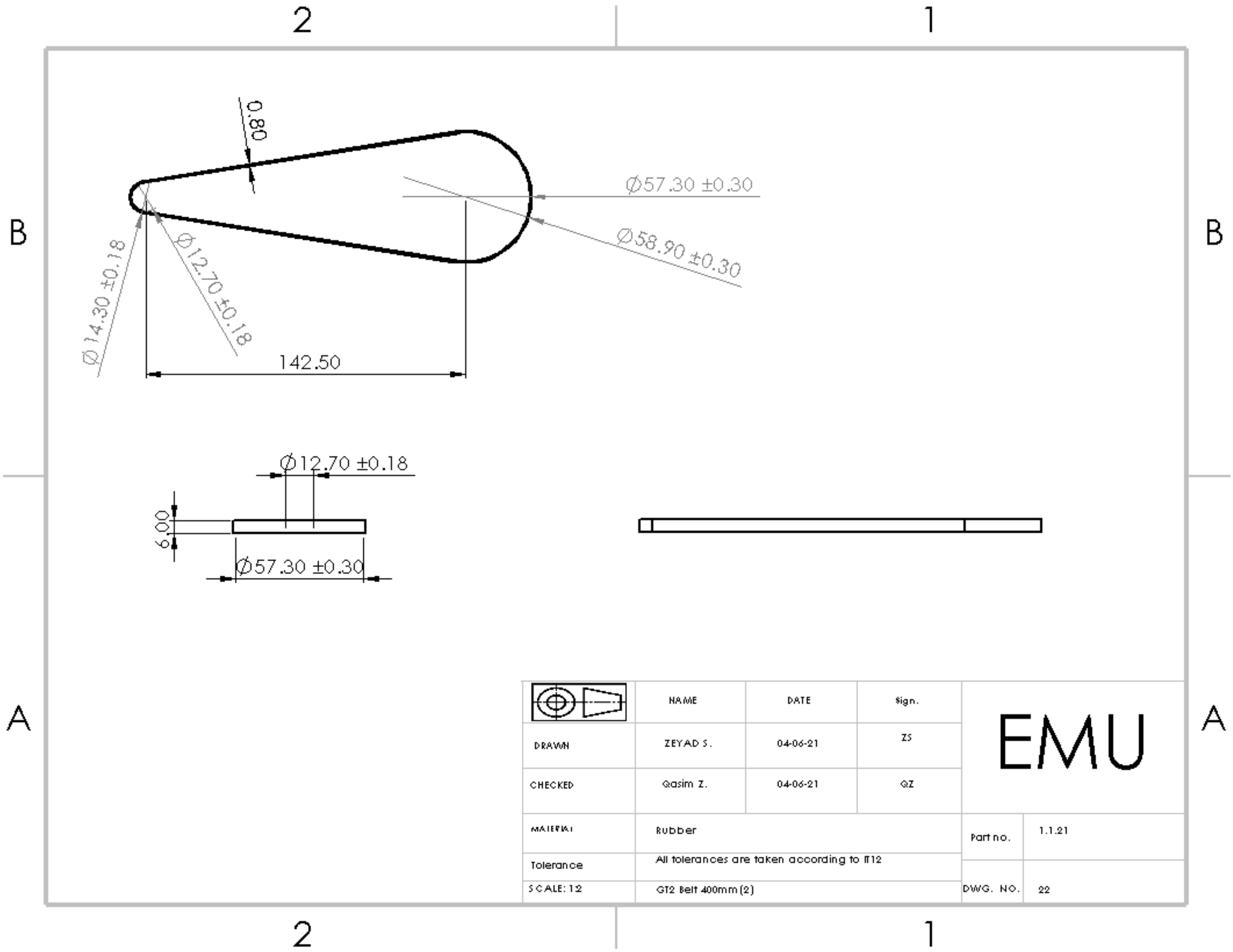

166.00
8.00
Ø58.60 ±0.30
Ø42.00 ±0.25
Ø28.00
Ø22.00
Ø14.00
Ø3.20 ±0.12
X2
Ø4.20 ±0.12
X2
42.00
Ø78.00
205.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.17
Tolerance
All tolerances are taken according to IT12
SCALE: 1:2
Arm 1
DWG. NO.
18



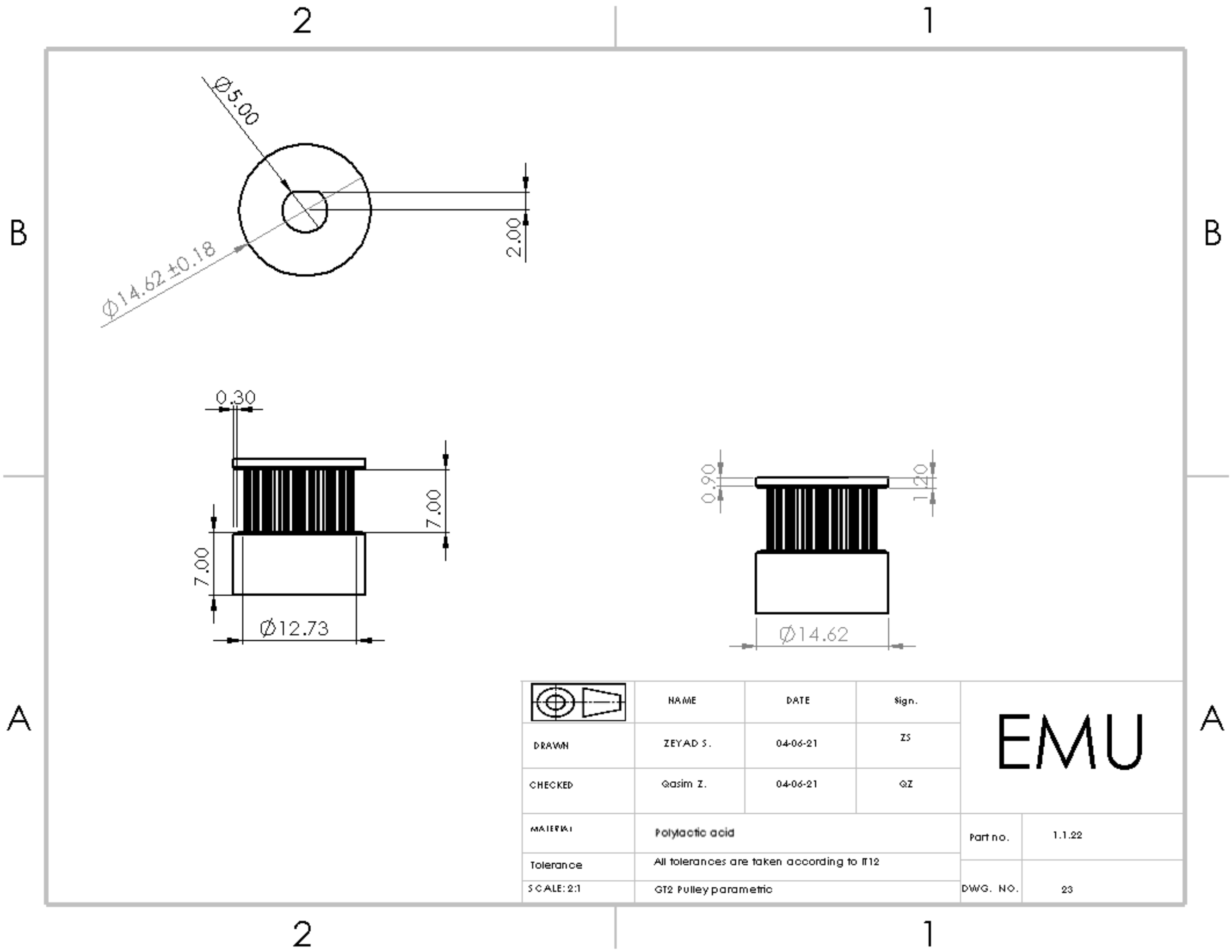
0.80
Ø57.30 ±0.30
Ø58.90 ±0.30
Ø14.30 ±0.18
Ø12.70 ±0.18
142.50
Ø12.70 ±0.18
6.00
Ø57.30 ±0.30
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Rubber
Part no.
1.1.18
Tolerance
All tolerances are taken according to IT12
SCALE: 1:2
GT2 Belt 400mm
DWG. NO.
19

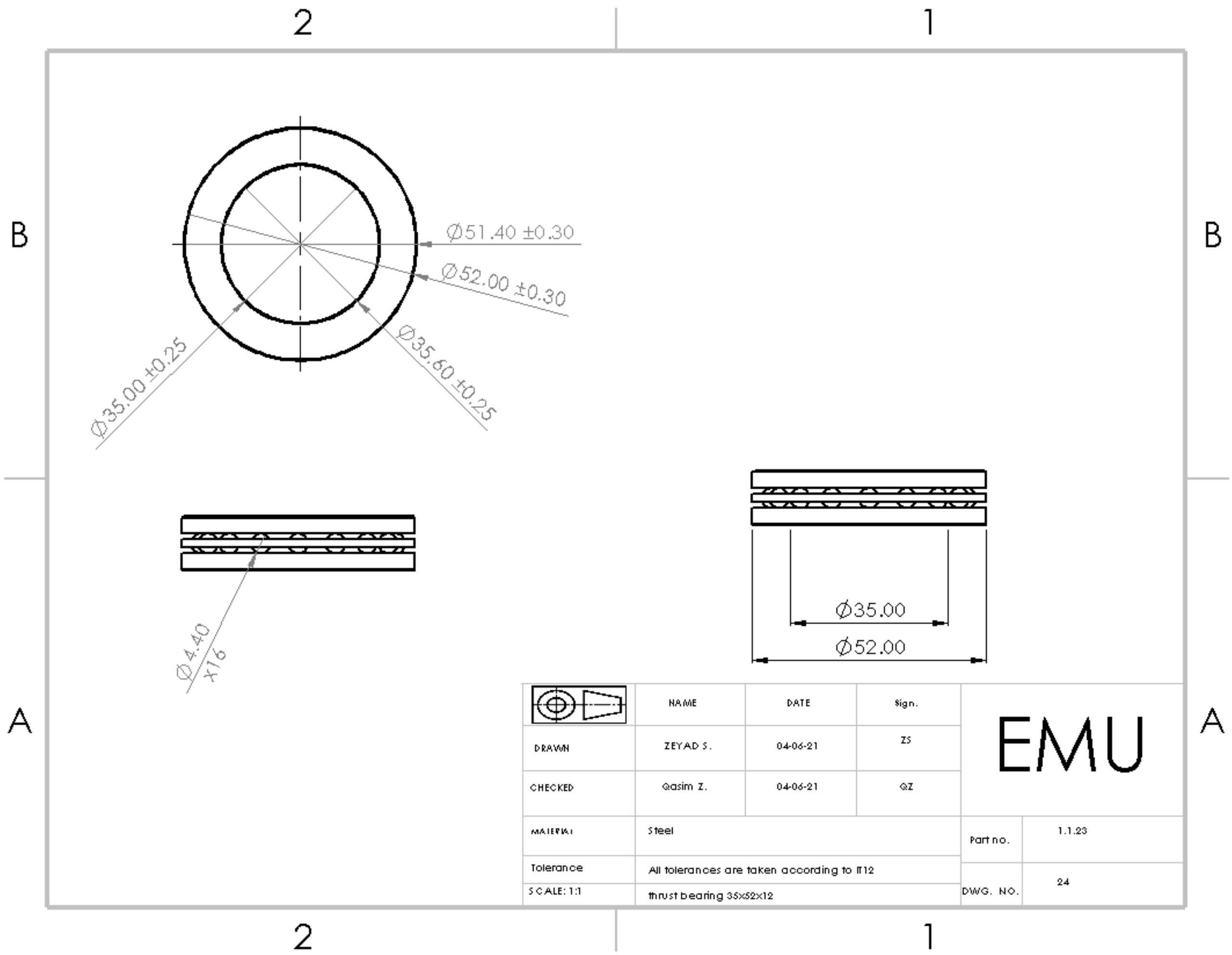

Ø60.46 ±0.30
ϕ12.50 ±0.18
ϕ3.60 ±0.12
X4
11.00
Ø30.00
7.00
Ø58.57
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.19
Tolerance
All Tolerances are taken according to IT12
SCALE: 1:1
GT2 pulley 92 teeth
DWG. NO.
20

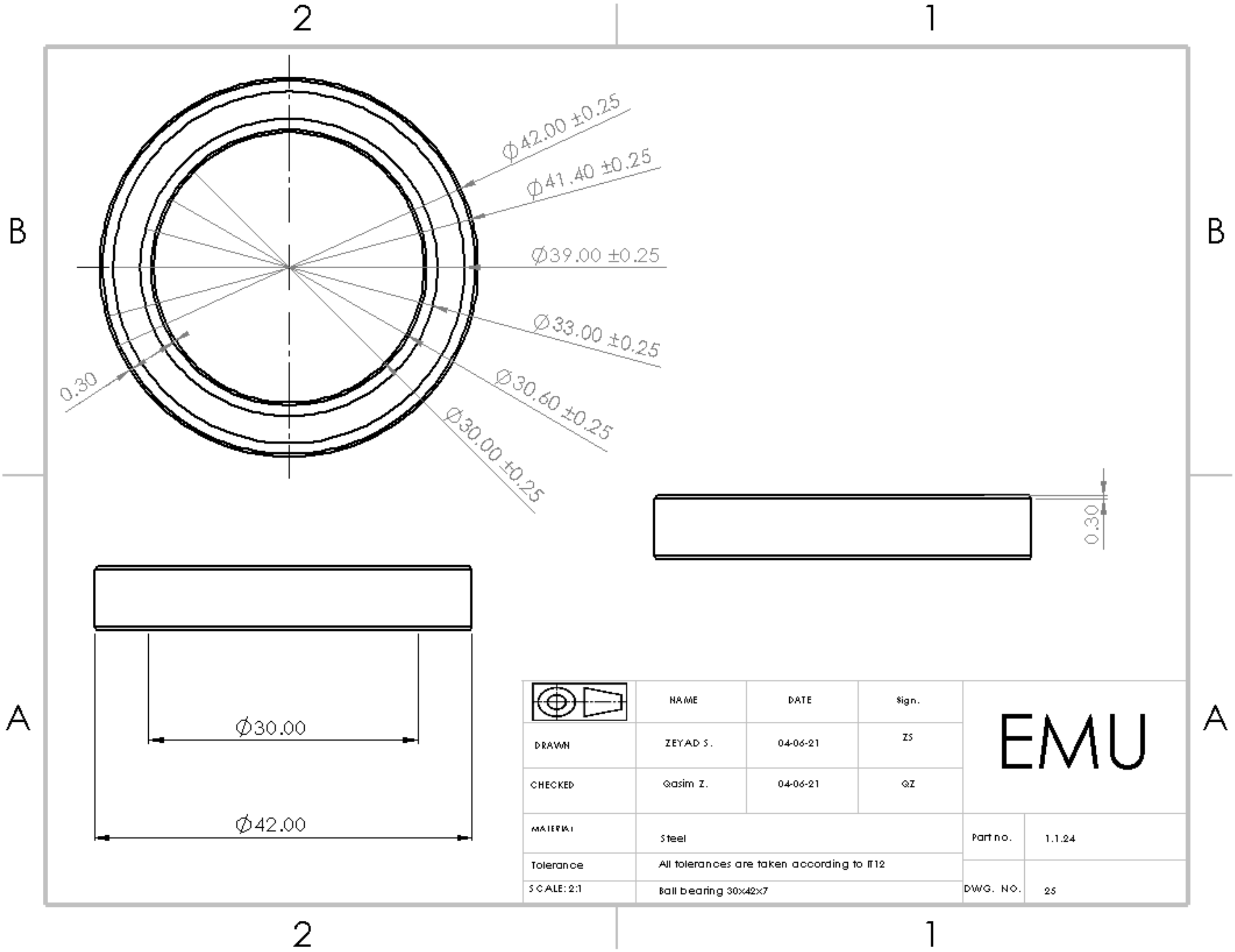

2
1
B
A
Ø8.00
Ø52.82
Ø15.90
Ø50.93
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.20
Tolerance
All tolerances are taken according to IT12
SCALE: 1:1
GT2 Pulley 22-80 teeth
DWG. NO.
21

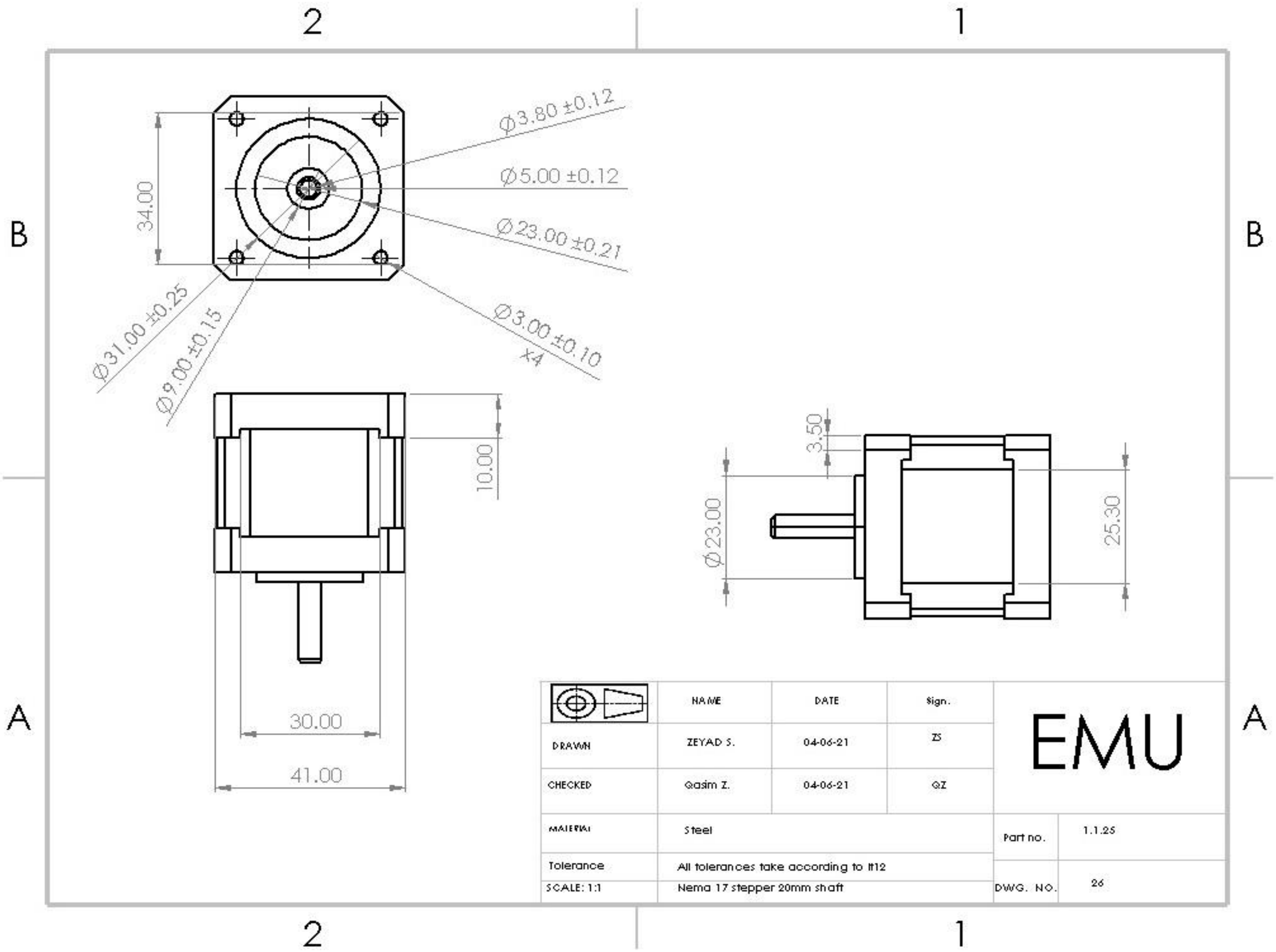


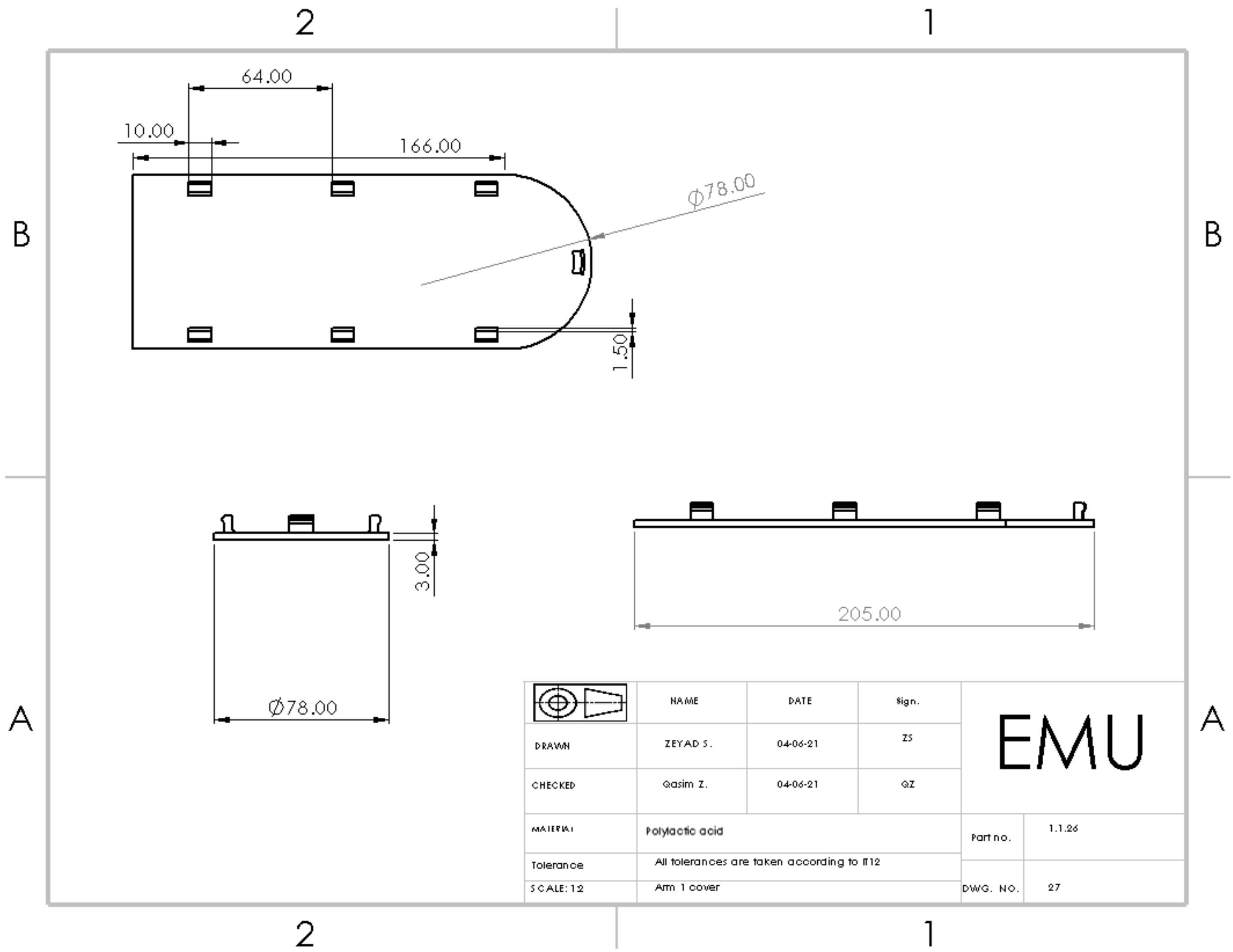
2
1
B
A
0.80
Ø57.30 ±0.30
Ø58.90 ±0.30
Ø14.30 ±0.18
Ø12.70 ±0.18
142.50
Ø12.70 ±0.18
6.00
Ø57.30 ±0.30
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Rubber
Part no.
1.1.21
Tolerance
All tolerances are taken according to IT12
SCALE: 1:2
GT2 Belt 400mm (2)
DWG. NO.
22


Ø5.00
2.00
Ø14.62 ±0.18
0.30
7.00
7.00
Ø12.73
0.90
1.20
Ø14.62
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.22
Tolerance
All tolerances are taken according to IT12
SCALE: 2:1
GT2 Pulley parametric
DWG. NO.
23

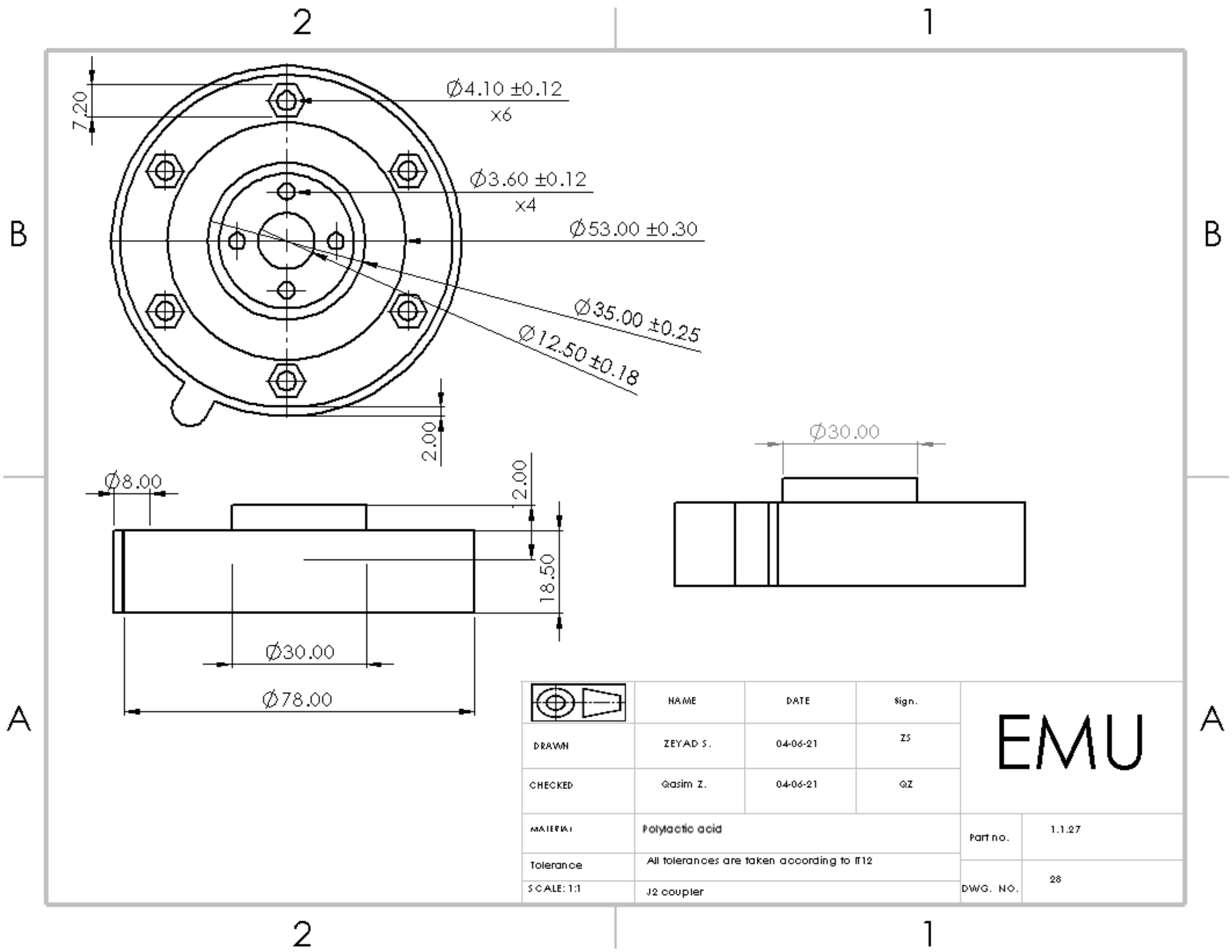

Ø51.40 ±0.30
Ø52.00 ±0.30
Ø35.00 ±0.25
Ø35.60 ±0.25
Ø4.40
X16
Ø35.00
Ø52.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Steel
Part no.
1.1.23
Tolerance
All tolerances are taken according to IT12
SCALE: 1:1
thrust bearing 35x52x12
DWG. NO.
24

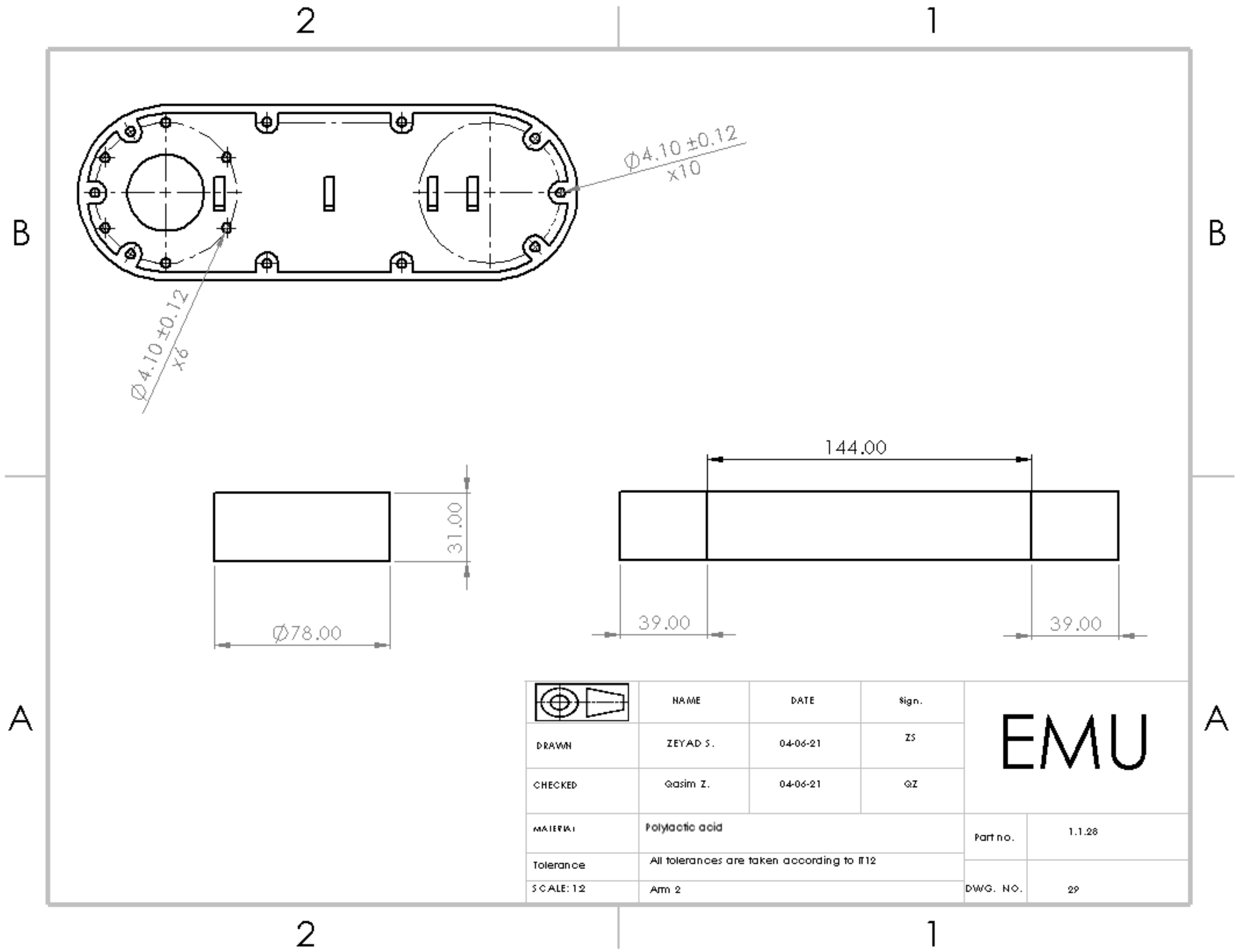

Ø42.00 ±0.25
Ø41.40 ±0.25
Ø39.00 ±0.25
Ø33.00 ±0.25
Ø30.60 ±0.25
Ø30.00 ±0.25
0.30
0.30
Ø30.00
Ø42.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Steel
Part no.
1.1.24
Tolerance
All tolerances are taken according to IT12
SCALE: 2:1
Ball bearing 30x42x7
DWG. NO.
25


Ø3.80 ±0.12
Ø5.00 ±0.12
Ø23.00 ±0.21
Ø3.00 ±0.10 X4
Ø31.00 ±0.25
Ø9.00 ±0.15
34.00
10.00
3.50
Ø23.00
25.30
30.00
41.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Steel
Part no.
1.1.25
Tolerance
All tolerances take according to it12
SCALE: 1:1
Nema 17 stepper 20mm shaft
DWG. NO.
26

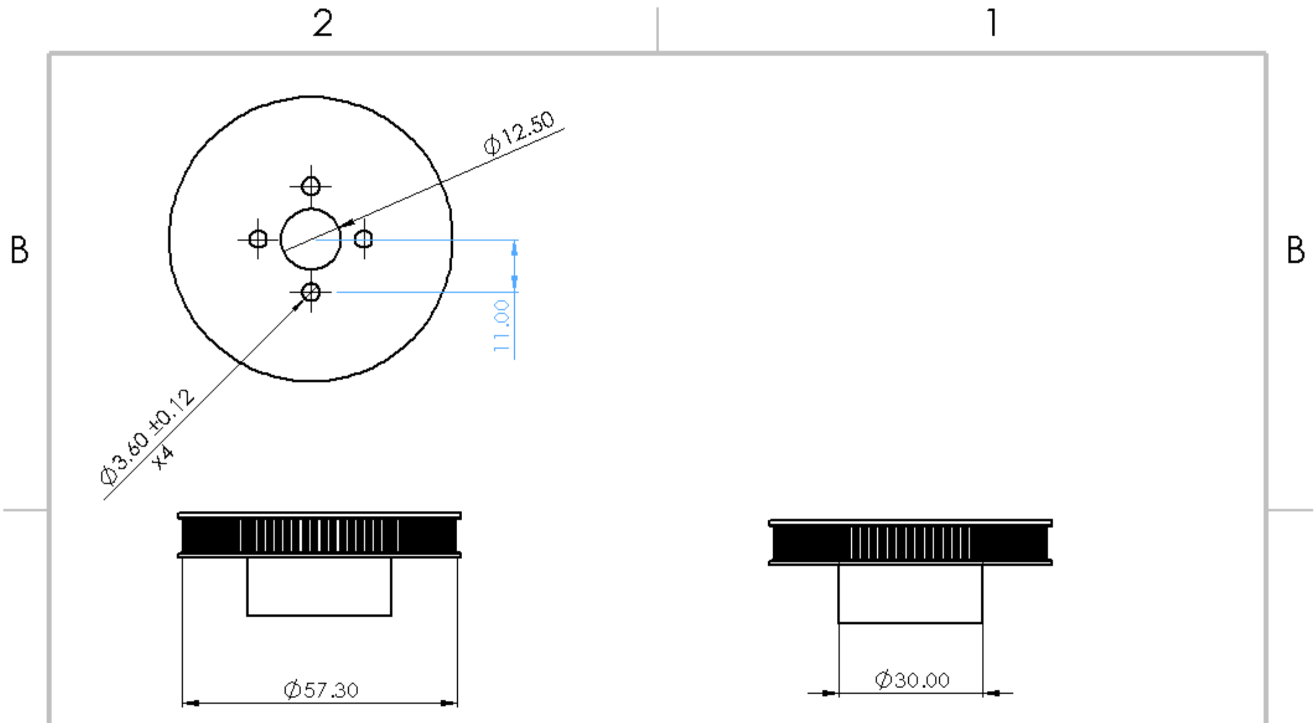


64.00
10.00
166.00
Ø78.00
1.50
3.00
205.00
Ø78.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.26
Tolerance
All tolerances are taken according to IT12
SCALE: 1:2
Arm 1 cover
DWG. NO.
27

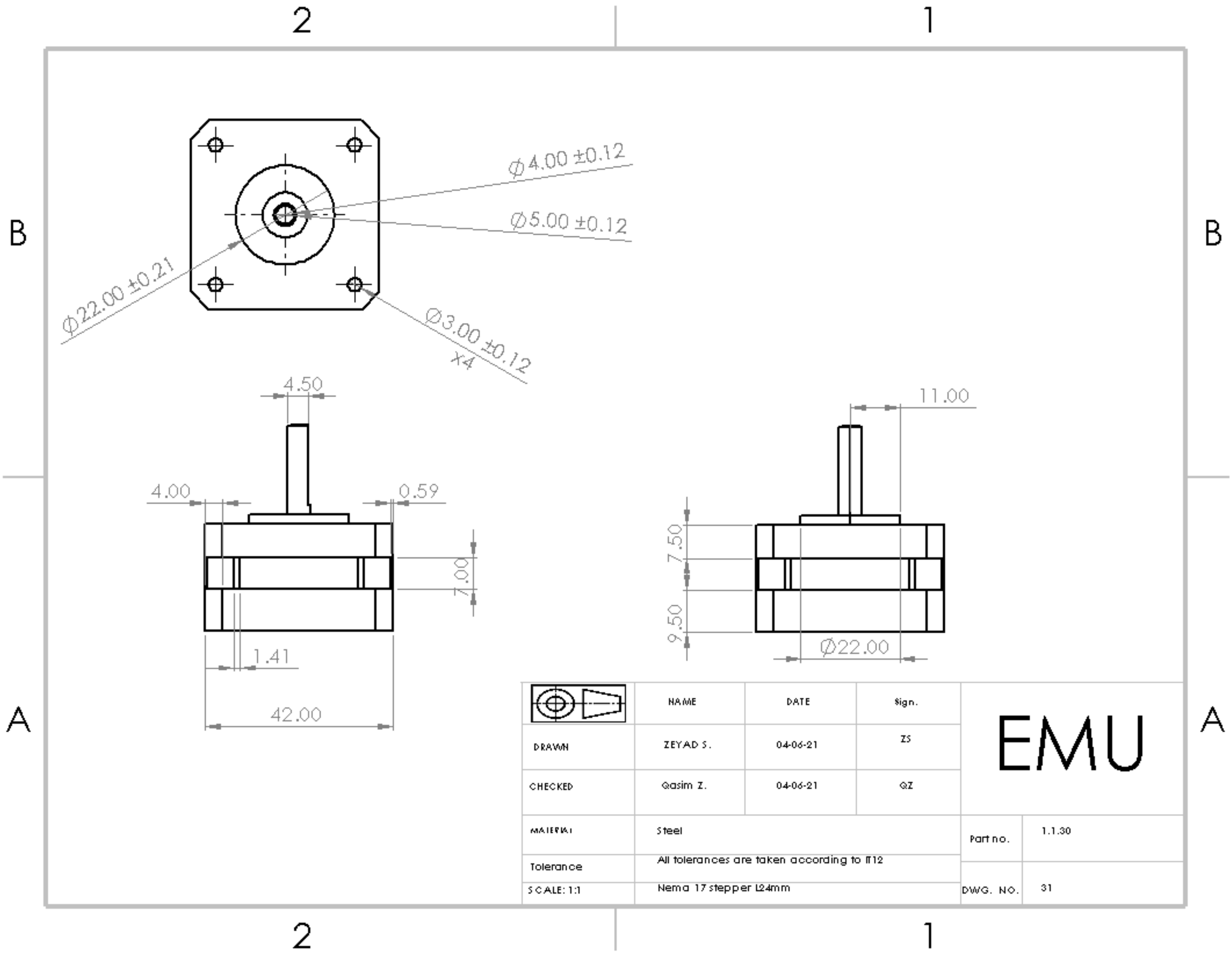

2
1
B
A
Ø4.10 ±0.12
x6
7.20
Ø3.60 ±0.12
x4
Ø53.00 ±0.30
Ø35.00 ±0.25
Ø12.50 ±0.18
2.00
Ø8.00
2.00
18.50
Ø30.00
Ø78.00
Ø30.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.27
Tolerance
All tolerances are taken according to IT12
SCALE: 1:1
J2 coupler
DWG. NO.
28

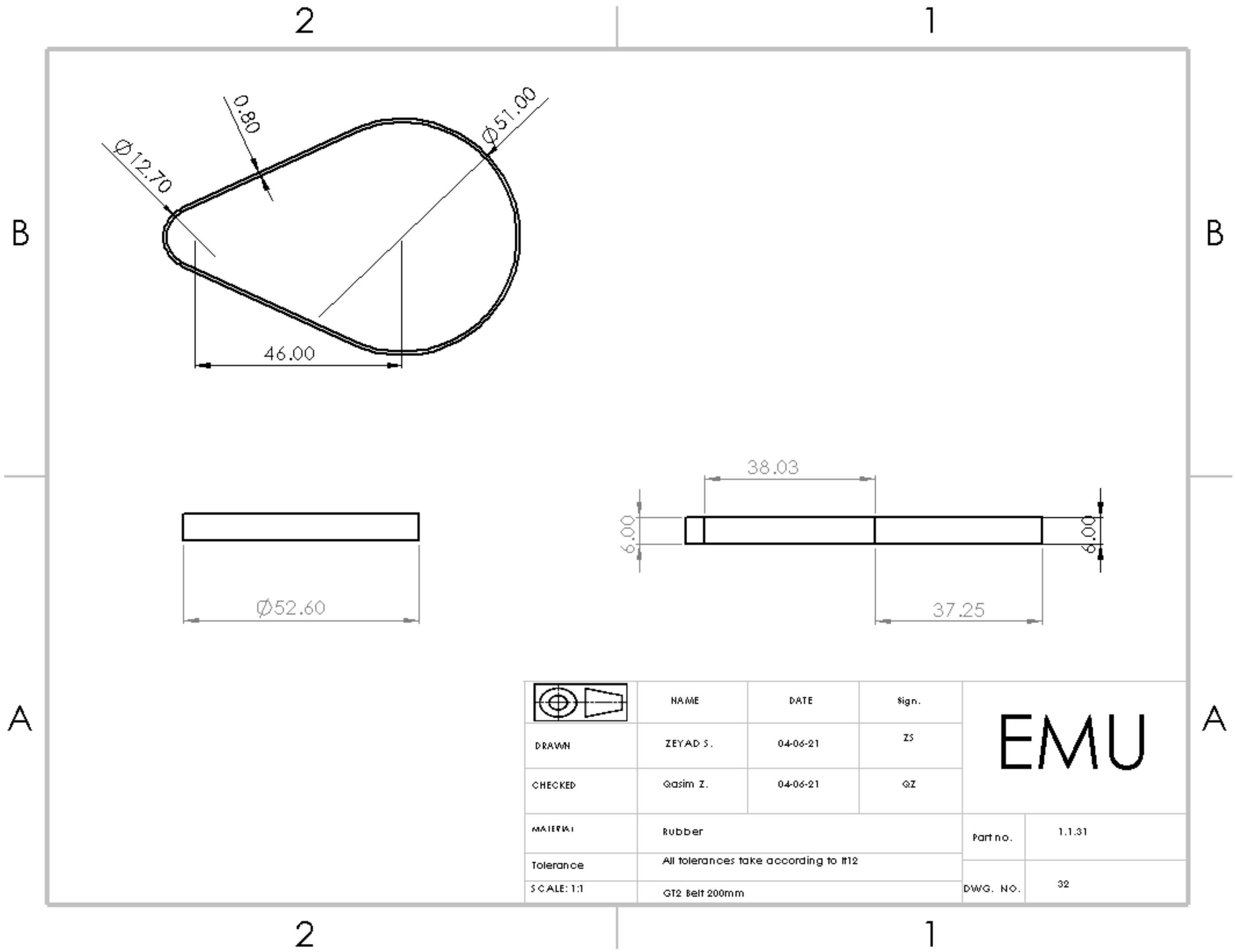


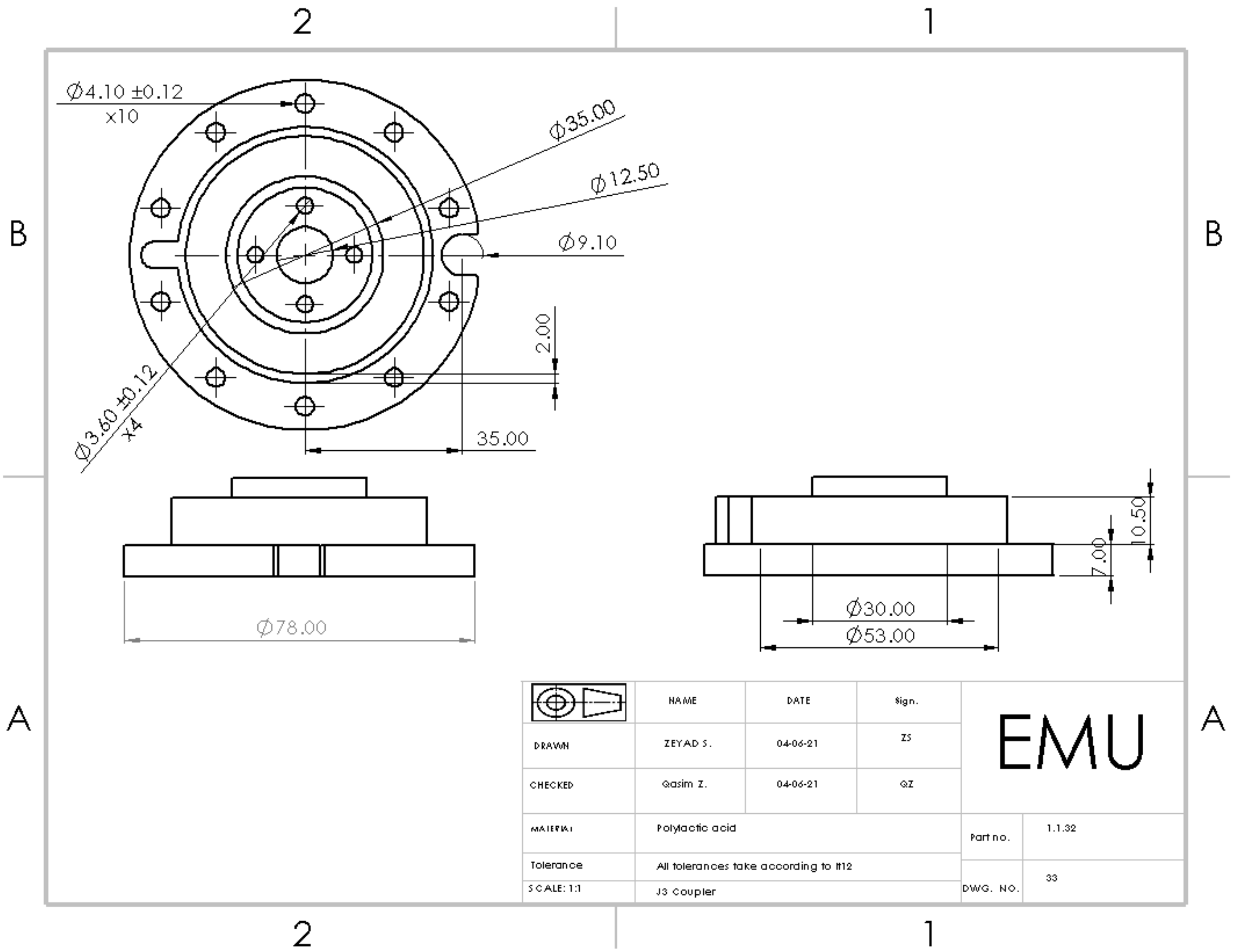
Ø4.10 ±0.12
x10
Ø4.10 ±0.12
x6
144.00
31.00
Ø78.00
39.00
39.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.28
Tolerance
All tolerances are taken according to IT12
SCALE: 1:2
Arm 2
DWG. NO.
29

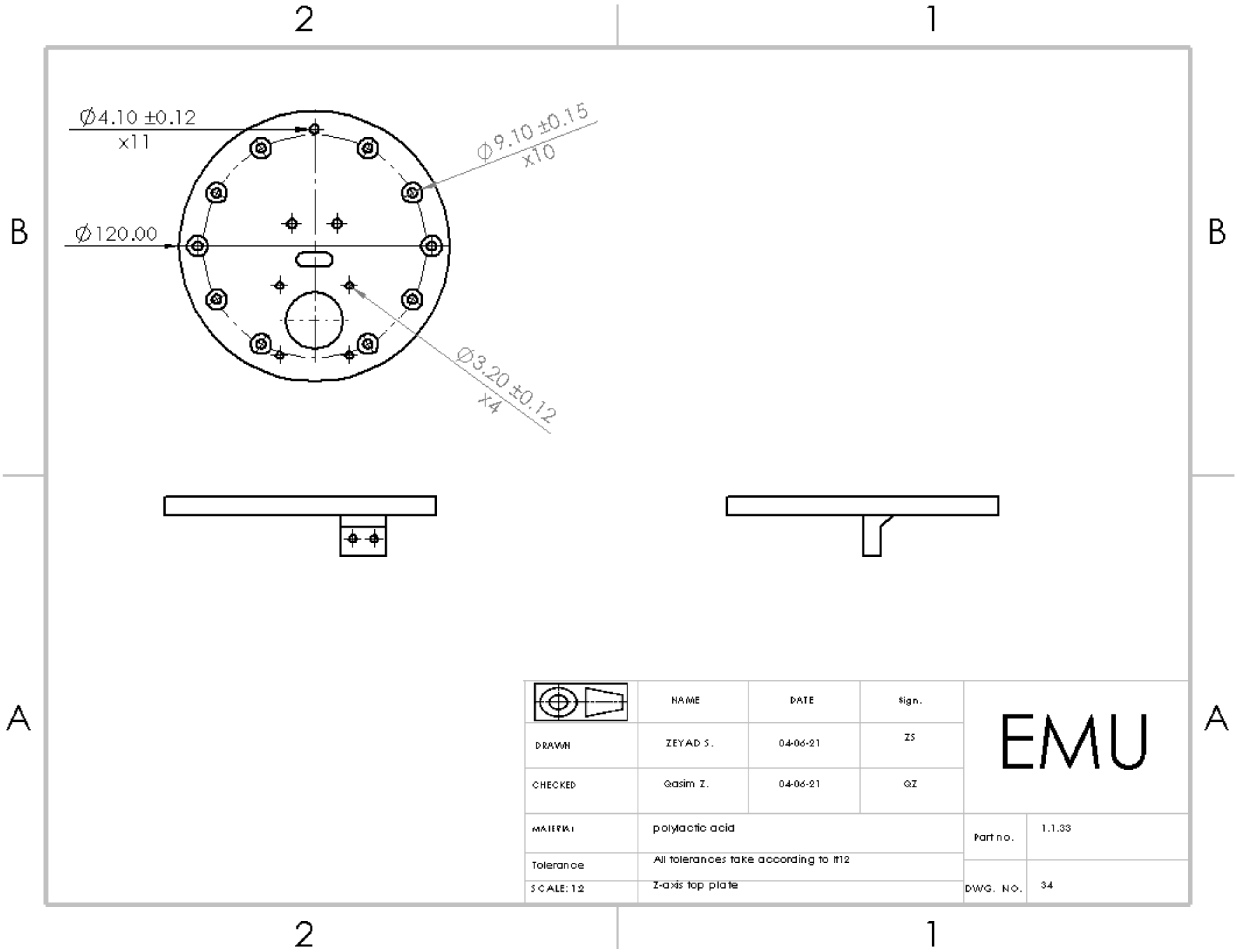


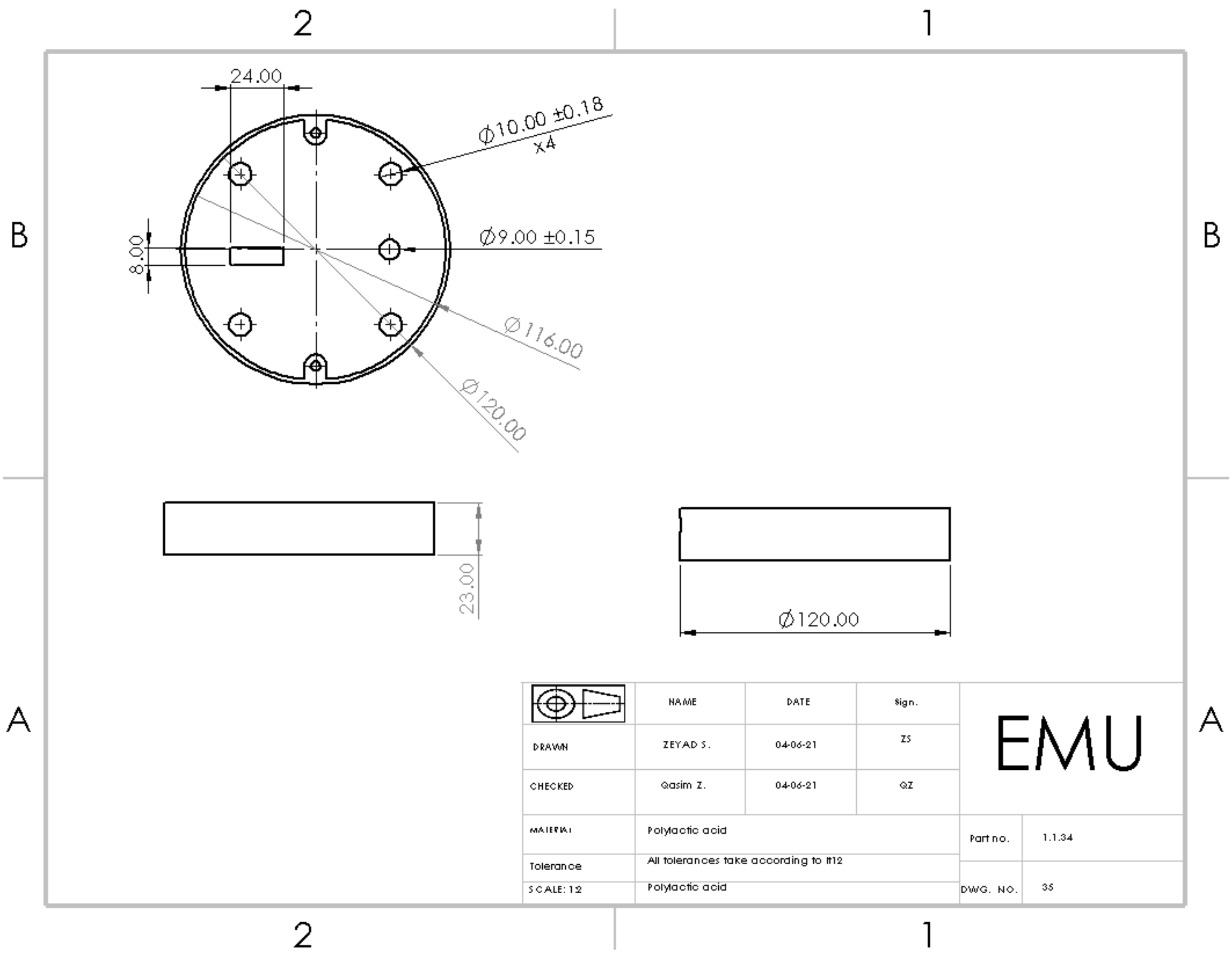
	NAME	DATE	Sign.	EMU
DRAWN	ZEYAD S.	04-06-21	ZS	
CHECKED	Qasim Z.	04-06-21	QZ	
MATERIAL	Polylactic acid		Part no.	1.1.29
Tolerance	All tolerances are taken according to IT12		DWG. NO.	30
SCALE: 1:1	GT2 pulley- 90 teeth-j3			


2
1
B
B
A
A
2
1
Ø4.00 ±0.12
Ø5.00 ±0.12
Ø22.00 ±0.21
Ø3.00 ±0.12
X4
4.50
4.00
0.59
7.00
1.41
42.00
11.00
7.50
9.50
Ø22.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Steel
Part no.
1.1.30
Tolerance
All tolerances are taken according to IT12
SCALE: 1:1
Nema 17 stepper L24mm
DWG. NO.
31

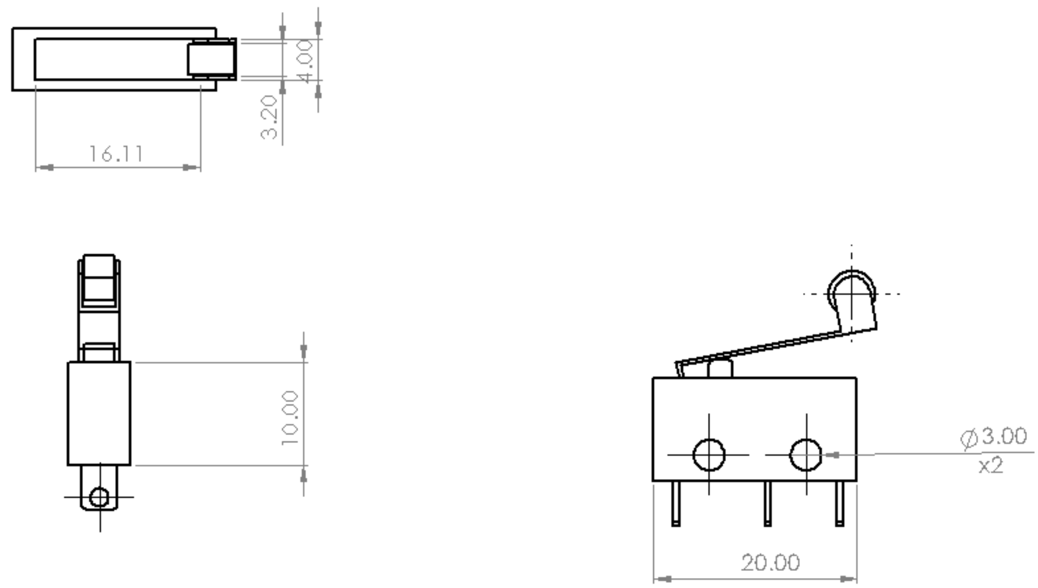

0.80
Ø12.70
Ø51.00
46.00
Ø52.60
38.03
6.00
6.00
37.25
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Rubber
Part no.
1.1.31
Tolerance
All tolerances take according to IT12
SCALE: 1:1
GT2 Belt 200mm
DWG. NO.
32


2
1
B
A
Ø4.10 ±0.12
x10
Ø35.00
Ø12.50
Ø9.10
2.00
Ø3.60 ±0.12
x4
35.00
Ø78.00
10.50
7.00
Ø30.00
Ø53.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.32
Tolerance
All tolerances take according to It12
SCALE: 1:1
J3 Coupler
DWG. NO.
33

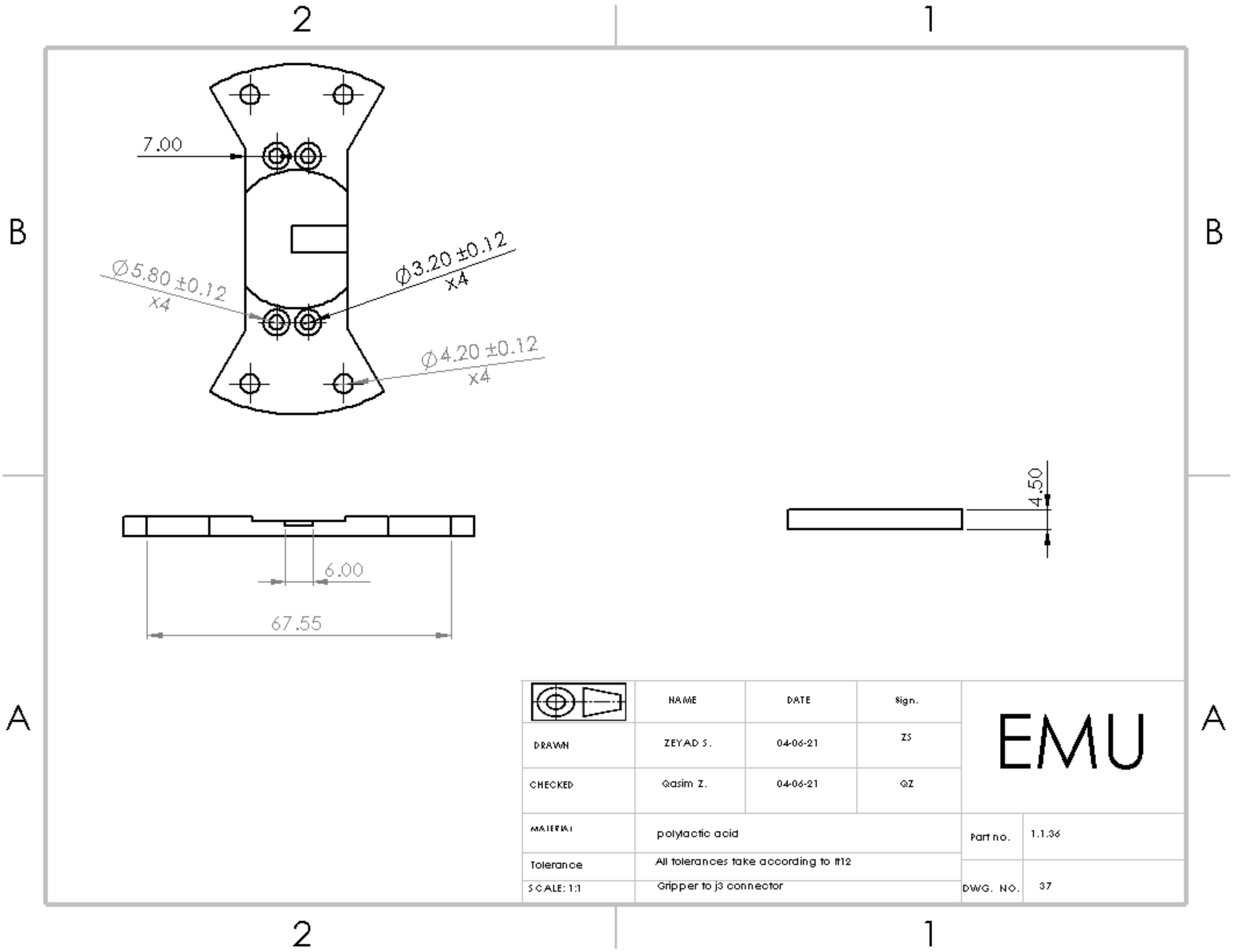

2
1
B
A
Ø4.10 ±0.12
x11
Ø9.10 ±0.15
x10
Ø120.00
Ø3.20 ±0.12
x4
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
polylactic acid
Part no.
1.1.33
Tolerance
All tolerances take according to It12
SCALE: 12
Z-axis top plate
DWG. NO.
34

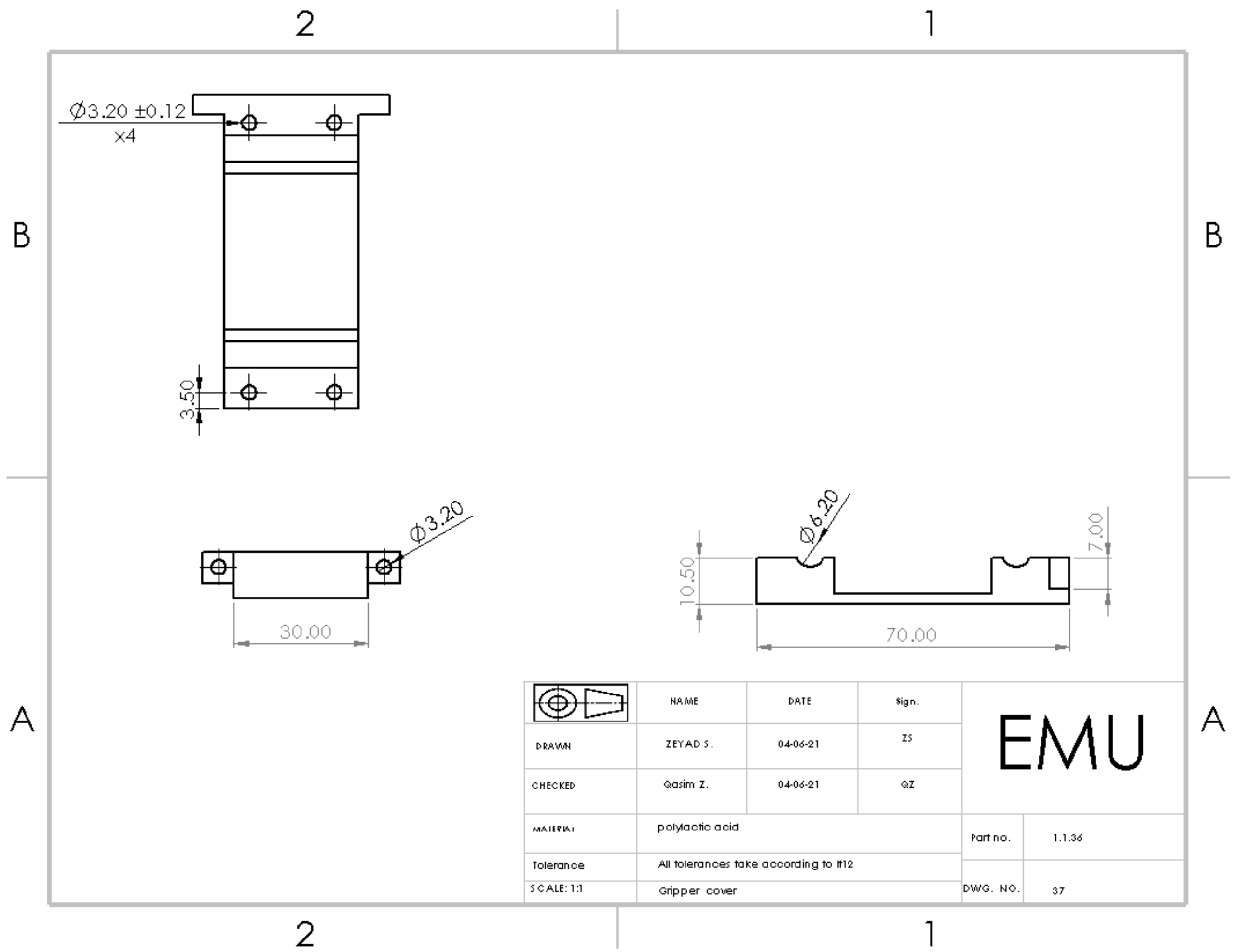


24.00
Ø10.00 ±0.18
X4
Ø9.00 ±0.15
8.00
Ø116.00
Ø120.00
23.00
Ø120.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.34
Tolerance
All tolerances take according to It12
SCALE: 1:2
Polylactic acid
DWG. NO.
35

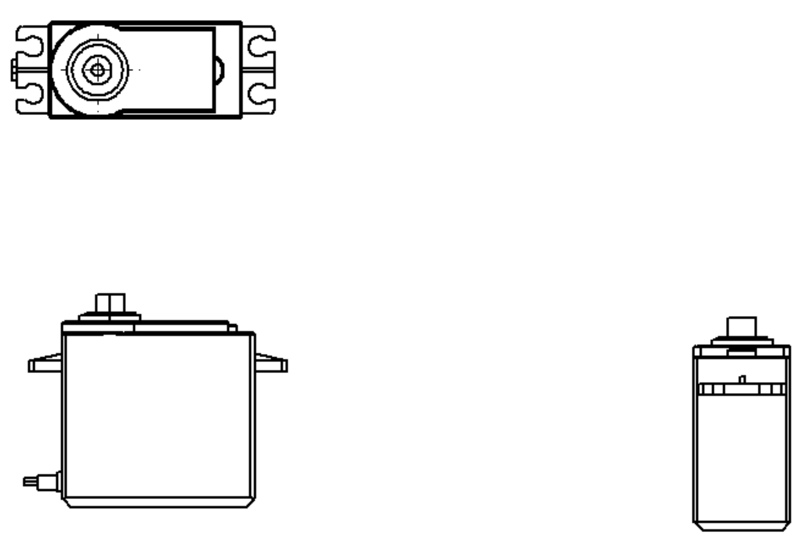


	NAME	DATE	Sign.	EMU	
DRAWN	ZEYAD S.	04-06-21	ZS		
CHECKED	Qasim Z.	04-06-21	QZ		
MATERIAL	Plastic			Part no.	1.1.35
Tolerance	All tolerances take according to IT12			DWG. NO.	36
SCALE: 2:1	Limit Switch				

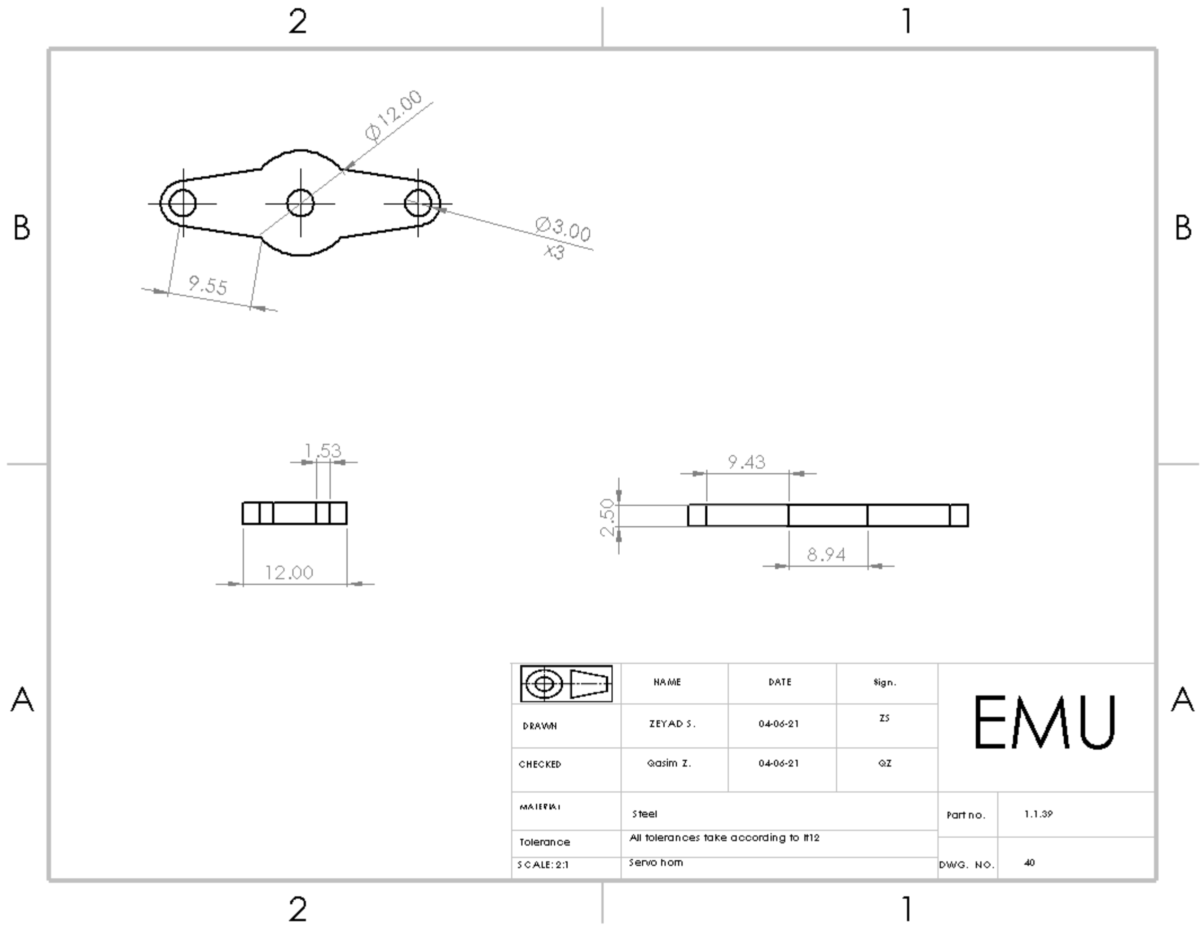

7.00
Ø5.80 ±0.12
x4
Ø3.20 ±0.12
x4
Ø4.20 ±0.12
x4
6.00
67.55
4.50
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
polylactic acid
Part no.
1.1.36
Tolerance
All tolerances take according to it12
SCALE: 1:1
Gripper to j3 connector
DWG. NO.
37



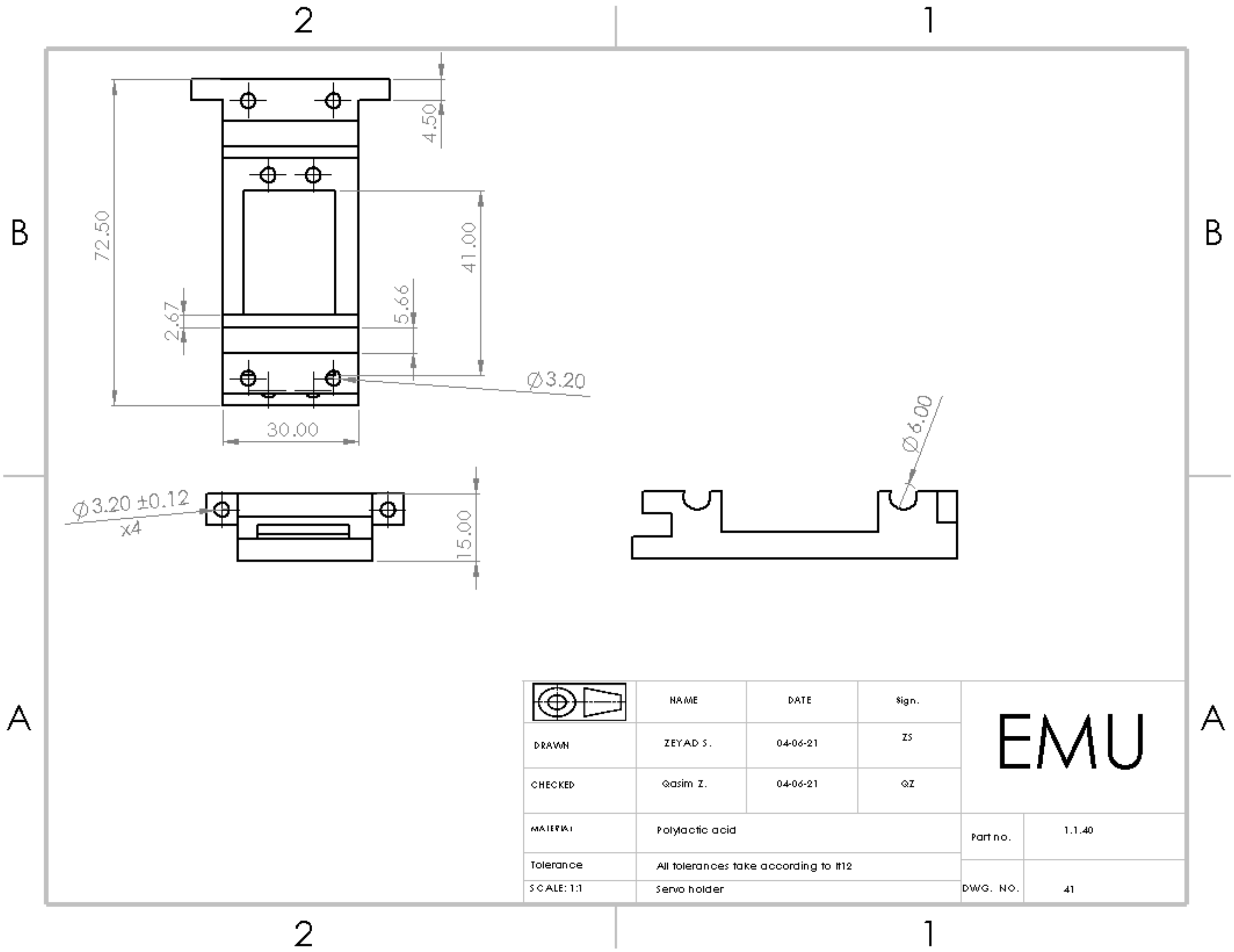
Ø3.20 ±0.12
x4
3.50
Ø3.20
30.00
Ø6.20
10.50
7.00
70.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
polylactic acid
Part no.
1.1.36
Tolerance
All tolerances take according to it12
SCALE: 1:1
Gripper cover
DWG. NO.
37



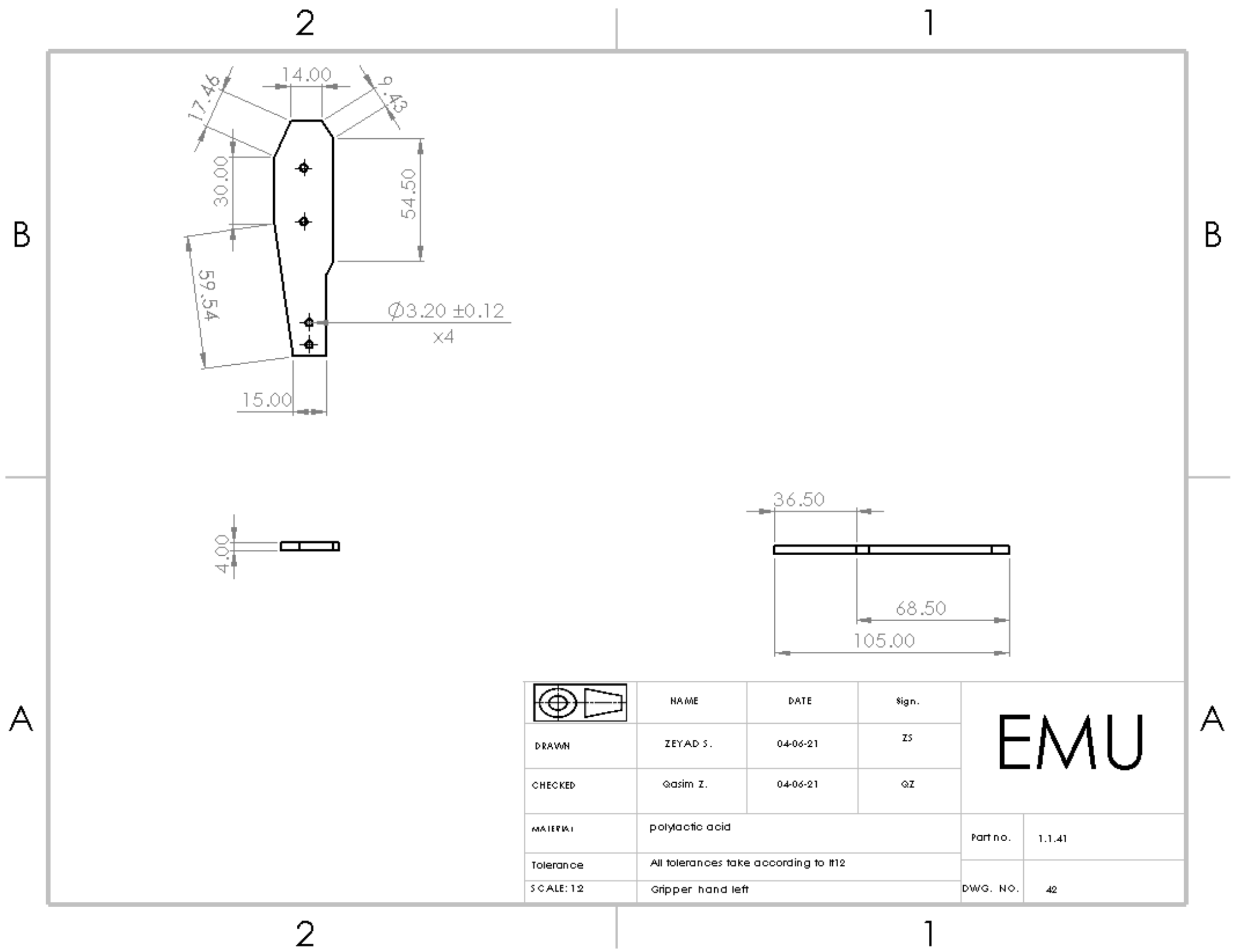
	NAME	DATE	Sign.	EMU
DRAWN	ZEYAD S.	04-06-21	ZS	
CHECKED	Qasim Z.	04-06-21	QZ	
MATERIAL	Metals and synthetics		Part no.	1.1.38
Tolerance	All tolerances take according to It12			39
SCALE: 1:1	Servo motor		DWG. NO.	

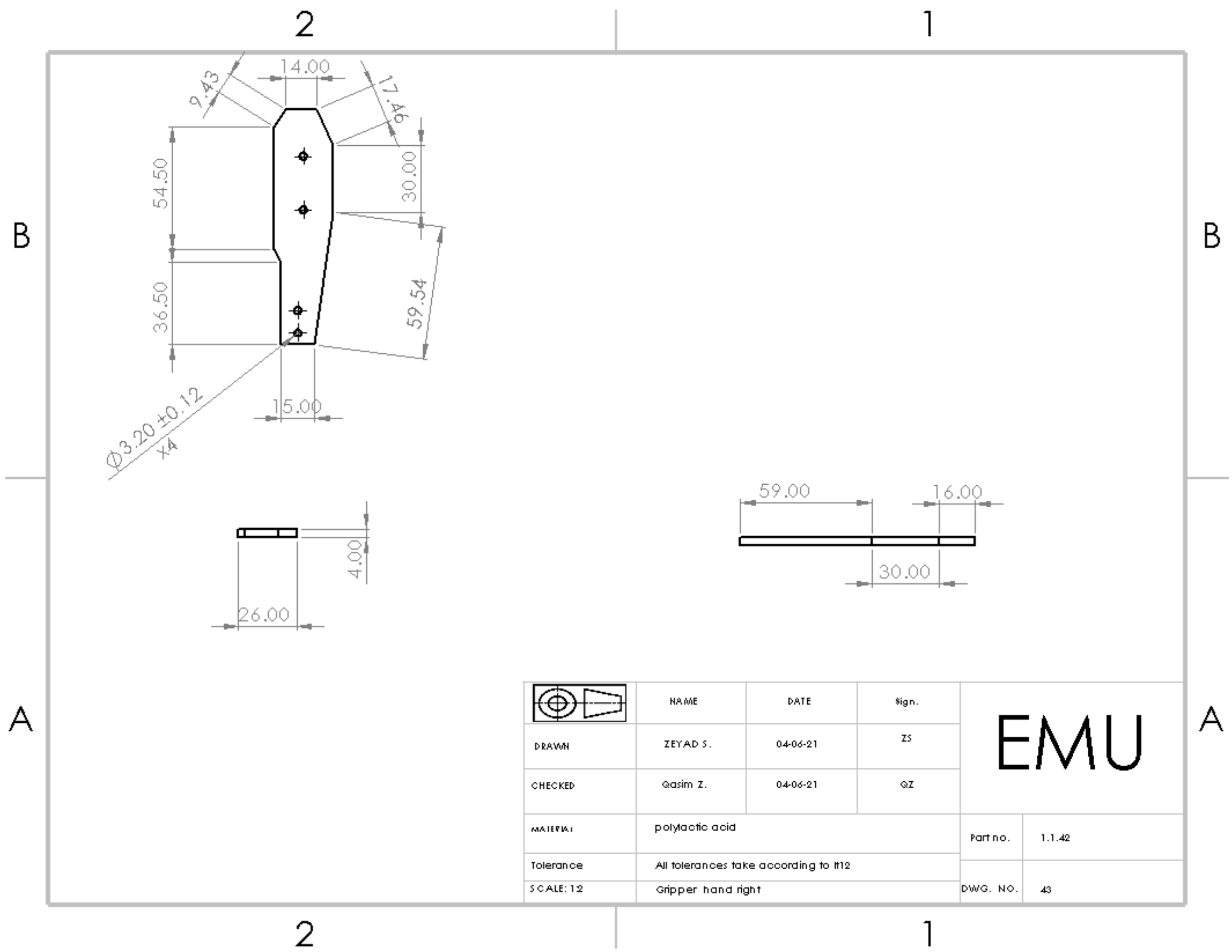


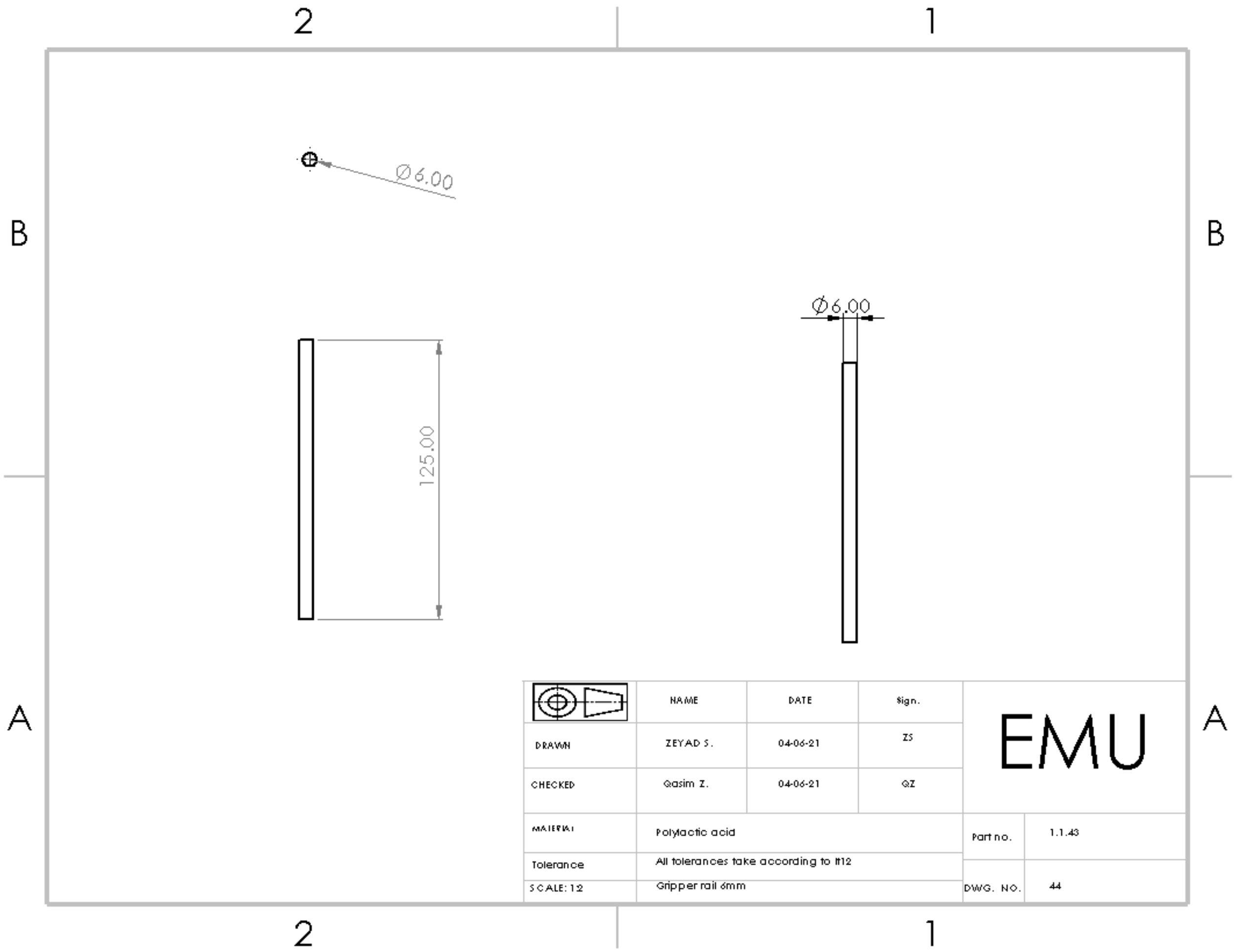
2
1
B
A
Ø12.00
Ø3.00
x3
9.55
1.53
12.00
9.43
2.50
8.94
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Steel
Part no.
1.1.39
Tolerance
All tolerances take according to It12
SCALE:2:1
Servo horn
DWG. NO.
40



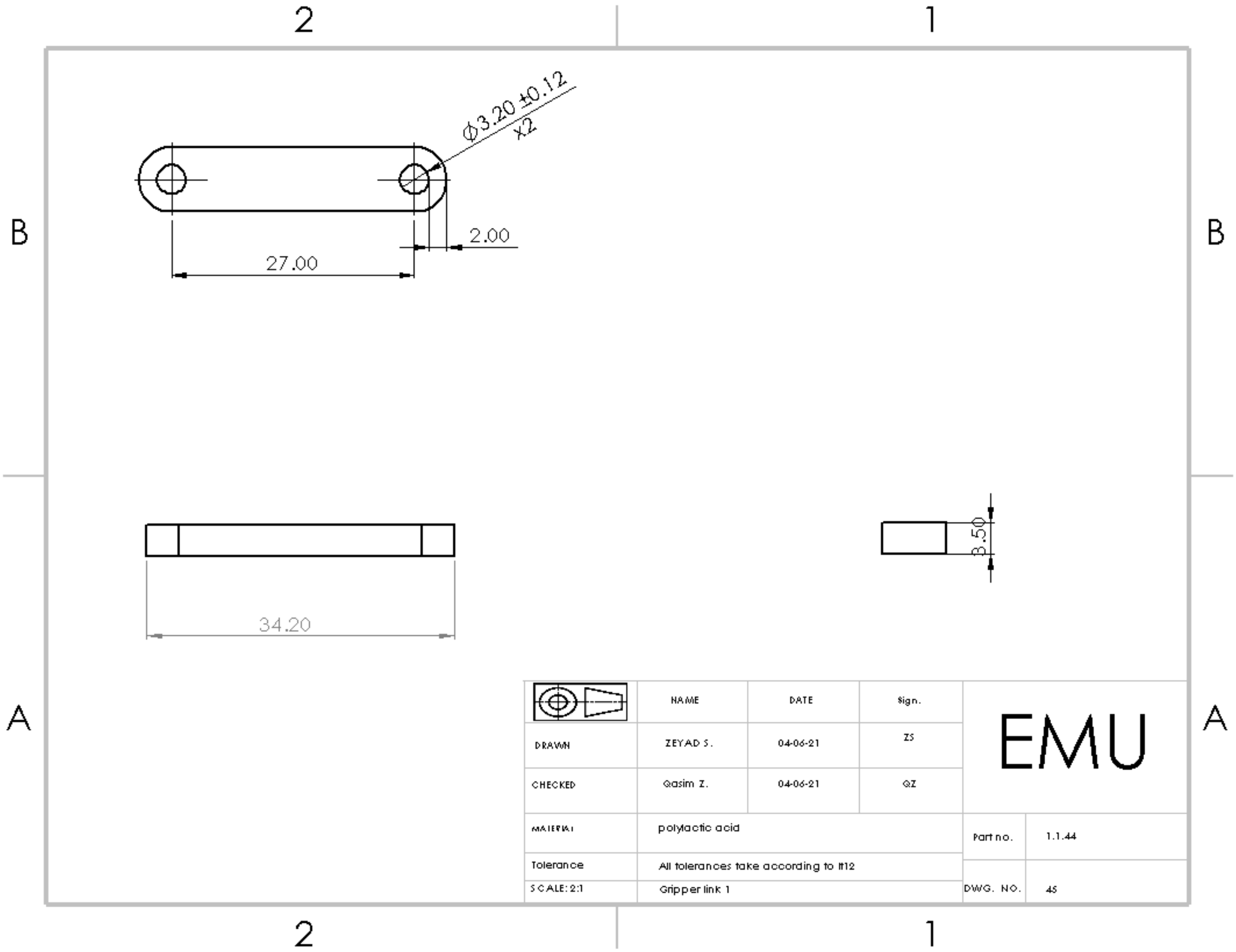
2
1
B
A
4.50
72.50
41.00
5.66
2.67
Ø3.20
30.00
Ø3.20 ±0.12
x4
15.00
Ø6.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.40
Tolerance
All tolerances take according to It12
SCALE: 1:1
Servo holder
DWG. NO.
41


2
1
B
A
14.00
17.46
9.43
30.00
54.50
59.54
Ø3.20 ±0.12
x4
15.00
4.00
36.50
68.50
105.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
polylactic acid
Part no.
1.1.41
Tolerance
All tolerances take according to IT12
SCALE: 1:2
Gripper hand left
DWG. NO.
42

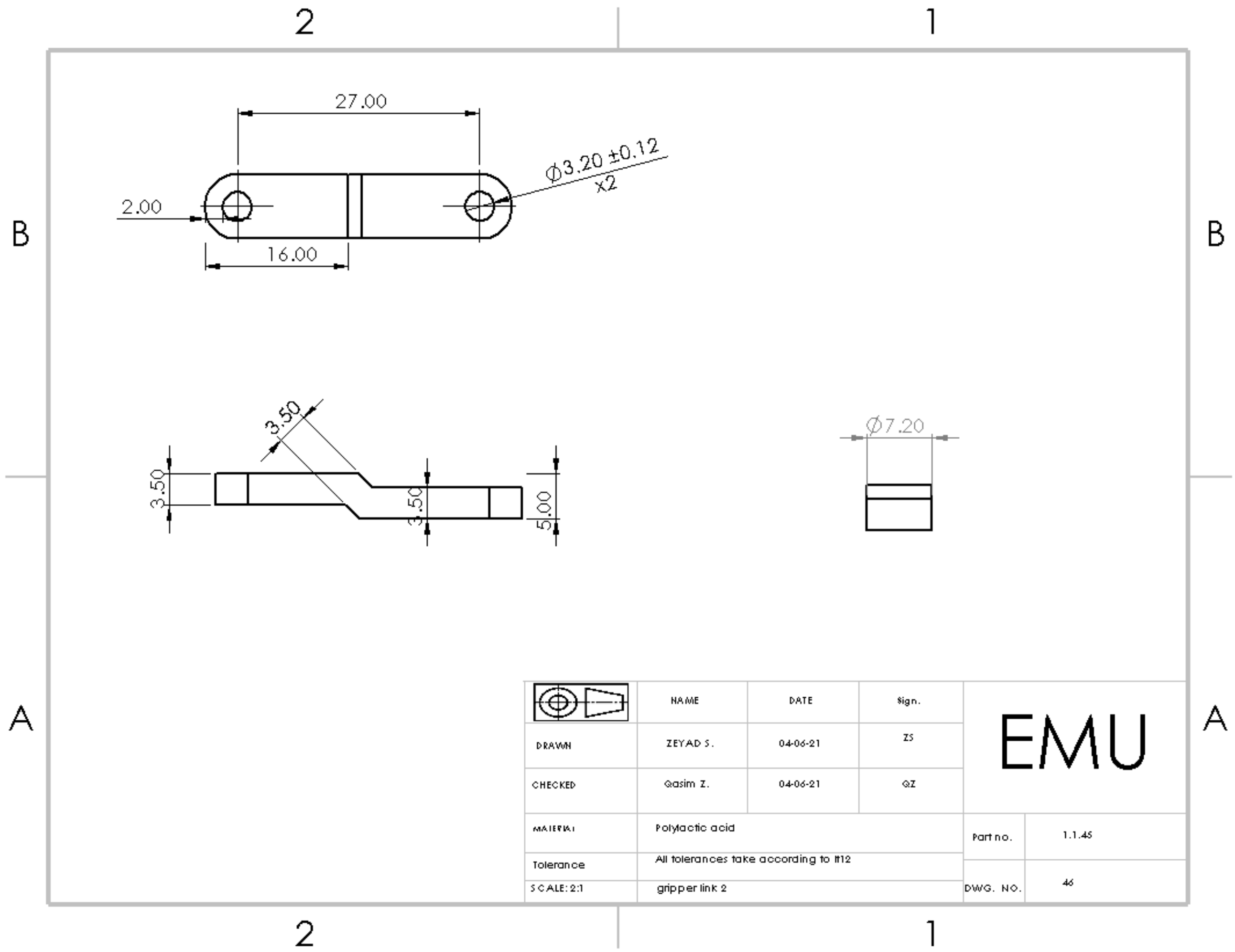

14.00
9.43
17.46
54.50
30.00
36.50
59.54
15.00
Ø3.20 ±0.12
X4
4.00
26.00
59.00
16.00
30.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
polylactic acid
Part no.
1.1.42
Tolerance
All tolerances take according to IT12
SCALE: 1:2
Gripper hand right
DWG. NO.
43

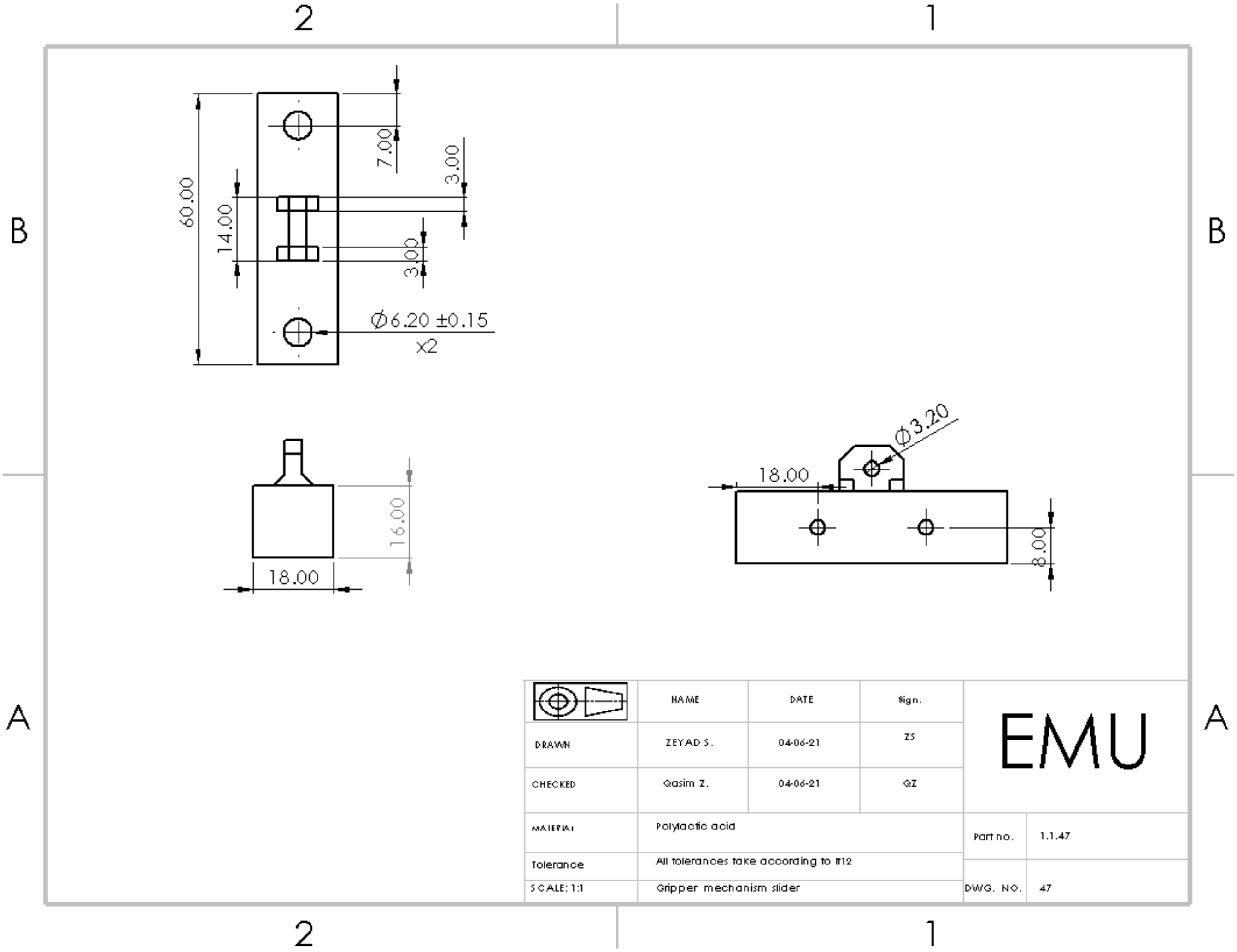


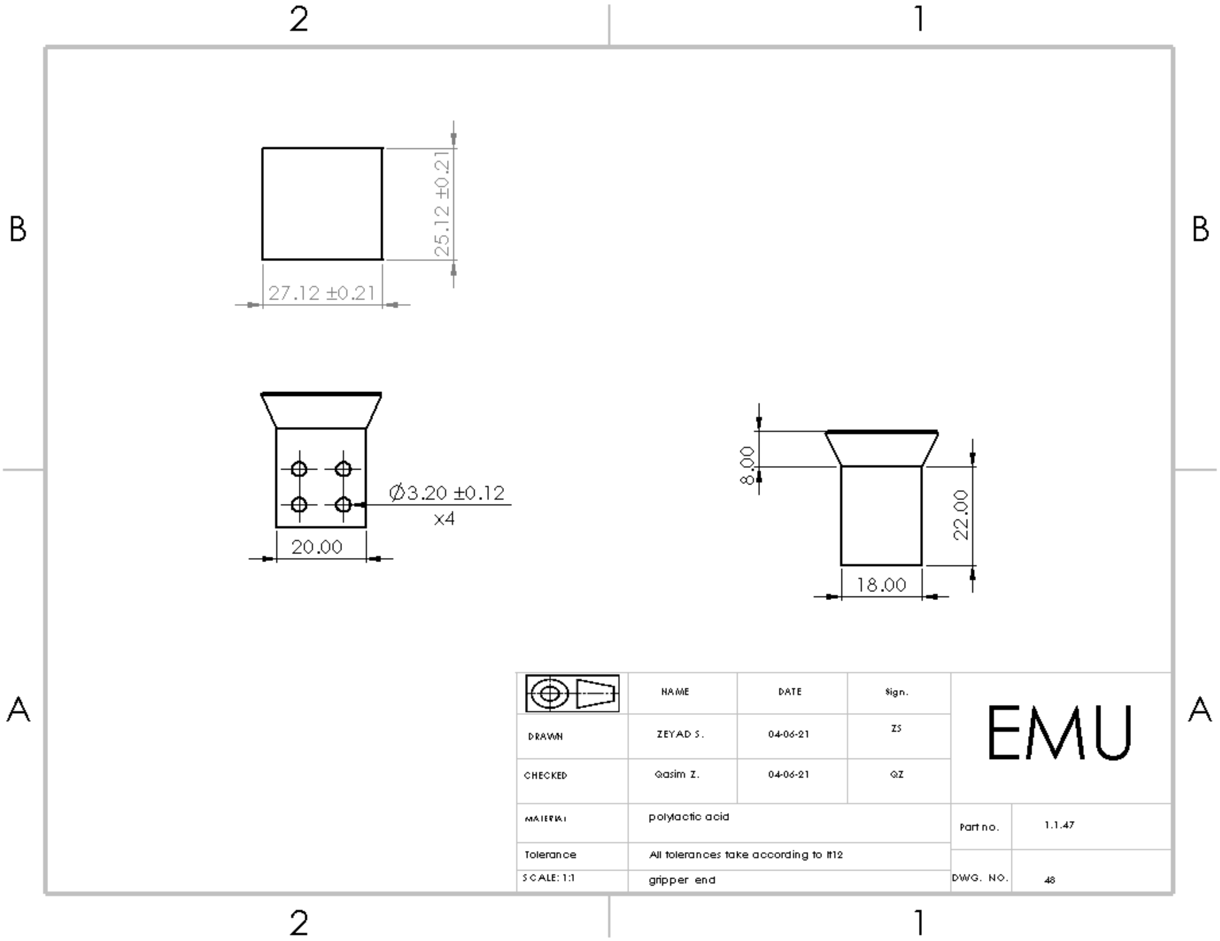
Ø6.00
125.00
Ø6.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Tolerance
All tolerances take according to It12
SCALE: 1:2
Gripper rail 6mm
Part no.
1.1.43
DWG. NO.
44

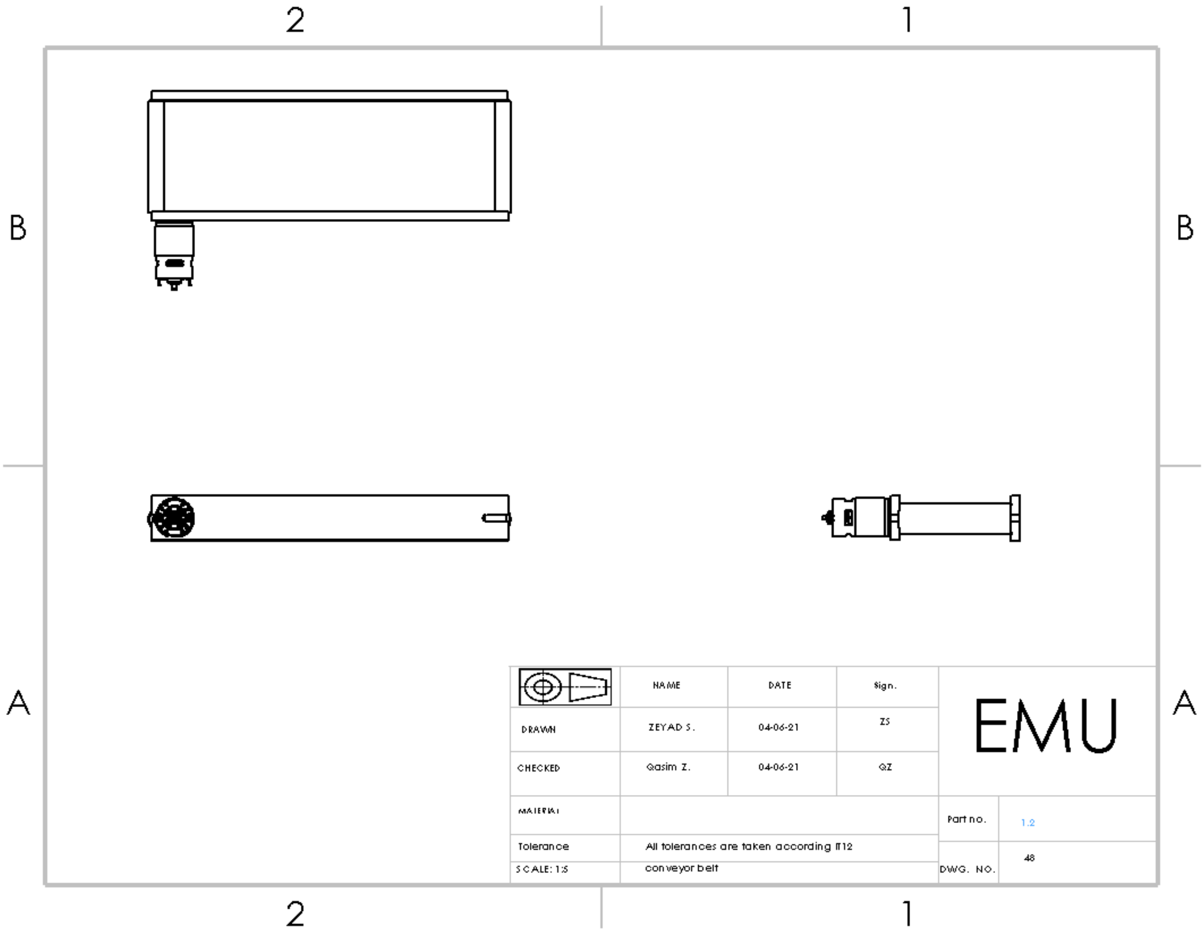


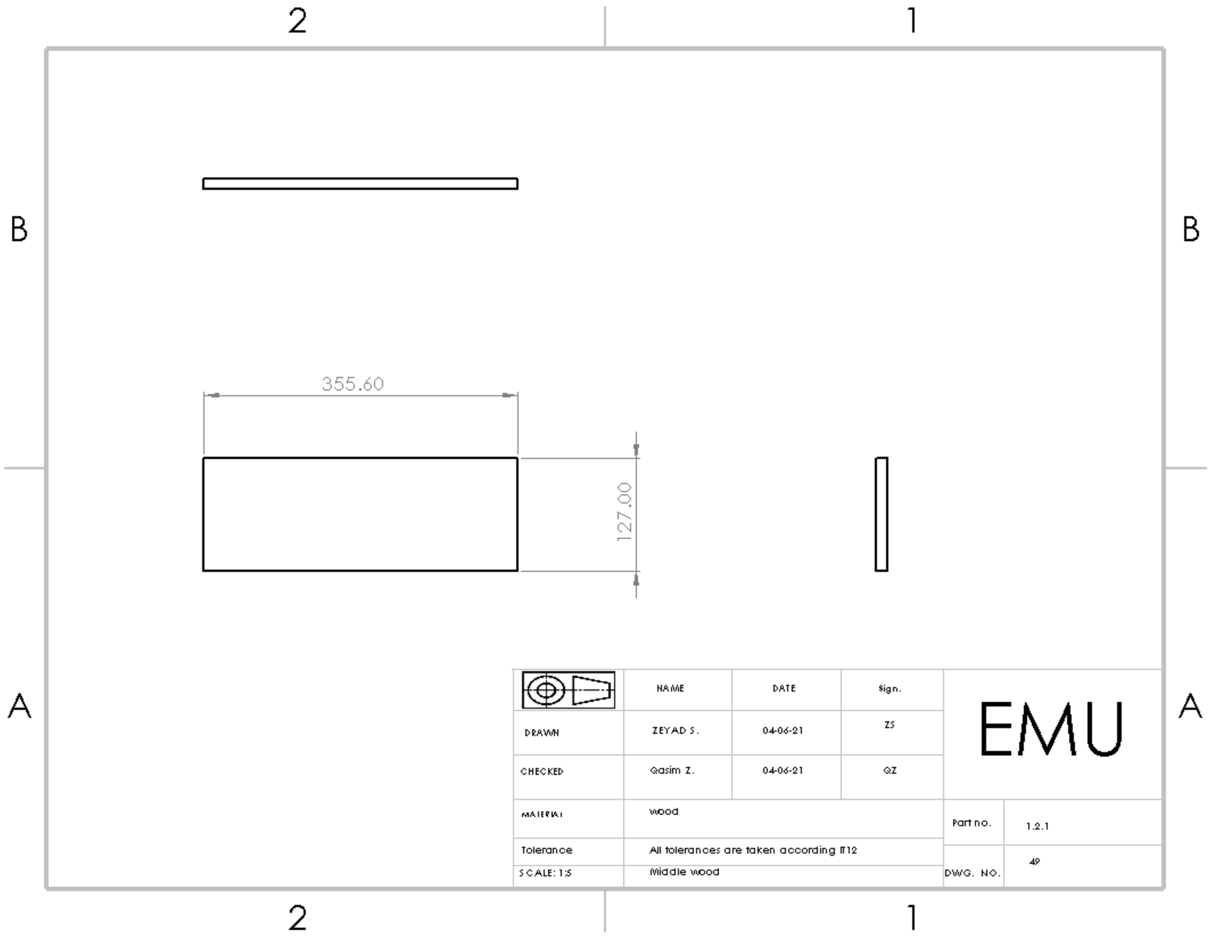
Ø3.20 ±0.12
X2
2.00
27.00
34.20
3.50
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
polylactic acid
Part no.
1.1.44
Tolerance
All tolerances take according to IT12
SCALE: 2:1
Gripper link 1
DWG. NO.
45


27.00
Ø3.20 ±0.12
x2
2.00
16.00
3.50
3.50
3.50
5.00
Ø7.20
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.46
Tolerance
All tolerances take according to IT12
SCALE: 2:1
gripper link 2
DWG. NO.
46

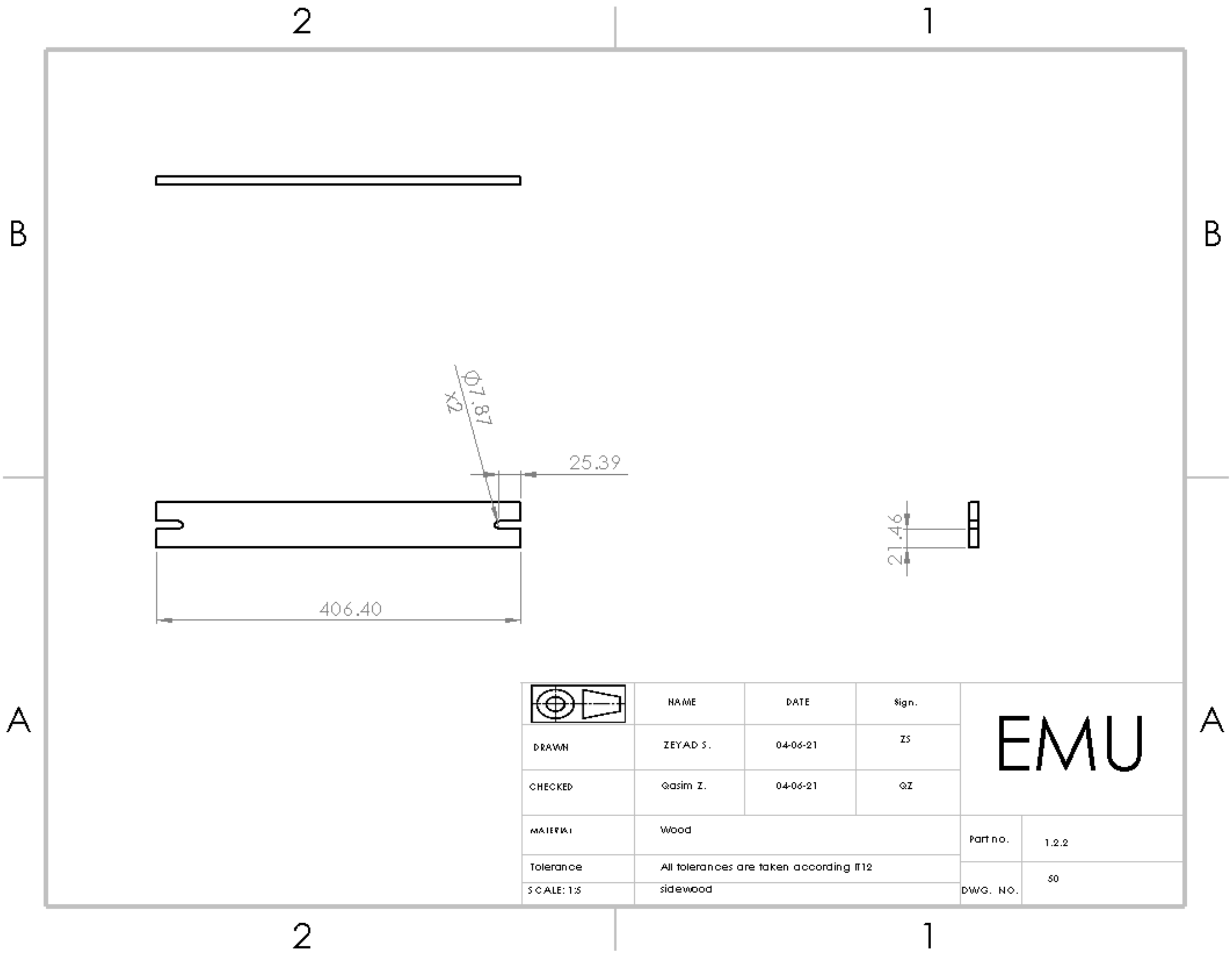

60.00
7.00
3.00
14.00
3.00
Ø6.20 ±0.15
x2
16.00
18.00
Ø3.20
18.00
8.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Polylactic acid
Part no.
1.1.47
Tolerance
All tolerances take according to IT12
SCALE: 1:1
Gripper mechanism slider
DWG. NO.
47

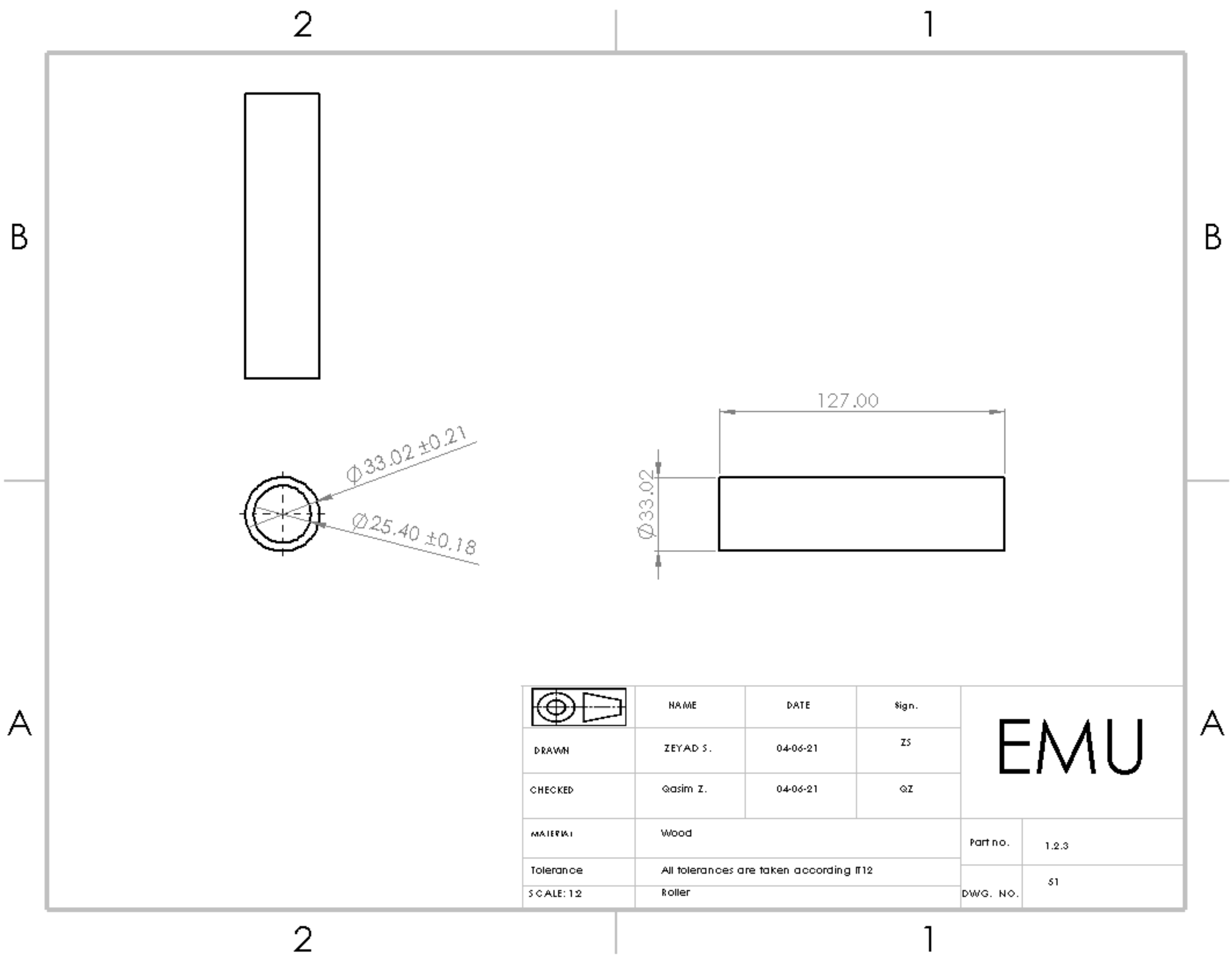

25.12 ±0.21
27.12 ±0.21
Ø3.20 ±0.12
x4
20.00
8.00
22.00
18.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
polylactic acid
Part no.
1.1.47
Tolerance
All tolerances take according to It12
SCALE: 1:1
gripper end
DWG. NO.
48


2
1
B
A
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Part no.
1.2
Tolerance
All tolerances are taken according IT12
SCALE: 1:5
conveyor belt
DWG. NO.
48

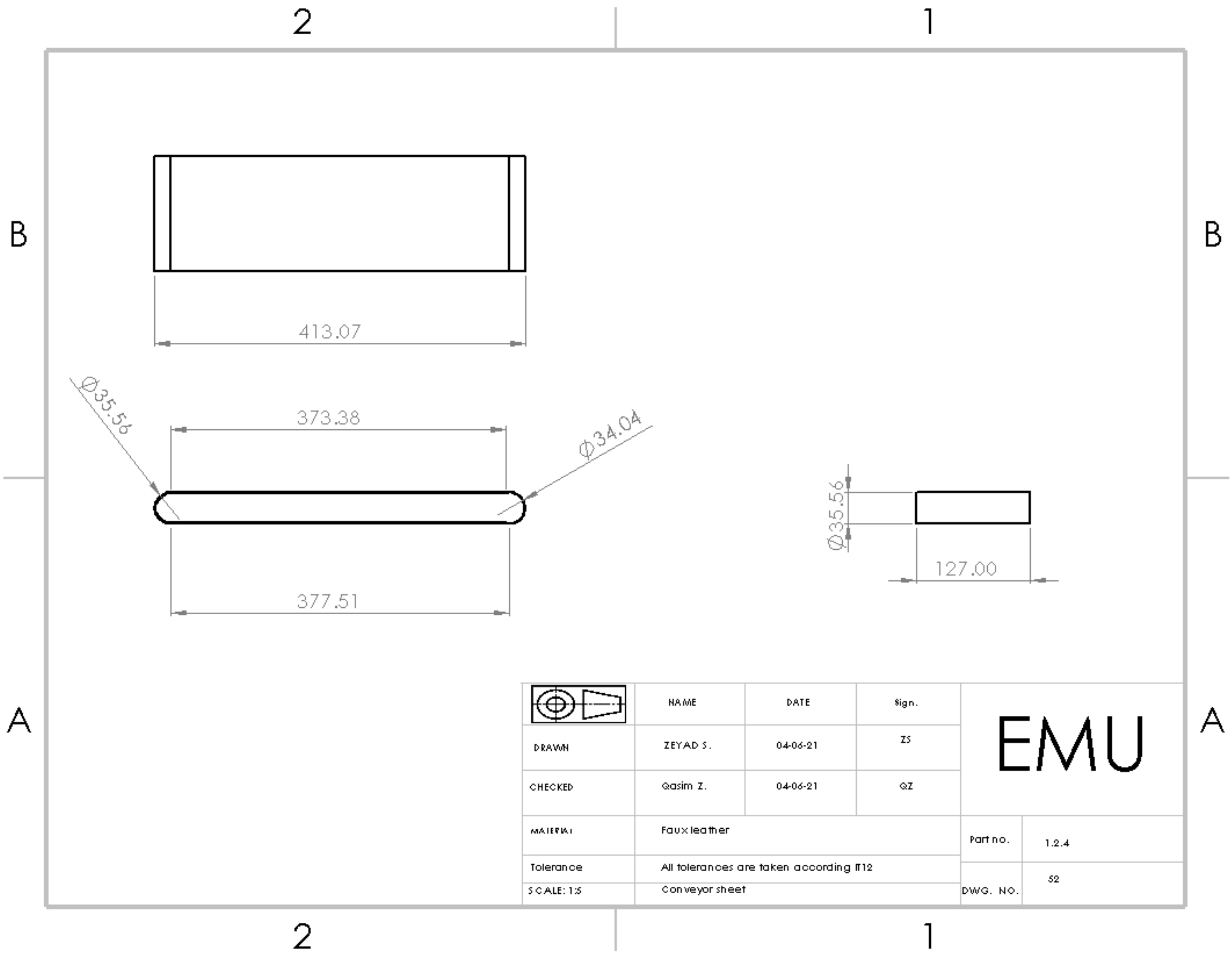


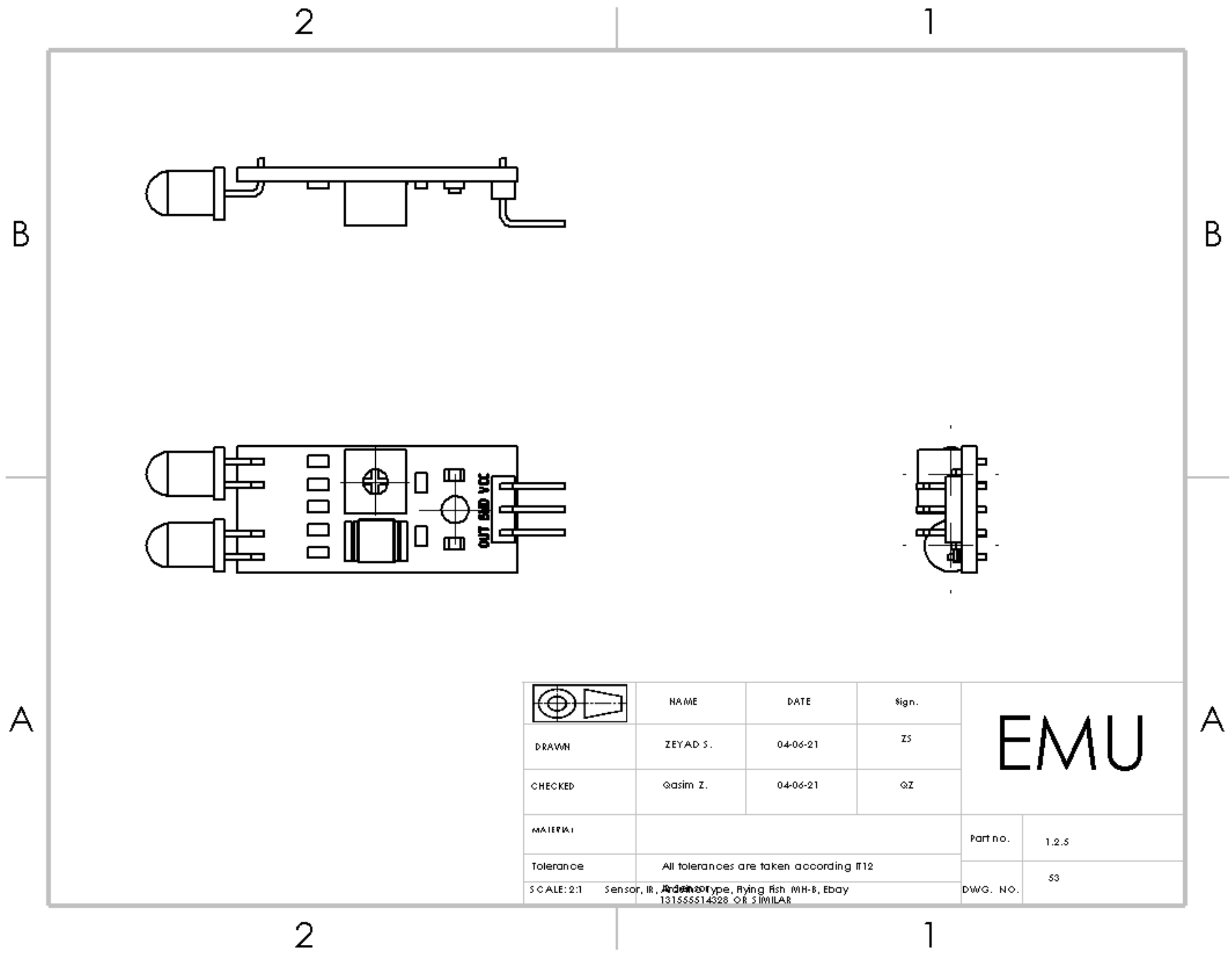
2
1
B
A
355.60
127.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
wood
Part no.
1.2.1
Tolerance
All tolerances are taken according IT12
SCALE: 1:5
Middle wood
DWG. NO.
49

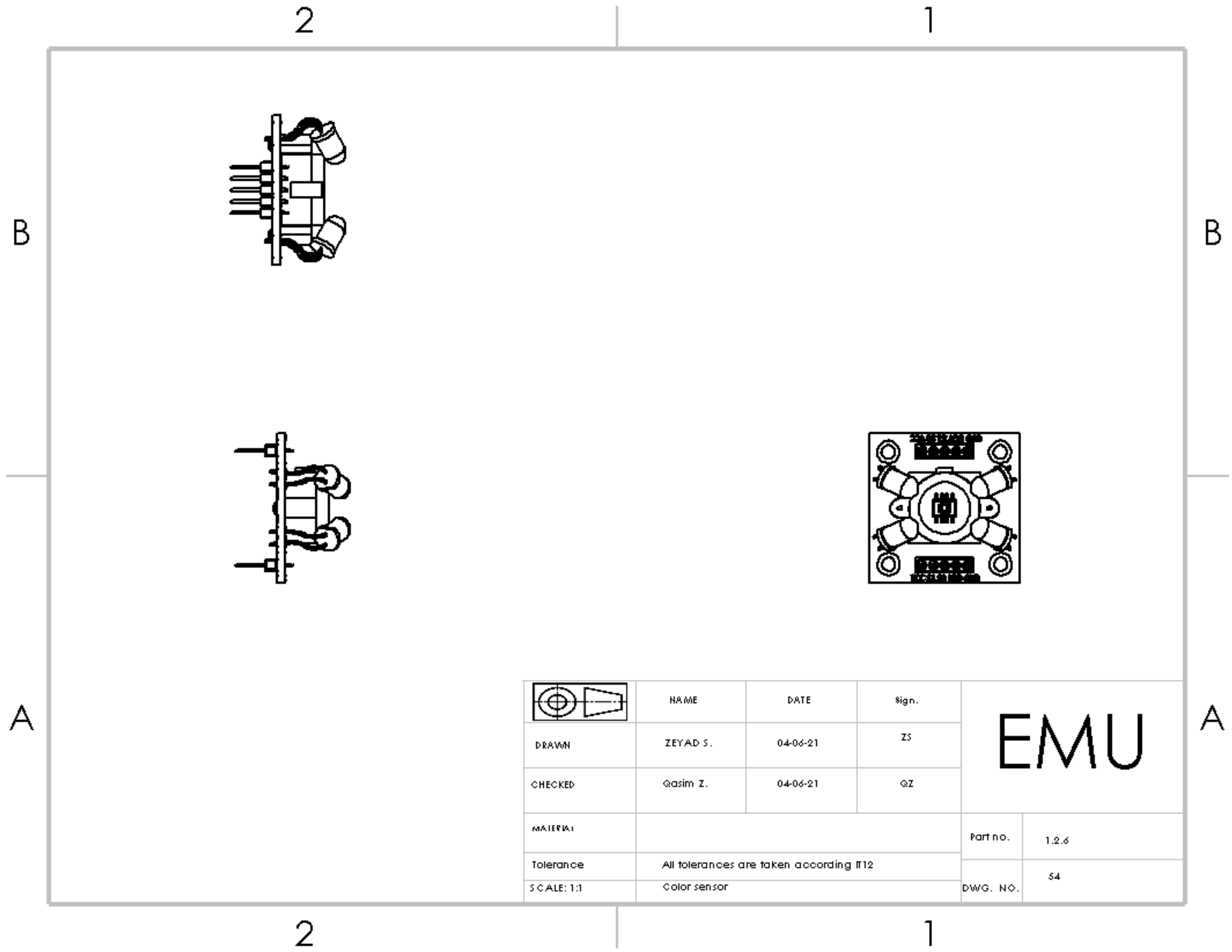

2
1
B
A
Φ7.87
X2
25.39
406.40
21.46
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
MATERIAL
Wood
Tolerance
All tolerances are taken according IT12
SCALE: 1:5
sidewood
Part no.
1.2.2
DWG. NO.
50
EMU

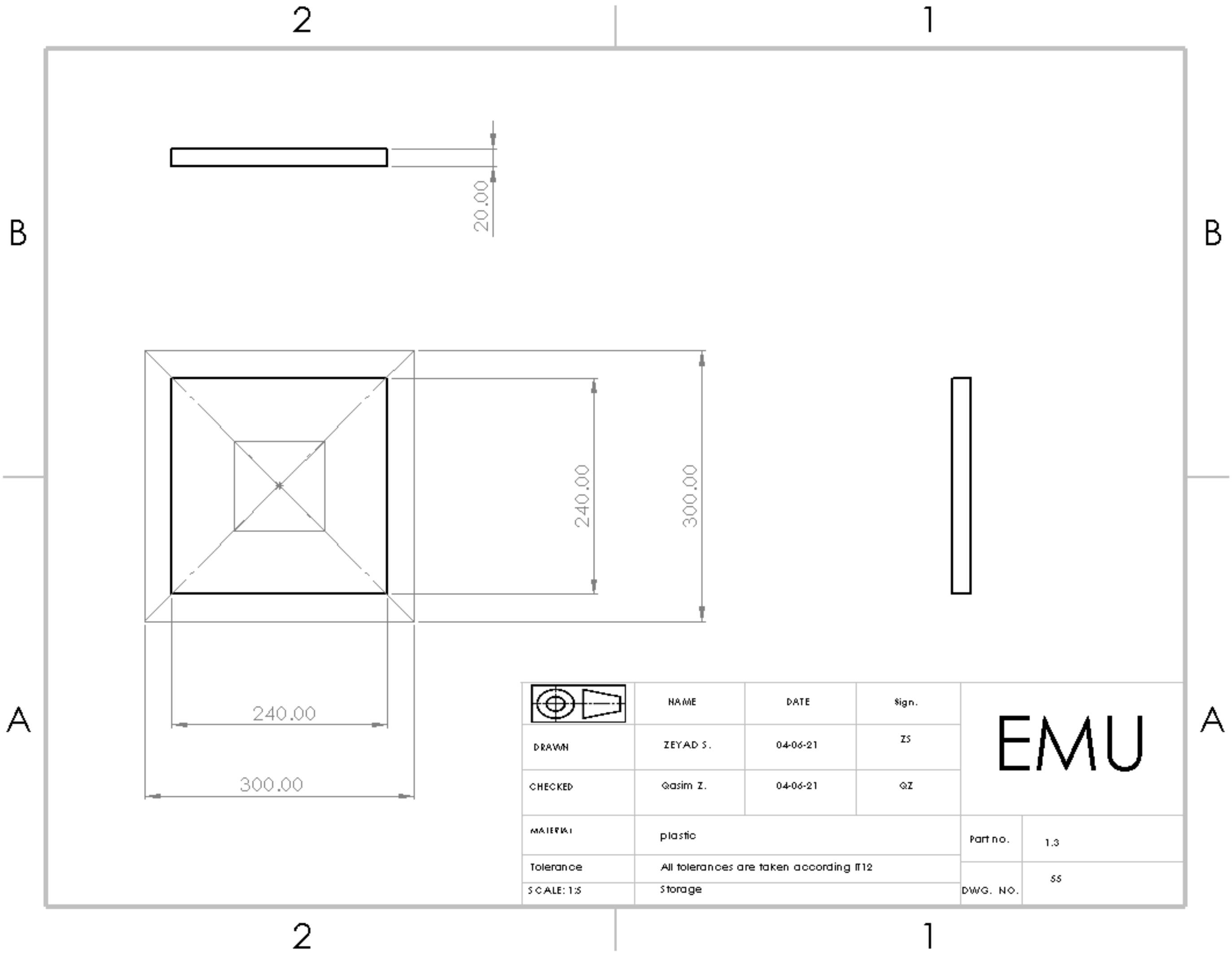


∅33.02 ±0.21
∅25.40 ±0.18
127.00
∅33.02
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
Wood
Part no.
1.2.3
Tolerance
All tolerances are taken according IT12
SCALE: 12
Roller
DWG. NO.
51


2
1
B
A
413.07
Ø35.56
373.38
Ø34.04
377.51
Ø35.56
127.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Faux leather
Part no.
1.2.4
Tolerance
All tolerances are taken according IT12
SCALE: 1:5
Conveyor sheet
DWG. NO.
52


2
1
B
A
OUT GND VCC
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Part no.
1.2.5
Tolerance
All tolerances are taken according IT12
SCALE: 2:1
Sensor, IR, Arduino Type, Flying Fish MH-B, Ebay
131555514328 OR SIMILAR
IR Sensor
DWG. NO.
53


2
1
B
A
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
Tolerance
All tolerances are taken according IT12
SCALE: 1:1
Color sensor
Part no.
1.2.6
DWG. NO.
54


2
1
B
A
20.00
240.00
300.00
240.00
300.00
NAME
DATE
Sign.
DRAWN
ZEYAD S.
04-06-21
ZS
CHECKED
Qasim Z.
04-06-21
QZ
EMU
MATERIAL
plastic
Part no.
1.3
Tolerance
All tolerances are taken according IT12
SCALE: 1:5
Storage
DWG. NO.
55

APPENDIX F: CODES

The following code is for the Scara robotic-arm:

```
#include <AccelStepper.h>

#include <Servo.h>

#define limitSwitchZ 11
#define limitSwitchY 10
#define limitSwitchX 9
#define limitSwitchA A3

AccelStepper stepperX (1, 2, 5);
AccelStepper stepperY(1, 3, 6);
AccelStepper stepperZ(1, 4, 7);
AccelStepper stepperA(1, 12, 13);

Servo gripperServo;

long initial_homingX=1;
long initial_homingY=1;
long initial_homingZ=1;
long initial_homingA=1;
int pooos=0;

void setup() {
  Serial.begin(9600);
  pinMode(A1,INPUT);
  pinMode(A2,INPUT);
  pinMode(limitSwitchX, INPUT_PULLUP);
  pinMode(limitSwitchY, INPUT_PULLUP);
  pinMode(limitSwitchZ, INPUT_PULLUP);
  pinMode(limitSwitchA, INPUT_PULLUP);


  stepperX.setMaxSpeed(500);
  stepperX.setAcceleration(250);
  stepperY.setMaxSpeed(1200);
  stepperY.setAcceleration(500);
  stepperZ.setMaxSpeed(500);
  stepperZ.setAcceleration(250);
  stepperA.setMaxSpeed(1500);
```

```
  stepperA.setAcceleration(500);
  gripperServo.attach(A0);

  gripperServo.write(40);

  delay(1000);
  homing();
}

void loop() {
  while(digitalRead(A2)== 0){
  delay(1000);

  while(digitalRead(A2)== 0){
  movement2();
  }
  }
    while(digitalRead(A1)== 0){
  movement1();
  }

  }
void homing(){
  //homing stepperA
  Serial.print("stepperA is homing...");
  while (digitalRead(limitSwitchA) != 1) {
      stepperA.moveTo(initial_homingA);
      initial_homingA++;
      stepperA.run();
      delay(0.5);
  }
   stepperA.setCurrentPosition(0);
    stepperA.setMaxSpeed(1500);
    stepperA.setAcceleration(500);
    initial_homingA=-1;

    while (digitalRead(limitSwitchA)== 1) {
      stepperA.moveTo(initial_homingA);
      stepperA.run();
      initial_homingA--;
      delay(0.5);
  }
      stepperA.setCurrentPosition(0);
      Serial.print("homing stepperA completed");
      stepperA.setMaxSpeed(1500);
      stepperA.setAcceleration(500);
```

```
   //homing stepperZ
   Serial.print("stepperZ is homing...");

 stepperZ.setCurrentPosition(0);


   //homing stepperY
    Serial.print("stepperY is homing...");
while (digitalRead(limitSwitchY)!= 1) {
   stepperY.moveTo(initial_homingY);
   initial_homingY++;
   stepperY.run();
   delay(0.5);
}
 stepperY.setCurrentPosition(0);
  stepperY.setMaxSpeed(500);
  stepperY.setAcceleration(500);
  initial_homingY=-1;

  while (digitalRead(limitSwitchY)==1) {
   stepperY.moveTo(initial_homingY);
   stepperY.run();
   initial_homingY--;
   delay(0.5);
}
   stepperY.setCurrentPosition(0);
   Serial.print("homing stepperY completed");
   stepperY.setMaxSpeed(1000);
   stepperY.setAcceleration(500);

   //homing stepperX
    Serial.print("stepperX is homing...");
while (digitalRead(limitSwitchX)!= 1) {
   stepperX.moveTo(initial_homingX);
   initial_homingX++;
   stepperX.run();
   delay(0.5);
}
 stepperX.setCurrentPosition(0);
  stepperX.setMaxSpeed(500);
  stepperX.setAcceleration(500);
  initial_homingX=-1;

  while (digitalRead(limitSwitchX)==1) {
   stepperX.moveTo(initial_homingX);
   stepperX.run();
   initial_homingX--;
```

```
      delay(0.5);
  }
      stepperX.setCurrentPosition(0);
      Serial.print("homing stepperX completed");
      stepperX.setMaxSpeed(500);
      stepperX.setAcceleration(500);

}

void movement1(){
  stepperX.setMaxSpeed(500);
  stepperX.setAcceleration(250);
  stepperY.setMaxSpeed(1200);
  stepperY.setAcceleration(500);
  stepperZ.setMaxSpeed(500);
  stepperZ.setAcceleration(250);
  stepperA.setMaxSpeed(1600);
  stepperA.setAcceleration(630);


  stepperA.moveTo(-2000);
  stepperY.moveTo(-1910);
  stepperX.moveTo(-1240);

  while((stepperA.currentPosition() != -2000 || stepperY.currentPosition() != -1910 ||
stepperX.currentPosition() != -1240 )){
    stepperA.run();
    stepperY.run();
    stepperX.run();
  }
  stepperA.moveTo(-2820);
  while((stepperA.currentPosition() != -2820)){
    stepperA.run();
  }

  if(stepperA.currentPosition() == -2820 && stepperY.currentPosition() == -1910 &&
stepperX.currentPosition() == -1240){
     gripperServo.write(145);
  }
  delay(1500);
    stepperA.moveTo(-2000);
  while((stepperA.currentPosition() != -2000)){
    stepperA.run();
  }

  stepperX.setMaxSpeed(500);
  stepperX.setAcceleration(250);
```

```
  stepperY.setMaxSpeed(1200);
  stepperY.setAcceleration(500);
  stepperZ.setMaxSpeed(500);
  stepperZ.setAcceleration(250);
  stepperA.setMaxSpeed(1500);
  stepperA.setAcceleration(500);

     stepperA.moveTo(-2000);
     stepperY.moveTo(-1400);
     stepperX.moveTo(-880);


  while((stepperA.currentPosition() != -2000 || stepperY.currentPosition() != -1400 ||
stepperX.currentPosition() != -880 )){
    stepperA.run();
    stepperY.run();
    stepperX.run();
    stepperZ.run();
  }
   stepperA.moveTo(-2800);
   while((stepperA.currentPosition() != -2800)){
    stepperA.run();
  }
     if(stepperA.currentPosition() == -2800 && stepperY.currentPosition() == -1400 &&
stepperX.currentPosition() == -880){
     gripperServo.write(40);
  }
  delay(1000);
  stepperA.moveTo(-1500);
   while((stepperA.currentPosition() != -1500)){
    stepperA.run();

  }
}

void movement2(){
    stepperX.setMaxSpeed(500);
  stepperX.setAcceleration(250);
  stepperY.setMaxSpeed(1200);
  stepperY.setAcceleration(500);
  stepperZ.setMaxSpeed(500);
  stepperZ.setAcceleration(250);
  stepperA.setMaxSpeed(1600);
  stepperA.setAcceleration(630);

 stepperA.moveTo(-2000);
  stepperY.moveTo(-1610);
```

```
  stepperX.moveTo(-1390);

  while((stepperA.currentPosition() != -2000 || stepperY.currentPosition() != -1610 ||
stepperX.currentPosition() != -1390 )){
    stepperA.run();
    stepperY.run();
    stepperX.run();
  }
  stepperA.moveTo(-2825);
  while((stepperA.currentPosition() != -2825)){
    stepperA.run();
  }

  if(stepperA.currentPosition() == -2825 && stepperY.currentPosition() == -1610 &&
stepperX.currentPosition() == -1390){
     gripperServo.write(140);
  }
    stepperA.moveTo(-2000);
  while((stepperA.currentPosition() != -2000)){
    stepperA.run();
  }

  stepperX.setMaxSpeed(700);
  stepperX.setAcceleration(350);
  stepperY.setMaxSpeed(1200);
  stepperY.setAcceleration(500);
  stepperZ.setMaxSpeed(500);
  stepperZ.setAcceleration(250);
  stepperA.setMaxSpeed(1500);
  stepperA.setAcceleration(500);

     stepperA.moveTo(-2000);
     stepperY.moveTo(-450);
     stepperX.moveTo(-150);

while((stepperA.currentPosition() != -2000 || stepperY.currentPosition() != -450 ||
stepperX.currentPosition() != -150 )){
    stepperA.run();
    stepperY.run();
    stepperX.run();
  }
  stepperA.moveTo(-2800);
  while((stepperA.currentPosition() != -2800)){
    stepperA.run();
  }
     if(stepperA.currentPosition() == -2800 && stepperY.currentPosition() == -450 &&
stepperX.currentPosition() == -150){
```

```
    gripperServo.write(40);
  }
  delay(1500);

    stepperA.moveTo(-2000);
  while((stepperA.currentPosition() != -2000)){
    stepperA.run();
  }
}
```

The following code is for the conveyor belts:

```
#define in1 9
#define in2 8
#define in3 7
#define in4 6
#define enA 10
#define enB 5

const int S0=2;
const int S1=3;
const int S2=4;
const int S3=11;
const int sensorOut=12;

int frequency = 0;
int color=0;

void setup() {

  pinMode(in1,OUTPUT);
  pinMode(in2,OUTPUT);
  pinMode(in3,OUTPUT);
  pinMode(in4,OUTPUT);

   pinMode(S0,OUTPUT);
   pinMode(S1,OUTPUT);
   pinMode(S2,OUTPUT);
   pinMode(S3,OUTPUT);
   pinMode(sensorOut,INPUT);

  digitalWrite(S0,HIGH);
  digitalWrite(S1,LOW);

  pinMode(enA,OUTPUT);
  pinMode(enB,OUTPUT);

   pinMode(A0, INPUT);
```

```
  pinMode(A2, INPUT);
  Serial.begin(9600);

}

void loop() {

 int LEFT_SENSOR = digitalRead(A0);
 int COV2_SENSOR = digitalRead(A2);

        //CONVEYOR 1 MOVEMENT
        if( LEFT_SENSOR==0 ){
          digitalWrite(in1, HIGH);
          digitalWrite(in2, LOW);
          analogWrite(enA, 100);
        }
        color = readColor();
 delay(10);
 switch (color) {
  case 1:
    delay(1000);
    digitalWrite(in1, LOW);
    digitalWrite(in2, LOW);
    analogWrite(enA, 0);
  break;
  case 2:
    delay(400);
    digitalWrite(in1, LOW);
    digitalWrite(in2, LOW);
    analogWrite(enA, 0);
  break;
  case 0:
  break;
 }
        // CONVEYOR 2 MOVEMENT
        if(COV2_SENSOR==0 ){
          delay(6000) ;
          digitalWrite(in3, HIGH);
          digitalWrite(in4, LOW);
          analogWrite(enB, 100);
          delay(3000);
            digitalWrite(in3, LOW);
          digitalWrite(in4, LOW);
          analogWrite(enB, 0);


        }
```

```
      color=0
  }
  int readColor() {
    // Setting red filtered photodiodes to be read
  digitalWrite(S2, LOW);
  digitalWrite(S3, LOW);
  // Reading the output frequency
  frequency = pulseIn(sensorOut, LOW);
  int R = frequency;
  // Printing the value on the serial monitor
  Serial.print("R= ");//printing name
  Serial.print(frequency);//printing RED color frequency
  Serial.print("  ");
  delay(50);
  // Setting Green filtered photodiodes to be read
  digitalWrite(S2, HIGH);
  digitalWrite(S3, HIGH);
  // Reading the output frequency
  frequency = pulseIn(sensorOut, LOW);
  int G = frequency;
  // Printing the value on the serial monitor
  Serial.print("G= ");//printing name
  Serial.print(frequency);//printing RED color frequency
  Serial.print("  ");
  delay(50);
  // Setting Blue filtered photodiodes to be read
  digitalWrite(S2, LOW);
  digitalWrite(S3, HIGH);
  // Reading the output frequency
  frequency = pulseIn(sensorOut, LOW);
  int B = frequency;
  // Printing the value on the serial monitor
  Serial.print("B= ");//printing name
  Serial.print(frequency);//printing RED color frequency
  Serial.println("  ");
  delay(50);
 if(R<85 & R>30 & G<80 & G>25){
   color = 1; // GREEN
  }
  if(G<150 & G>75 & B<95 &B>35){
   color = 2; // Orange
  }
   return color;
  }
```

APPENDIX G: SPECIFCATION SHEETS

Table 11 Servo motor specification sheet

Item	Specification
Size	40.4*19.9*37.5mm
Weight	58g
Gear type	5 Metal Gear
Limit angle	180°±5°
Bearing	DUAL BB
Horn gear spline	
Horn type	Metal
Case	Engineering plastics(Polyamide)
Connector wire	FP: 240mm±5mm JR: 300mm±5mm
Motor	DC motor
Splash water resistance	No

Item	Specification
Operation voltage	4.8V
Idle current	5mA
No load speed	0.17sec/60°
Running current	350mA
Peak stall torque	9.0kg.cm
Stall current	1500mA

Item	Specification
Command signal	Pulse width modification
Amplifier type	Digital controller
Pulse width range	500～2500usec
Neutral position	1500usec
Running degree	180±2°(when 500～2500usec)
Dead band width	4 use
Rotating direction	Counterclockwise (when 500～2500usec)

Table 12 PLA Spec. Sheet

Identification of Material	
Chemical Name	Polylactic Acid
Chemical Family	Thermoplastic Polylactic Acid
Use	3D Printing

Table 13 Printing Spec. Sheet

Printing settings guideline	
Nozzle temp.	220+- 10 degrees celsius
Bed temp.	Approximately 60 degrees celsius
Active cooling Fan	Yes 100%
Layer height	0.08 – 0.2 mm
Shell thickness	0.4 – 0.8 mm
Printing speed	40 – 80 mm/s

Table 14 Arduino Spec. Sheet

Microcontroller	ATmega328P – 8 bit AVR family microcontroller
Operating Voltage	5V
Recommended Input Voltage	7-12V
Input Voltage Limits	6-20V
Analog Input Pins	6 (A0 – A5)
Digital I/O Pins	14 (Out of which 6 provide PWM output)
DC Current on I/O Pins	40 mA
DC Current on 3.3V Pin	50 mA
Flash Memory	32 KB (0.5 KB is used for Bootloader)
SRAM	2 KB
Frequency (Clock Speed)	16 MHz

Table 15 NEMA 17 Stepper motor spec. sheet.

Item	Specification
Manufacturer Part Number:	17HS13-0316S
Motor Type:	Unipolar Stepper
Step Angle:	1.8 deg
Holding Torque:	15.8Ncm(22.4oz.in)
Rated Current/phase:	0.31A
Voltage:	12V
Phase Resistance:	38.5ohms
Inductance:	21mH ± 20%(1KHz)

Item	Specification
Frame Size:	42 x 42mm
Shaft Diameter:	Φ5mm
Front Shaft Length:	24mm
Number of Leads:	6
Lead Length:	300mm
Weight:	220g
Body Length:	33mm

Table 16 12V-100RPM DC Gear Motor Spec. Sheet

Item	Specification
Model:	GA25YN370
Rated power:	3.5W
Product type:	Brush dc motor
Rated voltage:	5-12V
Rated current:	0.06A
Outer diameter	25mm/1.0 in
Rated Torque:	4.2kg/cm
Stalled torque:	10.5kgf.cm
Shaft diameter:	3mm /0.1in
Shaft length:	10mm/0.4in
Weight:	96g/3.4oz