

CHAPTER 3 - METHODOLOGY

This section describes about the overview of the whole system, which contains of the block diagram of the system and the subsystem, electrical design, software design and safety design.

3.1 System Design Overview

In this sub-chapter, the block diagram of the whole system design will be shown, the input, processing unit, safety and the output that are used to construct the sticker cutting machine.

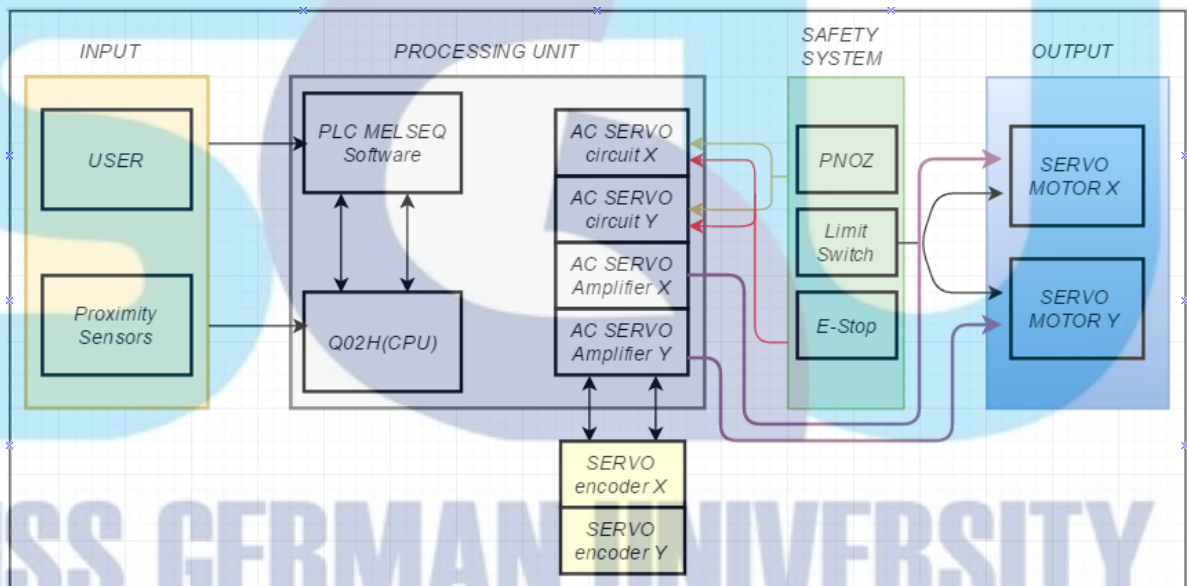


Figure 3-1 System design overview

Figure 3.1 above shows the block diagram of the system. The input unit consists of User and proximity sensor. The user will give command to the processing unit for controlling the servo motor while the proximity sensors will give signals to the processing unit for the homing and initial position. The processing unit consists of the PLC (Q02H (CPU)), the PLC software (MELSOFT GXworks2), and the AC servo amplifier (MR-J3-40A and MR-J3-20A). The PLC's CPU Q02H will communicate with the program. The servo encoder will communicate with the servo amplifier. Pulse train will generated by command from user and the software will send that command to the amplifier after that, the command will be translated into physical movement of the servo motor to move the

XY table of the cutting sticker machine. During the operation, the safety system always active to monitor the system. PNOZ, limit switch, and emergency stop will guarantee the safety of the operation.

The Use-Case Diagram of this system is shown below

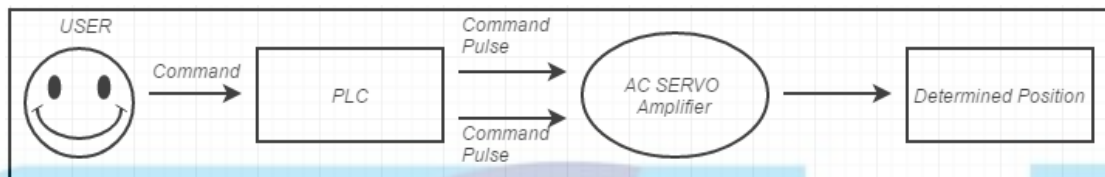


Figure 3-2 Use case diagram

3.2 State Machine Diagram

The state machine diagram represents the system possible state that could be happening during the operation. The explanation of each state is shown below:

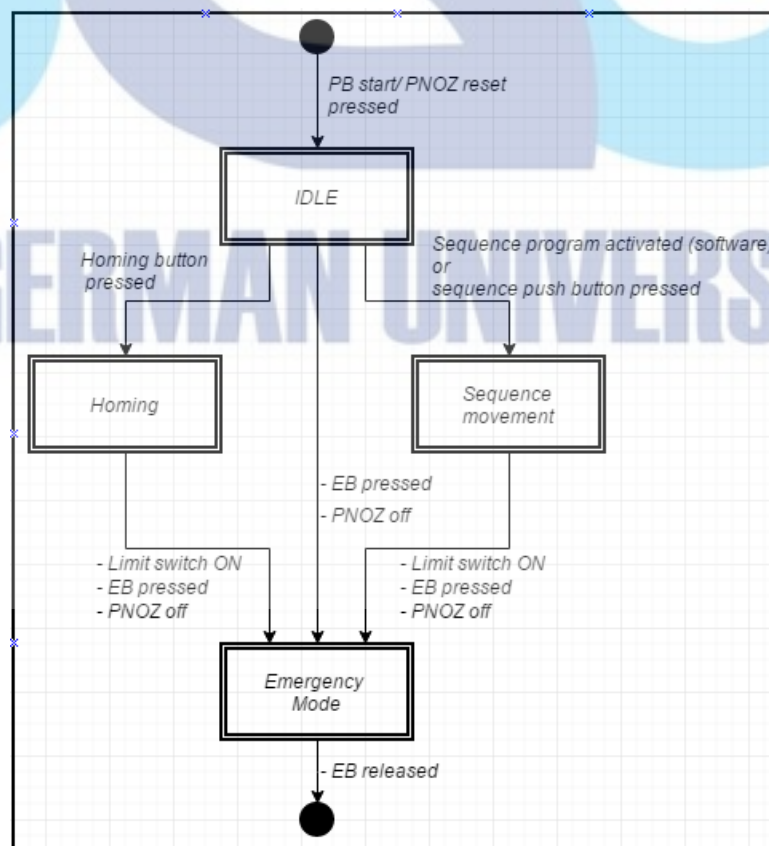


Figure 3-3 State machine diagram

a) Idle State:

- PLC is ON
- PNOZ ON
- Proximity sensor is ON
- MR-J3-40A and MR-J3-20A is ON

b) Homing State:

- PLC is ON
- GXworks2 is ON
- MR MR-J3-40A and MR-J3-20A is running
- Motor X and Y are running

c) Sequence movement State:

- PLC is ON
- GXworks 2 is ON
- MR-J3-40A and MR-J3-20A is running
- Motor X and Y are running

d) Emergency State :

- PNOZ is OFF
- MR-J3-40A and MR-J3-20A is OFF
- Motor X and Y stop

The positioning system can be ready by pressing the PB ON button. First the system is idle. Idle means that the PLC is ready, PNOZ is ready, the machine is in initial position, and the servo amplifier ready to receive signal. If the system in first start, the homing sequence is needed. Next, the user can send commands to the PLC by Gxworks2 program or by the push button for sequence movement and the PLC will give pulse to the servos. Emergency button can be pressed at any times when there is an emergency situation or when the servos cannot be controlled. Emergency state happened if PNOZ is OFF, limit swiches is on or the emergency button is pressed. When the EB button is

released, the system will reset and user needs to press the PB ON button again to make the system idle again.

3.3 Electrical Design

This chapter describe about the electrical component design of the system.

3.3.1 PNOZ

PNOZ is crucial component in this thesis because it ensures the safety of the servo amplifier MR-J3-20A and MR-J3-40A. Figure 3.4 is the internal wiring diagram of PNOZ. Inside PNOZ there are 3 set of relay k1, k2 and k3. PNOZ need 24Vdc as power supply at A1 (+) and A2 (-) the system will start if emergency stop is released and start button is pressed. The emergency stop will energize the k1.1 and k2.1 and the start button will energize the k3. After k3 is energized, the system will latch. k1 and k2 will ensure the system from welded contact that is common in relay usage and allow the system to self-diagnostic.

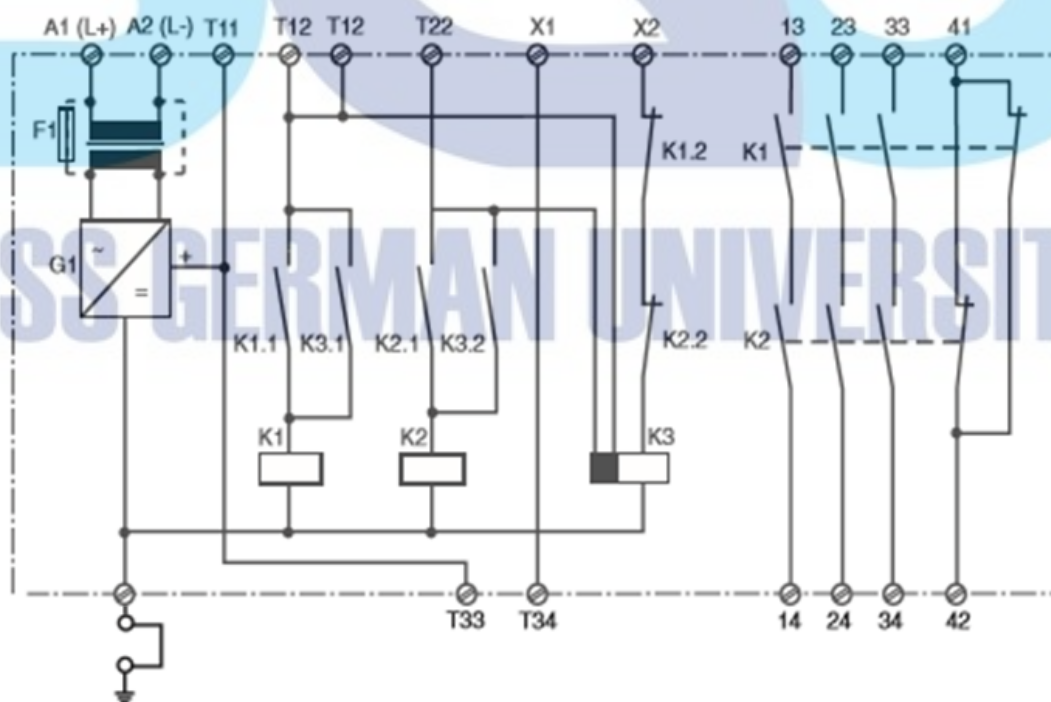


Figure 3-4 PNOZ internal circuit

Next is the connection between PNOZ and the amplifier.

Extra relay is added to the connection because there are only 3 point of PNOZ can be used for normally open connection (pin 13, 23, 33). But the servo amplifier needs 2 ports each.

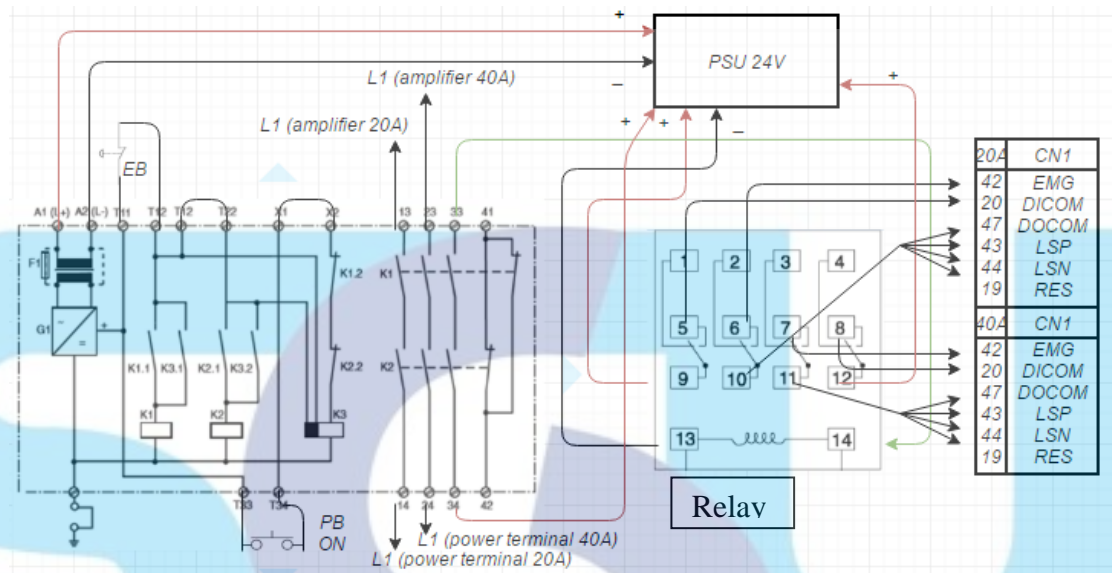


Figure 3-5 Electrical connection

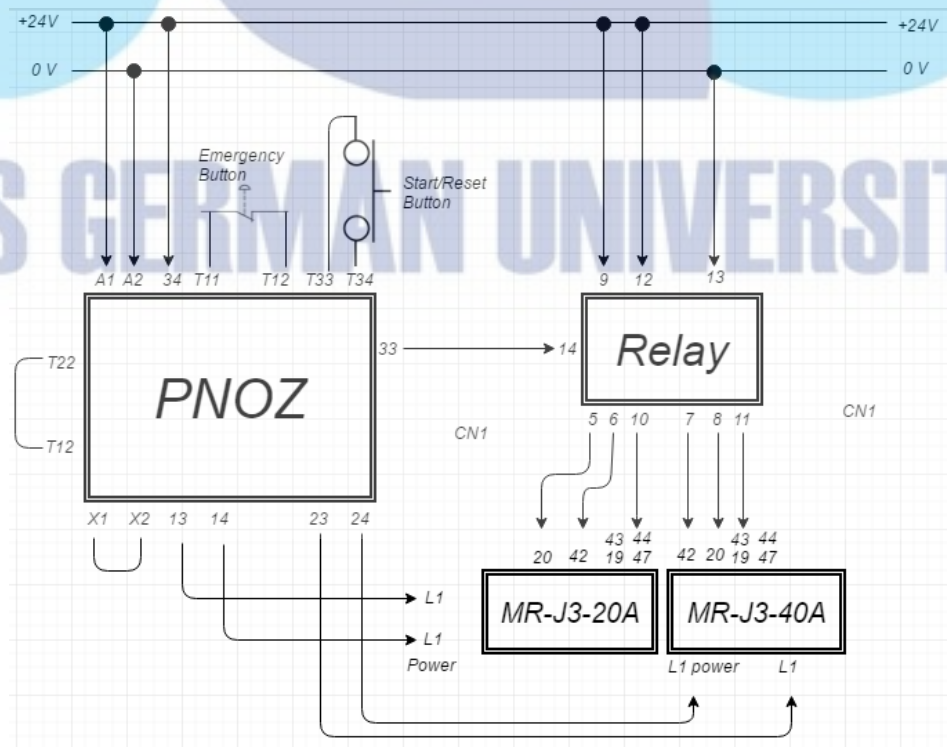


Figure 3-6 Electrical wiring diagram

3.3.2 Limit Switch

For mechanical safety, 2 limit switches added in the end position of each axis X and Y. All switches connected in normally open contact (NO). The switch will break the electrical connection if the faulty operation happened to prevent the damage to the hardware and operator

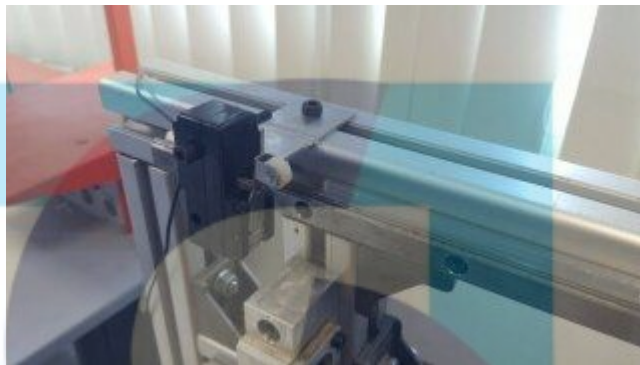


Figure 3-7 X-Axis Limit Switch

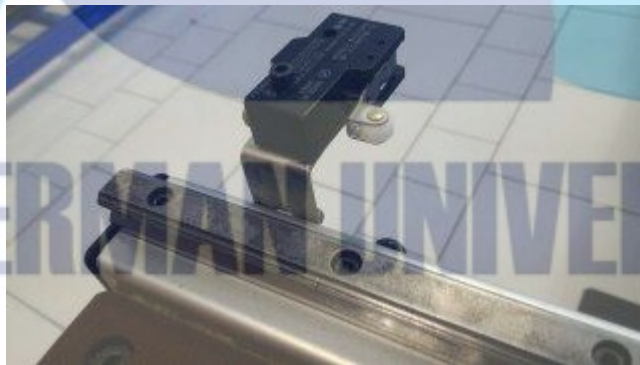


Figure 3-8 Y-Axis Limit Switch

3.3.3 CN1 Servo Amplifier MR-J3-20A

CN1 is a 50 pin connector from the MR-J3-20A servo amplifier. CN1 connect the amplifier with the motion control module QD75D4 via A6con1 so that the servo and the motion control can communicate. Each of the pin has specific usage, so not all 50 pin needed for position control. Each of the pin covered with heatshrink to ensure the safety of the pin (prevent short with neighbor pin).

These are the pin number used for position control mode MR-J3-20A :

Pin No.	Abbreviation	Function
8	LZ	Encoder Z-phase pulse (differential line driver)
9	LZR	Encoder Z-phase pulse (differential line driver)
10	PP	Forward/reverse rotation pulse train
11	PG	Forward/reverse rotation pulse train
15	SON	Servo-on
19	RES	Reset
20	DICOM	Digital I/F power supply input
35	NP	Forward/reverse rotation pulse train
36	NG	Forward/reverse rotation pulse train
41	CR	Clear
42	EMG	Emergency stop
43	LSP	Forward rotation stroke end
44	LSN	Reverse rotation stroke end
46	DOCOM	Digital I/F common
49	RD	Ready

Table 2. CN1 for MR-J3-20A

3.3.4 CN1 Servo Amplifier MR-J3-40A

Just like MR-J3-20A, MR-J3-40A also have CN1 as connector for the QD75D4 motion controller. Each of the pin covered with heatshrink to ensure safety of each pin. These are the pin number used for position control mode MR-J3-40A:

Pin No.	Abbreviation	Function
8	LZ	Encoder Z-phase pulse (differential line driver)
9	LZR	Encoder Z-phase pulse (differential line driver)
10	PP	Forward/reverse rotation pulse train
11	PG	Forward/reverse rotation pulse train
15	SON	Servo-on
19	RES	Reset
20	DICOM	Digital I/F power supply input
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36	NG	Forward/reverse rotation pulse train
41	CR	Clear
42	EMG	Emergency stop
43	LSP	Forward rotation stroke end
44	LSN	Reverse rotation stroke end
46	DOCOM	Digital I/F common
49	RD	Ready

Table 3. CN1 for MR-J3-40A

3.3.5 A6con1

A6con1 is 20 pin connector for motion control module QD75D4. Each of QD75D4 pin also have different function and each of the pin covered with heatshrink to ensure the safety of the pin (prevent short with another pin).

These are the pin number used in QD75D4 (Goes for both axis) :

Pin No	Abbreviation	Function
1	FLS	Upper Limit signal
2	RLS	Lower Limit signal
6	COM	Common
7	COM	Common
9	PG0	Zero signal
10	PG0 COM	Zero signal common
11	READY	Drive unit ready
12	RDY COM	Drive unit ready common
13	CLEAR	Deviation counter clear
14	CLEAR COM	Deviation counter clear common
15	PULSE F-	Pulse output F <CW>
16	PULSE F+	Pulse output F <CWCOM>
17	PULSE R+	Pulse output R <CCW>
18	PULSE R-	Pulse output R<CCWCOM>

Table 4 A6CON1 for both amplifier

Motion control and servo amplifier connection diagram:

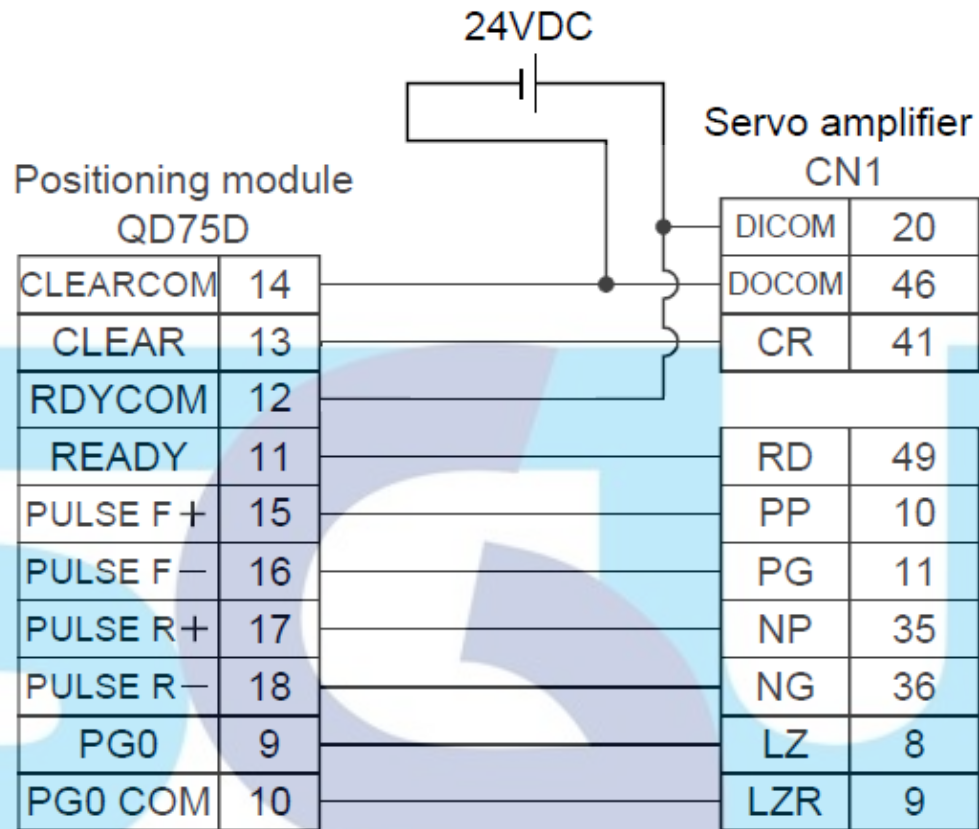


Figure 3-9 Pin connection



Figure 3-10 A6Con1 pin covered with heatshrink

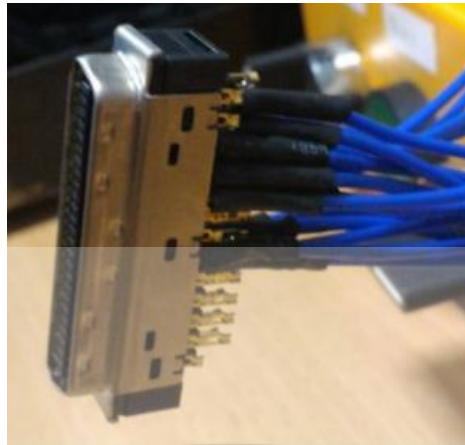


Figure 3-11 CN1 pin covered with heatshrink

3.4 Mechanical checking

This chapter describe the mechanical item checking and improvement made by the author.

3.4.1 Hardware Dimension

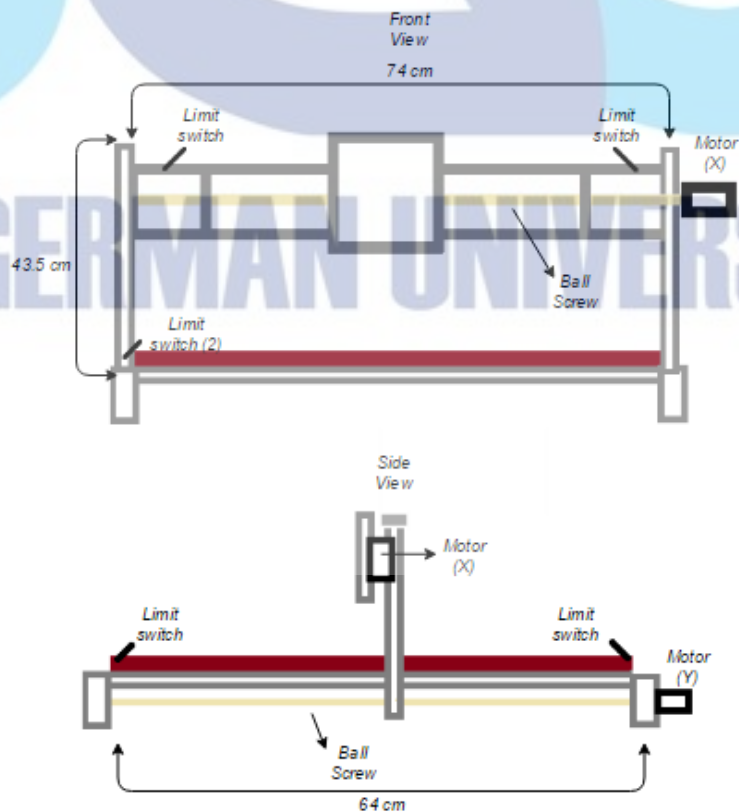


Figure 3-12 XY-Table dimension

Figure 3.12 show the hardware dimension from front and side view. The total length of X direction is 74 cm and the length of Y direction is 64 cm. All the proximity sensor is removed and changed to another position. limit switch is added in the end of both axis. This limit switch used for hardware end position at 12 cm and 48,5 cm for X axis and at 7,5 cm and 49 cm for Y axis. For safety reason, the software maximum workspace is 30x30 cm.

3.4.2 Moving Mechanism

The XY-table using ball screw as the moving mechanism. Ball screw mechanism is mechanical linear actuators that convert rotary motion into linear motor. Ball screw consist of high efficiency screw with the ball that making rolling motion in axis screw and nut. There are 2 ball screw located in each axis as moving mechanism. The one that installed on the table have 5 mm movement per revolution.



Figure 3-13 Ballscrew for X-Axis



Figure 3-14 Ballscrew for Y-Axis

3.4.3 Z-Axis

Z axis of the table will be added with DVD drive stepper motor with L298N as motor driver. The stepper motor will move up and down with command pulse from push button up and push button down. Before starting the cutting simulation the pen will be lowered and the pen will back to its original position when the process is done.

3.4.4 Homing Sensors

The existing proximity sensors that had been installed before in the table cannot be used because of the type of the sensor did not match with the type of PLC. The existing sensor is NPN proximity sensor, while the PLC works with PNP type sensors. These sensors connected to the motion control QD75D4 as guideline for the initialization position of the machine

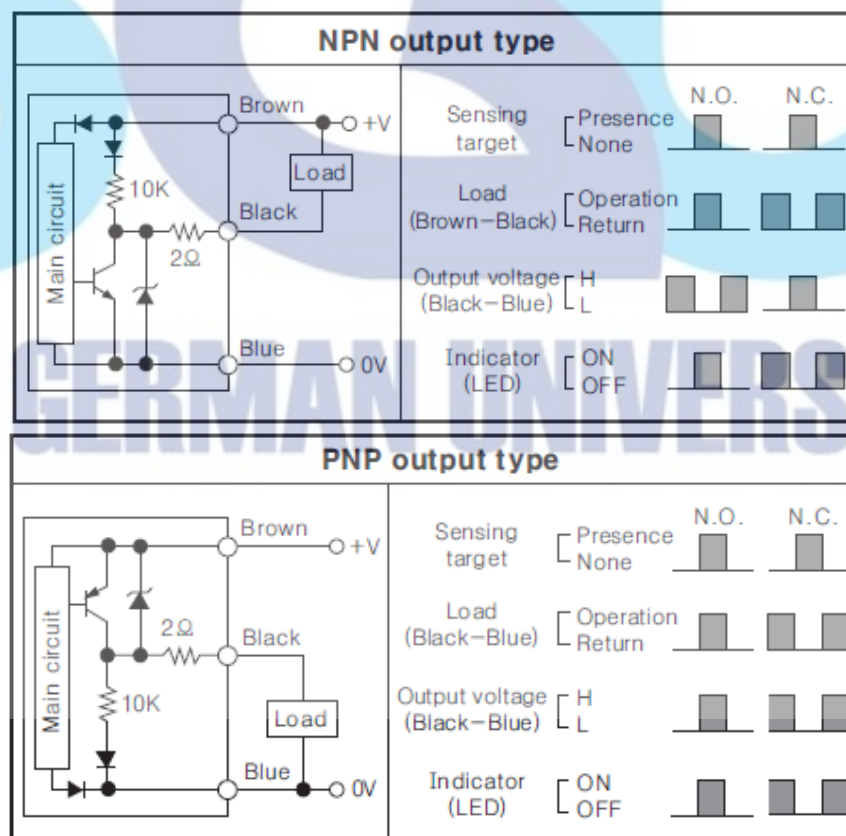


Figure 3-15 PNP and NPN sensor type

3.4.5 Limit Switches

The XY-table previously didn't have any limit switches installed on each axis. The table using 2 proximity sensors at the end position of each axis and 1 for homing. Because of safety reason, both of the proximity sensors are replaced with mechanical limit switches. The limit switches connect directly to the motion controller QD75D4. Software stroke limit also set by the user from program as software safety and if a failure operation happened then the limit switches act as hardware stroke limit to stop the motor and ensure the safety. All the limit switches installed in NC connection. NC connection can provide extra line of safety because if the cable is cut off or the cable is loose the system cannot be started at all. NO connection less safety because operator only know the condition of the switches when the object hit the switch, if the cable had been cut off or loose, the switch will not works and maybe its too late for the operator to react and cause the faulty operation.



Figure 3-16 First look of XY-table



Figure 3-17 Limit switch installed to the table

3.5 Amplifier and Wiring Checking

Before making the program for the PLC, the wiring and connection will be checked first with manual JOG operation for both amplifier MR-J3-20A and MR-J3-40A.

3.5.1 MR-J3-40A and MR-J3-20A JOG Operation

JOG or jogging operation refers to mode of operation that requires the operator to manually adjust the position of the robot, in this case the rotation of the motor. To perform JOG operation the emergency button must be installed and released, otherwise the amplifier will keep showing error notice AL.E6. There are 2 method of jogging: with MR-configurator, or manually press the amplifier's button. Figure 3.18 show step by step how to manually perform jog by pressing the amplifier's button. While doing JOG operation makes sure there is no external command.

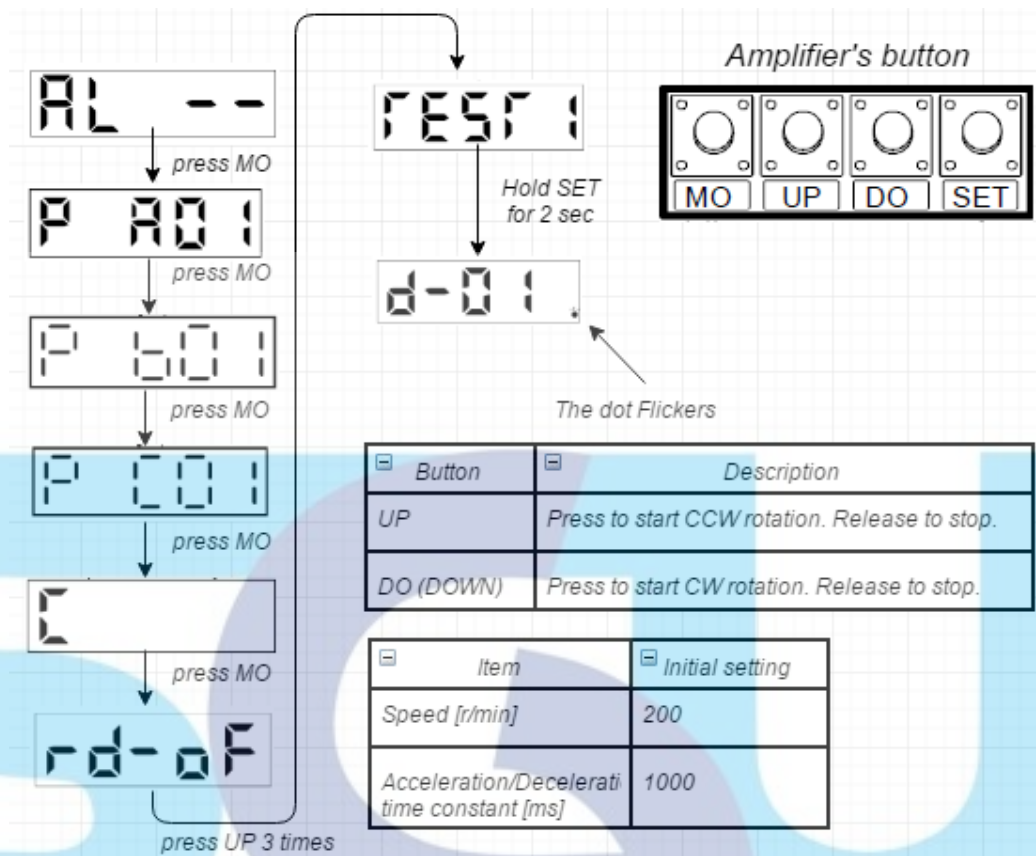


Figure 3-18 Amplifier JOG Step

3.6 Development Tools

This chapter describe about the software design of the system.

3.6.1 GXworks 2

GXworks2 is programming and Maintenance tool software for Mitsubishi PLC. GXworks2 can be programmed with ladder logic or with sequential function chart (SFC is graphical programming language). This software supports all type of Mitsubishi CPU. This project using ladder logic for programming.

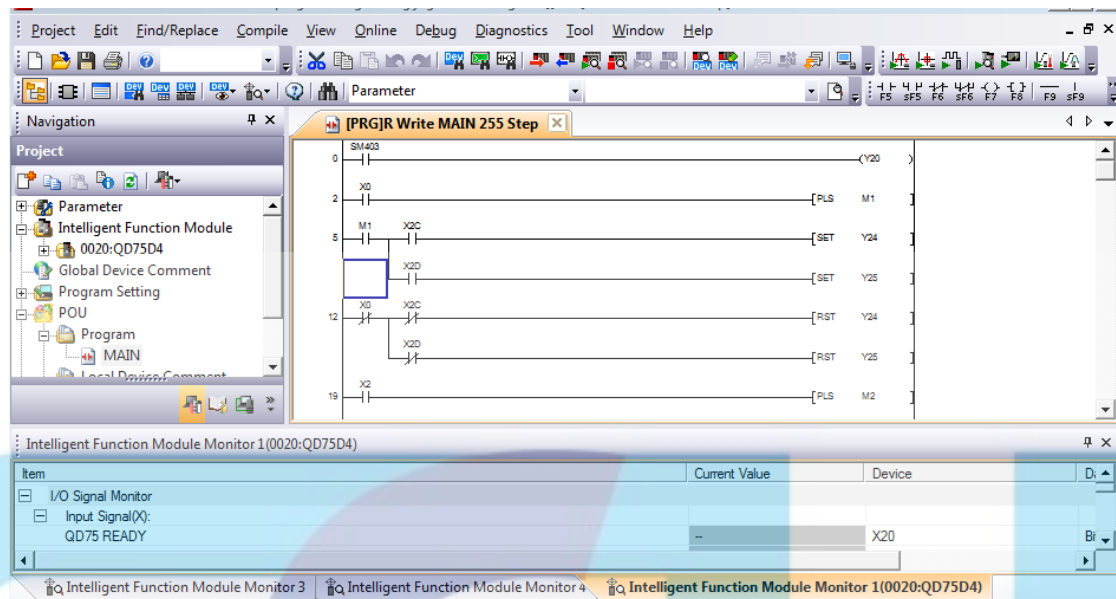


Figure 3-19 GXworks program

3.6.2 Ladder Program Design

Designing ladder program depends on the system and how operator want the machine to work. The programmer must know what input/output and addresses that used in the system. XY-table have 2 axis to be programmed with. Moving single axis and both axis require very different programming. Controlling single axis with program can be done by just sending command to JOG start or Positioning start to the amplifier without any step programming. If same type of program applied to both axis without step program, the motor will move simultaneously at anytime the pulse sent by the programmer. This kind of motor movement usefull at interpolation of both motor to make a diagonal or moving the table into zero position. Making a square require both motor to move after the another, therefore step program is needed. Step program means that the program will run (send pulse) if a certain condition is fullfilled and the action is done, then the next step will run until the last step end that will reset the whole step

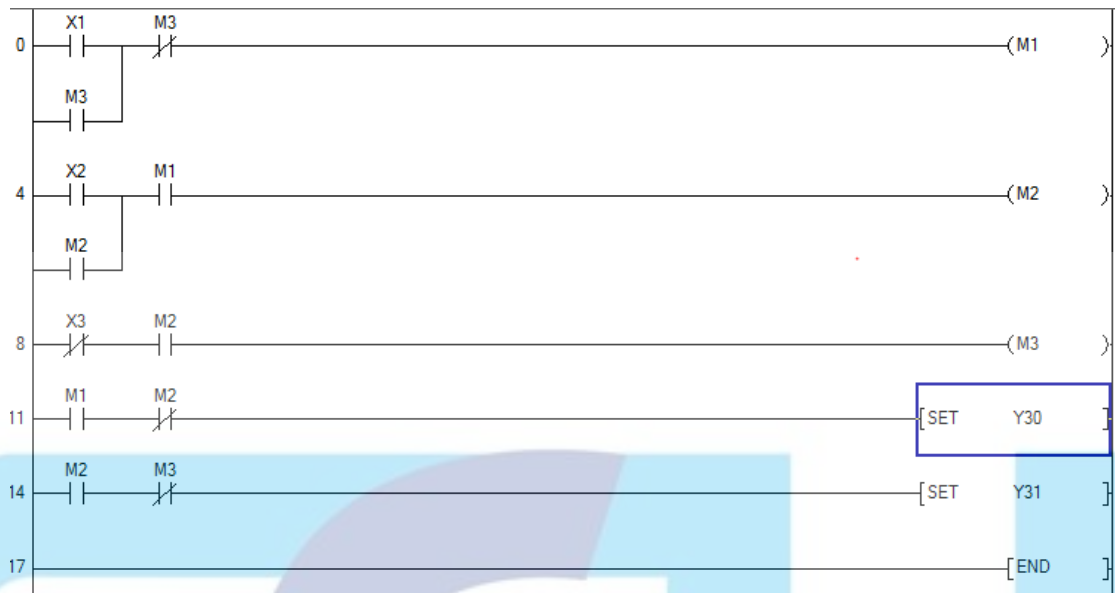


Figure 3-20 Step program example

3.6.2.1 Initial Program Design (Homing)

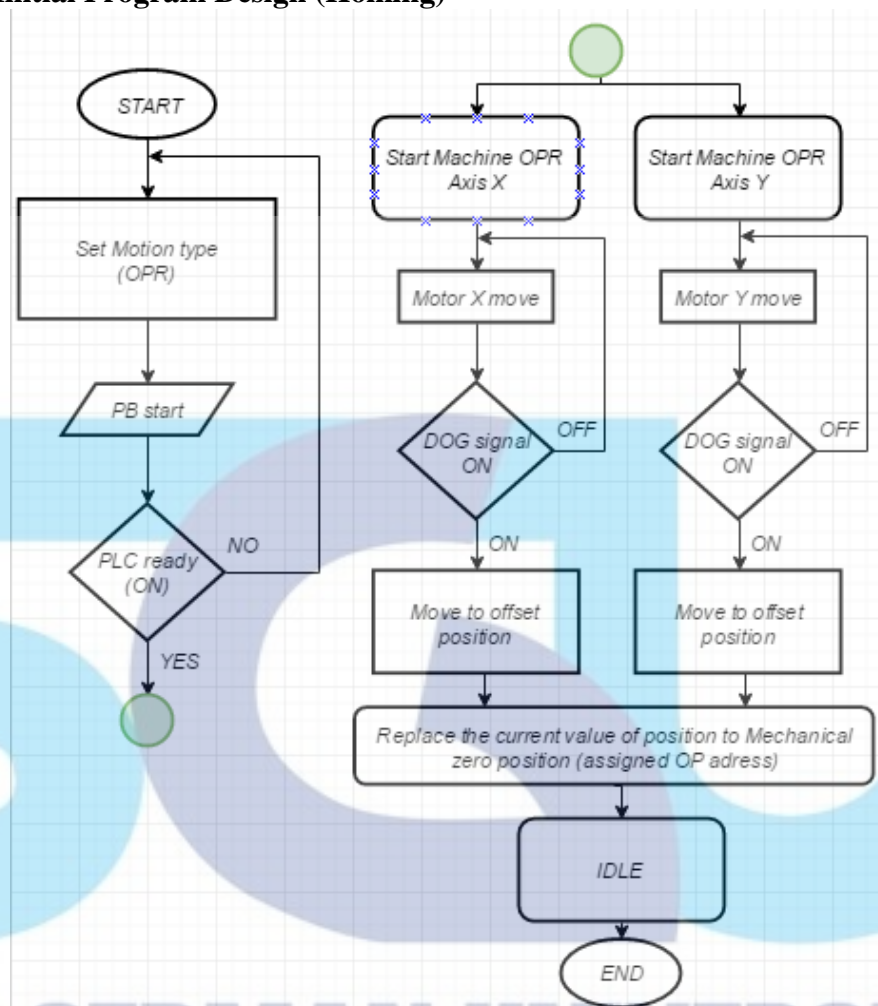


Figure 3-21 Homing Flowchart

Homing is very important in XY table operation. Any loss of power can stop the machine at any position and cause a problem if there is no homing sequence. Before the homing exist the operator must manually return the machine into its initial position, otherwise the machine will set the last position as the starting position of the table. This will cost much time and less safety for the operator. Homing in Mitsubishi MELSEC system Q is called OPR. The system start with the initial push button pressed. If the PLC is ready, then the motion control will send pulse to the amplifier to start machine OPR. The motor will continue to rotate until the homing sensor detects the machine. Then the homing sensor (dog signal) will send pulse back to the motion control and the motion control will send back pulse to the amplifier to move into offset address that had been set in the program

and set that position as zero position of the machine. After the homing is done, the other positions are safe to work.

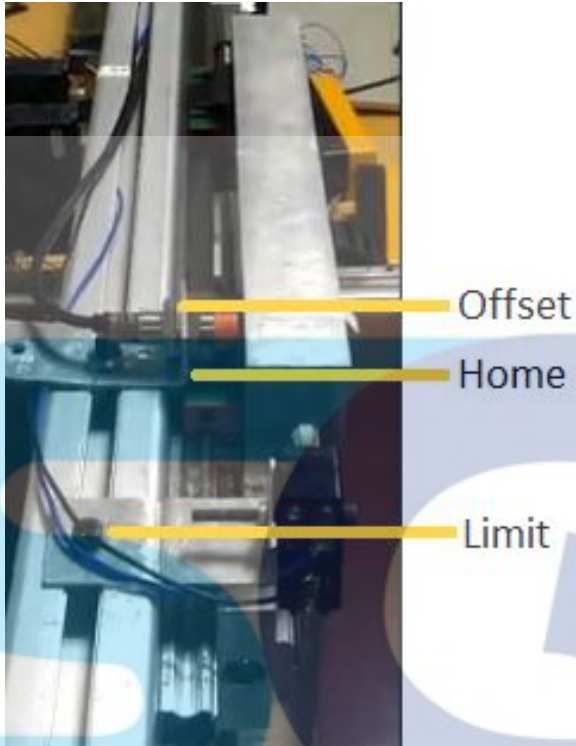


Figure 3-22 X-Axis homing



Figure 3-23 Y-Axis homing

3.6.2.2 Center Position Design

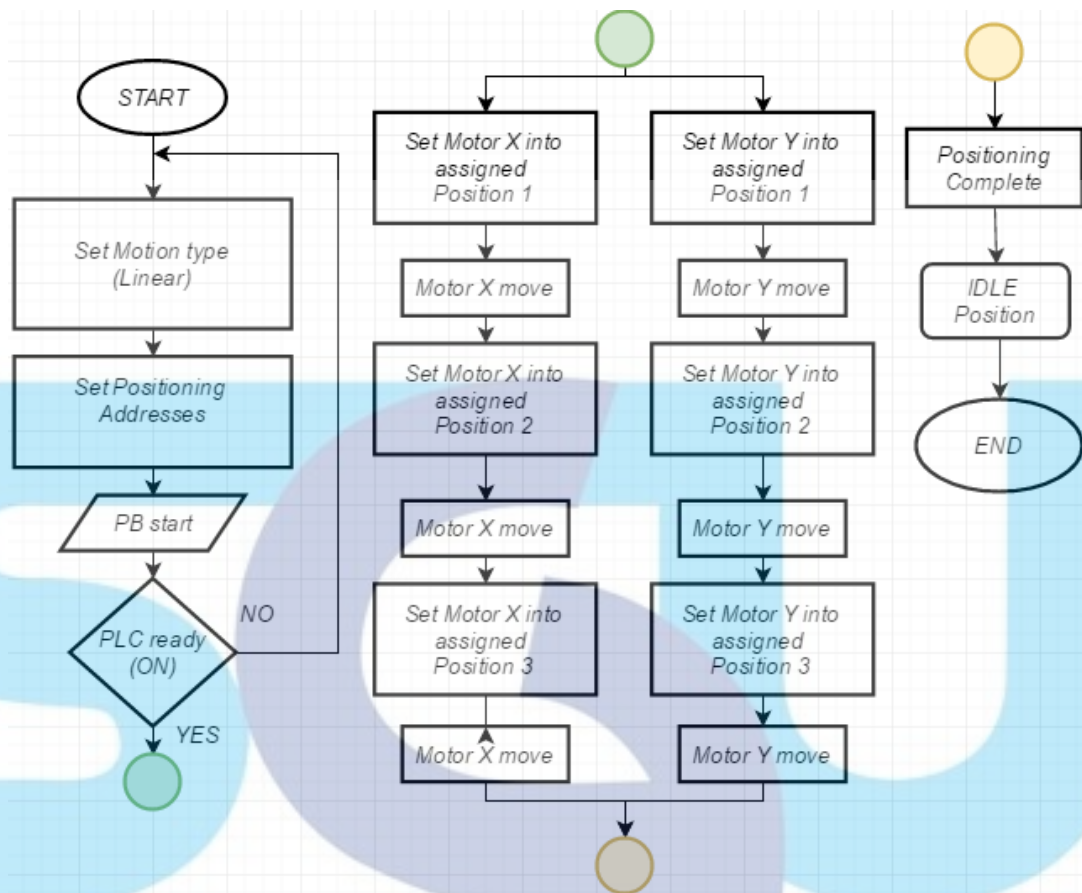


Figure 3-24 Center Position Flowchart

Center position and homing sequence is different. The author assign the homing sequence at the most up-left of X and Y direction of the machine as the home. The software will see the feed rate of the machine as 180224 pulses for X axis and -180224 pulses for Y axis. This center position will act as secondary checking of the homing and move to the center position (0,0). The centering positioning begins when the push button is pressed and the PLC is ON. After that the both motor move together into the position 1 until 3 and back to idle position.

3.6.2.3 Square Program Flowchart

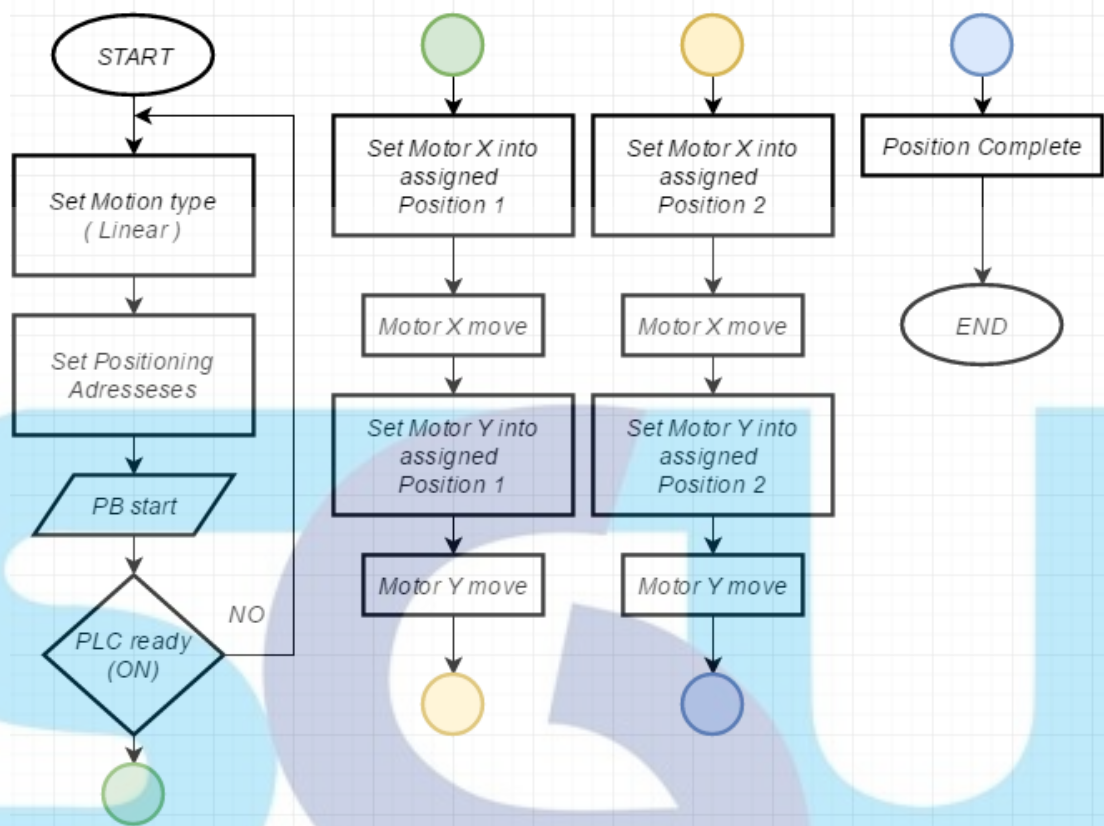


Figure 3-25 Square position Flowchart

There are 3 main shapes that focused on this project: Square, triangle and circle. Making a square with XY-table require the motor to moves one by one after another. After the push button pressed and PLC is ON, the motion control will send command pulse to the motor X to move into position 1, then the motor Y into position 1 after the position 1 of motor X is complete. After that the X motor will wait until the Y motor complete and continue moving into position 2 followed by motor Y move into position 2 after motor X complete and the positioning is complete.

3.6.2.4 Triangle Program Flowchart

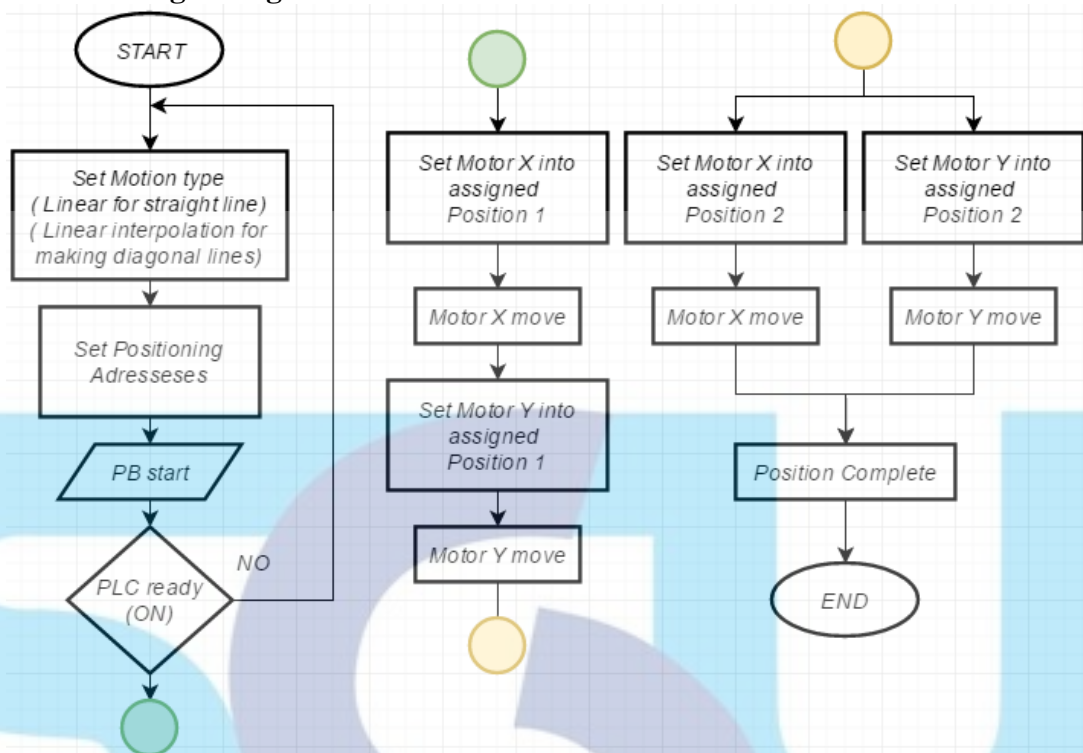


Figure 3-26 Triangle Program Flowchart

Make a triangle is more challenging than making a square. Making a diagonal line in XY-table require both of the motor moves simultaneously with perfect timing. The position address must calculate correctly to make the triangle connected. This flowchart shows the process of right-triangle positioning. The positioning start with the push button pressed and PLC ready is ON. Then the motor X will move to position 1 followed by motor Y move to position 1 after motor X is complete. After the Y motor is complete, both motor move simultaneously with interpolation into the position 2 and the positioning is complete

3.6.2.5 Circle Program Flowchart

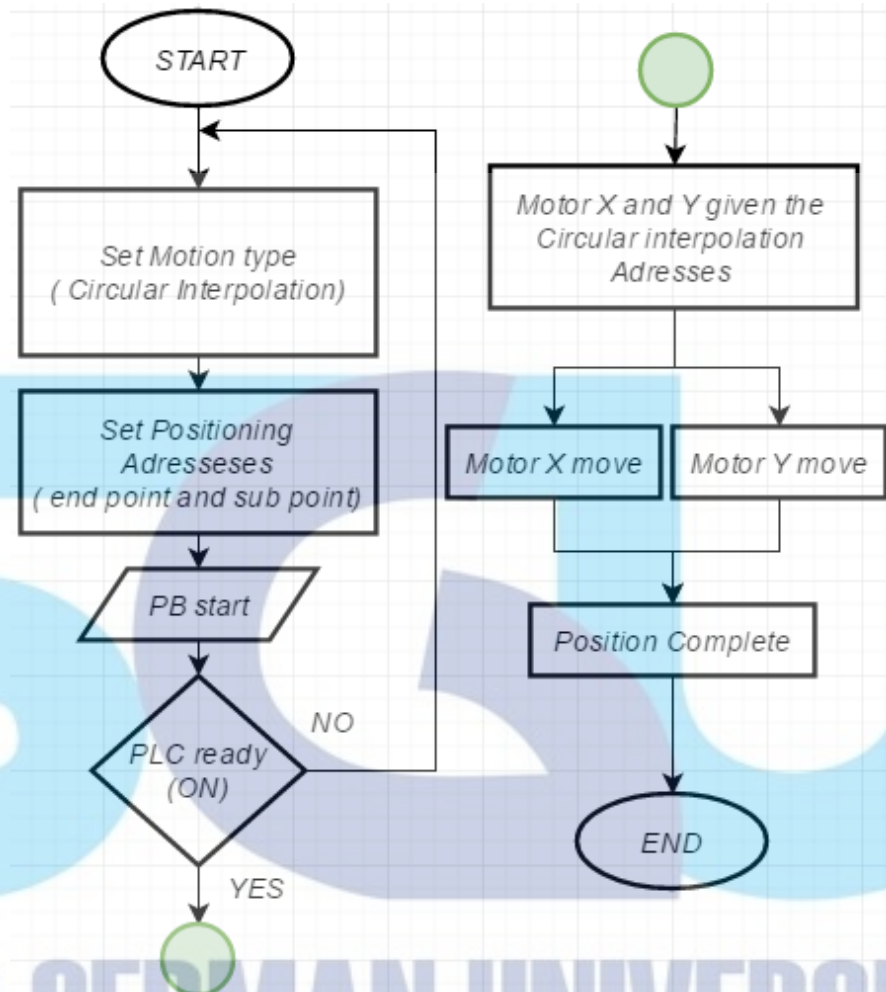


Figure 3-27 Circle Program Flowchart

Making a circle requires the interpolation of both motor from start to finish. Each of the axes must work simultaneously with the calculation of circular Arc. With the understanding of this Arc addresses, the circular movement can be controlled into making any type of circular arc. A full rotation of arc will create circle. The program will start after the push button is pressed and the PLC ready is ON. After that both motor will move simultaneously until the circle is completed (position 1 is the address and arc address). And the positioning is complete.

3.6.3 MR-Configurator

MR-configurator is programming tools for the amplifiers. The parameter of the amplifier can be set with this software and user can monitor the connection or wiring of the amplifier. Without program the amplifier still can be checked by test operation mode with MR-configurator (JOG, Positioning, and Motor-less).

3.6.4 Solidworks Design

The Z axis of the table will be made by 3D printer to print the holder for a pen. This 3D printed result will installed to the motor for Z axis. Figure 3.28 until 3.30 show the solidworks design of the material

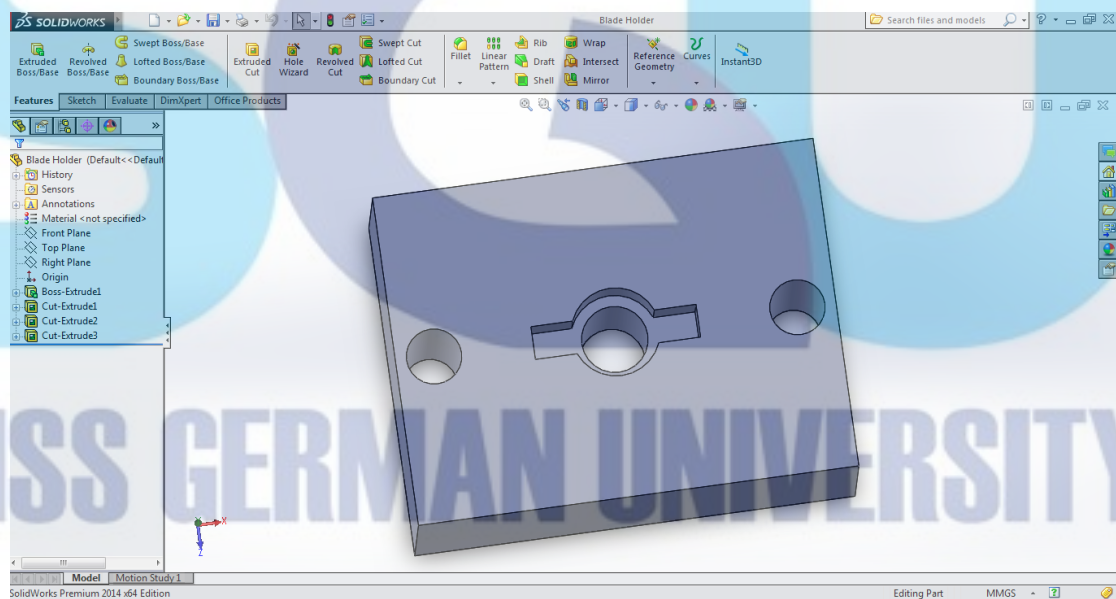


Figure 3-28 Base holder for Z-Axis side view

This is the front view of the pen holder. Pen will be placed in the middle and fastened with the C-clamp shaped fastener. The Base holder is 4cm x 3cm x 2cm .

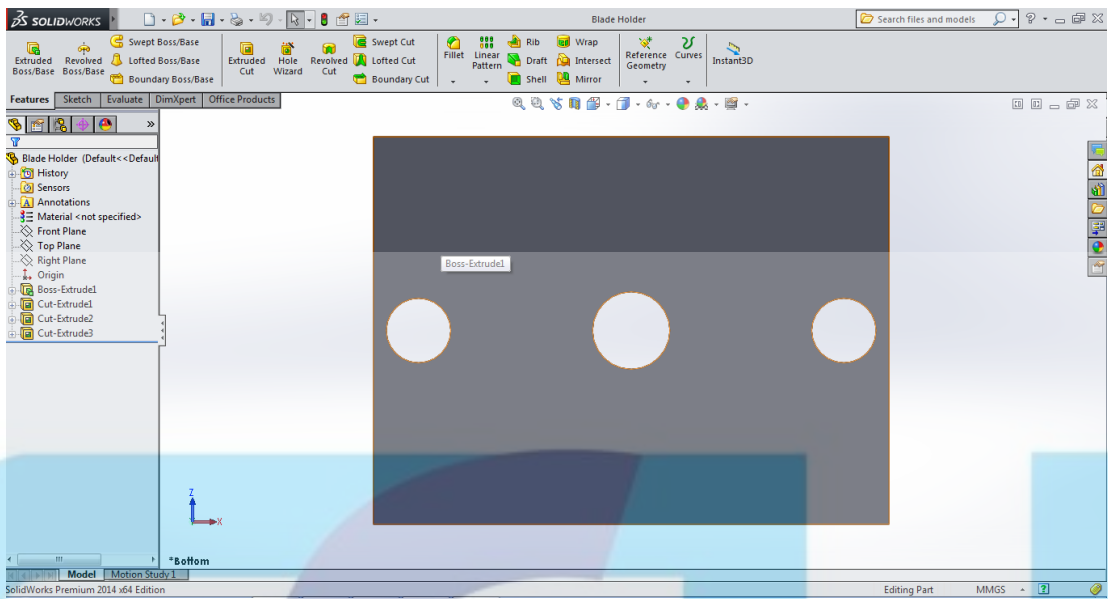


Figure 3-29 Base Holder for Z-Axis rear view

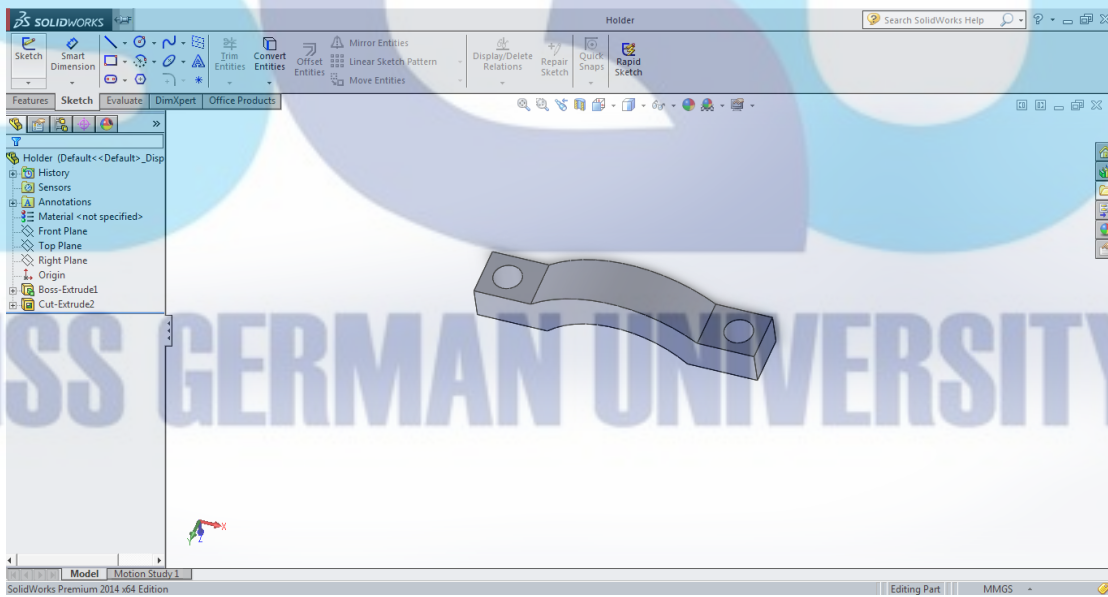


Figure 3-30 Clamp for Base Holder Z-Axis

3.6.5 Z axis

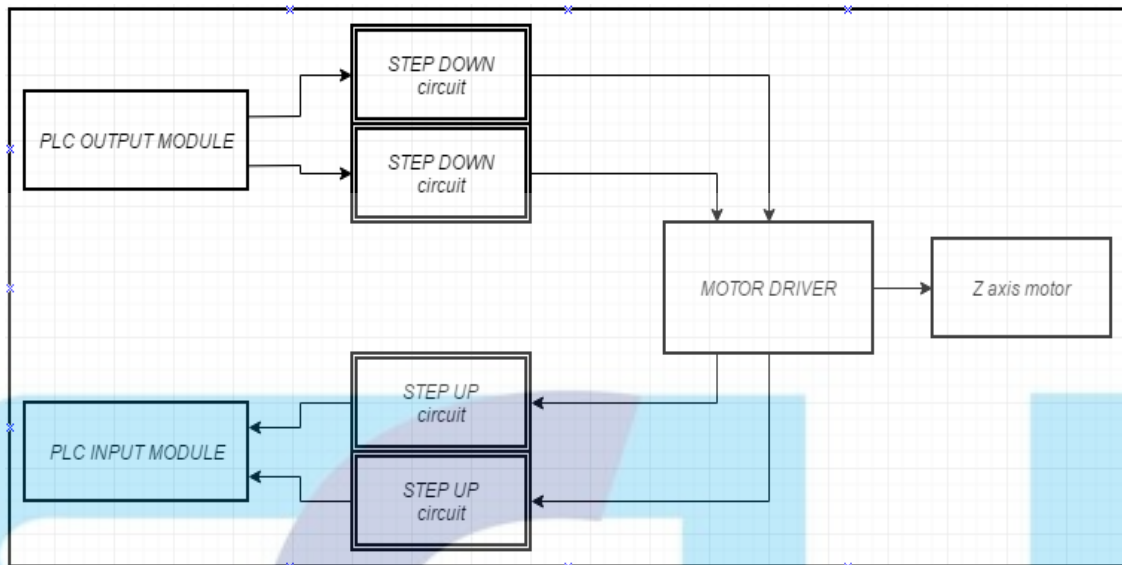


Figure 3-31 Z axis Communication

Figure 3.32 show the Z axis communication with the PLC module. To control the Z axis DVD stepper motor, motor driver L293 is needed. This motor driver can only take 5V of power and PLC input and PLC output works in 24V so a step up and a step down circuit is needed to control the motor driver via PLC. PLC will send command to the motor driver by signal, and the motor driver will drive the Z axis motor for UP and DOWN movement of the axis. After the UP or DOWN movement complete, the motor driver will give signal to the PLC as feedback.

3.6.6 Amplifier Resolution Calculation

The encoder of both motor has resolution of 18 bit which have 2^{18} pulse for one revolution. By lowering the resolution of the encoder to 2^{13} pulse now the encoder only need 8192 pulses from 262144 pulse which speed up the readings.

For the amount of rotation per pulse is calculated by : $5\text{mm}/8192\text{pulse} = 0,0006103515\text{mm/pulse}$ or $610,3515 \mu\text{m/pulse}$.

By this calculation the positioning addresses can be calculated to achieve precise movement of the motor.