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RUHR-UNIVERSITÄT BOCHUM



CONCEPTUAL DESIGN AND PROTOTYPE OF A DANCER SYSTEM

BACHELOR THESIS

PLACE 2023



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Abstract:

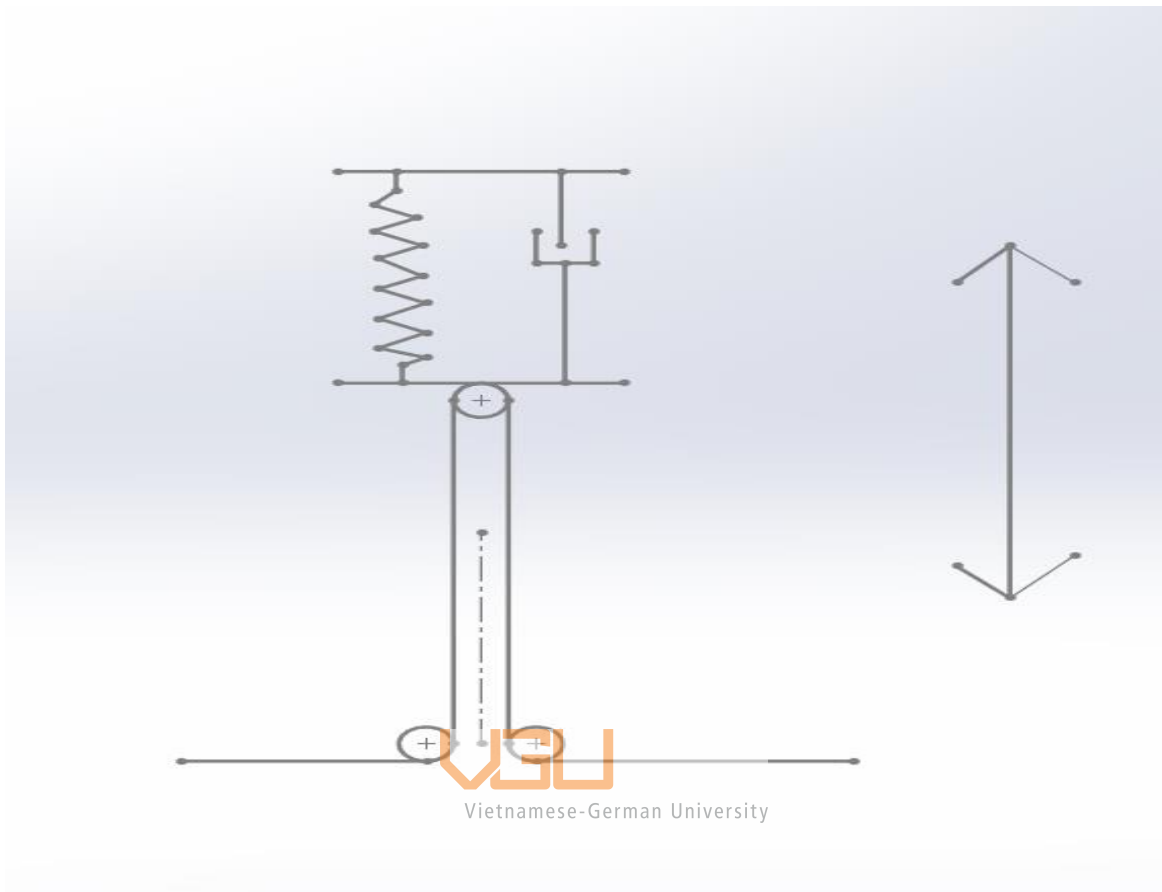


Figure 1 2D sketch of a dancer system

In some web-conveyed systems, such as roll-to-roll systems, printing machines, etc., a dancer system is provided to maintain and control the web tension with high precision. Dancer control systems play a significant role in preserving and adjusting consistent tension while transporting a web. Furthermore, properly designing a tension control system helps to stabilize and optimize the web material quality.

The components and simulation of a dancer system are designed and conducted on two programs: Solidwork for designing and manufacturing, TIA portal for simulating and programming.

The prototype attempted to meet three goals: the low price of maintaining and manufacturing, the ability to stabilize and adjust the tension in web material, and long working lifetime. However, the design still needs further development to optimize the working efficiency.

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1. Introduction:

1.1 Literature review:

A dancer roll system is a free moving idler, loaded with a force that is imparted to the web as tension as a result of the web positioning the dancer.

The dancer system includes a dancer roller for imparting tension to the web being conveyed, a dancer roller support for rotatably supporting the dancer roller, and a dancer roller support for supporting the dancer roller through the dancer roller support to adjust the tension imparted to the web by the dancer roller.

The dancer's arm should be made with the least amount of mass possible. "A body in motion tends to stay in motion, and a body at rest tends to stay at rest." (The first law of motion established by Newton). The arm's mass or inertia will influence the forces required to overcome a change in the resistive states in the dancer's arm. The addition of a compliant web as the control coupling complicates the challenge. Because the dancer roll system is a position-controlled device, with web velocity and web material coupling as the governing factors, consideration should be given to constructing a design with least mass in the dancer roll as the main priority. This is especially important for low tension webs. system of dancers. A correctly built dancer system will be able to absorb transients to the web without introducing extra stress difficulties.



Load cells are sensors that are specifically intended to measure tension in a web and convert the tension force into a proportional electrical signal. In the tension loop control, the electrical signal is amplified and used for display and/or feedback.

Strain gauges are used as the sensing element in the vast majority of load cell designs. The strain gauge element is available in foil or silicon. Load cells are often mounted in pairs, each with its own idler roll. When a tension force is applied, the strain gauges are internally attached to a mechanical structure that deflects. The bridge reports strain as an electrical signal proportional to the amount of force applied.

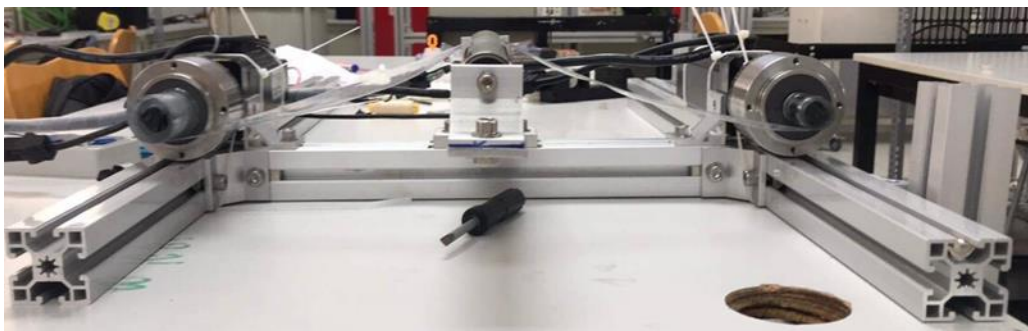


Figure 2: Load cell

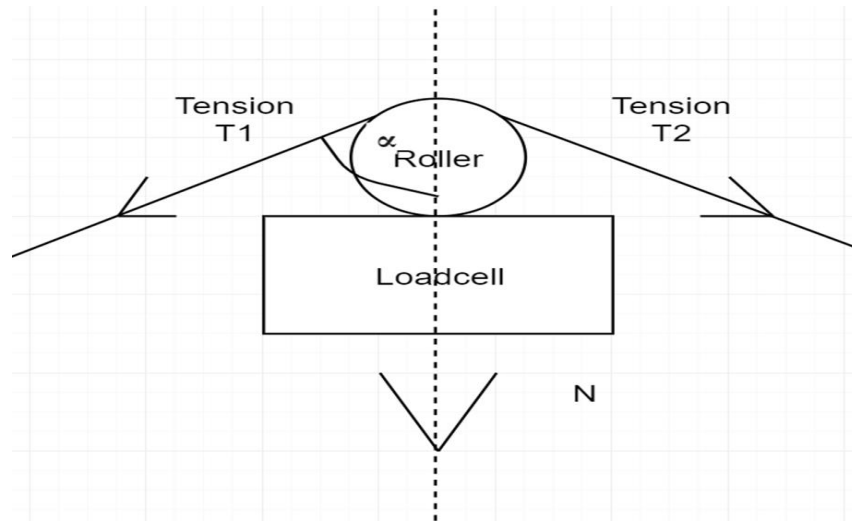


Figure 3 F.B.D of load cell

The fact that dancer tension controls give a specific amount of web storage means that the dancers accumulate a specific length of web in the machine direction. Its web aggregation ability allows it to absorb tension changes caused by a variety of reasons such as out-of-round rolls. Thus, by absorbing changes in stress zones, downstream web tension is maintained and smoothed. Accumulation also provides mechanical stability for high roll build ratios throughout the unwind and rewind procedures.



A material web can consist of anything from extremely thin foils and polymers to a wide range of textiles, papers, metals, and composites. Roll-to-roll systems are characterized as a continuous roll of flexible, thin roll or strip of material. The idea is to keep the web taut at all times. Dancer systems are critical for managing web tension and material location while it is carried through web machines for processing. A web cannot be controlled until the proper tension is applied.

1.2 Background study:

- **Component:** Without adequate tension, web cannot be controlled, and dancer systems give control as the material goes through the wind and unwind processes. A dancer system is nothing more than a preloaded idler arm. Its pressures and positions are determined from web tension during the winding and unwinding processes.
- **Tension zone:** every web transported machines have a number of tension zones that need to be take into account to ensure the quality and tension of the web. Tension zones are the areas between two places of a web that modify and affect tension. Each tension

zone is unique and must have independent feedback loop to maintain the correct web tension in the whole system

- **Closed loop/Open loop system:** (control method)

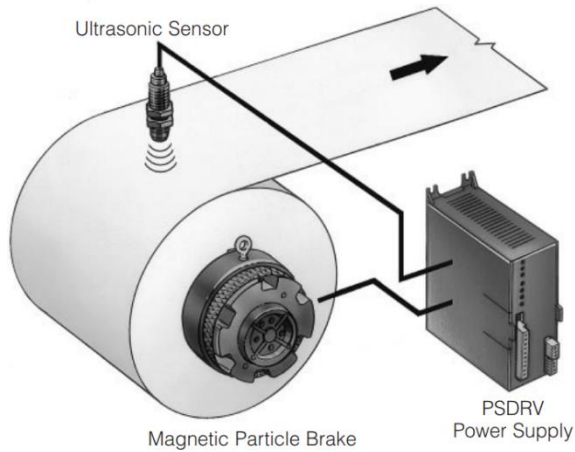


Figure 5 Open loop system

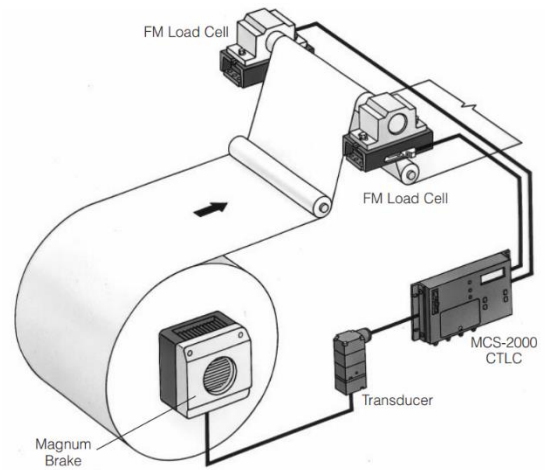


Figure 4 Closed loop system

Dancers are utilized in close-loop control systems as they have idler rolls or arms that are preloaded for one direction, and the web move them in opposite direction. Secondly, as web is drawn all over a dancer roll moves in response to any changes in its positions, is a result of a change in web tension.

- **Dancer mechanism:**

This is a basic description of dancer mechanism; we need to look closer to the force acting on the dancer roll in order to determine the effects of all the parameters on the dancer design. In its simplest design of a dancer roll and its loads are suspended by the web tension, as the tension increased while the roll rises.

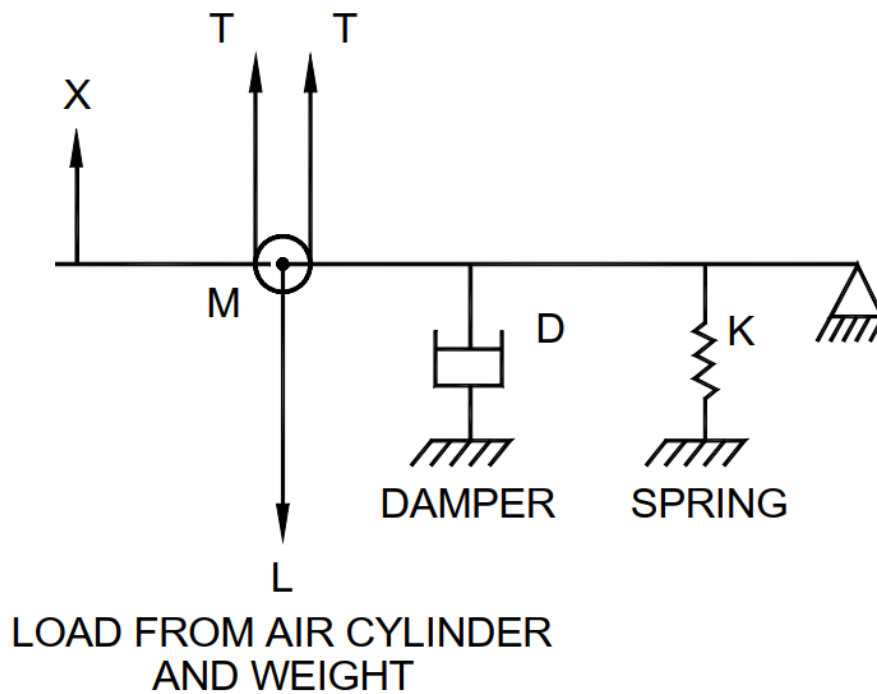


Figure 6 F.B.D of the primer dancer system



-The load on the dancer sets the tension in the web:

$$2T = L + M \frac{d^2 x}{dt^2} + D \frac{dx}{dt} + Kx$$

The term of the equation are as follows:

T= Web tension (N)

L= Load set by the cylinder plus the weight (N)

M= Mass of the dancer (kg)

$\frac{d^2 x}{dt^2}$ = acceleration = a (m/s²) | F=Ma

$\frac{dx}{dt}$ = velocity of damper = v (m/s)

K= spring rate

D= damping factor

X= deflection from set point (m)

The idea of the design is how to make the velocity of the damper (v), the deflection (x), and the mass of the roller (M) is approximately equal to zero, so that it can prevent the roller from oscillating to make the tension when loading is constant.

- **Roll to roll system:** Continuous processing of a flexible substrate as it is delivered along a roller-based processing line is involved in roll-to-roll materials manufacturing. The output is rolls of completed material that are manufactured in a cost-effective and efficient manner.



Figure 7 Roll-to-roll system in VGU's lab

- **Currently used type of dancers:**

PIVOT ARM DANCER

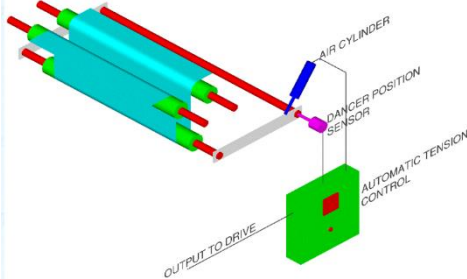


Figure 8 Pivot arm dancer

Advantage:

- One of the simplest designs
- Most common design of dancer roll tension control
- Least expensive design
- Can be designed with a large or small of web storage

LINEAR DANCER

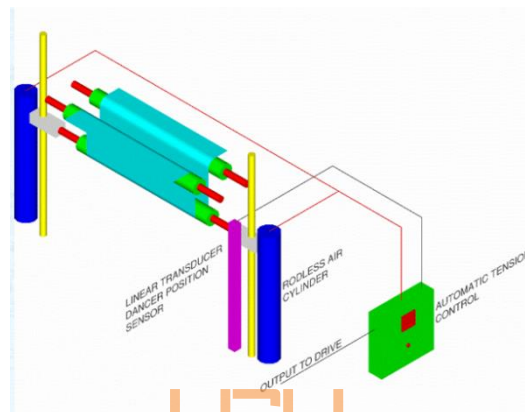


Figure 9 Linear dancer
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Advantage:

- This design is compact.
- Large amounts of web storage are available. Especially with multiple web passes. Excellent design for accumulation needs, to allow splices on the fly.
- Small package can be easy to install in existing equipment.

ROTATIONAL DANCER

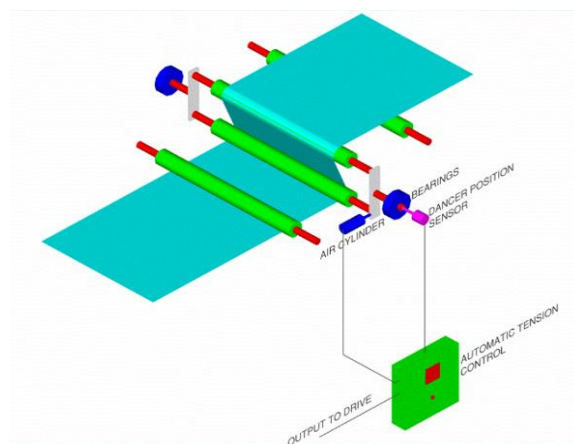


Figure 10 Rotational dancer

Advantage:

- This type of dancer roll design is not affected by gravity. Its dancer rollers are counterbalanced with each other.
- Momentum and inertia are greatly decreased with the “push/pull” motion.
- Generous web storage in a small package.

The design of my dancer system is based mainly on the design of linear dancer, but with a little change to utilized on the roll-to-roll system in VGU’s lab.

1.3 Scope of implementation:

The design is utilized for a roll-to-roll system at VGU’s lab, to maintain and adjusting tension of the web. In the requirement of the design, my prototype avoided using pneumatic cylinder and changed to a damper spring (shock absorber), as it can simplify to manufacturing process due to the tension appear in the whole system is low (about 50N). The most important thing of using a shock absorber is the cost of manufacturing and preserving in extremely low compared to others dancer system in industry.

The implementation of the dancer system will be divided into:

- Design a dancer system via SolidWork.
- Choosing the available products from the market: slider bar, square slider, lead screw mechanism, metal and aluminum sheet, shock absorber, bearing pillow blocks...
- Sketch a cutting file (.dxf) of parts: Aluminum and metal sheet, connector...
- Cutting above parts by “TruLaser 2030” laser cutting machine.
- Turning of a dancer roller shaft.
- Assembly of dancer base.
- Electrical wiring of PLC device and stepper motor.
- Programming the motion of lead screw mechanism via TIA portal.
- Test the program.
- Full assembly of dancer system
- Test the tension load to the dancer roll with load cell and programmed systems.
- Final checked and report.

With an HMI and PLC device make the system easier to be controlled or programmed.

1.4 Objectives:

The goal of the thesis is to adjust the tension of the web in the range of 50N from the lowest point to the highest point while the roll-to-roll system still operate smoothly. In order to achieve this requirement, the dancer roller must load tension and move up and down with as little oscillate as possible. Furthermore, the roller can move at five points at five different tensions along the moving path.

The dancer roller can be controlled with a device or a computer (laptop).

The tests were conducted by letting the dancer roller moving up and down, and then note down the tension forces at five different points within the moving path.

The result will be:

- User can adjust tension in the range of 5kN
- Roller moves smoothly
- Low tolerance

2. Methodology:

2.1: Design principle:

The first step is trying to identify the system and considerate existing technology. For dancer system, this product will be the tension controller in roll-to-roll system. In this field, many related designs were conducted by many manufacturers. After considering different types of models and making research, I have concluded a final design that fit the roll-to-roll system in VGU's lab, the design has to be sleek, light, and affordable. However, small error in the design is unavoidable.

Functionality:

The dancer roller will be able to perform basic task such as move up and down by lead screw mechanism attached with square sliders, rotate by ball bearing, hold the web on the roller to maintain and adjust tension.

Repeatability:

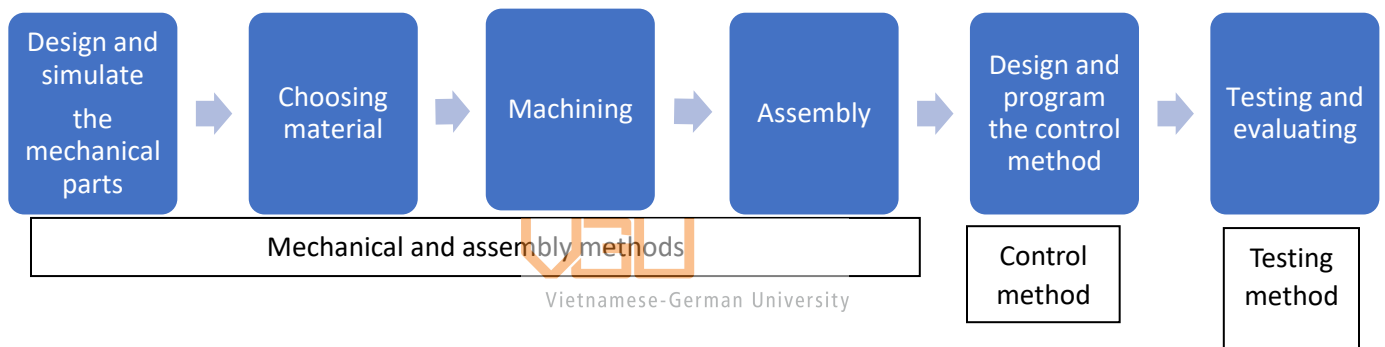
This model can have the ability to return to home position and repeatedly perform the given task. For my design, when hitting the home button, the dancer roller automatically returns to the lowest point which has the lowest tension, sensed by an asymptotic sensor.

Motion and speed:

Speed: after conducted many tests with the lead screw mechanism run by a stepper motor, we found that the systems operate smooth within 500 pulses to 3000 pulses.

Motion: the base of the dancer is moving in vertical direction by lead screw mechanism, which transform rotational motion of stepper motor to vertical motion of the base. The dancer roller is rotate with the direction of the Wind/Unwind roller of roll-to-roll system to maintain the torque of it so that can maintain the tension of the web. The vertical motion can be controlled by PLC systems programmed via TIA Portal.

Payload: The tension when dancer is on the lowest point is approximate 40N and the highest point is 110N



- For mechanical methods, the prototype has to be low weight by choosing suitable material, as I choose the aluminum for idle sheet. When designing and simulating, I choose SolidWork as design and simulate program, this method is conducted to ensured that the system would run smoothly when operating.
- For assembly method, the prototype was assembled mainly with bolts and nuts. Bolts and nuts were chosen when sketching and assembling with Solidwork.
- For control method, I decided to use PLC program as I had learned in MEN major of VGU. Firstly, I designed the electrical diagram of the stepper motor and PLC device based on the existed diagram, and then programmed the motion of it via TIA portal.
- For testing method, I tested the tension loaded by the load cell of the roll-to-roll system, from the lowest point to the highest point, noted down the data. Finally, I found out the pulse need to adjust 10N of the tension forces loaded on the dancer roller.

2.2 Mechanical design:

2.2.1 Parts and components:

The design is divided into 4 main parts: Base, roller shaft and bearing, leadscrew mechanism and connector (shock absorber).

i. Base:

For the design of the base, it must be solid and steady to carry a dancer roller without oscillation. The base consists of 2 aluminum profile, 1 dark metal sheet, 1 aluminum sheet, 2 slider bar, and 4 square sliders.

Aluminum profile: to make it easier to attached to roll-to-roll system, which is also use aluminum profile as main frame. Moreover, the profile has slide slot in every side, making connecting other much simpler. Required part such as slot keys, round-head stainless steel bolts, angle blocks are also ISO standard. Therefore, future any part replacements can be made at scene.

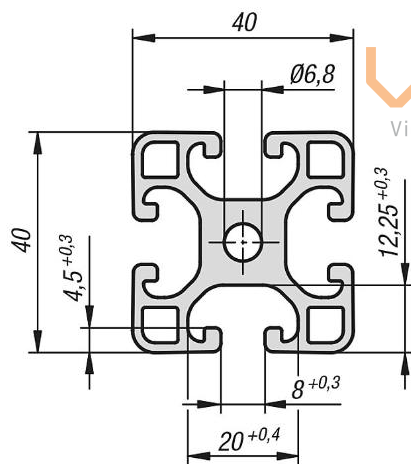


Figure 12 2D sketch of aluminum profile



Figure 11 Aluminum profile

Dark metal sheet(300x230x5mm): this sheet is connected directly to aluminum profile. It has raw surface and high weight so it can prevent slippery.

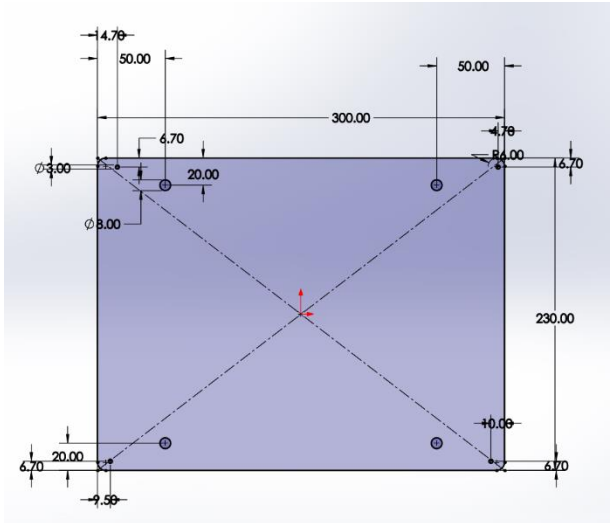


Figure 14 2D sketch of metal sheet



Figure 13 Metal sheet

Slider bar(300mm): The material used to manufacture is stainless steel and machined with very high precision, so it ensures the following factors: Low friction force, does not cause much noise, moves much smoother than other types of slide rails.

The sliders bar also ensure rigidity and durability, so they are used in many industrial machines, machine tools, food processing machines, and automatic conveyor belts for export products. Besides that, It is covered by a black powder coating layer to prevent corrosion.



Figure 15 Sliding bar

Square slider: small size, flat, using only one row of balls, making it optimal in the case of use for small loads.

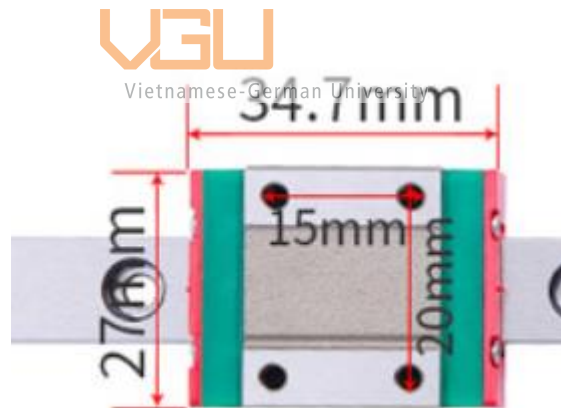


Figure 16: Square slider and it dimensions

Roller shaft: made of metal alloy, hard to bend, no corrosion and rust, can load large weight in long working time.

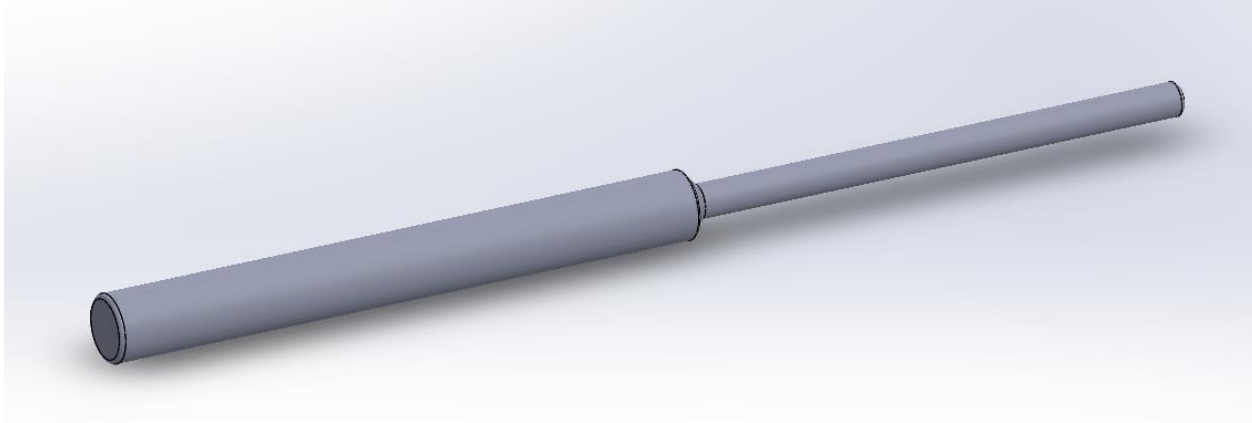


Figure 20 Roller shaft

iii. Lead screw mechanism:



Lead screw mechanism is designed and produced for sliding structures; it changes the rotational movement of a stepper (or servo) motor into horizontal (or vertical) movement. This system can load large weight and long working-life cycle, that it is used widely in industrial zone such as some machine that is need to use sliding structure like drilling, milling and turning machine...

The mechanism is designed in module, to help the engineer optimize their design structure and minimize the time of designing and manufacturing

The main parts of this module are: aluminum profile as base, axis pillow, industrial ball bearing, ball-lead screw axis, sliding rails, connecting joints... All the part is made by precision mechanical processes.

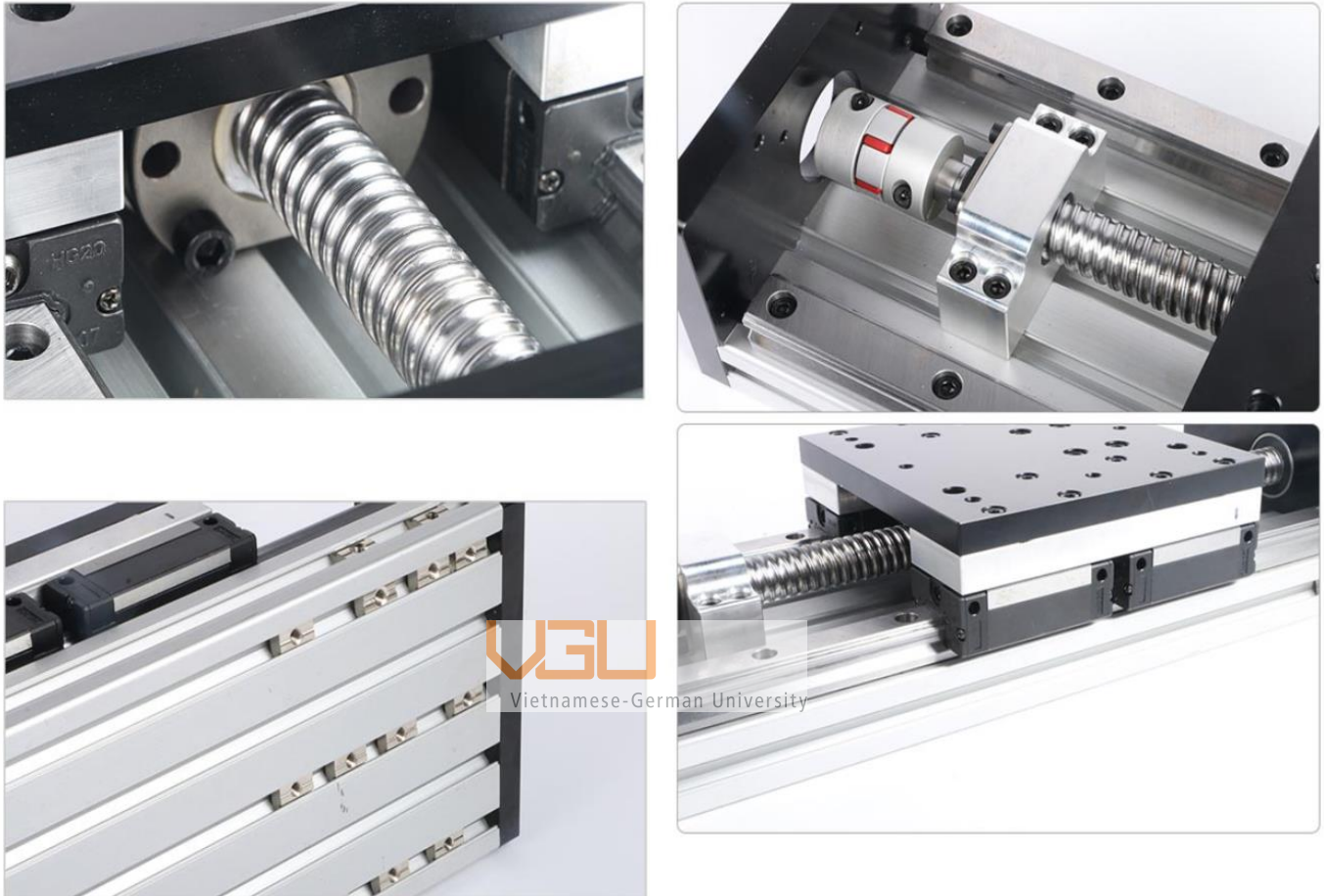


Figure 21 multi-view of lead screw mechanism

-Technical characteristics:

1. Utilizes in using stepper motor.
2. Sliding rails size 20 (large) with two idle blocks on two sides.
3. Industrial ball-lead screw SFU16 (diameter: 10mm)
4. CNC process of all mounting and sliding parts

5. Ball-bearing and pillow axis can load heavy weight

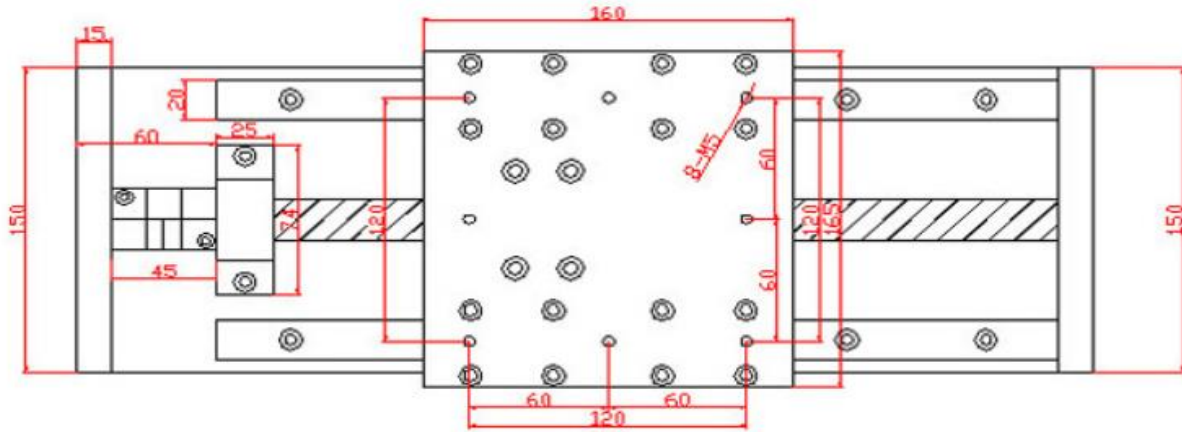


Figure 24 Top view dimension of lead screw

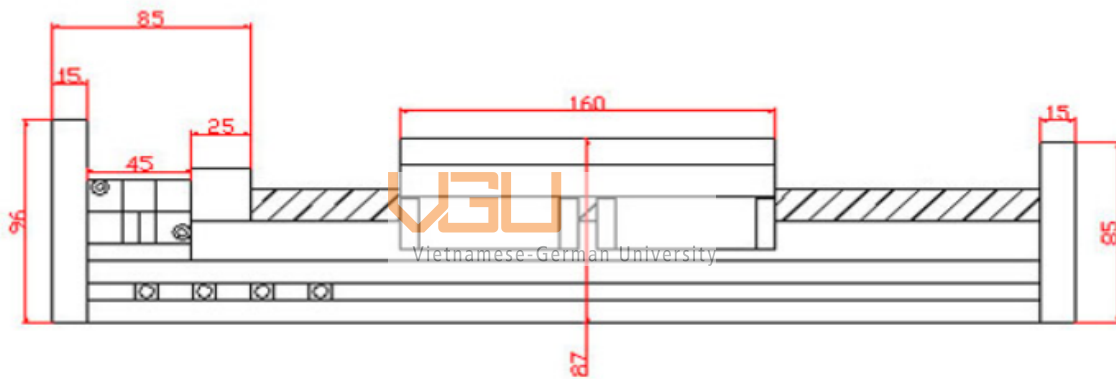


Figure 23 Side view dimension of lead screw

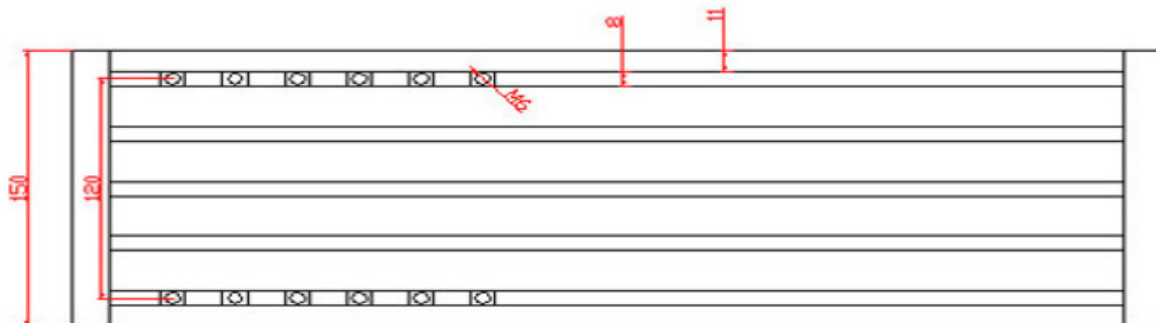


Figure 22 Bottom view dimension of lead screw

-Product specifications:

Table 1 Lead screw specification

Sliding journey	300 mm
Manufacture process	CNC
Aluminum face process	Anode
Material	Metal, Aluminum
Guiding	Square slider (size 20)
Transmission	Acme screw/ Trapezoidal shape (diameter: 10mm)
Journey per round of rotation	10mm
Motor	NEMA 23 stepper motor
Load	25 kg (vertical) 70kg (horizontal) compare to sliding block

iv. Shock absorber:



Figure 25 Shock absorber and it dimensions

-Damper and spring were designed for high function of shock absorption performance. Furthermore, it can enhance the shock absorption while performing a movement from any directions.

- Made of high-quality aluminum alloy to ensure the qualified hardness, using stainless steel spring covered with static painting help the product resistant to oxidation, corrosion and abrasion.

- With 750lb/ maximum load, the spring coefficient can be adjusted freely and easily by users with a separately adjustment knob.

v. other parts:

Beside the main parts, there are some extra parts to used to connect all the main parts together.

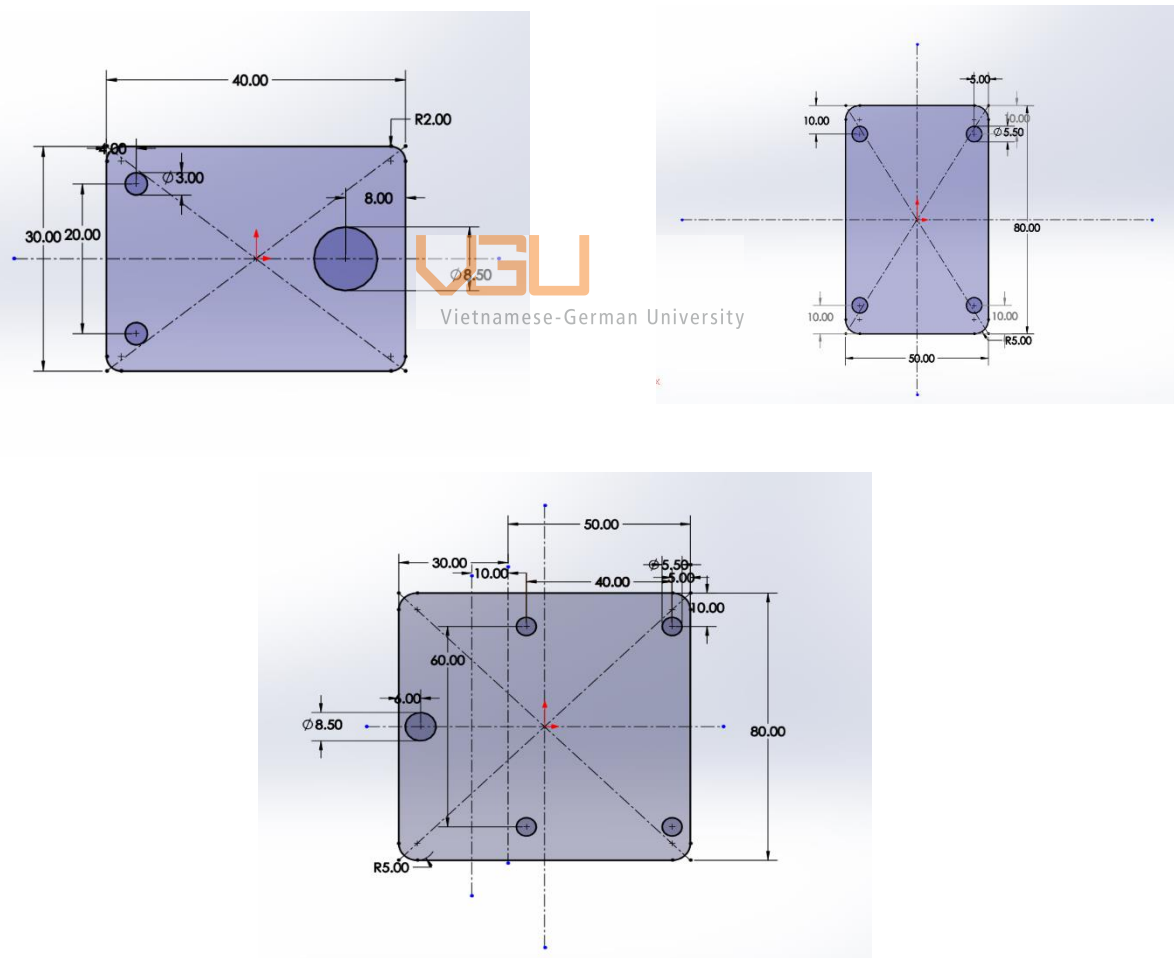


Figure 26 2D sketch of all connectors

Sensor: The E3F-DS30C4 infrared obstacle sensor uses infrared light to determine the distance to the obstacle for fast response and very little interference due to the use of eyes that receive and emit infrared rays at separate frequencies. The sensor can adjust the desired alarm distance through the rheostat, the sensor output is in the form of an open collector, so it is necessary to add 1 or more to the source at the output pin when in use.



Figure 27 Photogenic sensor

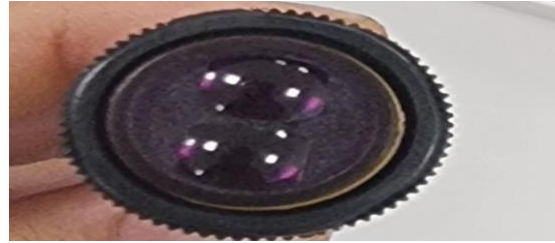


Figure 28 Sensor head

Sensor specification:

- Source: 6-36 VDC
- Sense distances: 5-30cm (can be adjusted by users)
- Output current: 300 mA
- NPN output helps to customize the output voltage, the higher the input voltage, the higher the output voltage will be.
- Material: hard plastic.
- Red led light to display output
- Size: 1.8cm (D) x 7.0cm (L)

Wiring diagram:

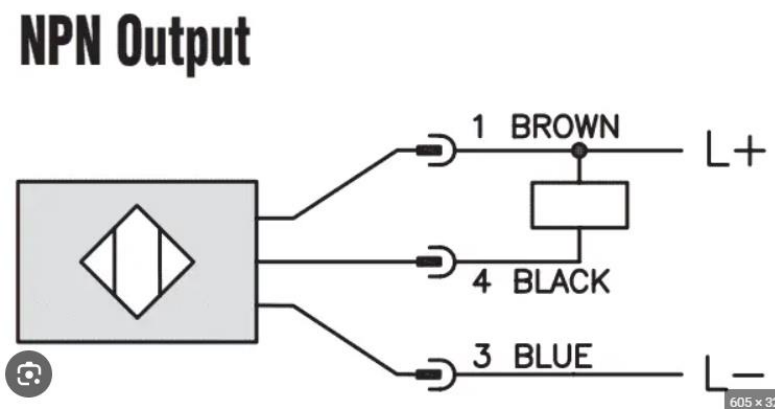


Figure 29 Sensor wiring diagram

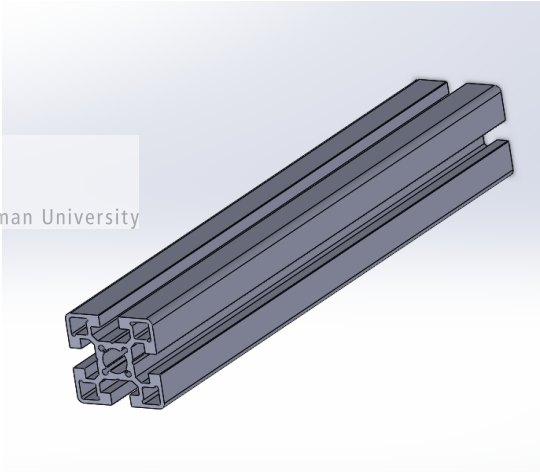
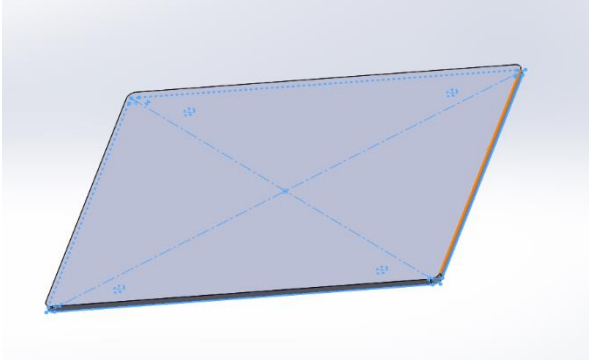
- Brown: VCC
- Black: display output
- Blue: GND

2.2.2 3D models of mechanical parts:

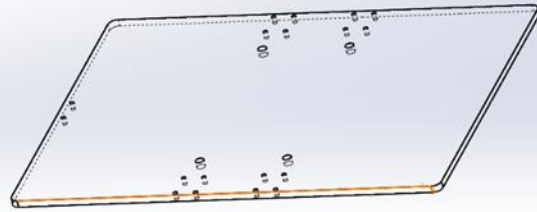
Parts and component:

- Base:

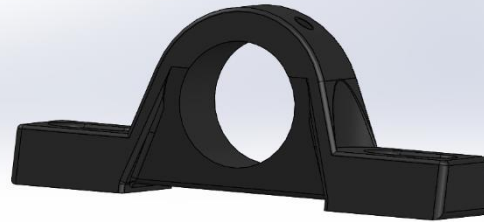
Table 2 Parts and components of base

Part name	3D model
Aluminum profile	 <p>The image shows a 3D CAD model of an aluminum profile. It has a U-shaped cross-section with a central channel. The model is rendered in a dark gray color. A watermark for 'VGU Vietnamese-German University' is visible in the background of the image.</p>
Metal sheet	 <p>The image shows a 3D CAD model of a metal sheet. It is a flat, rectangular plate. The model is rendered in a light blue color. A dashed blue outline is visible, and a solid orange line highlights one of the edges. The model is shown from an isometric perspective.</p>

Aluminum sheet

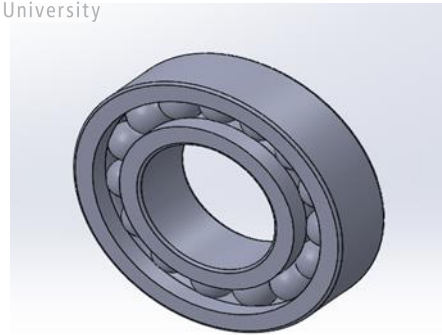


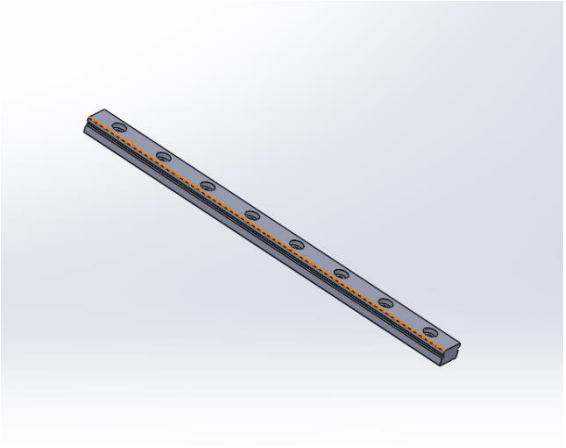
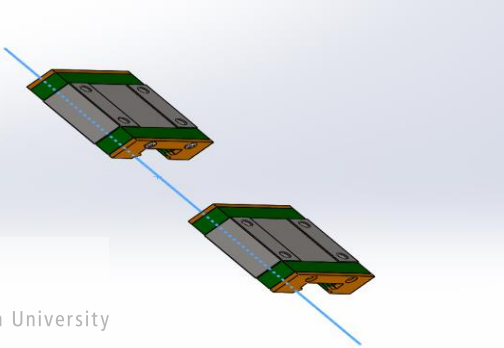
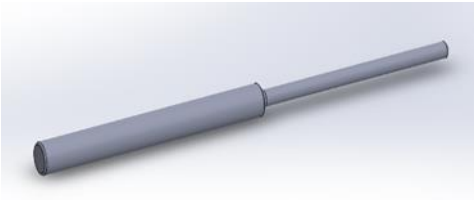
Pillow block



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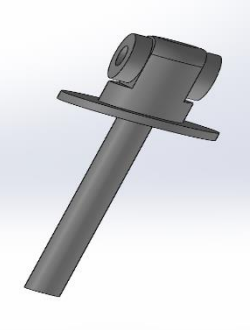
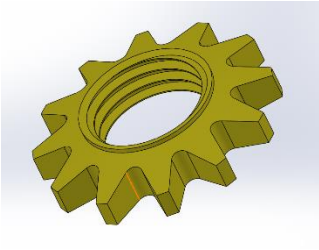
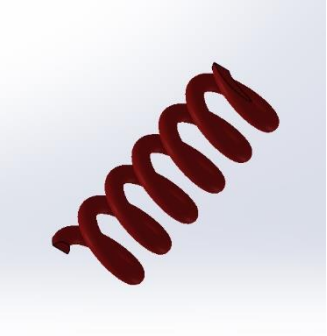

Ball bearing



<p>Slide bar</p>	 A 3D CAD model of a slide bar, which is a long, thin metal component with several small rollers or balls mounted along its length. The bar is shown at an angle against a light blue background.
<p>Square slider</p>	 A 3D CAD model showing two square sliders mounted on a blue shaft. The sliders are green and orange, with a square cross-section. The shaft is shown passing through the center of each slider. The VGU logo and text "Vietnamese-German University" are overlaid on the image.
<p>Roller shaft</p>	 A 3D CAD model of a roller shaft, which is a long, thin cylindrical component with a slightly larger diameter section in the middle. It is shown at an angle against a light blue background.

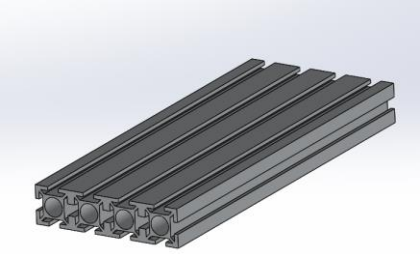
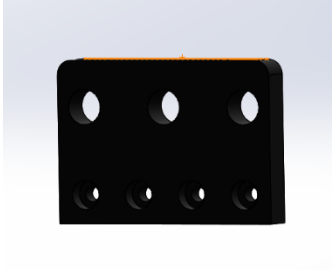

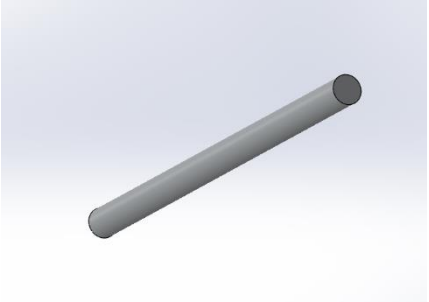

- Damper spring (shock absorber) :

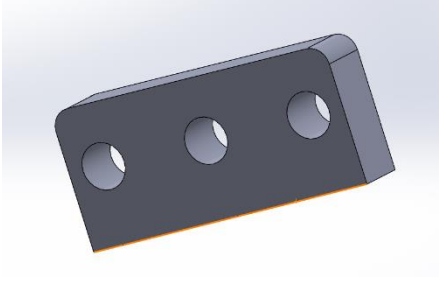
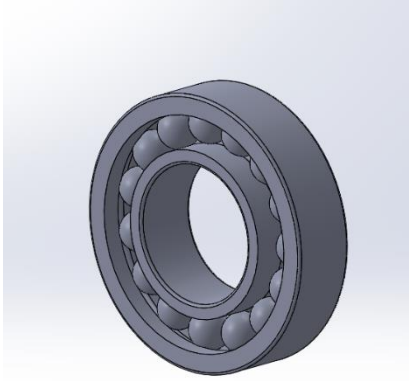
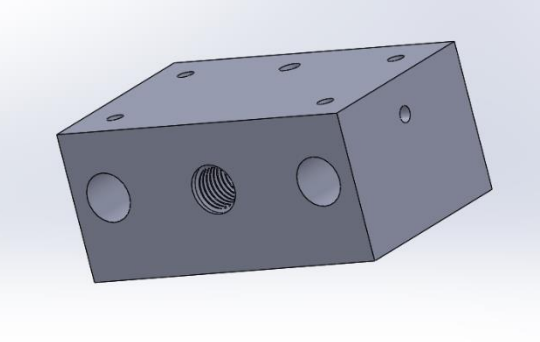
Table 3 Parts and components of shock absorber

Damper base	
Damper nut	
Damper spring	 <p data-bbox="646 1003 976 1098">VGU Vietnamese-German University</p>
Damper top rod	

- Lead screw:

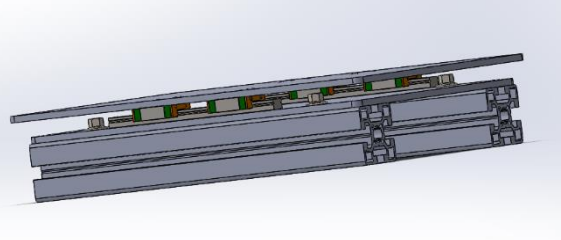
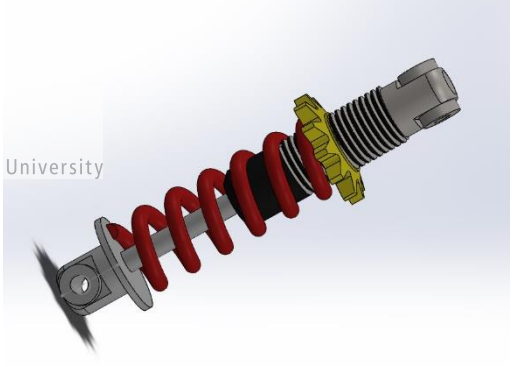

Table 4 Parts and components of lead screw

Base	
End shaft 1	
End shaft 2	
Rail	
Screw	

<p>Mid shaft</p>	
<p>Ball bearing</p>	
<p>Coupling</p>	
<p>Sliding block</p>	

Assembly model:

Table 5 Full assembly model of all parts

<p>Base</p>	
<p>Shock absorber</p>	
<p>Pillow block bearing and roller</p>	

Lead screw mechanism	
Full assembly	



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2.3 Electrical design:

As shown in section 2.2.1, the dancer system uses the lead screw mechanism to make it move up and down.

Lead screw:

-Working principle: mechanisms for converting rotary motion into linear motion. Lead screws are often preloaded with an axial load to help maintain consistent contact between the nut and screw filets. This may generate some heat in the contact area due to friction. As a result, lead screws are frequently restricted to low-duty applications with rotational speeds of 10 revolutions per second. In the case of vertical applications, a simple lead screw that self-locks under payload movement can provide a secure solution.

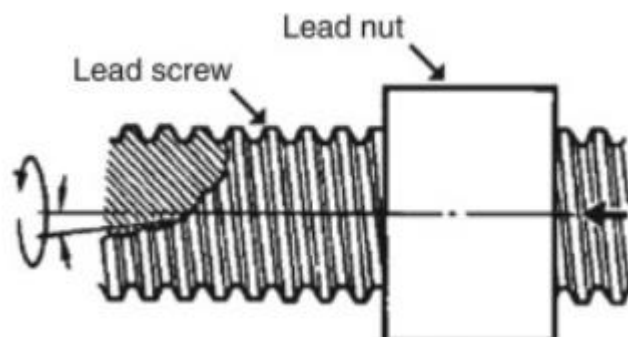
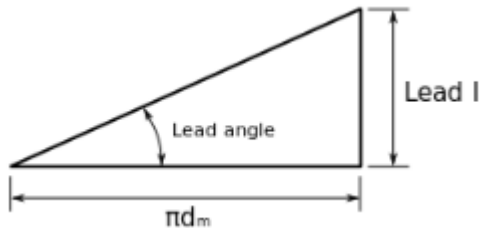


Figure 30 close view of the acme screw

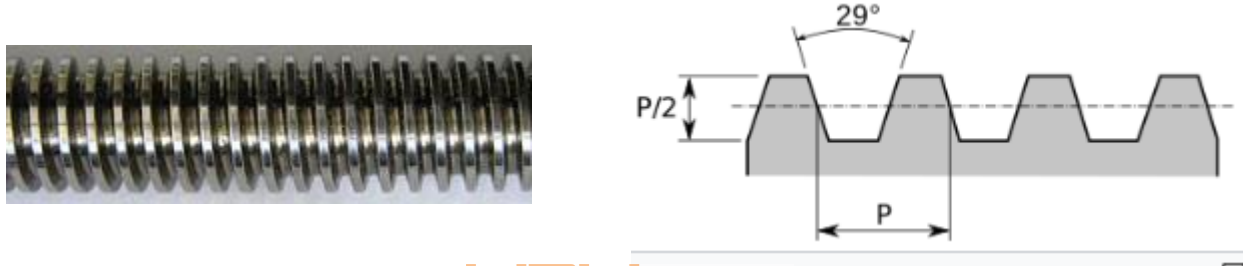
Type of thread: trapezoidal thread. They are the most common form to use in lead screw mechanism

Mathematic field:

- Rotary motion



The torque required to lift or lower a load can be calculated by "unwrapping" one revolution of



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$$T_{\text{raise}} = \frac{Fd_m}{2} \left(\frac{l + \pi\mu d_m}{\pi d_m - \mu l} \right) = \frac{Fd_m}{2} \tan(\phi + \lambda)$$

$$T_{\text{lower}} = \frac{Fd_m}{2} \left(\frac{\pi\mu d_m - l}{\pi d_m + \mu l} \right) = \frac{Fd_m}{2} \tan(\phi - \lambda)$$

a thread.

Where

T: torque to raise or lower the block (N)

F: load on the screw (N)

d_m : mean diameter

μ : coefficient of friction= 0.15->0.25 due to steel material

l: lead

Φ : angle of friction

λ : lead angle= 29 degree

$$\text{efficiency} = \frac{T_0}{T_{\text{raise}}} = \frac{Fl}{2\pi T_{\text{raise}}} = \frac{\tan \lambda}{\tan (\phi + \lambda)}$$

- Linear motion:

$$\omega = \frac{v * 2\pi}{p}$$

Where,

ω : rotative speed (rad/sec)

v: linear speed (m/sec)

p: lead step (mm) for current used screw, p= 10mm


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 $T = F_{\text{linear}} * p$

Where,

F linear: linear force (N)

T: torque (raise or lower) (N)

P: lead =10 mm

Stepper motor:

- Working principle: A stepper motor is a type of electric motor characterized by the fact that its shaft rotates in steps, or by moving by a fixed number of degrees. Stepper motors have a stationary (stator) and a moving (rotor) component.

- Basic characteristics:

Table 6 basic characteristic of stepper motor

Type of motor	Stepper motor 2 phase 4 wire
Motor code	57CM23
Frame size	NEMA23
Step angle	1.8 degree

Step angle tolerance	0.09 degree (full step with no load)
Axis diameter	8 mm
Moment	2.3 Nm
Current	5A
Heat when operate	Maximum 85 K
Working temperature	-10°C ~ 50°C
Insulation	Class B
Protection standard	IP40
Withstand voltage	500 VAC/ minute
Eccentricity	Maximum 0.025 mm (load 5N)
Shaft deviation	Maximum 0.075 mm (load 10N)
Driver	DM542-05

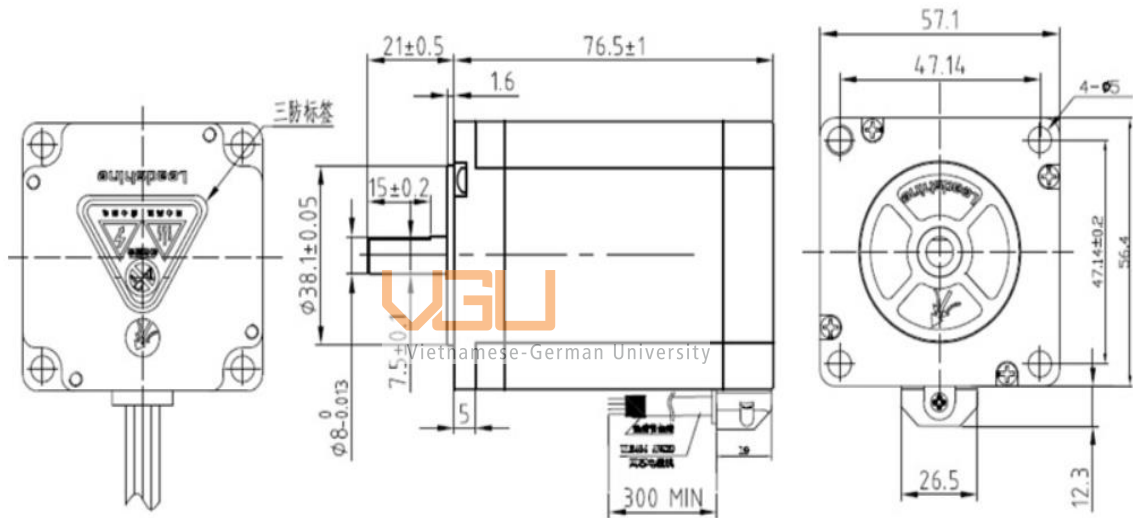


Figure 31 2D sketch of stepper motor

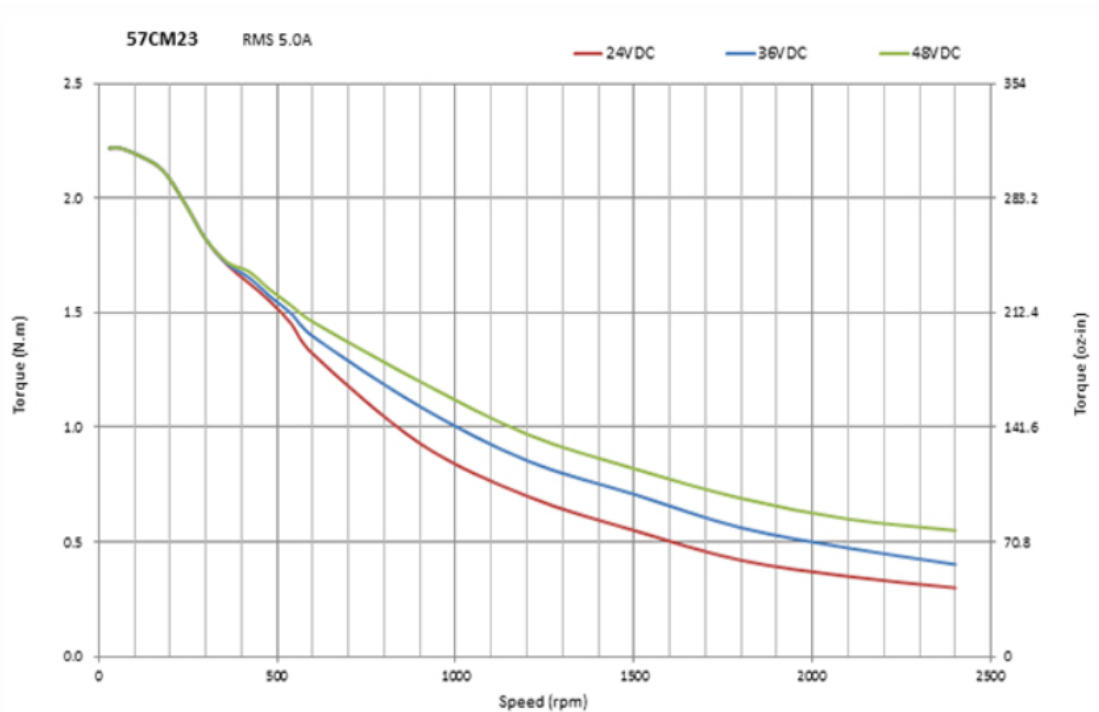


Figure 32 Diagram of torque and speed of stepper motor

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- Control method:

A stepper motor converts a series of input pulses into a carefully defined increment in mechanical shaft position, with each pulse moving the shaft by a predetermined angle. As long as the motor is carefully sized for the application in terms of torque and speed, the motor's position can then be guided to move and hold at one of these steps without the use of a feedback sensor (i.e., open loop Stepper Motor control). This input train of pulses is used by stepper motor control to direct the motor to travel to the desired location or at the desired speed.

Driver DM542-05 is specialized for stepper motors (Step 42 – Step 86) with current not exceeding 4.0A. This control circuit ensures that the motor runs slowly, noiseless, accurately, no slipping. This is a stepper motor driver with DSP 32 technology, low noise, high viscosity to help the motor achieve high performance.



Figure 33 Control driver
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Motion control method:

For the motion control, the system used a PLC-S7-1200 to provide signal to the driver of the stepper motor to operate.



Figure 34 S7-1200 PLC device

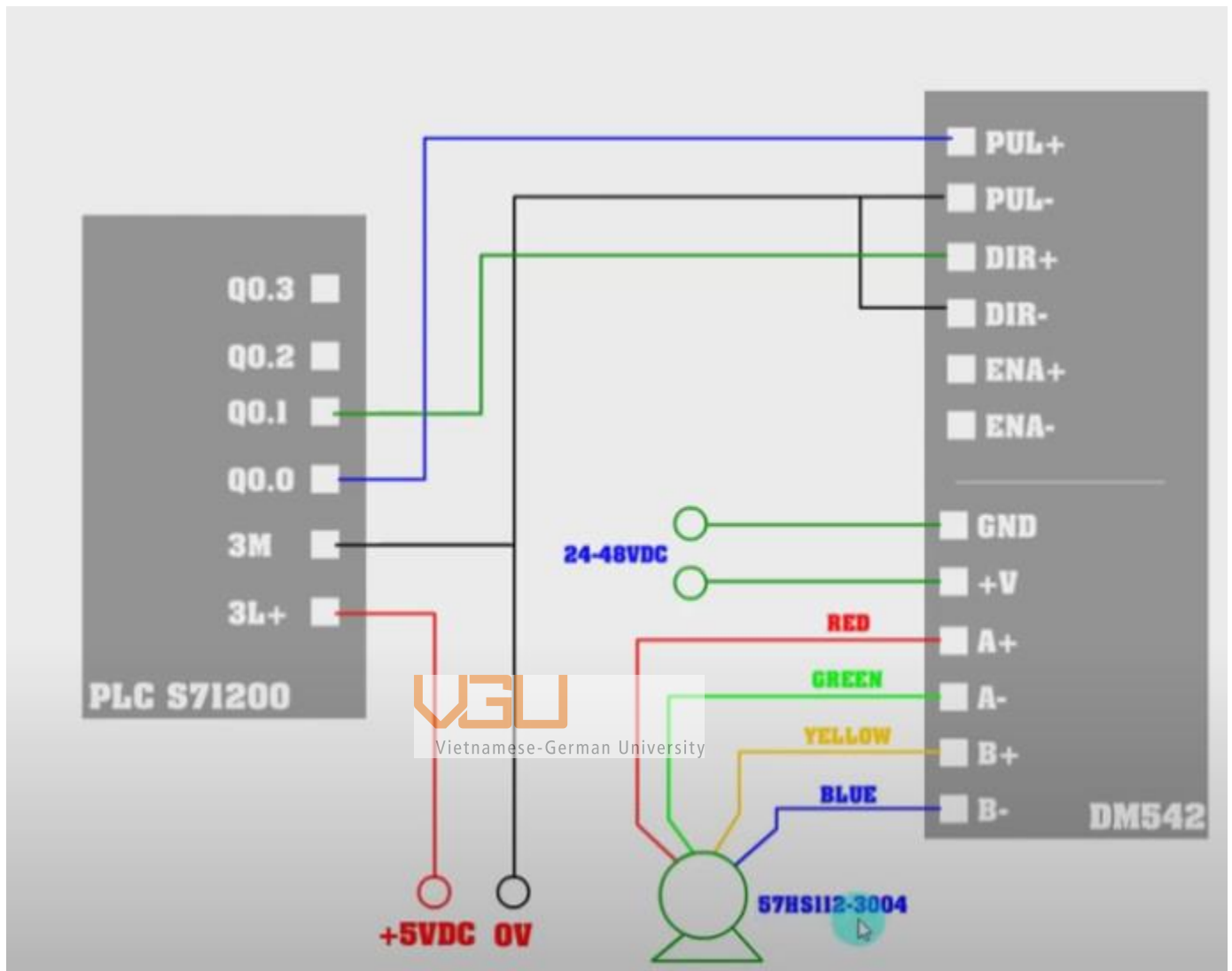


Figure 36 Control system wiring diagram

As shown in the above diagram, the driver of stepper motor and the PLC s7-1200 need the supply voltage of 24 VDC, when the electricity source is 220v, then we need to power supply



Figure 35 220V to 24V power supply

with the input of 220V and output of 24V to supply the source to PLC and stepper motor.
 The motion control then programmed via TIA-portal.

- Set up the technology object:
 - General: create the axis, choose the drive and the unit of measurement.

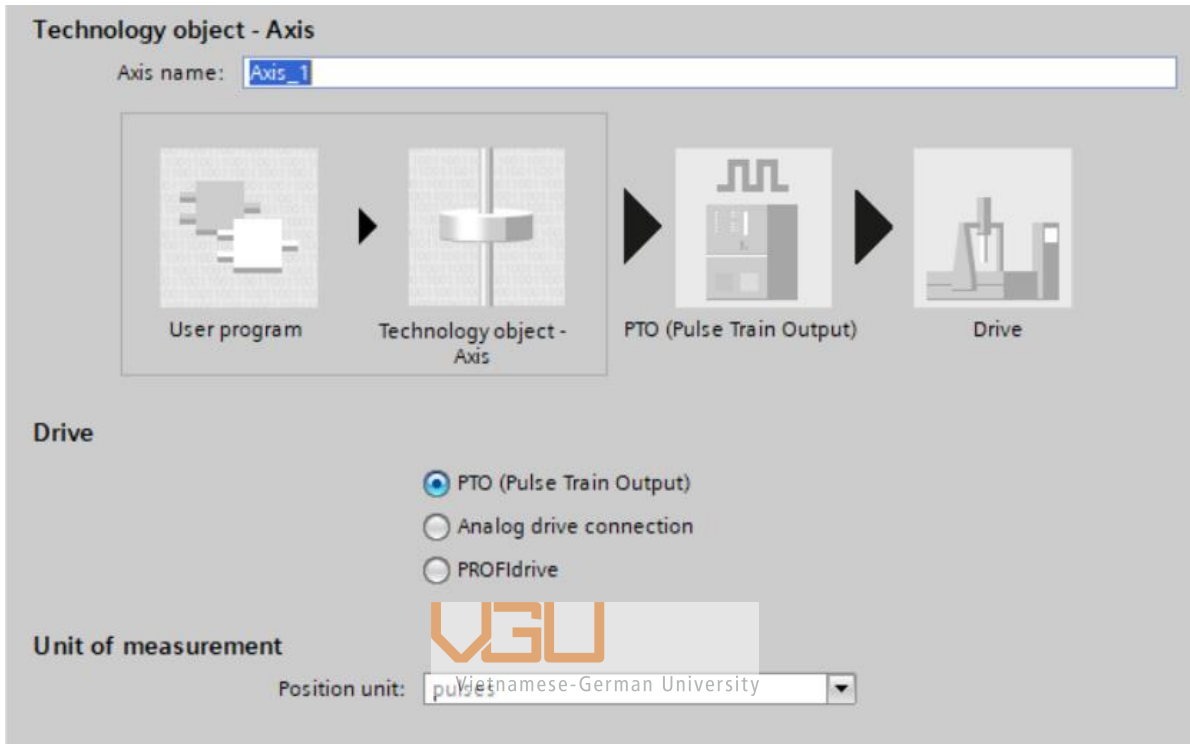


Figure 37 create the axis, drive and a unit of measurement

Set up the drive: choose the signal type and set up the output signal for PLC.

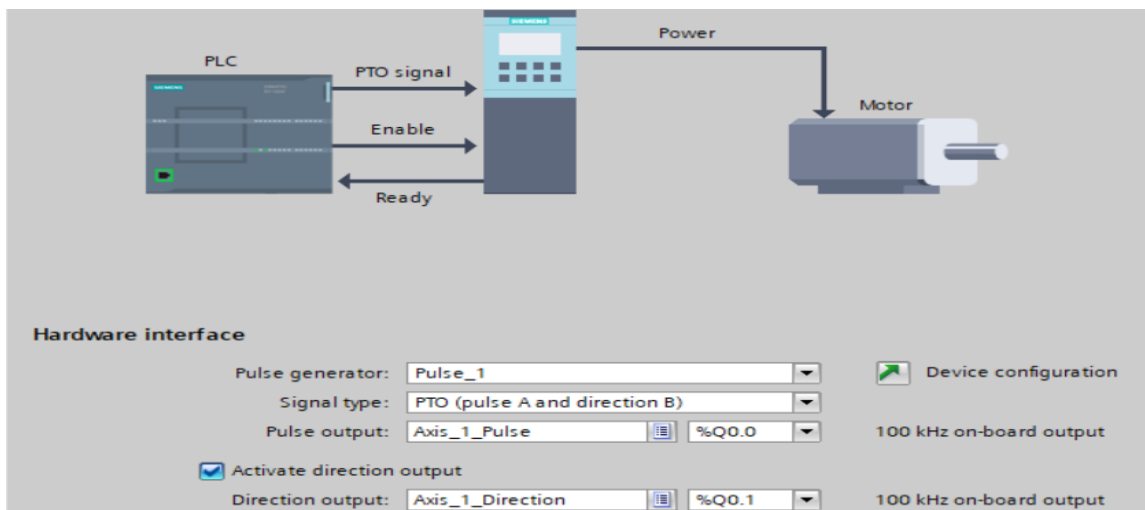


Figure 38 Hardware interface

Set up the pulse for motor: choose the pulse per revolution.

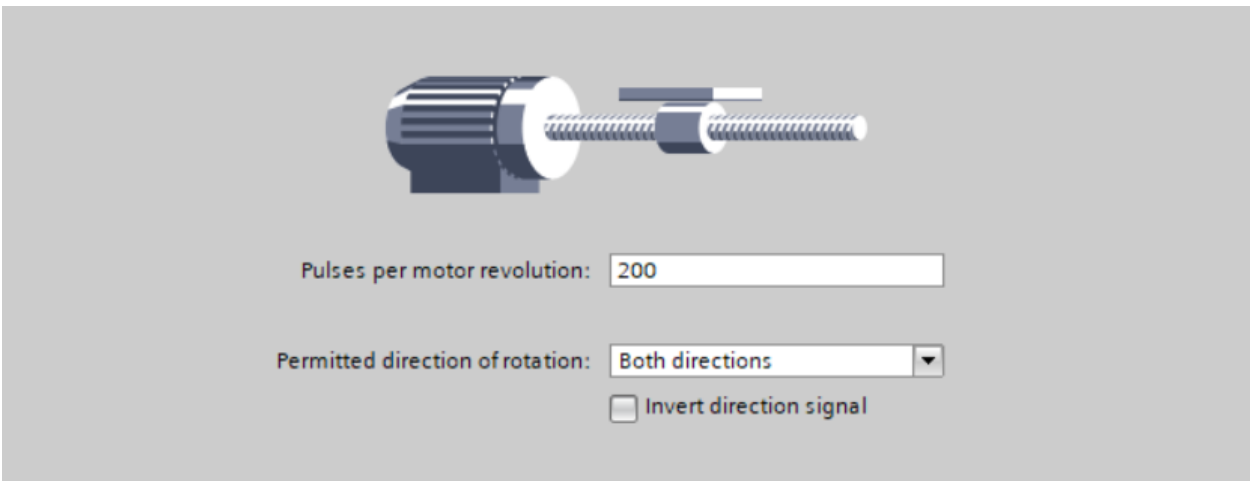


Figure 39 set up the pulse per revolution

Set up the position limit:

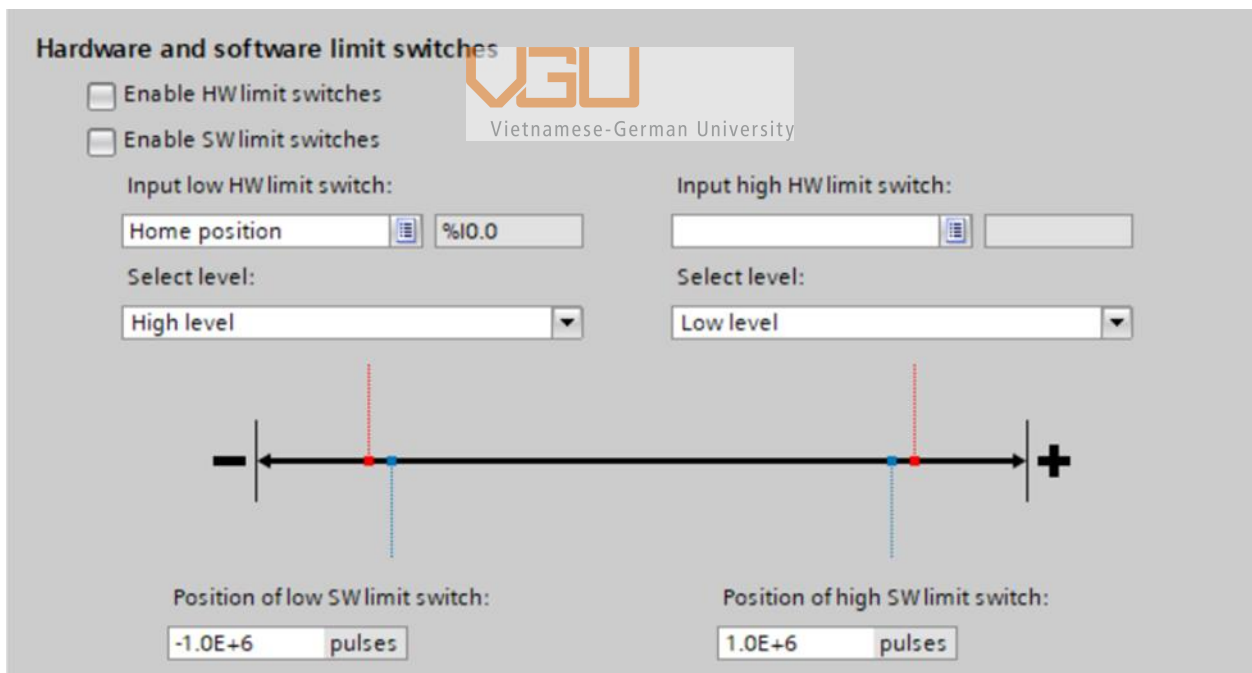


Figure 40 set up the position limit

Dynamics: set up the velocity and acceleration of motor.

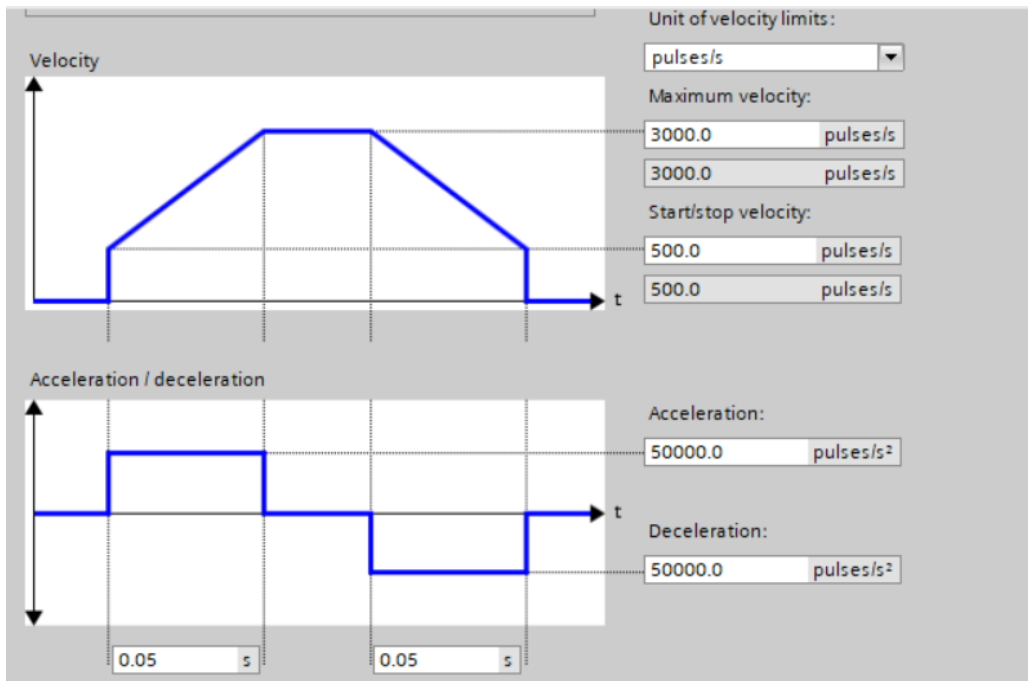


Figure 41 set up velocity and acceleration

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Set up the emergency stop:

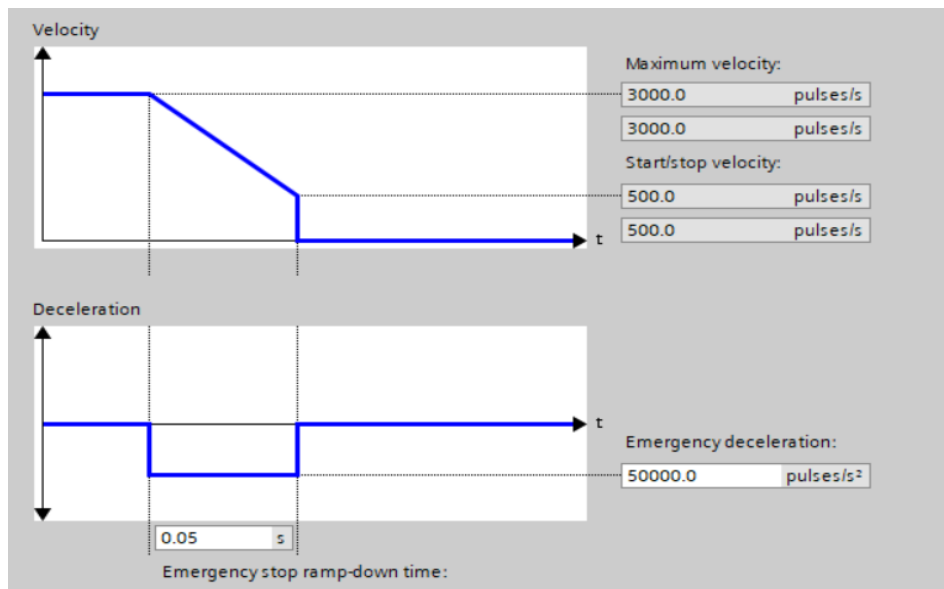


Figure 42 set up the emergency stop

Homing: set up home position.

For home position, I decided to put it at the lowest position of the dancer roller and sensed by a photogenic NPN sensor.

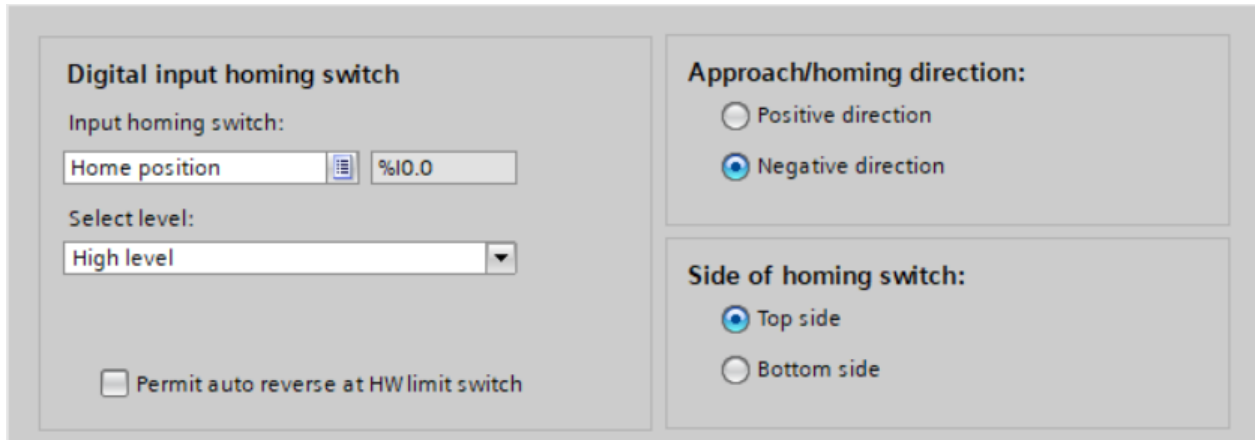


Figure 43 Insert the input address of home position

As shown in above figure, the input of the home position (sensor position) is %I0.0

Set up the homing velocity, and the way of homing (shown in the below diagram)

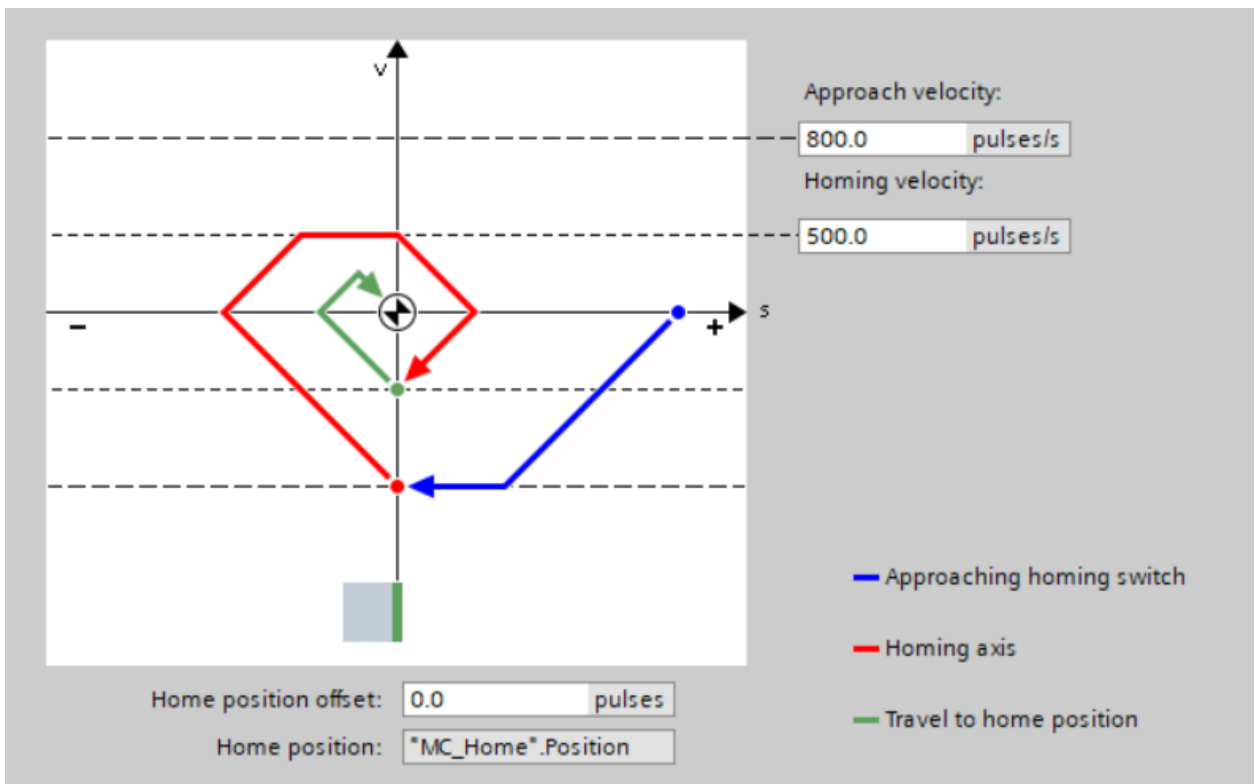


Figure 44 Homing diagram

After finish setting up the technology object, check the list (as shown in the figure below), green ticks mean the system is ready.



Figure 45 technology object check list

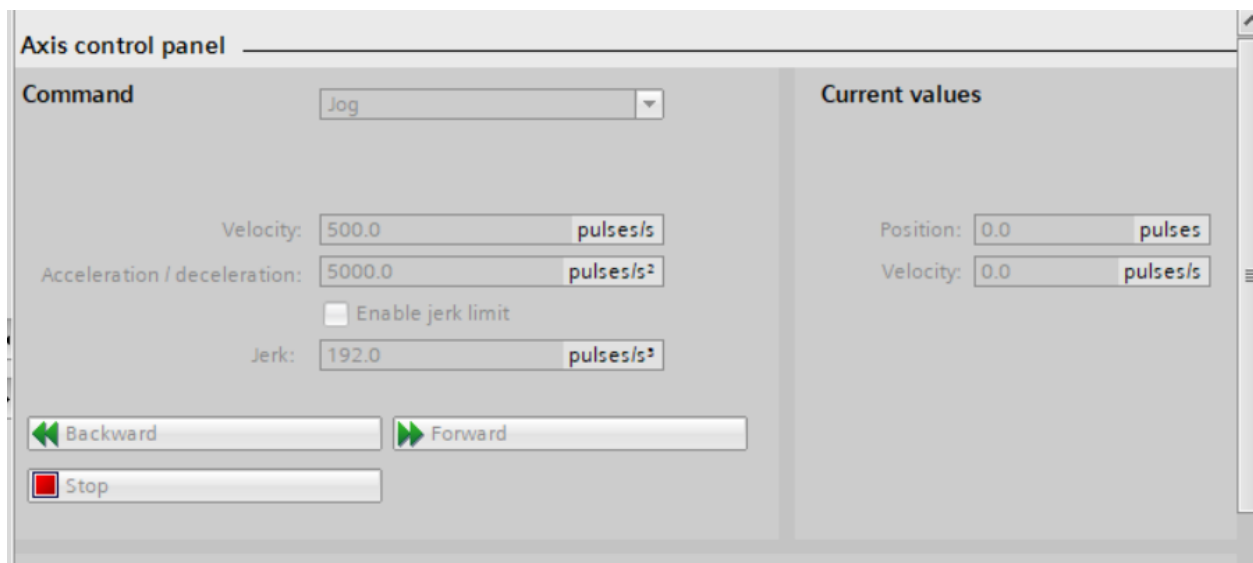


Figure 46 commissioning

Before programming, check the commissioning to ensure that the motor can operate normally.

After ensured that the motor is ready, then we started the programming step.
The signal to perform all the step in the program is digital signal.

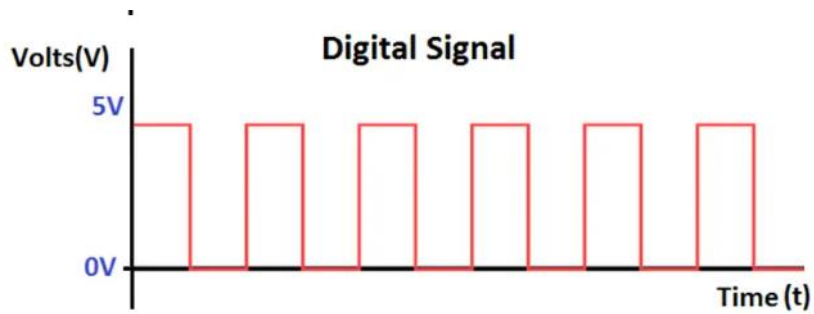


Figure 47 digital signal diagram



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Step 1: set up the power.

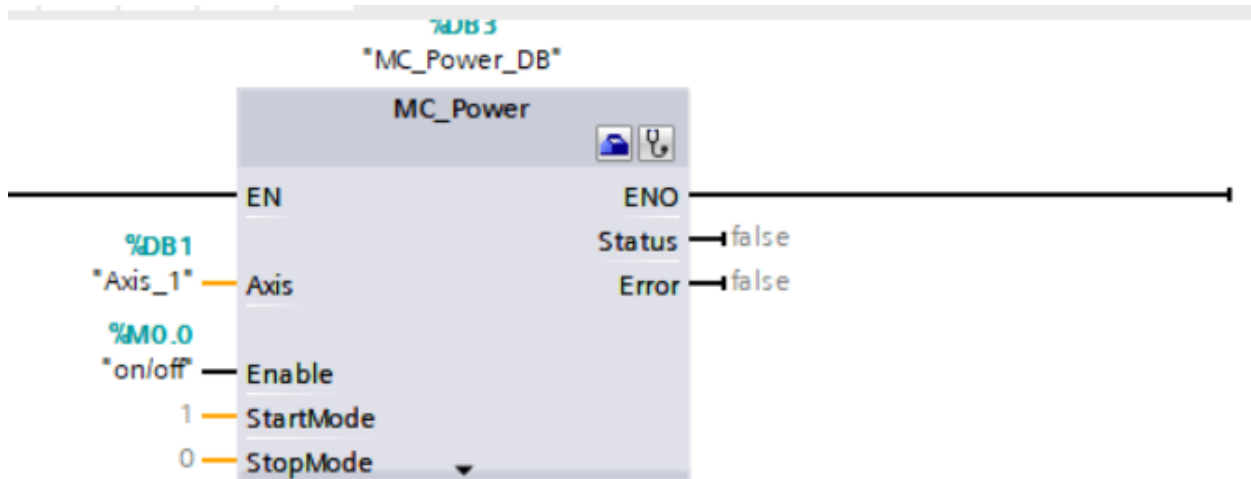


Figure 48 Power block

- %DB1: choose the axis that had been set up in technology object
- %M0.0 (physical output): digital signal of on/off button

Step 2: set up the motion (jog forward and backward)

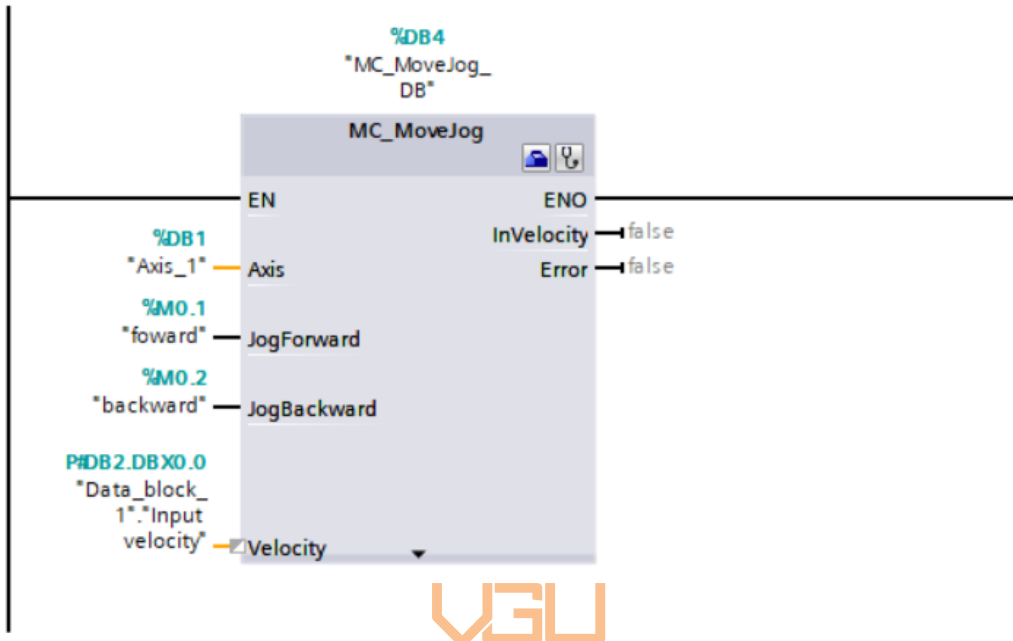


Figure 49 Move.jog block

- %M0.1(physical output): digital signal of jog forward button
- %M0.2(physical output): digital signal of jog backward
- P#DB2.DB X0.0: insert the input velocity of the motor (pulses)

Step 3: Set the home signal when the object is at home position

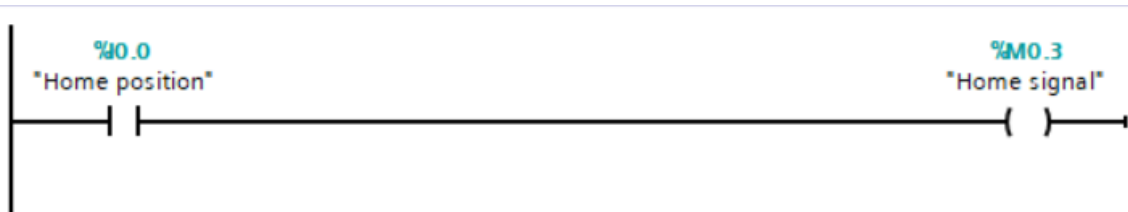


Figure 50 Home signal set

- %I0.0 (virtual input): digital signal of home position
- %M0.3(physical output): digital signal home signal

Step 4: set up the move home execution

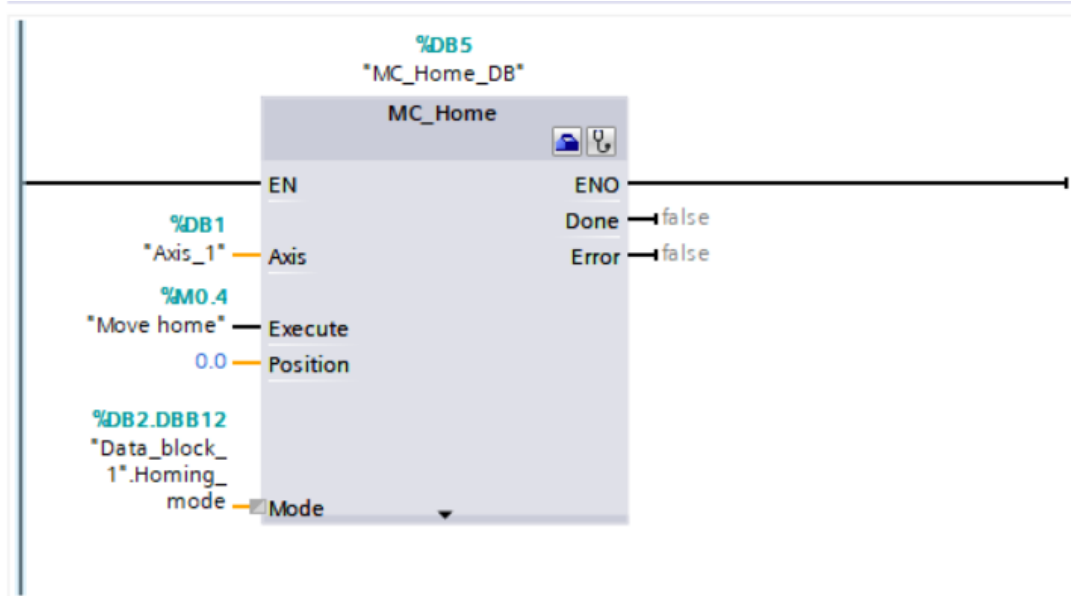


Figure 51 Home block

- %M0.4(physical output): digital signal move home executes
- %DB2.DBB12: insert the home position to the system

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Step 5: set up the reset button.

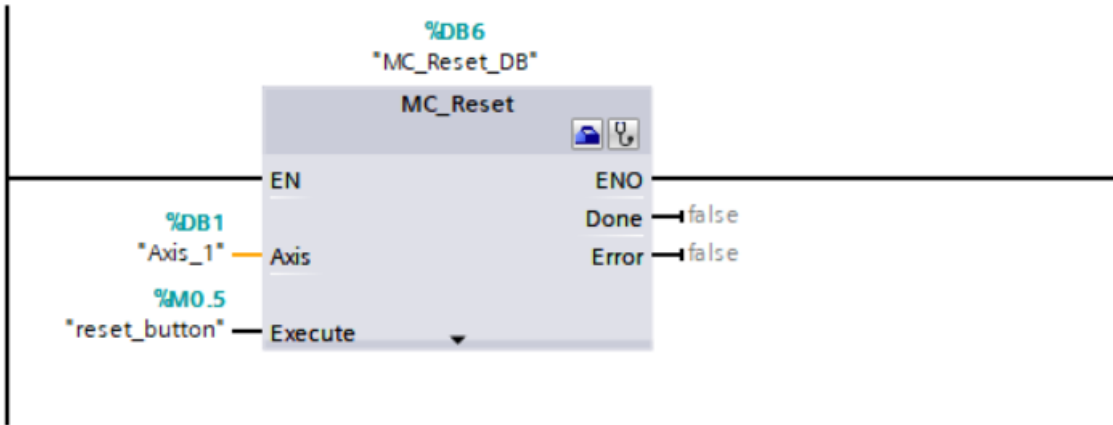


Figure 52 Reset block

- %M0.5 (physical output): digital signal to execute the reset button.

Step 6: set up the move absolute

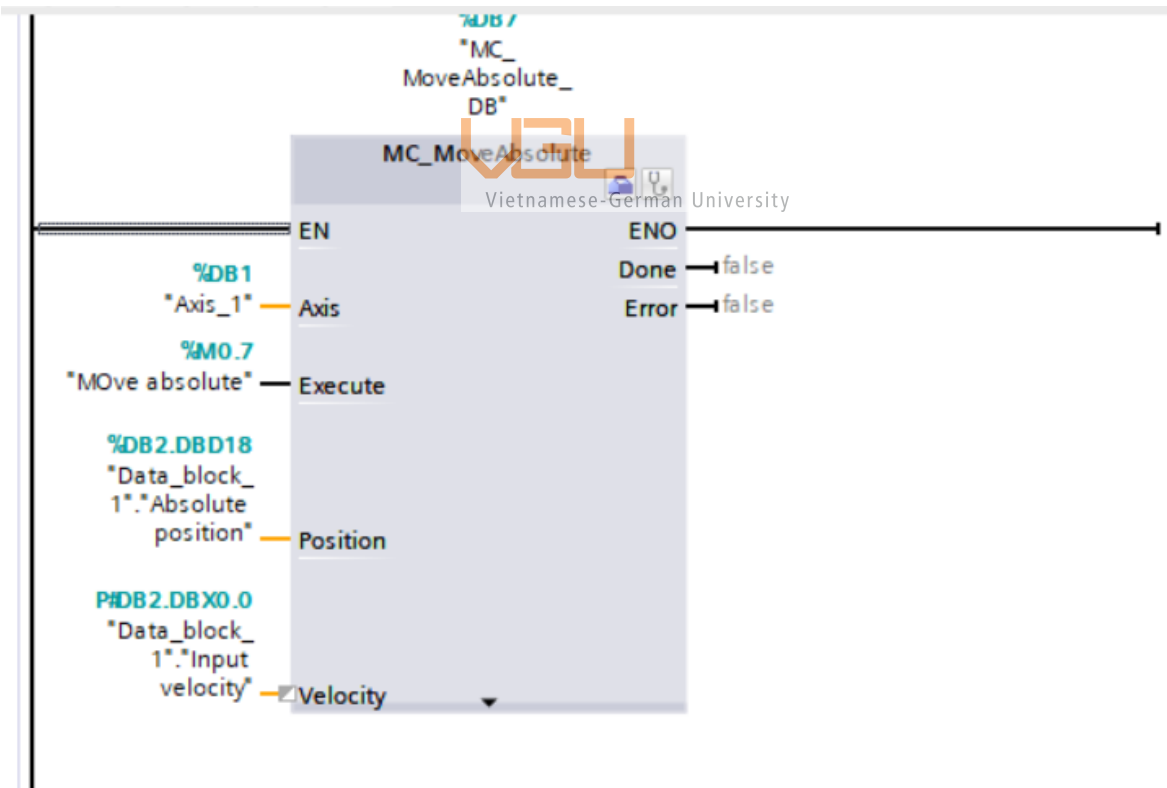


Figure 53 Move absolute block

- %M0.7(physical output): digital signal to execute the move absolute
- %DB2.DBD18: insert the position to move absolute
- P#DB2. DB X0.0: insert the input velocity to move absolute

Step 8: Set up the move absolute position

- Add the current position data to position 1 data

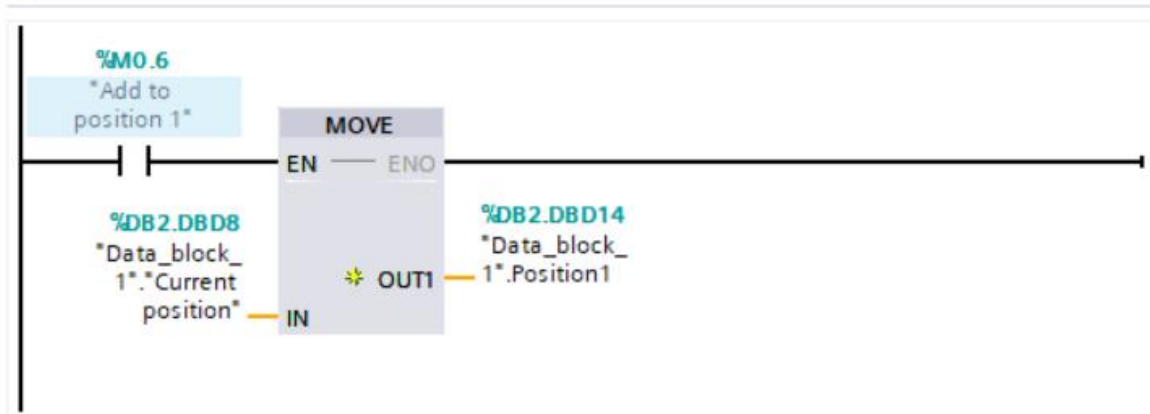


Figure 54 Add the current position to move absolute position

- Forward the position 1 data to move absolute position data.

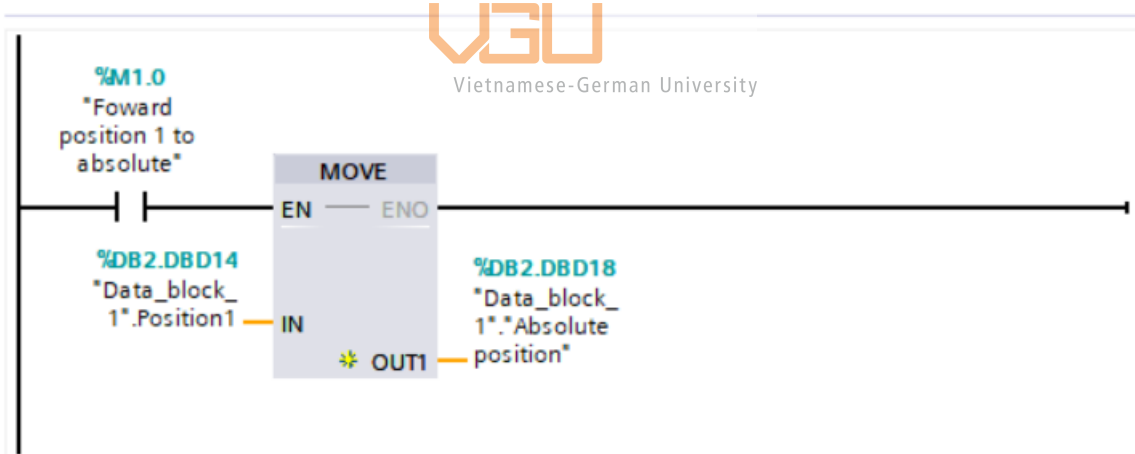


Figure 55 Forward the position to move absolute

- Move the position 1 data to current position data.

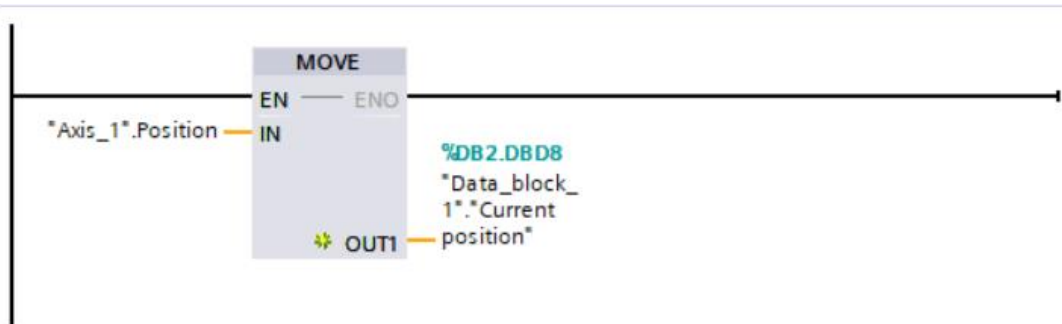


Figure 56 Move the current position to the position data

Because the requirement of the thesis is adjusted in range of 5kN, means from the home position, the tension increase 1kN at each point, the maximum is increase 5kN, that means we need 5 positions, so we add step 8 five times to get 5 move absolute positions.

The data block is need to set the data type of each variable (example: integer, real, long real, ...), in this case the program is applied to reality prototype, so the data type need is Real or Long real.

Data_block_1										
	Name	Data type	Offset	Start value	Retain	Accessible f...	Writa...	Visible in ...	Setpoint	Comment
1	Static				<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
2	Input velocity	LReal	0.0	0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
3	Current position	Real	8.0	0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
4	Homing_mode	USInt	12.0	3	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
5	Position1	Real	14.0	0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
6	Absolute position	Real	18.0	0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
7	Position2	Real	22.0	0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
8	position3	Real	26.0	0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
9	position4	Real	30.0	0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
10	position5	Real	34.0	0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	

Figure 57 Data blocks



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For the data type that need the execution (the physical output address %M and input address %I), the PLC tag is provided, in this case the data type is “Bool”.

Default tag table								
	Name	Data type	Address	Retain	Acces...	Writa...	Visibl...	Comment
1	Axis_1_Pulse	Bool	%Q0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
2	Axis_1_Direction	Bool	%Q0.1	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
3	on/off	Bool	%M0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
4	foward	Bool	%M0.1	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
5	backward	Bool	%M0.2	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
6	Home signal	Bool	%M0.3	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
7	Home position	Bool	%I0.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
8	Move home	Bool	%M0.4	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
9	reset_button	Bool	%M0.5	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
10	Add to position 1	Bool	%M0.6	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
11	MOve absolute	Bool	%M0.7	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
12	Foward position 1 to absolute	Bool	%M1.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
13	Foward pos2 to absolute	Bool	%M2.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
14	Add to pos 2	Bool	%M3.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
15	add to pos3	Bool	%M4.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
16	fw pos3 to ab	Bool	%M5.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
17	add to pos 4	Bool	%M6.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
18	fw pos 4 to ab	Bool	%M7.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
19	add to pos 5	Bool	%M8.0	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	

Figure 58 PLC tags

Step 9: set up the virtual HMI screen to control the stepper motor with all the above program.

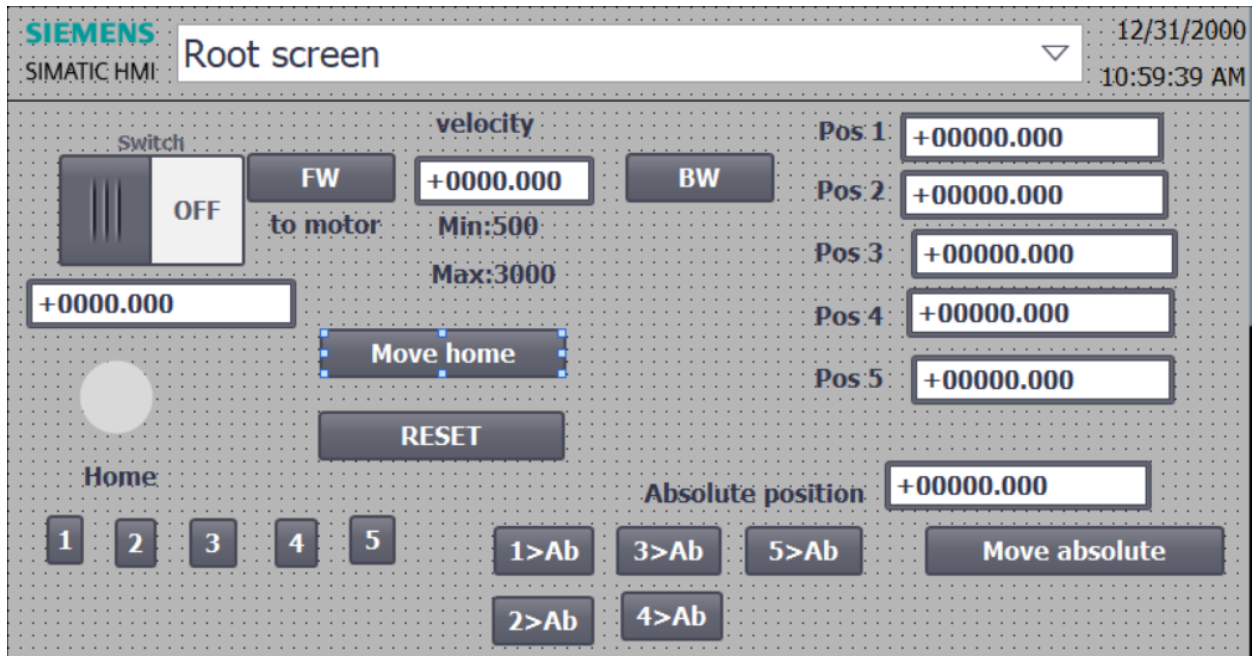


Figure 59 HMI screen

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This program has 3 types:

- Press and release button: grey square or rectangle button.
- Switch on and off button
- Data display or insert data box: white rectangle box
- Home signal: circle shape.

Press and release buttons were set up with SetBit (press) or ResetBit (release) function.

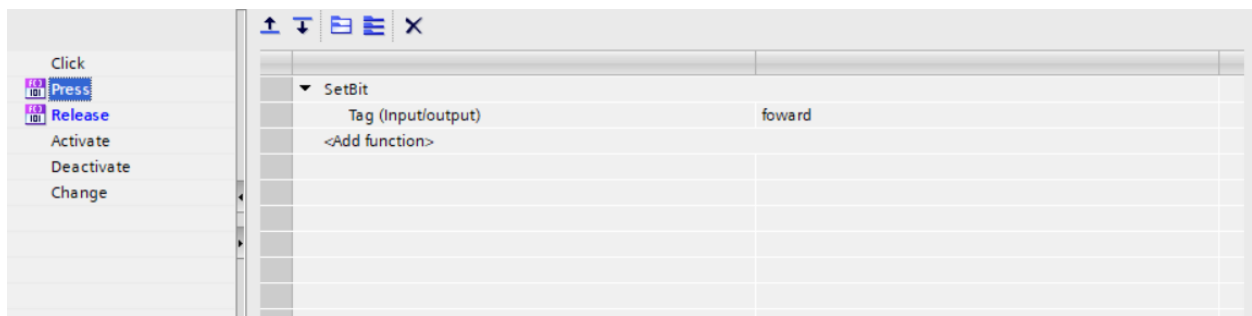


Figure 60 Setbit function

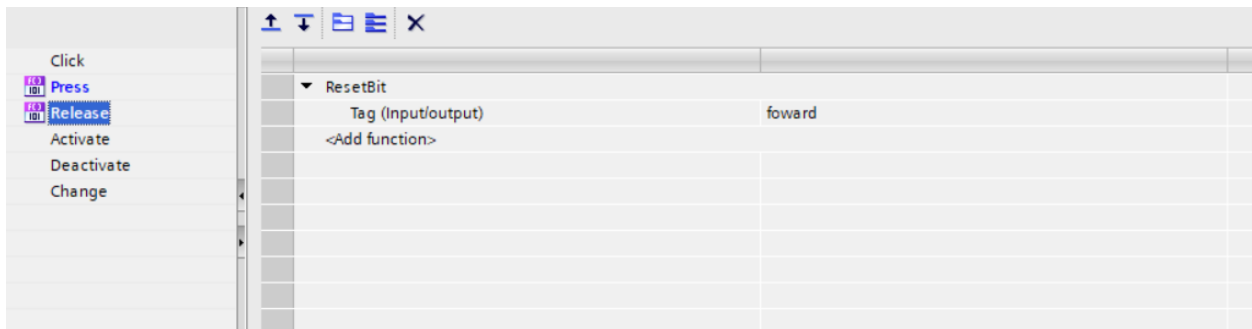


Figure 61 ResetBit function

Then select the PLC tags corresponding to that button (example: forward button with PLC tag name: forward (depend on what we name that tag)).

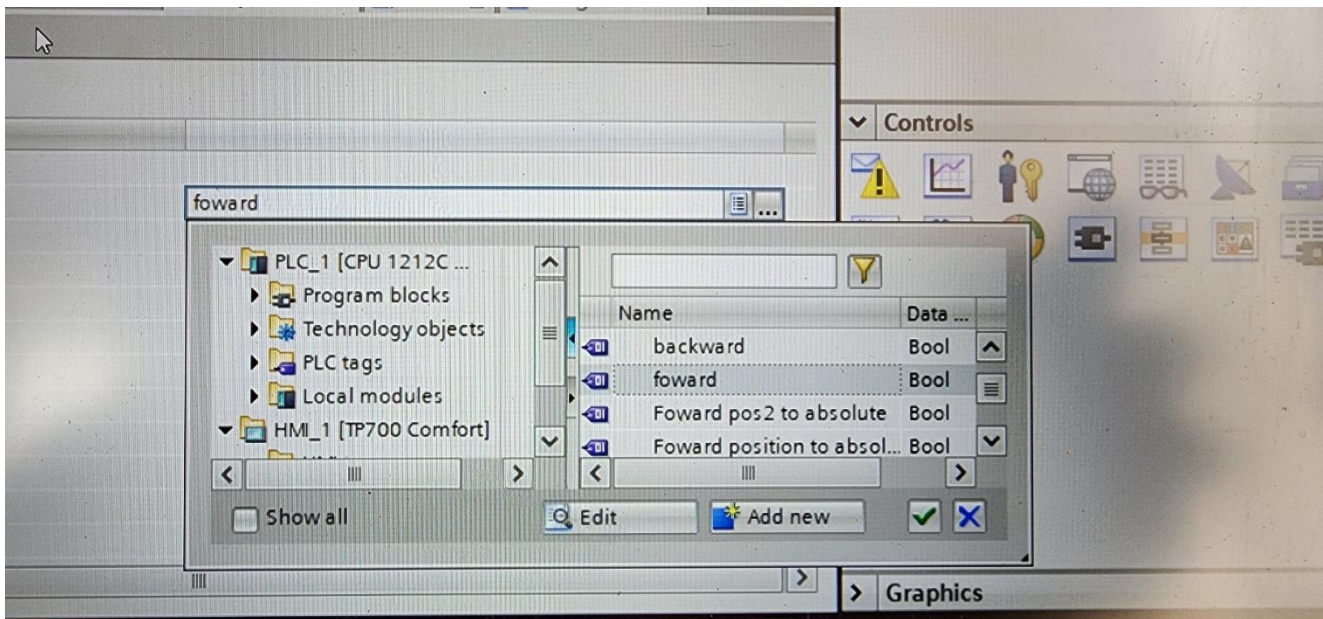


Figure 62 PLC tag selection to function

For the on and off switch, we add the Tag from Power block (mentioned in Step 1) to the process block.

General

Process

Tag: on/off

PLC tag: *on/off

Address: Bool

Value for "ON": 1

Mode

Format: Switch

Label

Show label

Title: Switch

ON: ON

OFF: OFF

Figure 63 Process of on/off switch

The data display or insert data box is the same as on and off switch, we choose the data corresponds to that box.



General

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Process

Tag: Data_block_1_Position2

PLC tag: Data_block_1.Position2

Address: Real

Type

Mode: Input/output

Format

Display format: Decimal

Decimal places: 0

Field length: 9

Leading zeros:

Format pattern: s99999.999

Figure 64 Process of insert data box

The format of the data displayed can be changed in the Format pattern (showed in the figure above).

The home signal is set up to light up when the block is at home position.

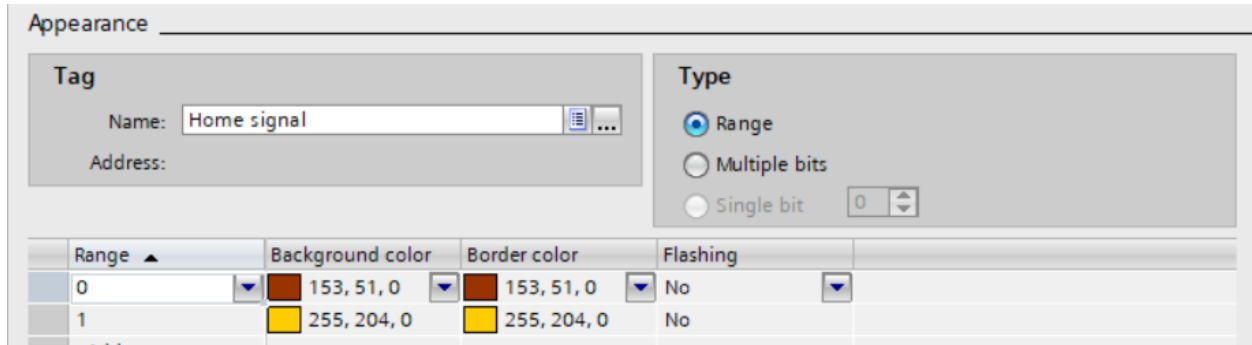


Figure 65 Home signal set up

After finished setting up HMI device we changed the acquisition cycle in HMI tag to make the delay of all the buttons are as low as possible.

Name	Access mode	Acquisition cycle
Add to pos 2	<symbolic access>	100 ms
add to pos 4	<symbolic access>	100 ms
add to pos 5	<symbolic access>	100 ms
add to pos3	<symbolic access>	100 ms
Add to position 1	<symbolic access>	100 ms
Axis_1_Position	<symbolic access>	100 ms
backward	<symbolic access>	100 ms
Data_block_1_Absolute position	<symbolic access>	100 ms
Data_block_1_Input velocity	<symbolic access>	100 ms
Data_block_1_Position1	<symbolic access>	100 ms
Data_block_1_Position2	<symbolic access>	100 ms
Data_block_1_position3	<symbolic access>	100 ms
Data_block_1_position4	<symbolic access>	100 ms
Data_block_1_position5	<symbolic access>	100 ms
foward	<symbolic access>	100 ms
Foward pos2 to absolute	<symbolic access>	100 ms
Foward position to absolute	<symbolic access>	100 ms
fw pos 4 to ab	<symbolic access>	100 ms
fw pos 5 to ab	<symbolic access>	100 ms

Figure 66 HMI tag

3. Prototyping:

3.1 Manufacturing processes:

- Mechanical machining: The processes of machining the parts of the dancer system are mainly performed by automatic machine in VGU GPEM's lab.

3.1.1: Laser cutting:

For the machining of dark metal sheet and aluminum sheet were performed by a “TruLaser 2030” laser cutting machine, with easy control operation, fast, automatic, and precision cutting.



Figure 67 Laser cutting machine in VGU lab

Table 7 Basic characteristic of laser cutting machine

Dispensed product	multi-material
Type	laser
Product handled	sheet, panel
Other characteristics	for aeronautics
X travel	3,000 mm (118 in)
Y travel	1,500 mm (59 in)



The cutting files of the two sheets were sketched by Solidwork and then need to be exported to .dxf file for the machine to read.

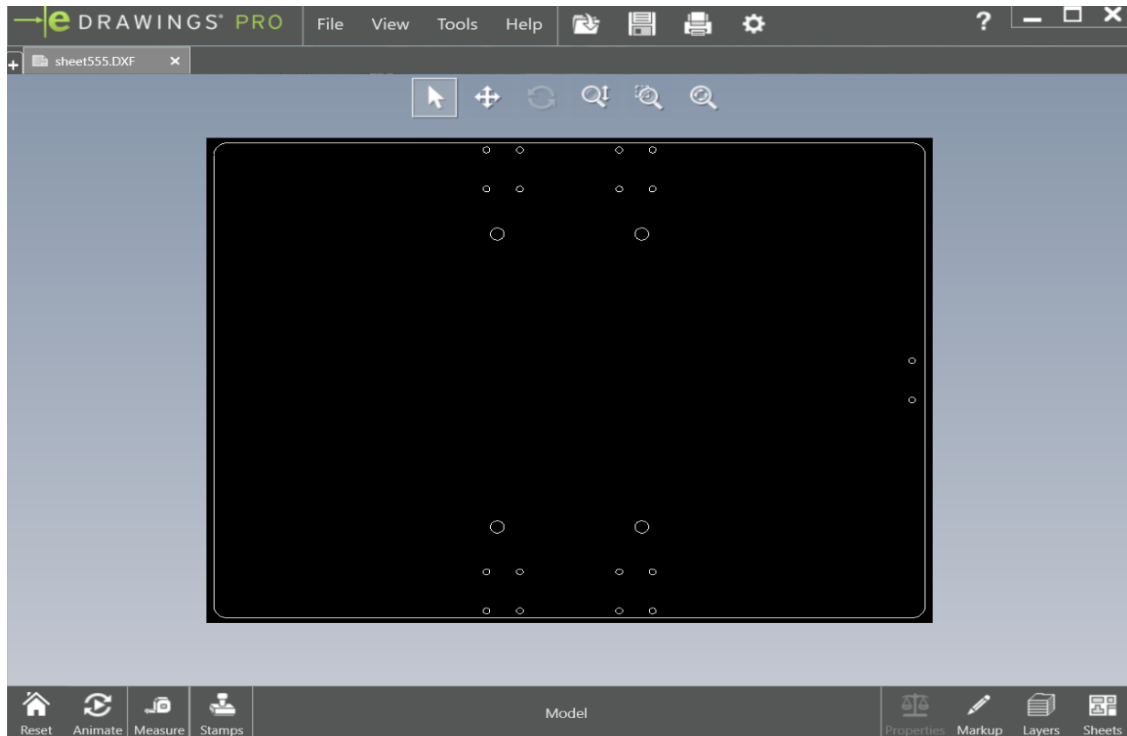


Figure 68 Cutting file of aluminum sheet

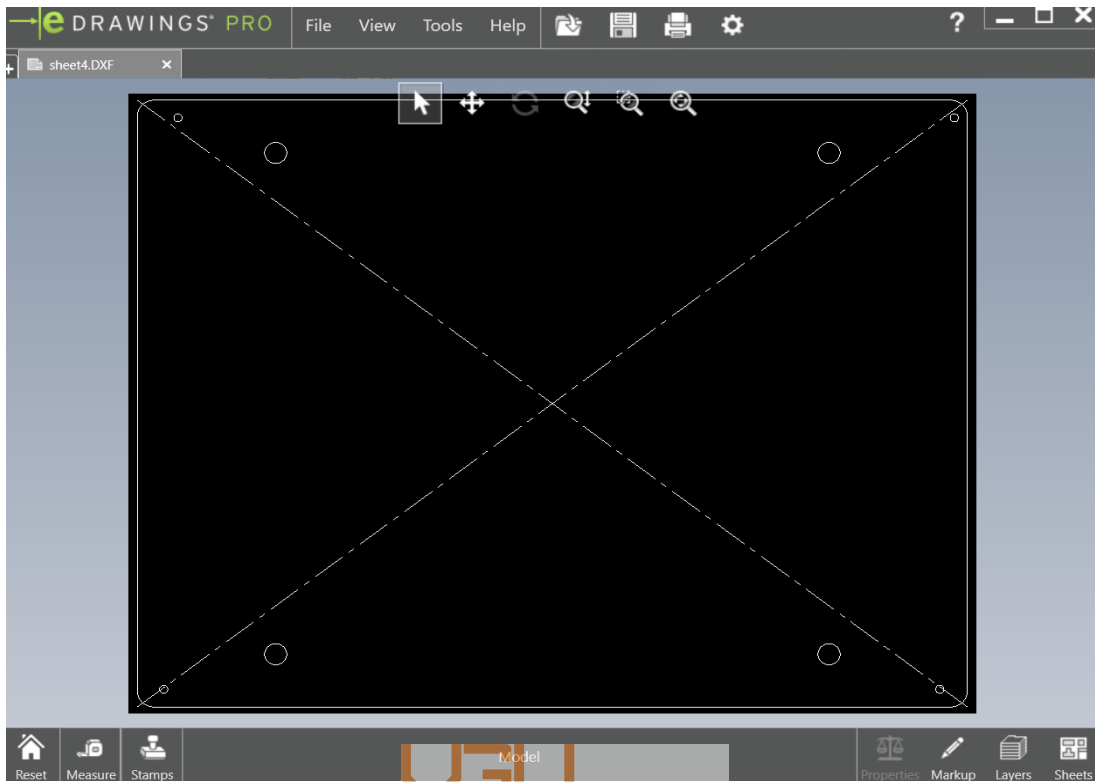


Figure 69 Cutting file of metal sheet
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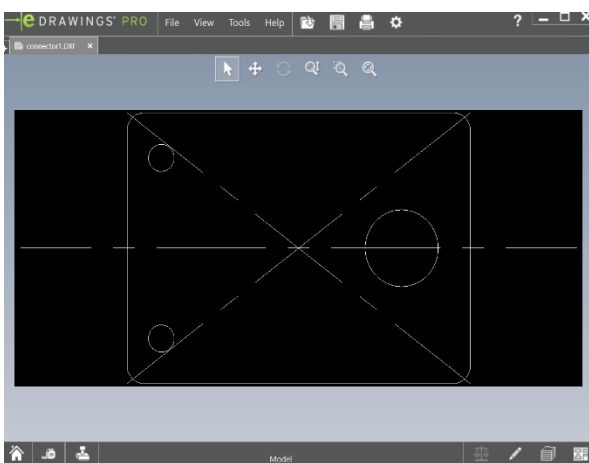


Figure 71 Cutting file of connector 1

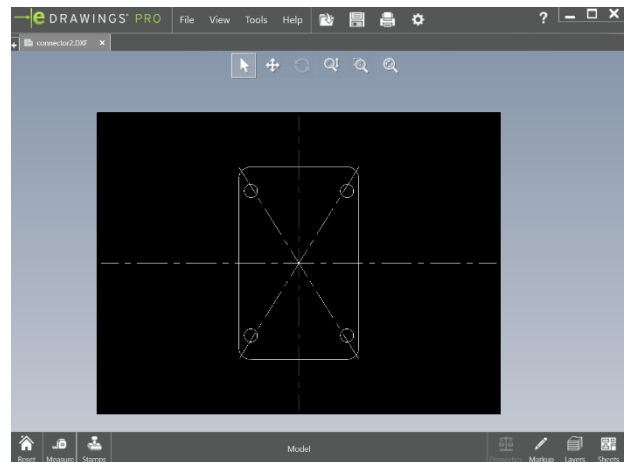


Figure 70 Cutting file of connector 2

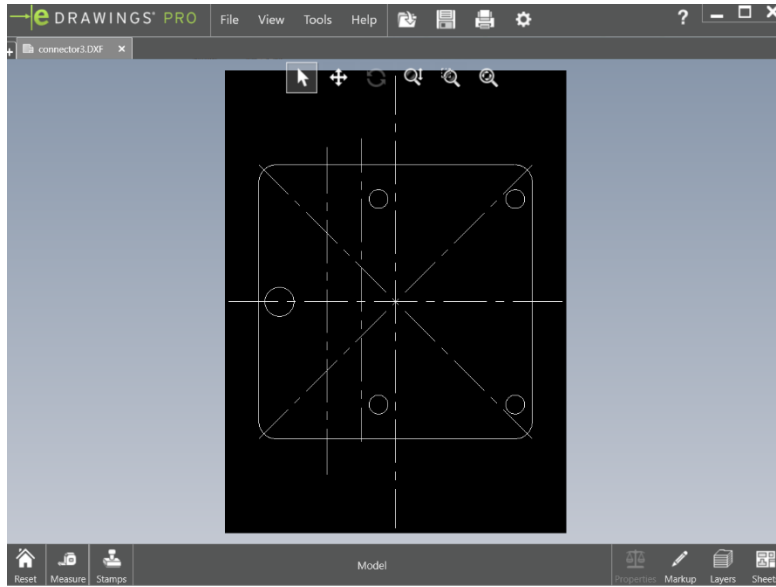


Figure 72 Cutting file of connector 3

Table 8 Cutting data

Material	Thickness	Cutting gas	Cutting head
Dark metal	5mm	Oxygen (O ₂)	17mm
Aluminum	5mm	Nitrogen (N ₂)	23mm



Figure 74 Cutting gas station in VGU lab



Figure 73 Cutting head

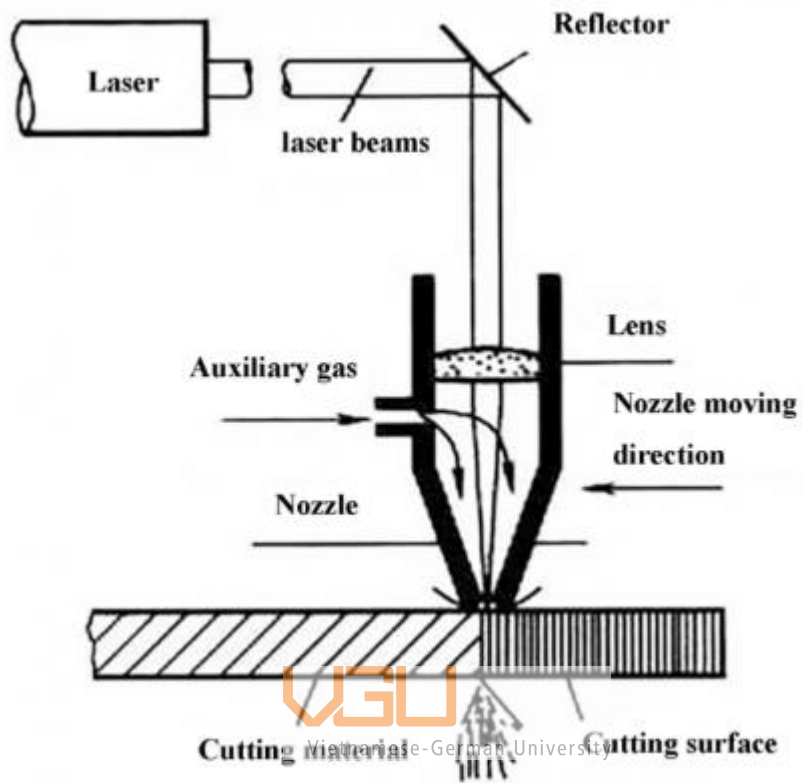


Figure 75 Cutting process

3.1.2 Turning of roller shaft:

For the turning process of roller shaft, we use the “WEILEA DA 210-AC” semi-automatic turning machine.



Figure 76 Turning machine in VGU lab

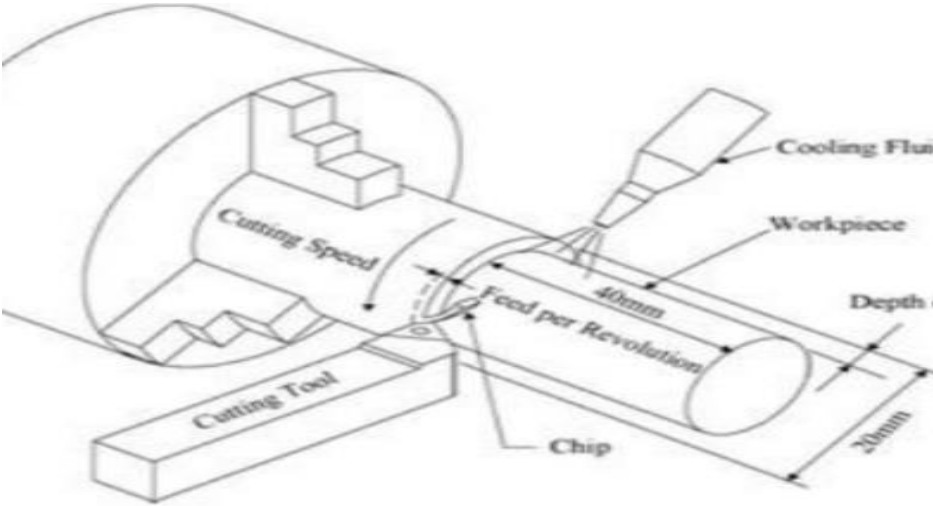


Figure 77 Turning process

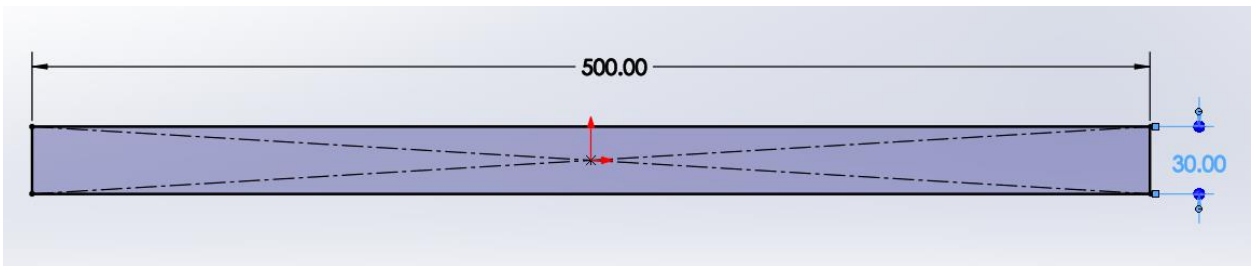


Figure 78 Original ingot 2D sketch

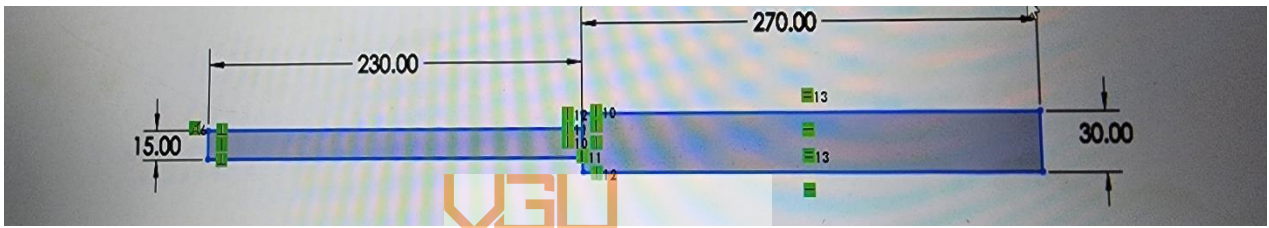


Figure 79 After turning ingot 2D sketch



Figure 80 Original ingot





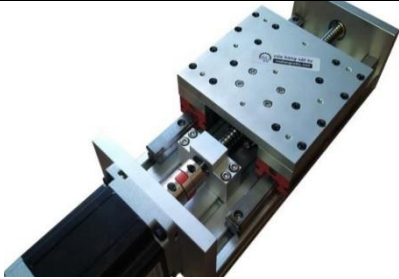


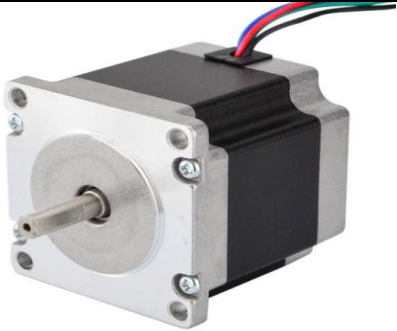

Figure 81 After turning

3.1.3 Other parts:

For the other parts, with high precision need, I have to choose available parts on the markets with ISO standard (see the table below):

Table 9 Other parts information

No	Product name	Image	Amount	Price (VND) per one product	Total (VND)
1	P002 vertical axis bearing pillow block		2	35.000	70.000
2	300mm Slider bar		2	255.000	510.000
3	1 side ball square slider	 VGU Vietnamese-German University	4	210.000	840.000
4	Damper-spring shock absorber		1	110.000	110.000
5	Lead screw mechanism		1	2.350.000	2.350.000

6	NEMA 23 stepper motor Model:57cm23 1.8°/5A		1	650.000	650.000
7	Stepper motor driver		1	800.000	800.000



3.2 Full assembly of the prototype: Vietnamese-German University

- Base and roller bearing:



Figure 82 Side view of base

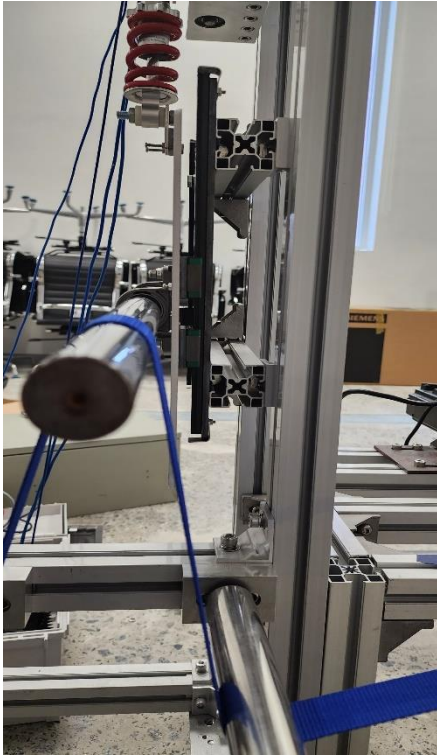


Figure 84 Front view of base

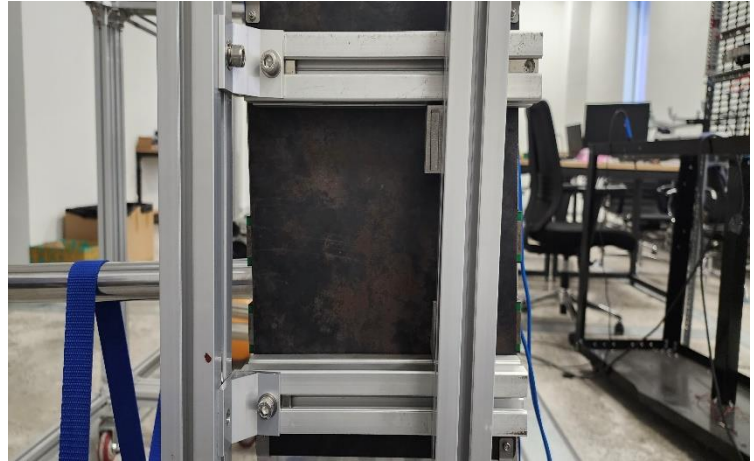


Figure 85 Back view of base

- Connector (shock absorber):

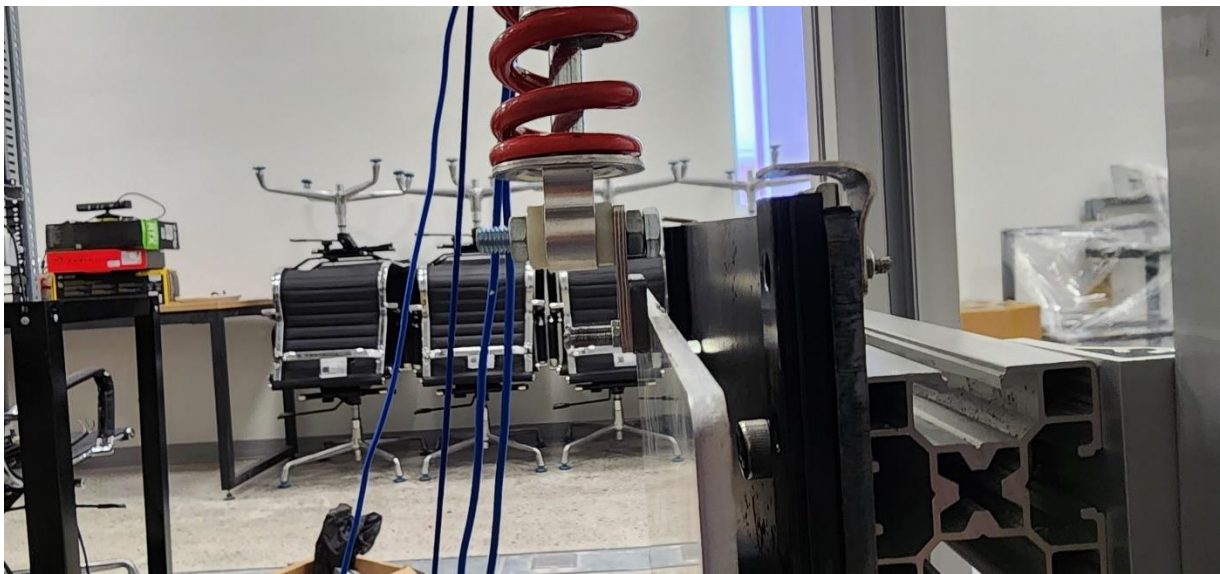


Figure 83 Connector with base side view



Figure 87 Connector with base front view

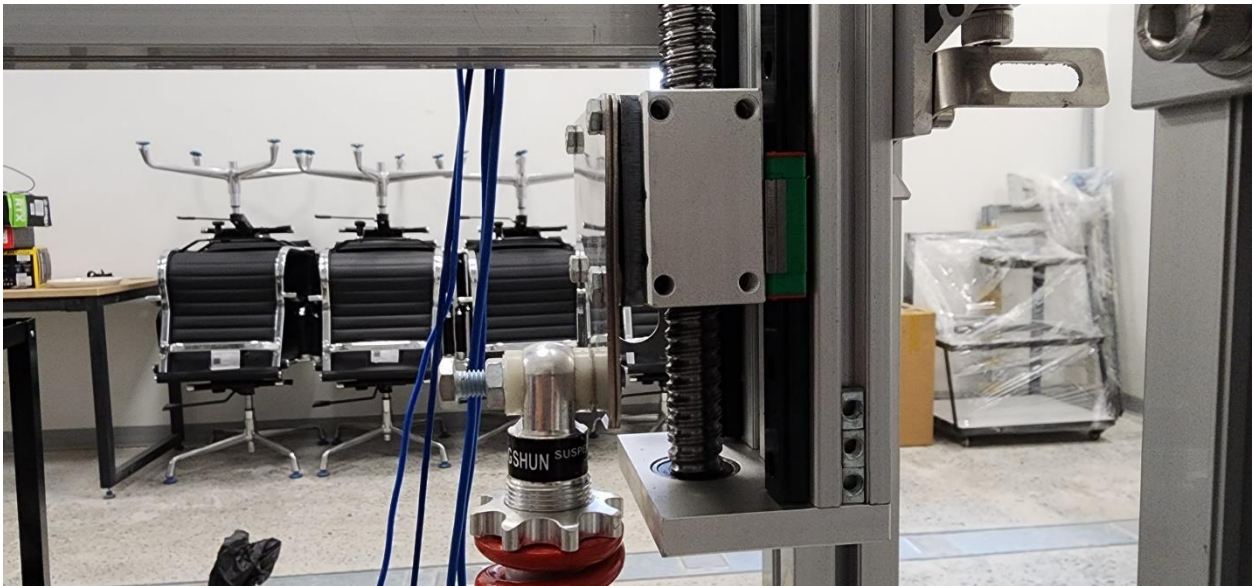


Figure 86 Connector with lead screw side view

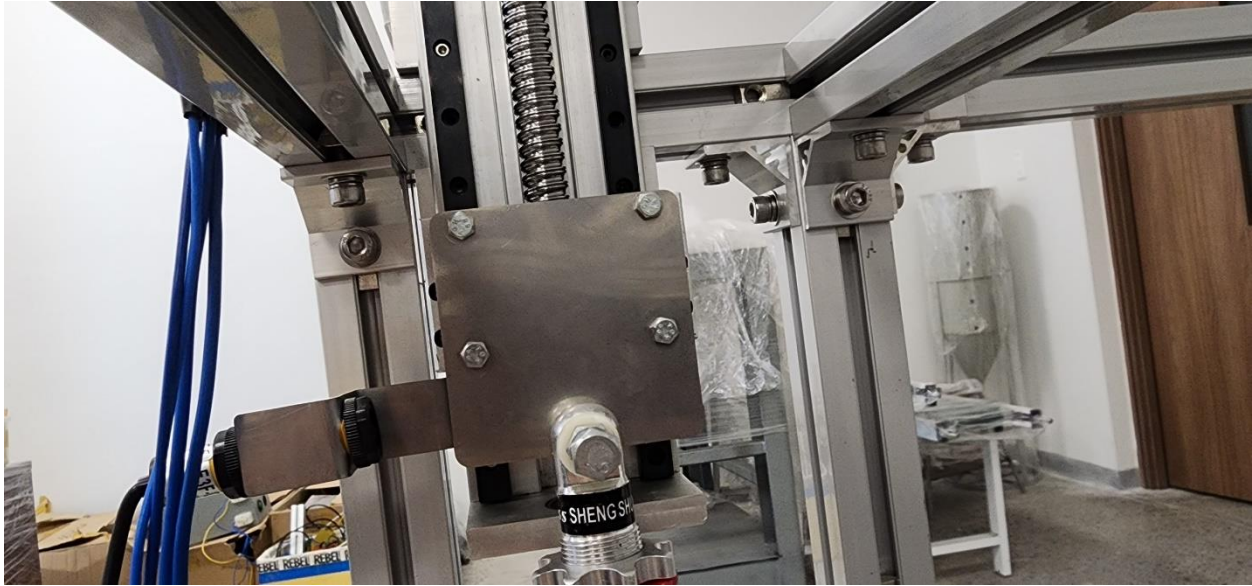


Figure 88 Connector with lead screw front view



Figure 89 Connector side view



Figure 90 Connector front view

- Lead screw:



Figure 92 Lead screw side view



Figure 91 Lead screw front view



Figure 93 Lead screw back view



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- Sensor:



Figure 94 Sensor front view



Figure 95 Sensor side view

- Full assembly:



Figure 97 Full assembly front view

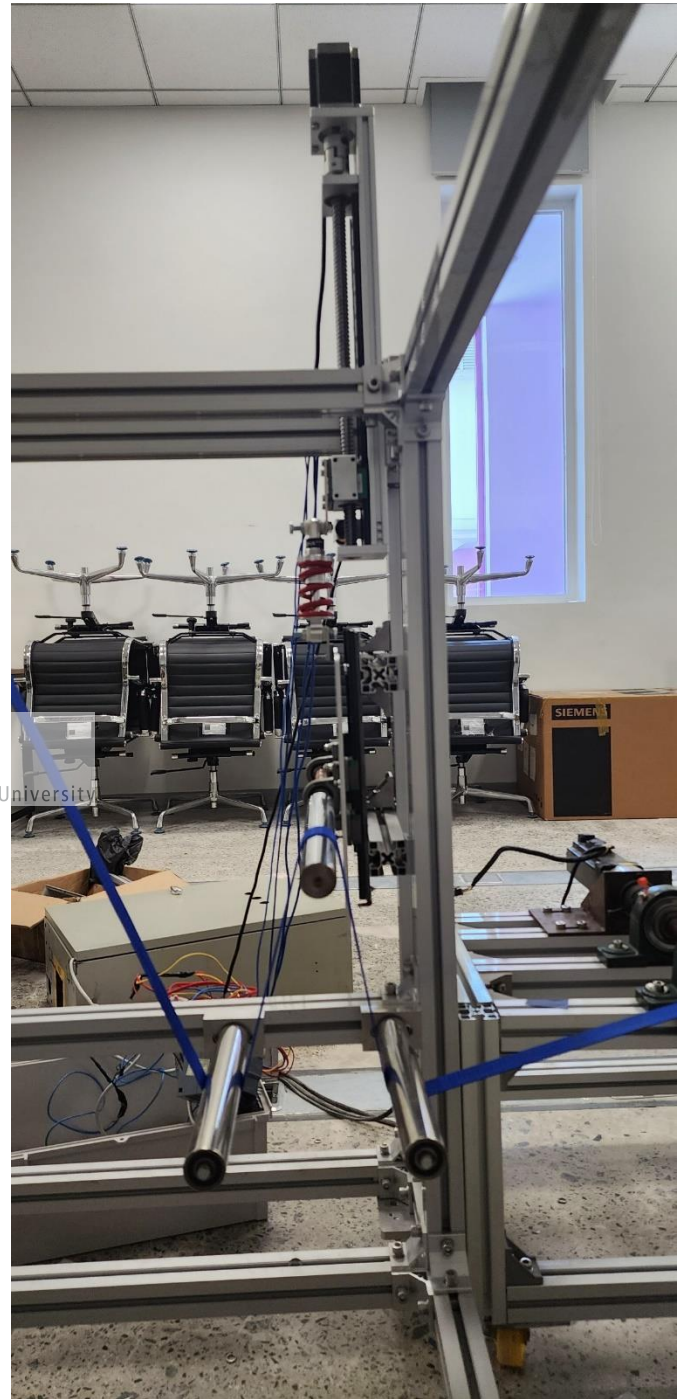


Figure 96 Full assembly side view



Figure 98 Full assembly back view

4. Testing result and discussion:

4.1 Testing result:

For testing method, I load the roller with web tension, and then control it move from home position (lowest point) to higher points to check the tension at each point. From the requirement of the thesis, I let the system move at 5 points at 5 different tension loads. Each tension more or less than each other 10N, with the maximum load is at the highest point. The result is displayed and noted down by the load cell (tension measure device).



Figure 99 Load cell front view



Figure 100 Load cell side view



Figure 103 Load the tension to the dancer roller



Figure 102 Dancer roller is at home position



Figure 101 Dancer roller is at the highest point

For testing process, I conducted it in 2 attempts.

- Attempt 1:

No.	Position (pulses)	Position (mm)	Tension (N) \pm 0.05N
0	Home (pulse=0)	0	43
1	330	16.5	54
2	665	33.25	67
3	930	46.5	85
4	1250	62.5	96
5	1505	75.25	117

- Attempt 2:

No.	Position (pulses)	Position (mm)	Tension (N) \pm 0.05N
0	Home (pulse=0)	0	47
1	315	15.75	52
2	640	32	66
3	940	47	87
4	1240	62	96
5	1540	77	119

Table 10 Testing result

Note:

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From the setting of PLC program (section 2.3)

Pulse per motor revolution: 200 pulses mean it took 200 pulses for motor to rotate 360 degrees

As lead screw characteristic: the moving step of screw is 10 mm means motor rotate 360 degrees, lead screw's block moving 10mm

So, 200 pulses, block moves 10mm => 1 pulse, block moves 0.05 mm

4.2 Discussion:

From the result of table 10, we can see that the motor rotated approximately 300 pulses, so the block moved approximately 15mm, to make the tension increase 10N (start from home position, pulse = 0), that fulfilled the requirement of the thesis from the manufacturer (as mentioned in section 1.3).

For the repeatability of the system, after finish attempt 1 and hit the move home button, the system immediately moved to home position, and can start conducted attempt 2 after that.

For the mechanism, the motor rotated smoothly, no sign of missed step. The dancer roller, and the lead screw moved up and down with no oscillation.

For the control system, the dancer is moving exactly as being programmed, the delay is minimized (100 millisecond).

Overall, the testing result and the design had been conducted properly, and the program had been written correctly.

5. Conclusion:

In conclusion, the prototype meets up the basic requirement:

- Low cost of manufacturing and developing.
- Clearly design and operating correctly.

However, the prototype still needs further development to utilize the usage of the product. Nevertheless, the system operates with minimum error in controlling aspect, and there absolutely no failure or damaging in mechanical field, expect for a minor oscillate at the roller when loading web tension.

The tolerance of the dancer roller is high regarding to low tension level of the roll-to-roll system, all other parameter such as parallelism, or perpendicularity is conducted strictly to the design manual. Bearing pillow block, lead screw mechanism, and others part are well-manufactured, which proved a long working life of the system.

During conducting the project, I had a huge opportunity to develop manufacturing skills, such as laser cutting, turning, milling, drawing, PLC program, which is make me utilize the knowledges that I have learnt in academic years in VGU.



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