School of Science and Technology (SST)

MANU2476 – Automated System Design

Lab 2 Report

PLC Program Design

Team 8

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1. Introduction

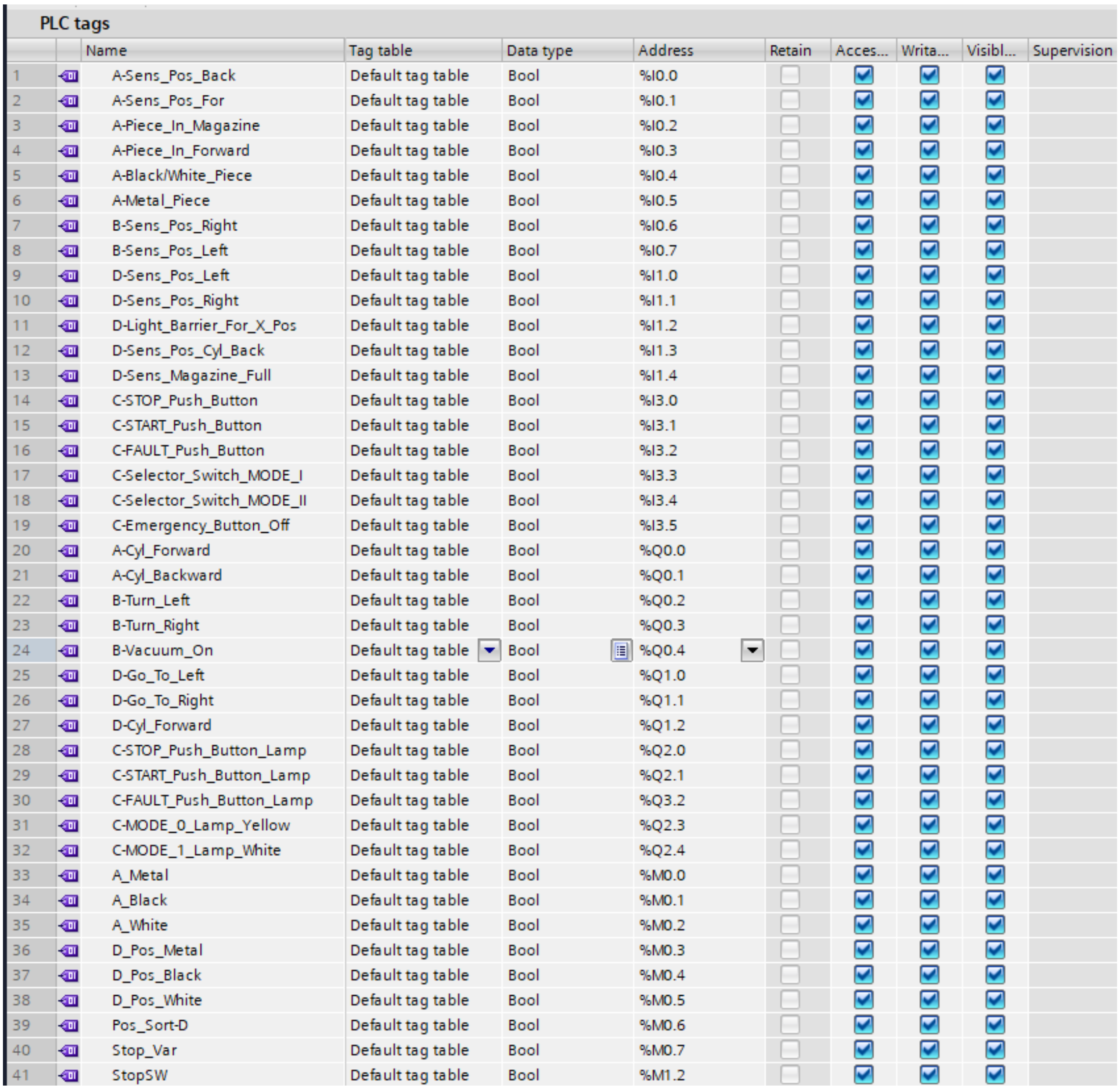
In this report, a discussion over the development of a PLC ladder program design proposed for an automated sorting application is presented. The main goal of the system is to perform an automation task of categorizing black or white plastic and metal workpieces into slots of their respective materials and colours. In this manufacturing application, the PLC program controls the interaction between 3 different modules of the system to accomplish the sorting task. Starting from module A as a processing module that stores and categorizes workpieces, the system activates module B's vacuum to transfer one workpiece at a time to the sorting module D, where it will eventually be sorted into a slot of its corresponding material. The system operates in two different modes determined by the "Selector" switch, including mode I (i.e. running once) and mode II (i.e. running continuously). When the "Start" button is pressed, the sorting sequence for a single workpiece is only performed once during mode I while such a sequence is repeated after the workpiece has been successfully sorted in module D during mode II. Besides halting when reaching the end of the sequence in mode I, the system also stops working in three other cases. The first case is when an error is detected in the system. In this case, the "Fault" button's internal lamp will light up indicating an error and the system's operation is automatically disrupted while the source of error is cleared. After that, the "Fault" button should be pressed to confirm that there is no longer any error before the system starts running again. The possible errors that may happen are when:

- The magazine of module A for workpiece storage is empty.
- One of the module D's sorting slots is full.
- The arm of module B is stuck for more than 5 seconds.

In the second case, when the "Stop" button is pressed, the system will deactivate all working modules and return them to their initial positions at the sequence beginning. In the last case, when the "Emergency Stop" button is pressed, all running modules will be disabled immediately and the system remains deactivated until the "Emergency Stop" button is released. Subsequently, all modules idle until the "Start" button is pressed, initiating a new sorting sequence.

2. PLC Program Design

2.1. IO Assignments



PLC tags

	Name	Tag table	Data type	Address	Retain	Acces...	Writa...	Visibl...	Supervision
1	A-Sens_Pos_Back	Default tag table	Bool	%I0.0	☐	☑	☑	☑	
2	A-Sens_Pos_For	Default tag table	Bool	%I0.1	☐	☑	☑	☑	
3	A-Piece_In_Magazine	Default tag table	Bool	%I0.2	☐	☑	☑	☑	
4	A-Piece_In_Forward	Default tag table	Bool	%I0.3	☐	☑	☑	☑	
5	A-Black/White_Piece	Default tag table	Bool	%I0.4	☐	☑	☑	☑	
6	A-Metal_Piece	Default tag table	Bool	%I0.5	☐	☑	☑	☑	
7	B-Sens_Pos_Right	Default tag table	Bool	%I0.6	☐	☑	☑	☑	
8	B-Sens_Pos_Left	Default tag table	Bool	%I0.7	☐	☑	☑	☑	
9	D-Sens_Pos_Left	Default tag table	Bool	%I1.0	☐	☑	☑	☑	
10	D-Sens_Pos_Right	Default tag table	Bool	%I1.1	☐	☑	☑	☑	
11	D-Light_Barrier_For_X_Pos	Default tag table	Bool	%I1.2	☐	☑	☑	☑	
12	D-Sens_Pos_Cyl_Back	Default tag table	Bool	%I1.3	☐	☑	☑	☑	
13	D-Sens_Magazine_Full	Default tag table	Bool	%I1.4	☐	☑	☑	☑	
14	C-STOP_Push_Button	Default tag table	Bool	%I3.0	☐	☑	☑	☑	
15	C-START_Push_Button	Default tag table	Bool	%I3.1	☐	☑	☑	☑	
16	C-FAULT_Push_Button	Default tag table	Bool	%I3.2	☐	☑	☑	☑	
17	C-Selector_Switch_MODE_I	Default tag table	Bool	%I3.3	☐	☑	☑	☑	
18	C-Selector_Switch_MODE_II	Default tag table	Bool	%I3.4	☐	☑	☑	☑	
19	C-Emergency_Button_Off	Default tag table	Bool	%I3.5	☐	☑	☑	☑	
20	A-Cyl_Forward	Default tag table	Bool	%Q0.0	☐	☑	☑	☑	
21	A-Cyl_Backward	Default tag table	Bool	%Q0.1	☐	☑	☑	☑	
22	B-Turn_Left	Default tag table	Bool	%Q0.2	☐	☑	☑	☑	
23	B-Turn_Right	Default tag table	Bool	%Q0.3	☐	☑	☑	☑	
24	B-Vacuum_On	Default tag table	Bool	%Q0.4	☐	☑	☑	☑	
25	D-Go_To_Left	Default tag table	Bool	%Q1.0	☐	☑	☑	☑	
26	D-Go_To_Right	Default tag table	Bool	%Q1.1	☐	☑	☑	☑	
27	D-Cyl_Forward	Default tag table	Bool	%Q1.2	☐	☑	☑	☑	
28	C-STOP_Push_Button_Lamp	Default tag table	Bool	%Q2.0	☐	☑	☑	☑	
29	C-START_Push_Button_Lamp	Default tag table	Bool	%Q2.1	☐	☑	☑	☑	
30	C-FAULT_Push_Button_Lamp	Default tag table	Bool	%Q3.2	☐	☑	☑	☑	
31	C-MODE_0_Lamp_Yellow	Default tag table	Bool	%Q2.3	☐	☑	☑	☑	
32	C-MODE_1_Lamp_White	Default tag table	Bool	%Q2.4	☐	☑	☑	☑	
33	A_Metal	Default tag table	Bool	%M0.0	☐	☑	☑	☑	
34	A_Black	Default tag table	Bool	%M0.1	☐	☑	☑	☑	
35	A_White	Default tag table	Bool	%M0.2	☐	☑	☑	☑	
36	D_Pos_Metal	Default tag table	Bool	%M0.3	☐	☑	☑	☑	
37	D_Pos_Black	Default tag table	Bool	%M0.4	☐	☑	☑	☑	
38	D_Pos_White	Default tag table	Bool	%M0.5	☐	☑	☑	☑	
39	Pos_Sort-D	Default tag table	Bool	%M0.6	☐	☑	☑	☑	
40	Stop_Var	Default tag table	Bool	%M0.7	☐	☑	☑	☑	
41	StopSW	Default tag table	Bool	%M1.2	☐	☑	☑	☑	

Figure 1: IO assignments in the Siemens' TIA Portal

As shown in the figure above, there are 19 inputs, 13 outputs, and 9 memory variables defined in this program. The interaction among these assignments to implement the sorting system is shown in the PLC program blocks below.

2.2. Main and Control Module Block (FC4)

Figure 2: Module Control Panel 6A

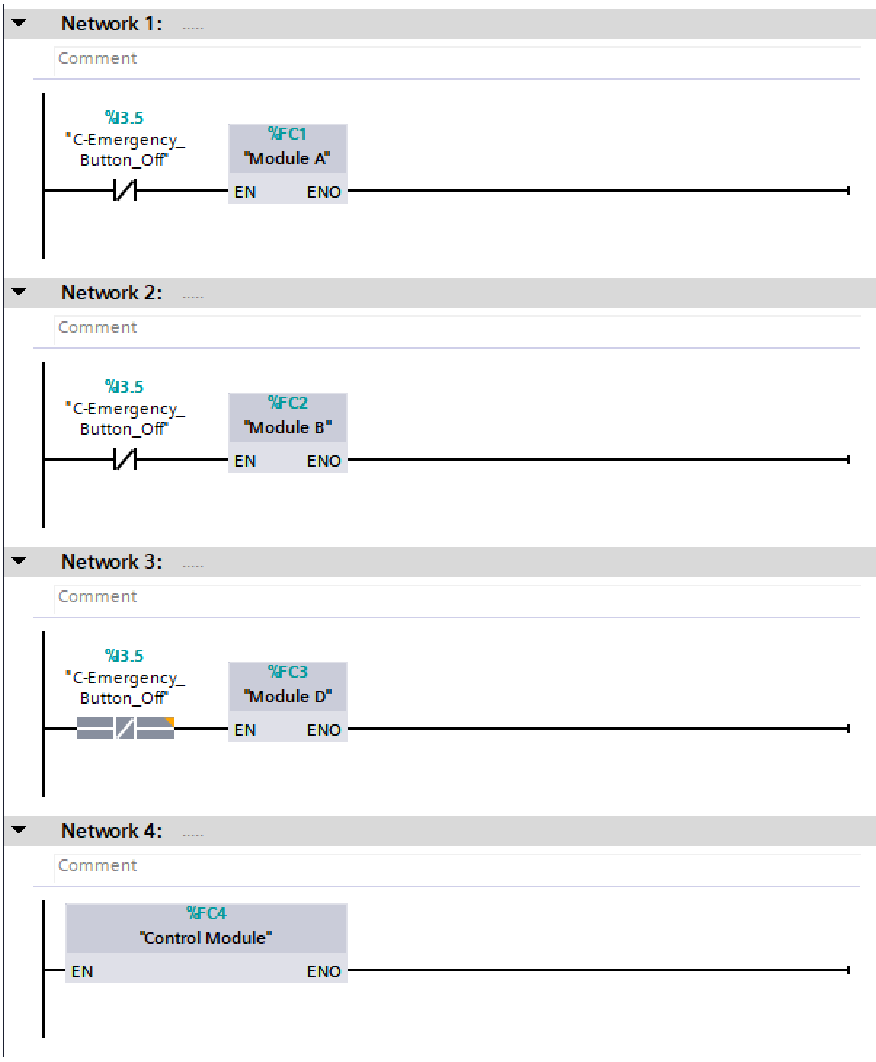


Figure 3: Main Block

The main block is where all modules used in our design are enabled, including module A, B, D and the control module. The physical control module is the control station of the whole system, consisting of the “Selector” switch as well as the “Start”, “Fault”, “Stop”, and “Emergency Stop” buttons as shown in figure 2. The emergency stop function is one of the prominent safety features of the system. Therefore, the relay switch “C-Emergency_Button_Off” (I3.5) is placed in front of every module-enabling block to generate such a function. Since the “Emergency Stop” button is active high, its activation will make the normally closed I3.5 relay switch open, cutting off the enabling signal to all modules except for the control module. The emergency stop does not affect the control module since we want to simulate module B’s arm stuck error addressed later in this report.

The remaining control functions can be done in the control module block. These include detecting system errors, generating a start or stop signal for the whole system, as well as lighting up the “Fault” button in case of errors. For this purpose, 3 inputs (I3.0, I3.1, and I3.2), 1 output (Q3.2), and 2 memory variables (M0.7 and M1.2) are defined for the control module. The stop variable M0.7 is represented as an SR memory in this module to generate the stop signal pulse. Since any error detected also requires generating a stop signal, the M1.2 variable is used as a stop switch triggered when there is such an error. The stop switch then acts as a relay switch that can also generate a stop pulse by activating M0.7. Each network in the control module is presented below.

Network 1:

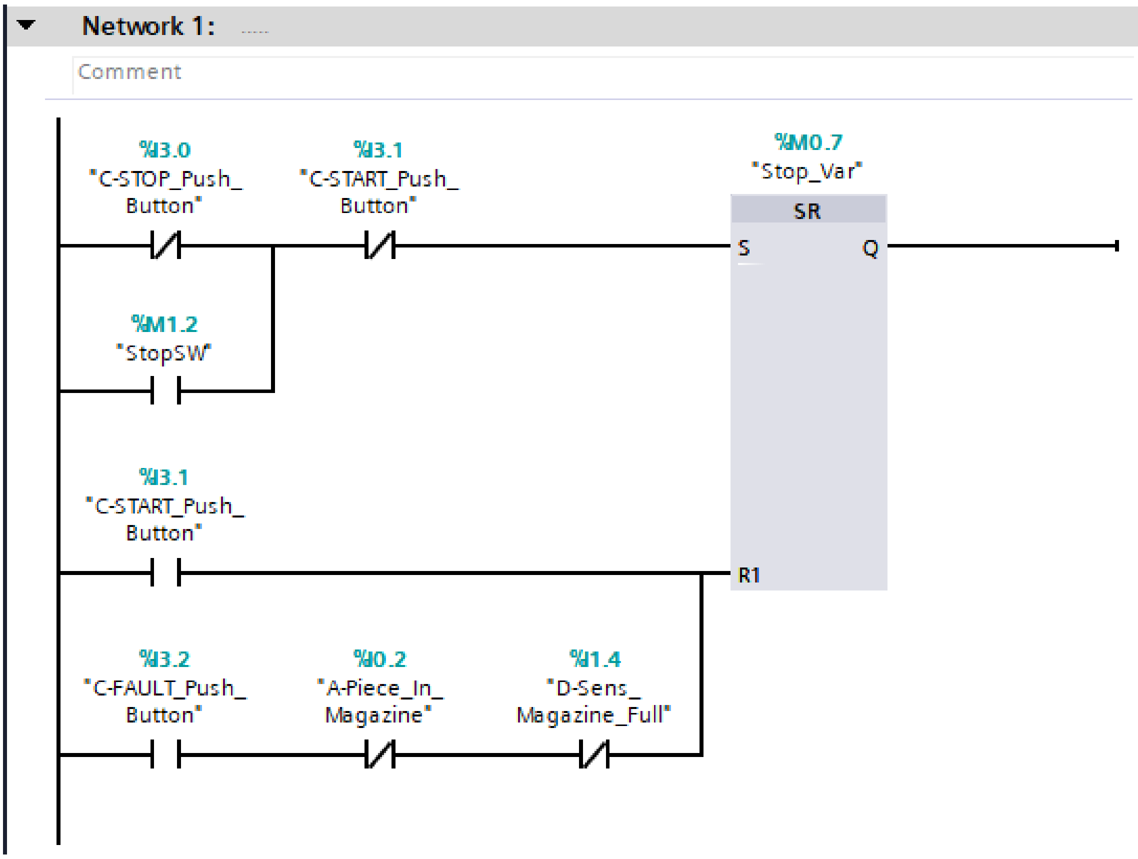


Figure 4: Network 1 in the control module block

Network 1 is generally in charge of generating the aforementioned start and stop pulses. Specifically, there are two cases when a stop signal is needed. The first case is when the “Stop” button (I3.0) is pressed, while the second case is when a system error is detected. Now that the “Stop” button is active low, I3.0 is left normally closed in the first rung so that the normally high signal from the “Stop” button will disconnect the I3.0 relay switch and thus preventing that signal from activating the “Stop_Var” M0.7. The “StopSW” M1.2 switched on by any error detection from network 2 can also activate the set port of the M0.7 SR memory.

The stop signal should no longer persist as soon as the “Start” button (I3.1) is pressed, though. That is why the start signal I3.1 is placed at the reset port of M0.7 in the third rung to deactivate the “Stop_Var”. At the same time, the normally closed I3.1 relay switch in the first rung becomes open, cutting off the signal to the set port of the SR memory. The “Fault” button also has a similar function to the “Start” button. The only difference is that the former one is condition-based and only valid if the magazine of module A is not empty and the slot of module D is not full. Hence, “C-FAULT_Push_Button” (I3.2) in series with the two mentioned conditions in the last rung is put in parallel with the “Start” button.

Network 2:

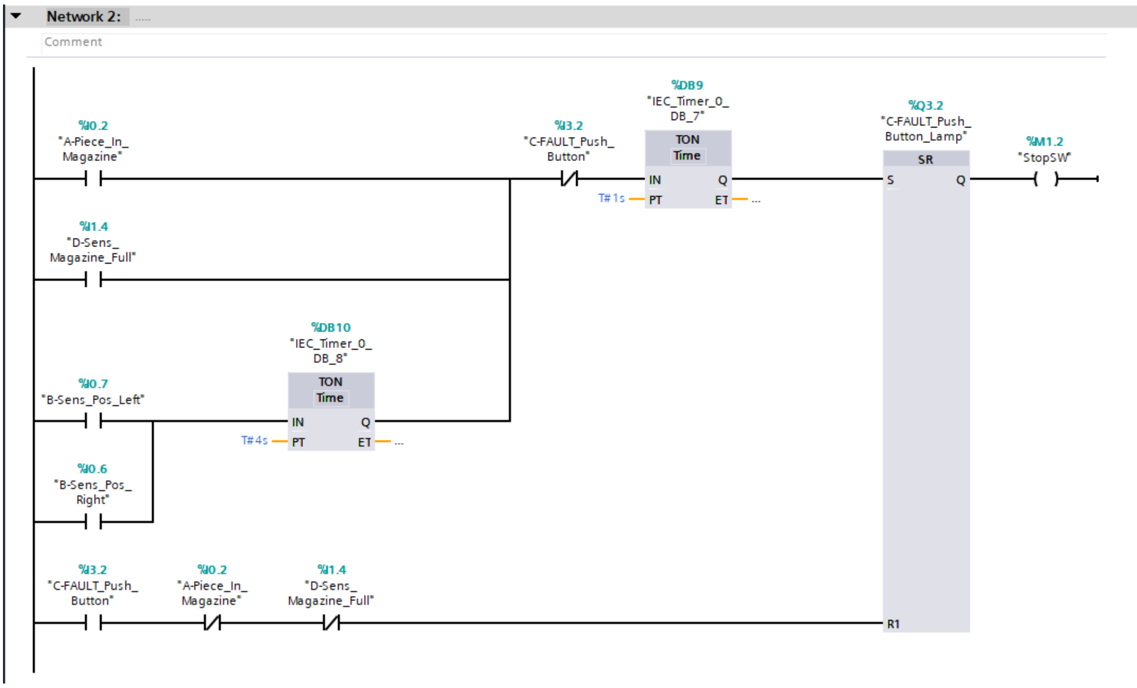


Figure 5: Network 2 in the control module block

The purpose of network 2 is to light up the “Fault” button when there is a detected error and then trigger the stop switch. The system errors described in the design requirements are translated into four rungs. If the magazine of module A is empty, its one-way-light barrier should return a high signal that closes the I0.2 relay switch in the first rung. If the emptiness persists for 1 second, the signal will in turn light up the “C-FAULT_Button_Lamp” (Q3.2) and trigger the stop switch as an output of the Q3.2 SR memory.

Similarly, there are three other relay switches in parallel with I0.2 standing for the other errors. If the sorting slot of module D is full for 1 second (i.e. I1.4 closes for 1 second), Q3.2 and M1.2 are also turned on. If the arm of module B stays on its left or right for a total of 5 seconds as shown in the third and fourth rungs, the same thing goes to Q3.2 and M1.2.

The question is how to turn off the “Fault” button lamp. Since as long as it is on, even the “Start” button can not re-initiate the system due to the ongoing pulse from the stop switch. That is the reason why the last rung is introduced to reset the lamp as well as the stop switch. Specifically, when the “Fault” button is pressed and no more error is detected, the Q3.2 lamp will be turned off, consequently switching off M1.2 and stops the signal passing to the set port of “Stop_Var” in network 1. Meanwhile, the normally closed I3.2 relay switch in the first rung also becomes open, deactivating the set port of the Q3.2 SR memory.

2.3. Module A Block (FC1)

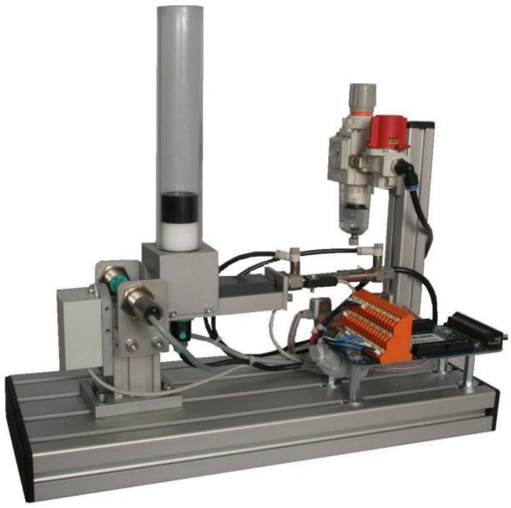


Figure 6: Image of module A

In module A, the main purpose of module A shown in figure 6 above is to push the workpieces separately from the magazine case by double-acting cylinder to prepare to transfer the workpieces to module B. Additionally, this module also detects characteristic of the workpieces which include White, Black and Metal workpieces. By using the two sensors, one is to classify the metal workpieces (I0.5), and another is to detect the black workpieces (I0.4). There are two modes for this system, mode I demonstrates the working principle for only **one** workpiece and mode II is to demonstrate **continuously one by one** workpiece until empty the magazine in module A or full the magazine in module D. Therefore, inputs I3.3 and I3.4 represent the selector switches I and II.

There are two sensors to record the backward or forward position of the cylinder, I0.0 and I0.1. Moreover, I0.2 is represented by a sensor placed at the linear bottom of the magazine to check the availability of the workpiece. In addition, I1.4 is a sensor that checks the capacity status at module D. When the cylinder is advanced, the workpieces will be immediately pushed and reached the end position, where it triggers a micro switch representing the input I0.3. Furthermore, Inputs I3.1 and I3.0 are represented for a start button and stop button. Similarly, the input I3.2 represents the Fault button. The positions right and left of module B represent inputs I0.6 and I0.7. A timer on DB8 is added to the system what delays the input signal by 2 seconds. A stop variable is created which represents M0.7. There are two outputs Q0.0 and Q0.1 which represent for cylinder forward and backwards.

For the characteristic detection of the material, inputs I0.5 and I0.4 are represented for Metal and Black or White pieces. Therefore, the **Set** and **Reset** memory M0.0, M0.1 and M0.2 are detected as Metal, Black and White workpieces.

There are 6 networks presented in this module.

Network 1:

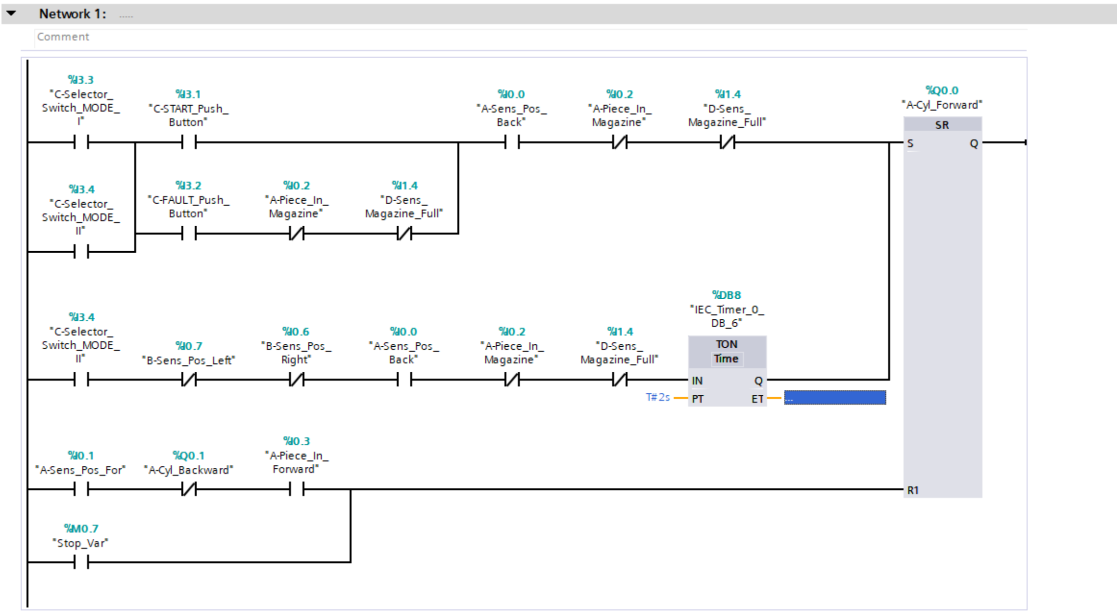


Figure 7: Image of Network 1 in module A

In network 1, the main purpose is to control the cylinder going forward for pushing the workpieces to the workspace. Hence, after finishing pushing the pieces, the signal of going forward (Q0.0) must be reset and wait until the next operation from network 2.

There are 3 conditions to satisfy the **Set** for the output Q0.0 which present by 3 rungs. At the first rung, if we press the start button after switching to mode I and satisfy that the cylinder is in backward position (I0.0) as well as there are not empty (I0.2) and full the magazine (I1.4) in module A and D, the output Q0.0 will be **Set**. In the second rung, setting conditions for the output Q0.0 of mode II are the same as mode I. However, in continuous mode II when the system is faulty because of running out of pieces in storage or full magazine, we need to press the **Fault** button (I3.2) instead of the **Start** button (I3.1)**,** to start running the system again after fixing issues. At the third rung, this is the main thing to make the system run continuously. Hence, when the system finishes one cycle of working, it will repeat the cycle as the beginning after 2 seconds if the position of module B is not left (I0.7) and right (I0.6) as well as satisfying all the same conditions of first and second rungs.

For the **reset** Q0.0, it will be triggered if it satisfies one of two conditions representing the fourth and fifth rungs. The fourth rung is triggered when the cylinder is placed in the forward position (I0.1) as well as the pieces touch the microswitch (I0.3). Moreover, the fifth rung will be closed when the stop variation is triggered (M0.7).

Network 2:

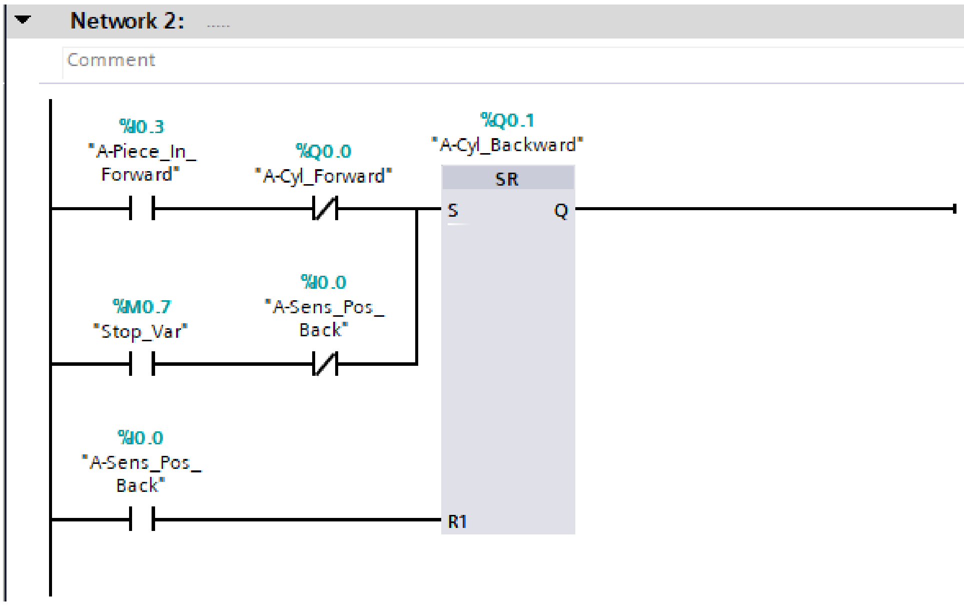


Figure 8: Image of Network 2 in module A

According to network 1, after finishing network 1, network 2 will be received the input signal and do the next operation. The main purpose of this network is to make the cylinder go backwards and reset the signal of Q0.1 after the cylinder is placed at the end backward position.

In this network, the **Set** of Q0.1, which makes the cylinder move backwards, is triggered when satisfies one of two conditions. At the first conditions, meaning the first rung, if the piece is in the forward position (I0.3) and the cylinder is not gone forward anymore (Q0.0), the **Set** of Q0.1 will receive a signal. Secondly, the **Set** is also triggered when the stop variable (M0.7) and non-backward position of the cylinder (I0.0) is detected.

The only condition is to Reset the Q0.1 which represents by the third rung. When the cylinder is placed in the backward position (I0.0), the **Reset** will be triggered for the output Q0.1.

Network 3,4 and 5:

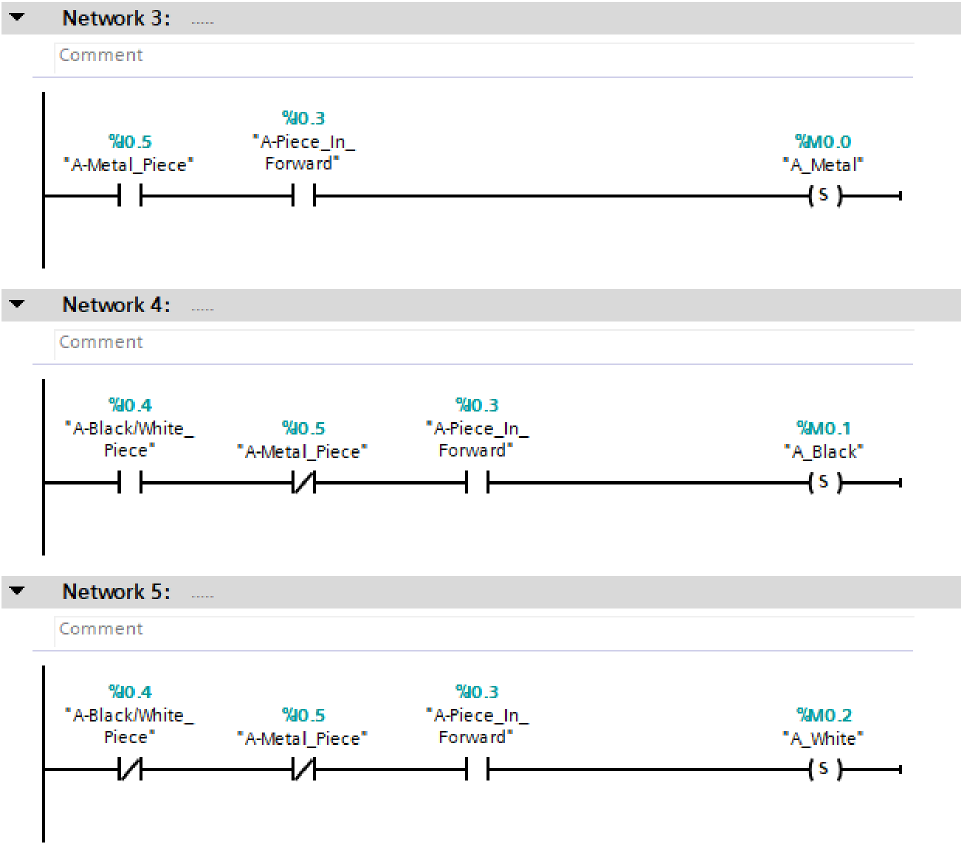


Figure 9: Image of Network 3, 4 and 5 in module A

Generally, networks 3, 4, and 5 are represented for classifying metal, black and white workpieces. All networks need the pieces being placed in a forward position and touching the microswitch (I0.3). If the sensor detects a metal (I0.5) workpiece, the set memory for metal (M0.0) will be immediately triggered. On the other hand, if sensors are classified that is non-metal (I0.5) and black (I0.4) workpiece, the set memory for black (M0.1) will be immediately triggered. Lastly, when the pieces are not detected as metal or black materials, the set memory for white (M0.2) will be immediately triggered.

Network 6:

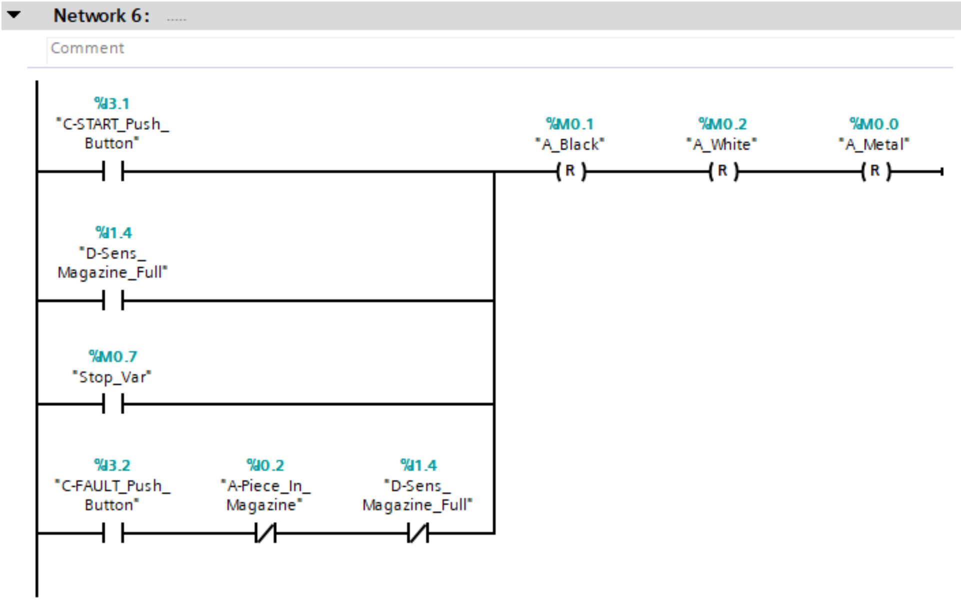


Figure 10: Image of Network 6 in module A

After we finish one cycle of working for the whole module, the system needs to reset the memory setting in the previous networks 3, 4 and 5. There are 4 conditions to perform that work which are presented 4 rungs in network 6.

In the first rung, the start button (I3.1) is pressed, the reset memory will be triggered. Similarly, when the magazine in module D (I1.4) is full, the system will reset the memory. Thirdly, it happens when the stop variable (M0.7) is triggered. Lastly, if the fault button (I3.2) is pressed and not empty storage in module A (I0.2) as well as not full magazine (I1.4) in module D, the reset memory will be triggered.

2.4. Module B Block (FC2)

Figure 11: Module W4764-5B

In a sorting sequence, module B functions as a swivel transporter to carry a workpiece from the processing module A to the sorting module D. Since module A is installed on the far left of the system while module D is laid on the far right, module B should be able to use its vacuum suction to lift and carry the processed workpiece from left to right. Then, it turns off the vacuum to release the workpiece onto module D's carrier before returning to the upright position to get ready for the next sequence. Besides, module B should be designed to comply with all system stop cases, including the end of mode I, a detected fault, the "Stop" button press as well as the "Emergency Stop" activation.

To meet the design requirements, two inputs and three outputs are defined for module B in the PLC program. The two inputs are "B-Sens_Pos_Right" (I0.6) and "B-Sens_Pos_Left" (I0.7), reading signals from two position sensors integrated within module B. Specifically, if the swivel unit is on the right, the right sensor will be triggered and subsequently close the I0.6 relay switch. If the swivel unit is on the left, the left sensor will be triggered and close the I0.7 relay switch. These two inputs allow the program to recognize the current position of module B and accordingly control the module to perform its next action. The action of module B, on the other hand, is controlled by a 5/3-way valve and a 5/2-way valve. When "B-Turn_Left" (Q0.2) is turned on, an activation pressure will be applied to port 14 of the 5/3-way valve and move module B's arm to the left. Similarly, when "B-Turn_Right" (Q0.3) is turned on, an activation pressure will be applied to port 12 of the 5/3-way valve and move the module B's arm to the right. To control the vacuum suction, "B-Vacuum_On" (Q0.4) is turned on, generating an applied pressure at port 14 of the 5/2-way valve and thus activating module B's vacuum. This module block in the PLC program includes the interaction among three networks to implement the desired module B's action. The implementation of each network to meet the design requirements is explained below.

Network 1:

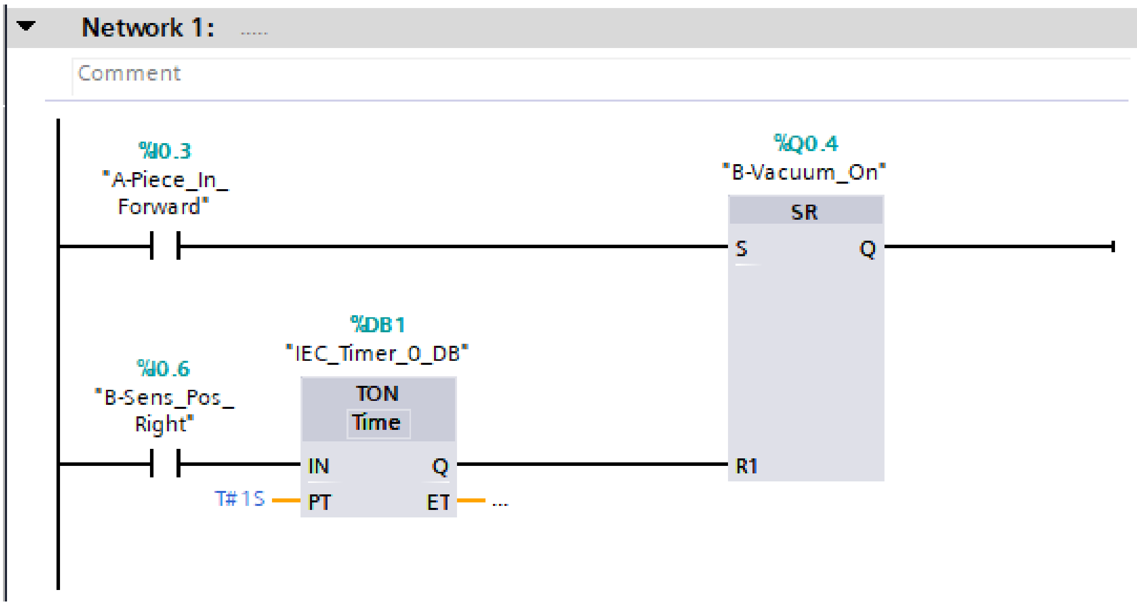


Figure 12: Network 1 in the module B block

The purpose of network 1 is to control the activation and deactivation of the vacuum suction. Specifically, the vacuum should be turned on as soon as a processed workpiece is available in module A, indicated when the workpiece is pushed forward by a cylinder in module A and briefly touches a microswitch during the forward movement. The actuation of the microswitch triggers the I0.3 relay switch and consequently activates the set port of the Q0.4 SR memory. Although there is no longer any signal from I0.3 afterwards, Q0.4 remains active until reset.

When the workpiece has been carried to the right, the vacuum should be turned off to release the workpiece onto module D. The right position of module B can be sensed when the I0.6 relay switch is connected. After that, timer DB1 will block the signal from I0.6 for 1 second to wait until the swivel unit settles down before closing its internal relay switch, allowing the signal from I0.6 to pass through and activates the reset port of the Q0.4 SR memory.

Network 2:

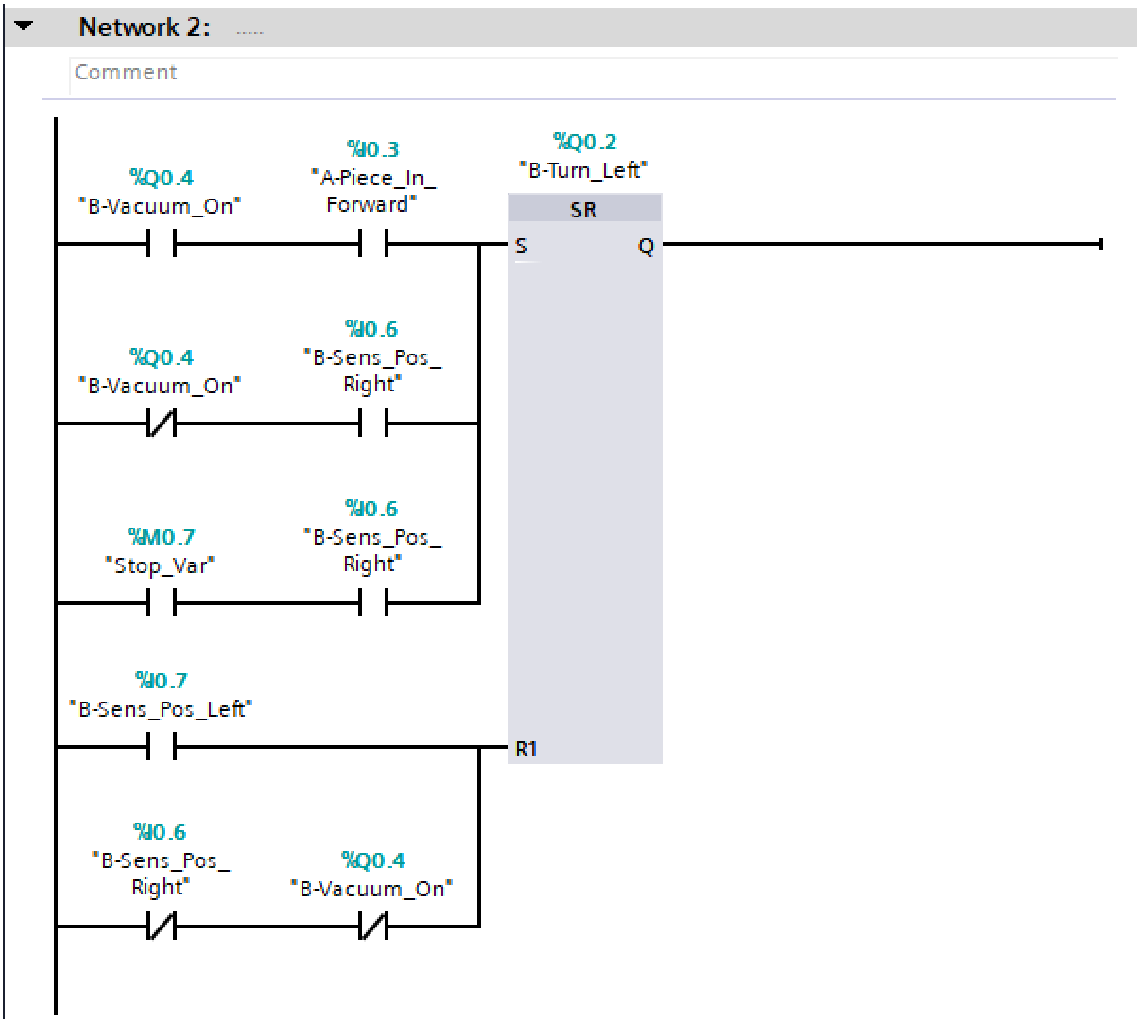


Figure 13: Network 2 in the module B block

The purpose of network 2 is to control the activation and deactivation of the turning left motion. There are three occasions when module B's arm is required to turn left. The first occasion is when a processed workpiece in module A is available to be transferred and the vacuum has already turned on, meaning that both the Q0.4 and I0.3 relay switches are triggered as shown in the first rung. Once the arm has reached the workpiece on its left, the I0.7 relay switch closes and stops the turning left motion as shown in the fourth rung. Otherwise, the arm keeps moving to the left regardless of the workpiece obstruction and may damage itself.

The second occasion is when the arm needs to return to the upright position to get ready for the next sequence after the workpiece has been released onto module D. The release is indicated when the vacuum has already turned off and the arm is on its right. Therefore, as shown in the second rung, Q0.4 is left normally closed while I0.6 is normally open so that if Q0.4 is not being activated (i.e. the vacuum is inactive) and I0.6 is being activated, the arm will start turning left. However, the arm is required to stop at the upright position instead of turning to its leftmost position. That is why the last rung was implemented to stop the motion as soon as the arm is no longer on its right and the vacuum is currently off.

The last occasion is when the arm needs to return to the upright position when there is a system stop intervention from either a detected fault or the “Stop” button. The “Emergency Stop” button is not implemented in this block but rather in the main block. To create the stop intervention, as shown in the third rung, the memory variable “Stop_Var” (M0.7) from the control module block is used as a relay switch in series with module B’s right sensor I0.6. This means that once the M0.7 relay switch is activated by either the “Stop” button or a detected error, the ongoing signal from this switch will pass through the closed I0.6 input provided that the arm is currently on its right. After a short while of turning left, affected by the last rung, the arm stops moving around the upright position.

Network 3:

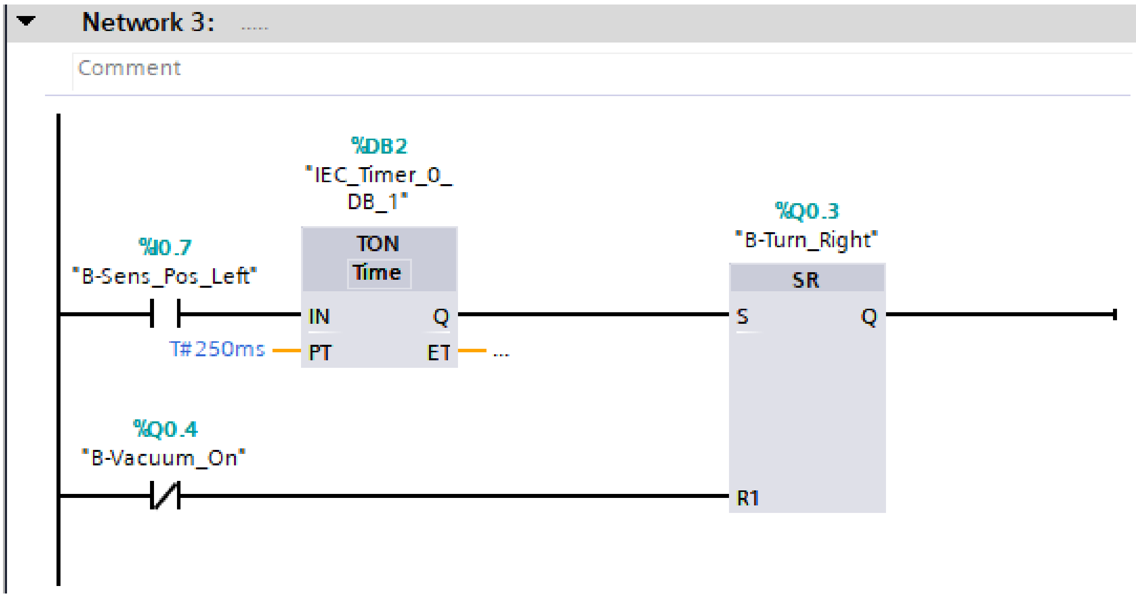


Figure 14: Network 3 in the module B block

Network 3 is used to control the activation and deactivation of the turning right motion. To carry a processed workpiece from left to right, once the arm has reached the workpiece and the left position is sensed, the I0.7 relay switch is closed and its signal is held by timer DB2 for 250ms before moving the arm to the right as shown in the first rung. As soon as the vacuum is off, meaning that the arm has been on the right for 1 second, the arm stops moving right as shown in the second rung and starts moving left to return to the upright position.

2.5. Module D Block (FC3)

The final sequence of the whole system is module D. Module D is used to sort workpieces into a slot of its corresponding material and colour. The sequence of it is when module B places workpiece into the module D's carrier, depending on different material and colour, E-Motor will transport the workpiece to the sorting position. Then a cylinder extends and pushes the workpiece down to its allocated slot. The module is also designed to satisfy the requirement cases of the "Stop" and "Start" button is pressed, mode 2 is selected, a detected fault, the motor will go back to the left and ready for the next step. There is a case when the "Emergency Stop" button activates, module D stops at where it is.

To meet the above requirements. The system in module D uses an E-Motor and 5/2-Way cylinder as its output. E-Motor is used to transport workpieces move right and left on the slides, and a 5/2-Way cylinder is to push the workpieces to the arrangement position. To control the outputs, we utilize inputs: a fork light barrier I1.2 "D-Light_Barrier_For_X_Pos", I1.0 "D-sens_Pos_Left", I1.1 "D-Sens_Pos_Right" and I1.4 "D-Sens_Magacine_Full". A fork light barrier I1.2 "D-Light_Barrier_For_X_Pos" helps the workpieces are transferred to the correct position. I1.0 "D-sens_Pos_Left" and I1.1 "D-Sens_Pos_Right" is to detect the position of the linear unit is left or right and a sensor One-way-light barrier I1.4 "D-Sens_Magacine_Full" to detect whether the sorting magazine is full or not. There are 8 networks in module D. The function of each network is detailed below.

Network 6:

The module starts with network 6. The main reason we create network 6 is to let the carrier which contains the workpiece move to the right, increase the counter value of network 1 and then use it as the input of other networks. In network 6, we use SR block as the output to activate and deactivate its action.

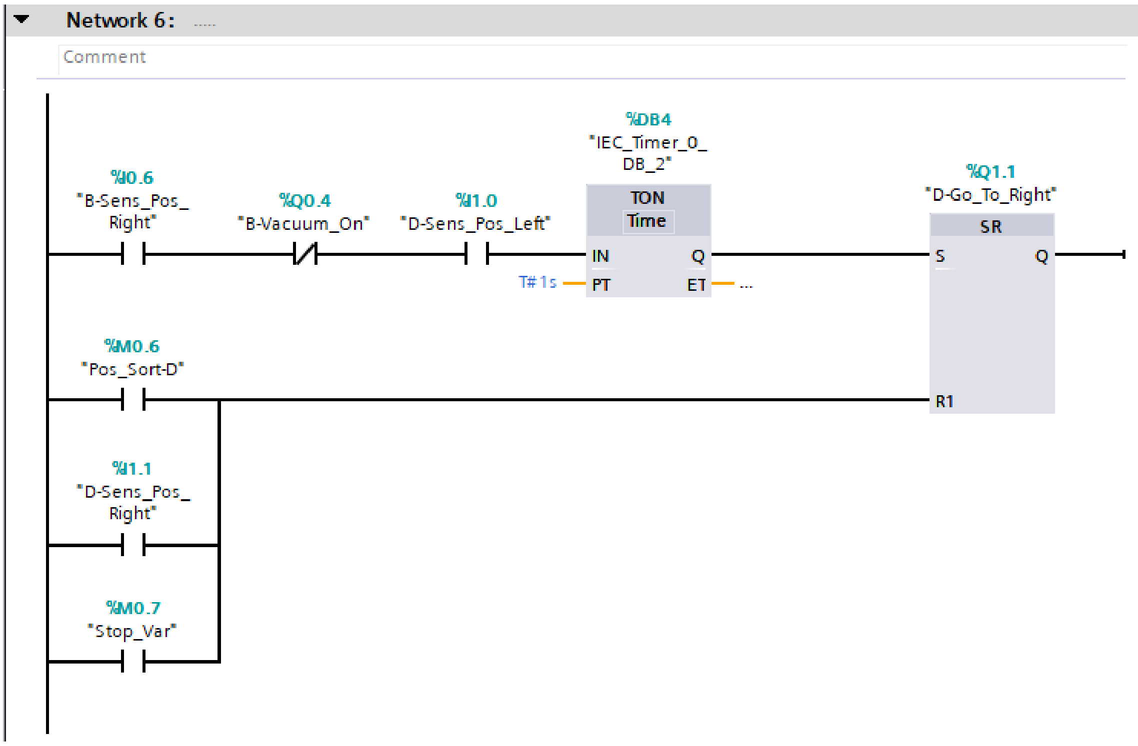


Figure 15: Network 6 in the module D block.

To let the carrier of module D go to the right, we utilize rung 1 to activate the motor goes to the right. And the output Q1.1 “D-Go_To_Right” is activated when the arm of module B is in the right position (or the sensor to detect the right position of module B’s arm is on) and the vacuum of module B turned off and the carrier is in the left position. Then after 1s, the carrier goes to the right.

The reset instruction of output Q2.1 “D-Go_To_Right” happens when there is a signal on contact M4.1 “Pos_Sort-D" or carrier of module D is in the right position or when the Stop button is pressed (Stop button will activate M0.7 “Stop_Var” contact). The purpose of the reset instruction is that the carrier can go to the left without any conflict and do not move out of the module.

Network 8:

The purpose we create network 8 is to let the carrier which contains the workpiece move back to the left position after transferring the workpiece in the desired position and to ready for the next cycle. Then it’s used as the input of other networks. In network 8, we use an SR block as the output block to activate and deactivate the action of the output.

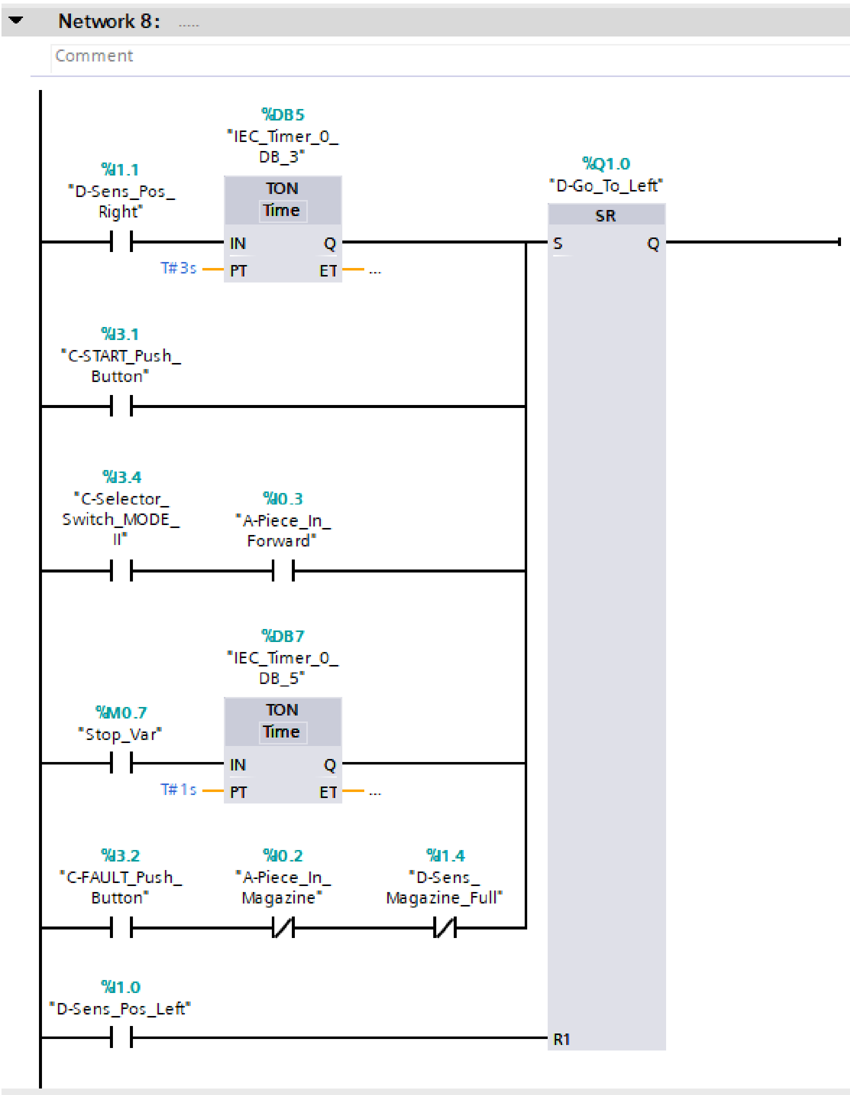


Figure 16: Network 8 in the module D block.

There are 5 ways to activate the signal of S of output Q1.0 which move the carrier to the left. Firstly, rung 1: doing the function when the carrier is in the right position, it has to go back to the left after 3s thank to the timer on the block. Secondly, rung 2: when the Start button is pressed, the carrier goes to the ready position to receive the workpiece. Thirdly, rung 3: instead of pressing the start button to start the new process in once mode, we replace the signal from the start button with mode 2 and the workpiece in module A is in the forward position (or the micro button in module A is touched) to run the automatic mode. When the system is in. Fourth, rung 4: to satisfy the Stop condition. The carrier goes back to its initial position when the Stop button is pressed, the carrier moves to its initial position after 1s. Finally, rung 5: when the case of Fault is clear by pressing the fault button and to make sure there is a workpiece in module A's magazine and the storage for one of the materials in module D is not full.

When the carrier is in the left position, the reset instruction is received and the carrier stops moving to the left. The purpose of the reset instruction is that the carrier can go to the right without any conflict and do not move out of the module.

Network 1:

The main function of network 1 is used to set the counter value for up and down counter function block DB3 “IEC_Counter_0_DB”. When the workpiece is placed on the carrier of module D, the E-Motor goes to the right, it increases the current value (CV). Then the current value will be sent to network 2, 3, 4 for the next purpose.

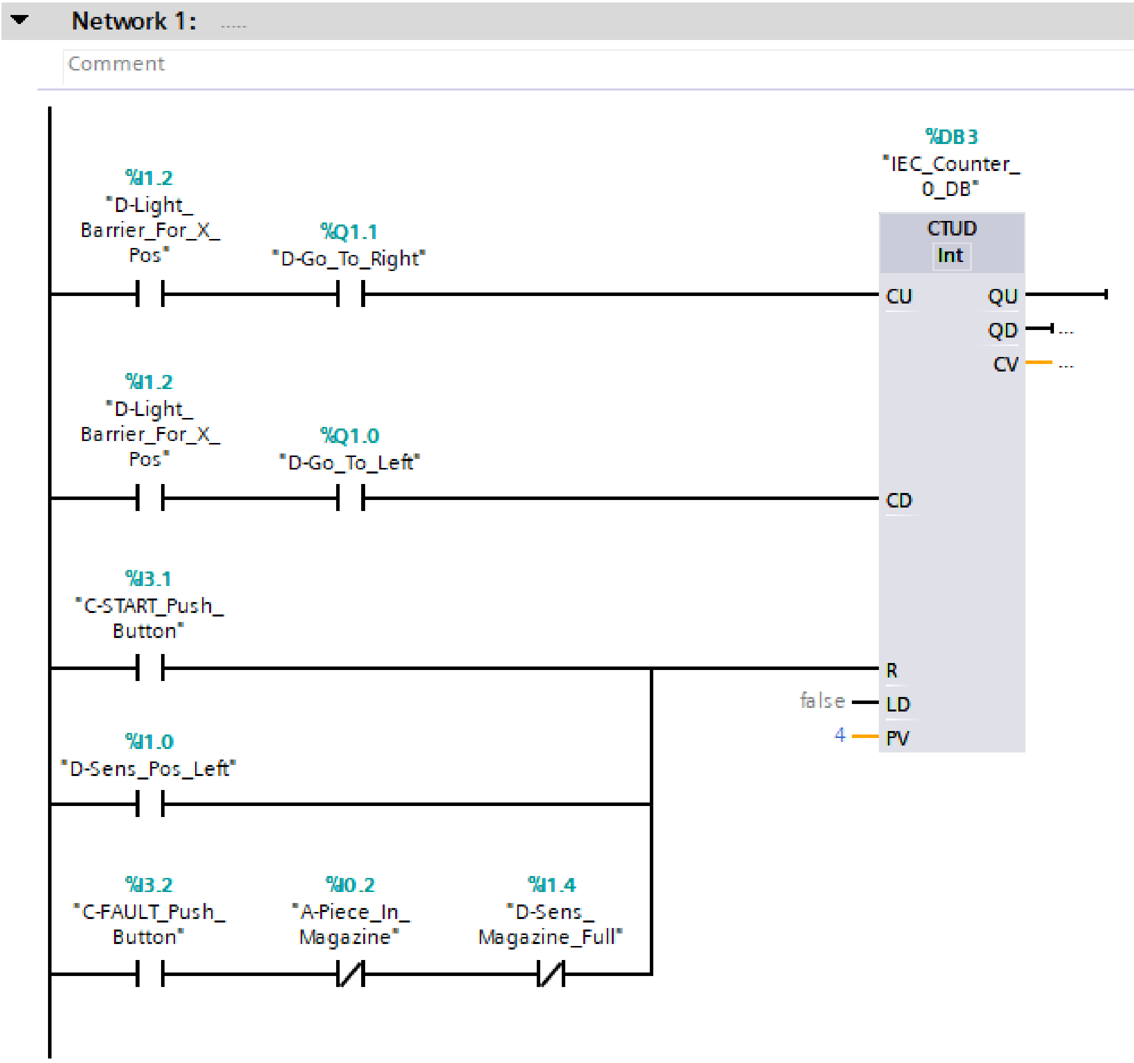


Figure 17: Network 1 in the module D block.

In order to make “CV” (current value) in the output DB3 “IEC_Counter_0_DB” increase by 1, the signal from I1.2 “D-Light_Barrier_For_X_Pos” and Q1.1 “D-Go_To_Right” contact from network 6 is turned on. And vice versa it will decrease by 1 when the signal from I1.2 “D-Light_Barrier_For_X_Pos” and Q1.0 “D-Go_To_Left” contact from network 8 is on

To reset the counter value “CV” to 0, input R (reset) of output block DB3 “IEC_Counter_0_DB” is high. There are 3 cases to activate the Reset in DB3. The first case is when the Start button is pressed. The second case is the carrier in the left position or the sensor to detect the left position is on. And the final case is Fault button is pushed and there are workpieces in module A, and sorting position in module D.

Network 2, 3, 4:

As the current value of DB3 is taken from network 1. The general function of network 2, 3, 4 is that depending on the value of the current value of DB3 and different materials and colors, these networks will send a signal out for other networks to stop the carrier in the correct position.

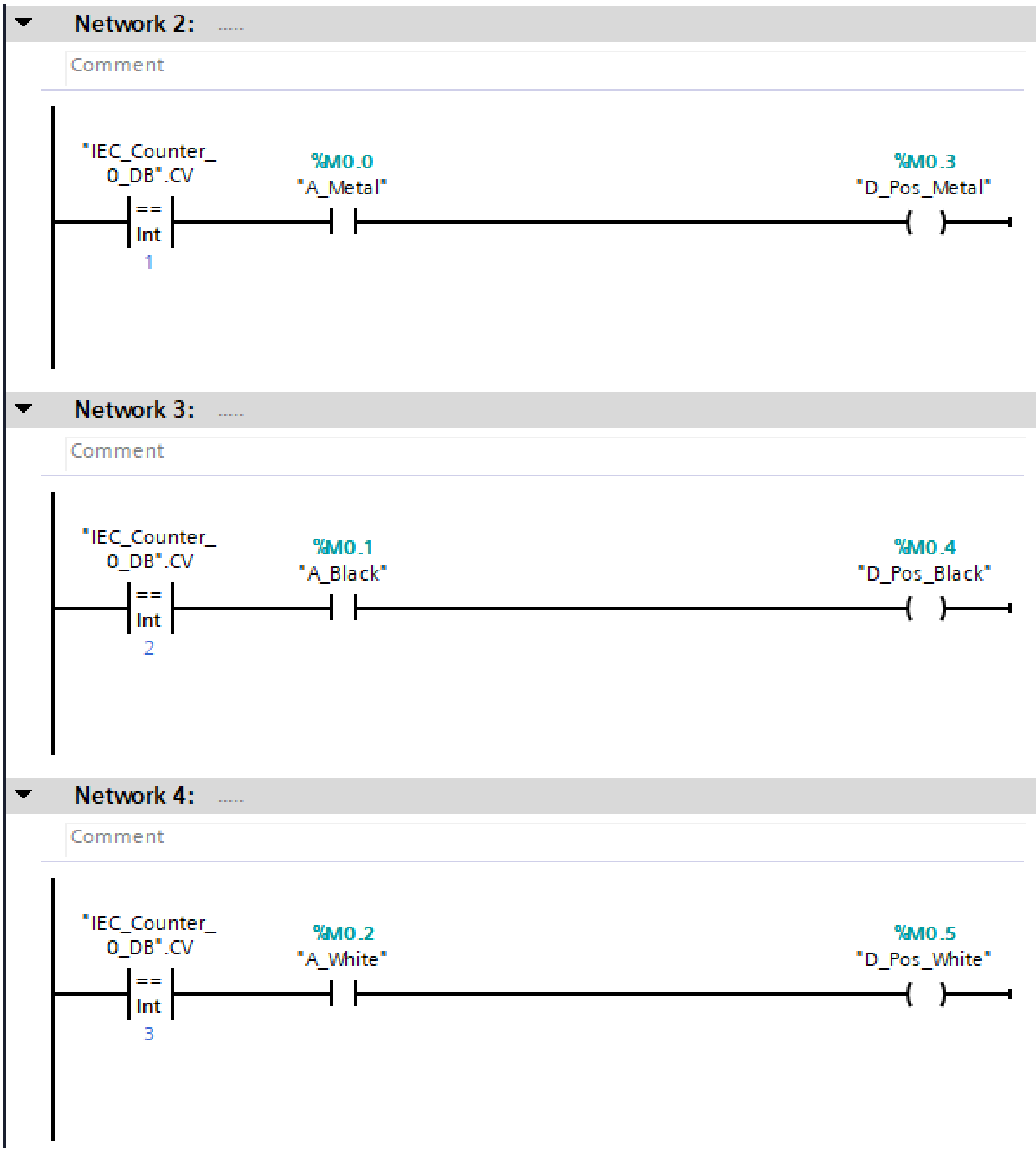


Figure 18: Network 2, 3, 4 in the module D block.

We choose the sorting position 1, 2, 3 respectively metal, black, white. Hence, network 2 will send the signal to stop the carrier at the position of metal when the current value of DB3 is 1 and the metal detection sensor of module A is on. Network 3 will send the signal to stop the carrier at the position of black plastic when the current value of DB3 is 2 and the black plastic detection sensor of module A is on. The same with network 2 and 3, network 4 will send the signal to stop the carrier at the position of white plastic when the current value of DB3 is 3 and the white plastic detection sensor of module A is on.

Network 5:

Network 5 is the place where the output signal from network 2, 3, 4 is assembled. And then memory variable output of network 5 sends to its contact in network 6 and network 7 to correctly stop the carrier in the sorting position and push the workpiece down.

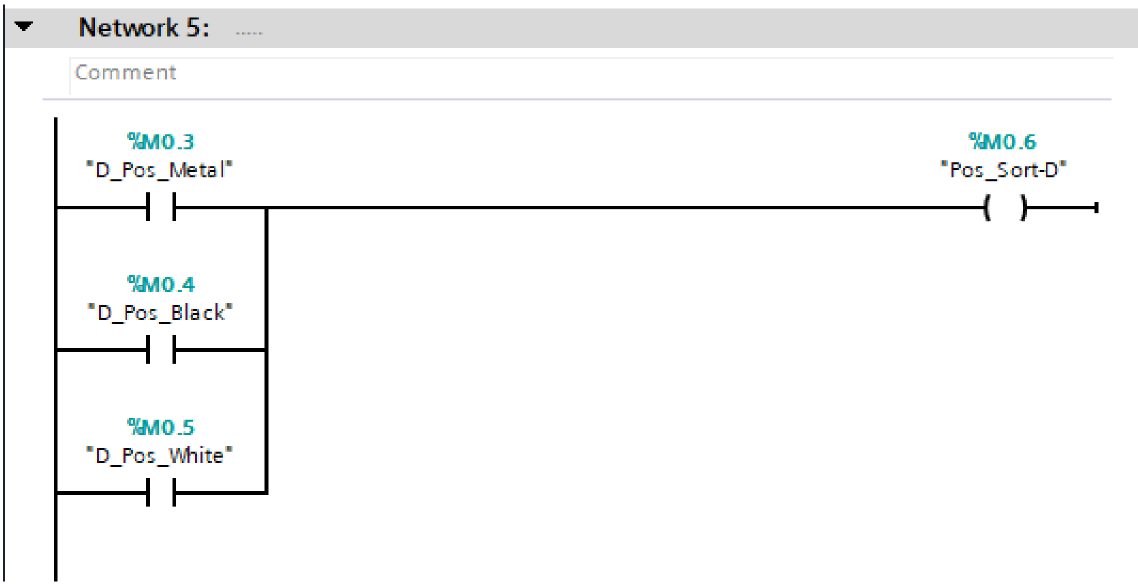


Figure 19: Network 5 in the module D block.

Whenever outputs from network 2, 3, 4 are activated, they will turn on their contacts in network 5. Then these contacts will activate the output M0.6 “Pos_Sort-D"

Network 7:

The function of network 7 is to activate the cylinder and pushes the workpiece down to end the sequence of module D and the whole system.

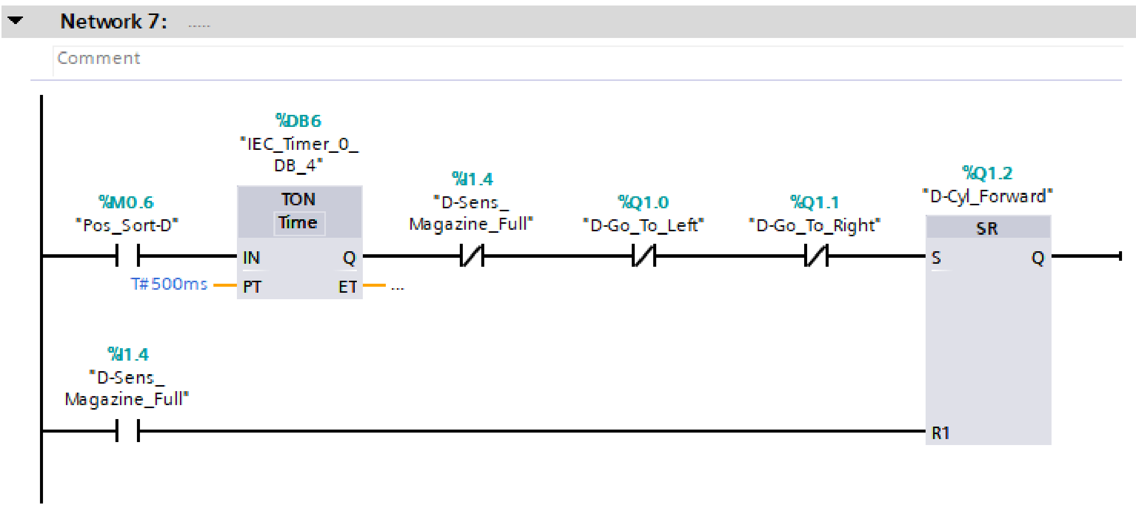


Figure 20: Network 7 in the module D block.

To extend the cylinder to push the workpiece down, rung 1 is utilized. When contact M0.6 receives a signal, after 0.5s if the sorting position in module D is not full and the carrier is not moving to the left or right (or the carrier standstill). The cylinder will extend.

And to disable the cylinder to pushes workpieces to the full magazine, we use sensor I1.4 to detect. When the magazine is full, it will send a signal to reset Q1.2 and the cylinder will be retracted.

3. Discussion

To evaluate the implemented PLC logic, several test cases are derived from the design description and summarized in table 1 below.

Table 1: Test cases of the PLC system

No.	Test cases	Description	Testing	Comments (if applicable)
1	"Start" button	When the "Start" button is pressed, the system starts running.	Pass	-
2	"Selector" switch – Mode I	Once initiated, the system only runs once and then stops.	Pass	The module D's carrier does not automatically return left after a workpiece has been successfully sorted to avoid any undesired actuation besides sorting the workpiece.
3	"Selector" switch – Mode II	Once initiated, the system runs continuously until an error occurs.	Pass	There is a short delay between each repeated sequence to wait for module D to fully retract its sorting cylinder. This is to avoid the case when the cylinder gets stuck in a sorting slot.
4	Sorting	Workpieces of different materials (i.e. black or white plastic and metal) are correctly sorted into their respective slots, during both modes I and II.	Pass	-
5	System error 1	When one of the sorting slots of module D is full, the system stops working and the "Fault" button's	Pass	-

		internal lamp turns on.		
6	“Fault” button	Whenever an error occurs, the system stops working while the source of the error is cleared. After that, when the “Fault” button is pressed, if no error is detected, the system will start running again. Otherwise, the system remains deactivated.	Pass	-
7	“Stop” button	When the “Stop” button is pressed, the system will return all working modules to their initial states.	Pass	Module A retracts its cylinder immediately. Module D returns its carrier to the left after 1 second. As for module B, when its arm is on the right, it will immediately return to the upright position. Otherwise, module B would finish its operation first before returning its arm to the upright position.
8	System error 2	When the magazine of module A is empty, the system stops working and the “Fault” button’s internal lamp turns on.	Pass	-
9	“Emergency Stop” button	When the “Emergency Stop” button is pressed, the system will disable all working modules immediately. After the button is released, either the “Start” or the “Fault” button is	Pass	After the button is released, certain conditions in each module are met and thus some re-initializing actions are expected. Then, the system remains idle until further control.

		used to re-initiate the system.		
10	System error 3	When the arm of module B is stuck for more than 5 seconds, the system stops working and the “Fault” button’s internal lamp turns on.	Pass	For safety reasons, the “Emergency Stop” button will be used to disable the arm for more than 5 seconds to simulate this system error.

To consider whether this system is applicable in the real-life industrial environment or not, safety, automation level, and task efficiency are the three main criteria. The first and foremost requirement is that the PLC program integrates safety features for both the operator and the physical system. The safety measures in our system are the implementation of the “Start”, “Fault”, “Stop”, and “Emergency Stop” buttons in the control panel as well as the automatic error detection feature.

For instance, the system should only initiate upon the trigger of the “Start” button especially in the continuous mode to avoid any unexpected incidents. Therefore, one of our previous designs uses the high pulse of the one-way light barrier in module D to indicate the repetition of another sorting cycle. In other words, as the workpiece is sorted into an allocated slot, there will be a short instant of time it is detected by the light barrier, creating a short triggering pulse to activate a new sequence starting from module A as shown in the third rung in figure 21. However, this design was more error-prone than our current design due to the higher frequency of module D’s cylinder getting stuck in one of the sorting slots. Experiments show that our latter design was more reliable in exchange for slower speed than the first design, but the conditions for a new cycle activation in the second design automatically re-initiated the whole system. This means that the “Start” button is not the only option in the continuous mode, violating the safety requirements. Still, both of the mentioned designs have a great potential for further improvements.

As for the automation level, it can be seen that there are four occasions when the operator intervention is required to make the system work, including the module calibration before running the system, pressing the “Start” button or the “Fault” button, and resolving any detected error. Regarding the task efficiency, there are three pending issues in our design. Firstly, although the “Stop” button currently functions as required, it is not responsive enough to be considered in real-life application. As described in test case number 7 in table 1, the “Stop” button can be improved so that it could return every module to the initial position smoothly under all circumstances. Secondly, the “Emergency Stop” button should disable the whole system including the control station instead of being used as a mean of system error testing. Thirdly, the delay between each sequence can still be further minimized to ensure the fastest sorting speed possible while maintaining safety.

From the evaluation results above, it can be technically concluded that the implemented system fundamentally meets the design requirements. Nonetheless, some suggested future improvements are:

- More versatile automatic error detection

- Making the “Start” button the only way to initiate the system once turned on for safety
- Maximizing the automation level by minimizing the beforehand system calibration
- More responsive “Stop” button, able to return the module B’s arm from all states to its upright position
- The “Emergency Stop” button completely disabling the whole system’s functional operations
- Sorting speed enhancement

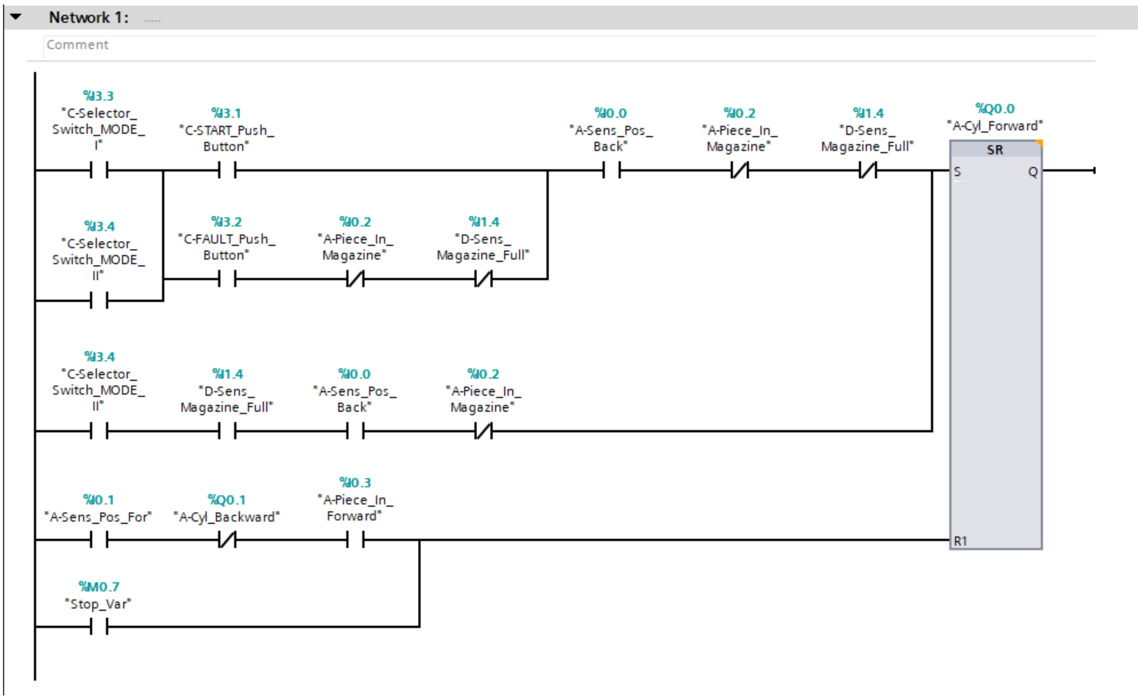


Figure 21: Network 1 of module A block from the previous design

4. Conclusion

From the process of analyzing how modules interact with each other and the requirements of the project, a ladder program design via the Siemens TIA Portal platform has been developed in the PLC system to obtain the desired results. According to the test cases in table 1, the system has been successfully analysed, designed, and implemented. That is the system can transfer the workpieces through module A, B, and D, and pieces are allocated into correct slots. Plus, it also satisfies the requirements in mode 1 and mode 2 as well as some special cases like stop, fault, and emergency condition.

Although the goals of the project were achieved, the system could still be further improved by:

- Decreasing the delay time to increase the speed of the system
- Simplifying the program with the same functionality for better readability, understanding, and efficient implementation
- Maximizing the automation level by minimizing the beforehand system calibration
- More responsive “Stop” button, able to return the module B’s arm from all states to its upright position.