Mechatronics

PLC and HMI Programming

Advanced PLC Training System

Courseware Sample

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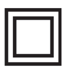
Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger. Consult the relevant user documentation.
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
⎓	Direct current
∿	Alternating current
≂	Both direct and alternating current
3∿	Three-phase alternating current
⏚	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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Preface

Programmable logic controllers (PLCs) are at the center of a multitude of automated systems. Some industries that benefit from these systems include manufacturing plants, breweries, wastewater treatment plants, mining facilities, and automotive assembly plants.

This manual introduces students to four PLC programming languages: ladder, sequential function chart, function block, and structured text. The most common PLC instructions are used within Rockwell's *Studio 5000* software environment. In addition to PLC programming, students learn how to conceive interface screens with *FactoryTalk View Studio* and make them work along with the PLC project.

In terms of hardware, the Advanced PLC Training System uses modern, industrial-grade equipment that is instrumental in teaching theoretical and hands-on knowledge required to work in the automation industry. Optional applications can be purchased and connected to the PLC suitcase to add real-world sensors and actuators to the setups.

In order to perform the exercises in this manual, the *Studio 5000* and the *FactoryTalk View Studio* software must be installed on the student's computer.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

About This Manual

Manual objectives

When you have completed this manual, you will be able to navigate through the *Studio 5000* and *FactoryTalk View Studio* software from Rockwell and use the online resources. You will know how to create PLC routines in ladder, sequential function chart, function block, and structured text, and how to develop operator interfaces.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Reference material

The resource kit DVD-ROM contains the PLC and HMI projects that will be needed throughout the exercises.

Prerequisite

As a prerequisite to this course, you should have a basic understanding of electricity. It is assumed that you have a general understanding of these concepts:

- DC and ac voltage, current, and power
- Basic electrical components (resistor/potentiometer, inductor, capacitor, diode, transistor)
- Ohm's law
- Series and parallel circuits
- Electrical measurement

Systems of units

Units are expressed using the International System of Units (SI) followed by units expressed in the U.S. customary system of units (between parentheses).

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Sample Exercise

Extracted from

the Student Manual

and the Instructor Guide

Clamp and Stamp Application (LAD)

EXERCISE OBJECTIVE

In this exercise, you will:

- Open an existing PLC project
- Revise the tags
- Create a ladder routine
- Insert rungs and bit instructions
- Test the PLC program with an application (real or simulated)

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Clamp and work
- Two types of sensors
- Pneumatic cylinders
- Directional control valves
- Latch and unlatch output instructions
  Output Latch instruction. Output Unlatch instruction.

DISCUSSION

Clamp and work

Clamp and work systems usually consist of two hydraulic or pneumatic cylinders. The clamp cylinder extends until it stalls against the workpiece. The work cylinder advances and retracts a machining tool to perform a particular task on the clamped workpiece, such as bending, pressing, drilling, cutting, stamping, or grinding. The sequence may resemble that of Figure 79.

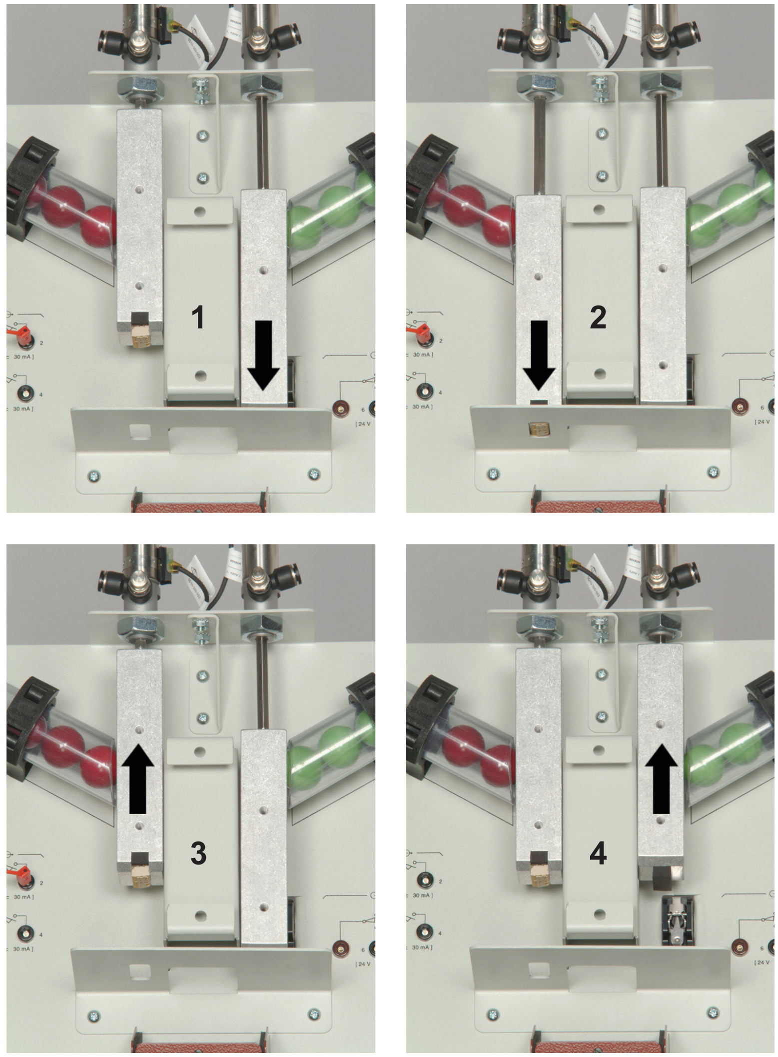


Figure 79. Clamp and work cycle.

1. The clamp cylinder extends.
2. The work cylinder extends.
3. The work cylinder retracts.
4. The clamp cylinder retracts.

In this particular example, the clamp cylinder cannot release its grip on the workpiece until the work cylinder has completely retracted. This ensures that the workpiece remains clamped while being worked on. Proximity detectors may be used to verify the position of the cylinders during the operation.

Two types of sensors

The physical application that you will be using in this exercise features two different types of sensors: a **mechanical limit switch** and two reed switches.

The single proximity detector at the bottom of the right cylinder is a mechanical limit switch, shown in Figure 80. It is a single pole, double throw switch, which means that it has both a normally open and a normally closed contact. The normally open contact closes when the mechanical arm is pushed. A spring returns the arm to its original position.

Figure 80. Mechanical limit switch.

The two **reed switches** are located on the left cylinder, as shown in Figure 81. These single pole, single throw switches are only closed when the plunger inside the cylinder is close to the switch.

Reed switches are actuated when an applied magnetic field joins the pair of ferrous metal reed contacts located inside a hermetically sealed envelope.

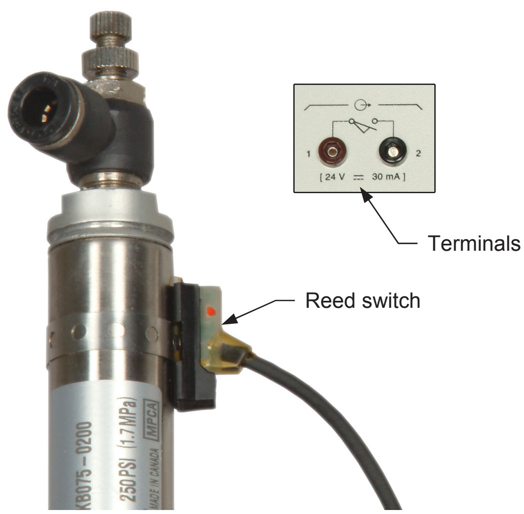


Figure 81. Reed switch on a pneumatic cylinder.

Pneumatic cylinders

A **pneumatic cylinder** is an actuator that converts fluid energy into straight-line or linear mechanical energy. Single-acting cylinders generate forces in a single direction whereas double-acting cylinders generate forces during both extension and retraction of the rod.

A double-acting cylinder is shown in Figure 82. It contains two fluid ports and does not include a spring. When fluid enters one port of the cylinder, the piston moves toward the other port. The corresponding symbol is shown in Figure 83.

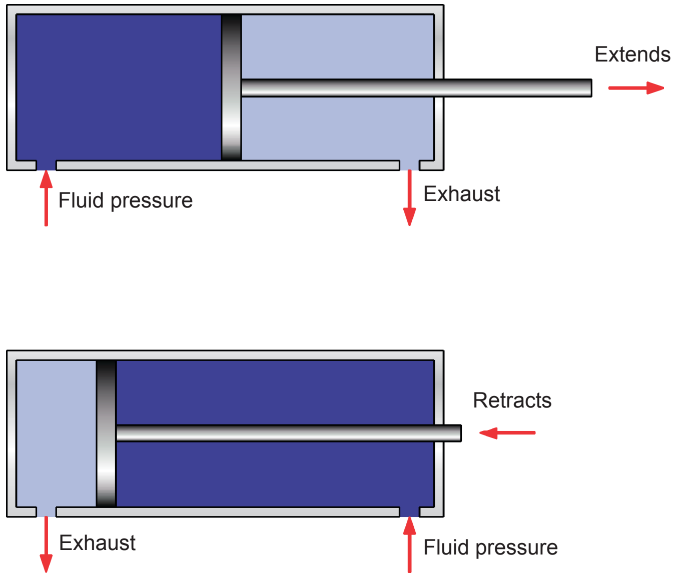


Figure 82. Double-acting cylinder extending and retracting.

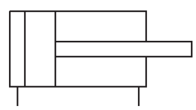


Figure 83. Double-acting cylinder symbol.

Directional control valves

Directional control valves (DCVs) such as the one shown in Figure 84 are used to control the flow in a fluid power branch circuit. They can perform three functions:

- block fluid flow
- allow fluid flow
- change the direction of fluid flow

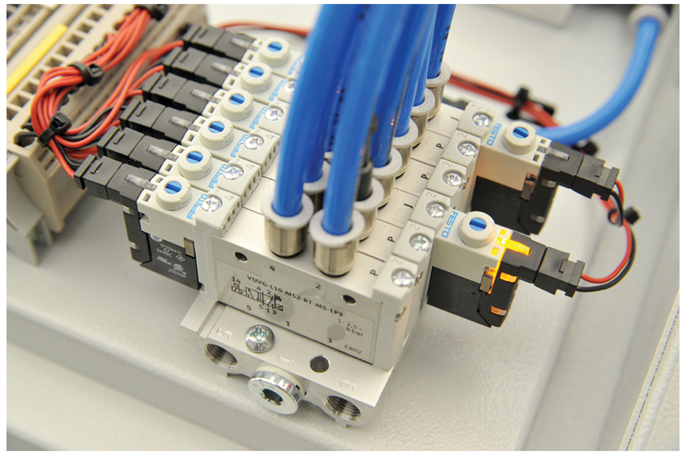


Figure 84. Directional control valves.

Directional control valves are described according to:

- the number of controlled openings, called ports or ways
- the number of positions or states that the valve can assume
- the type of valve actuators (also called operators) used to switch the valve from one position to another

The symbols used for directional control valves indicate the above three characteristics and also show a simplified flow path for each position. The symbols do not provide any information about the physical construction of the valve; they simply indicate the function of the valve.

Let us ignore the valve operators for the moment and consider only the number of ports and positions of a valve. Most directional control valves have two or three positions. Each position of the valve provides a different flow path configuration. Valve types are identified using two numbers of the form "*m/n*" where the first number *m* is the number of ports and the second number *n* is the number of positions.

The symbol for a directional control valve consists of two or more blocks (sometimes referred to as envelopes). There is a separate block for each position and each block illustrates a different flow path. Ports are shown as lines protruding from one of the blocks. The block with lines protruding, or with ports identified by a letter or a number, shows the flow path through the valve in its normal position (or return position). The other positions are called operated positions (or actuated positions or working positions).

As an example, the symbol for a two-port, two-position (2/2) directional control valve is shown in Figure 85. On the block showing the normal position of the valve, the ports are numbered. The open (passing) flow path is shown as an arrow. Ports that are closed (non-passing) are shown using short lines drawn at right angles.

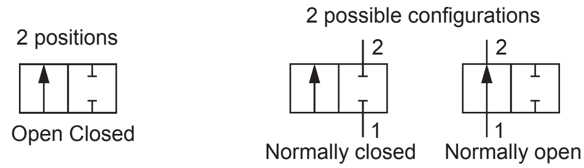


Figure 85. 2-port, 2-position directional control valve.

The devices used to switch the valve from one position (state) to another are called valve actuators or operators. Different types of valve actuators may be used. Figure 86 shows a valve with an electrical actuator (a solenoid) and a spring return. Since this valve is normally open, the normal position shows the flowpath from port 1 to 2.

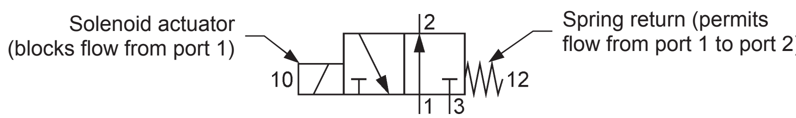


Figure 86. 3-port, 2-position, normally open, solenoid operating, spring return valve symbol.

Latch and unlatch output instructions

The **Output Energize instruction** (OTE) we saw in the previous lesson is considered to be a non-retentive instruction. In other words, the OTE instruction does not retain its value when the rung is false. The output status changes with the rung status:

- If the rung is true, the OTE instruction becomes true and the output turns on
- If the rung is false, the OTE instruction becomes false and the output turns off

There are, however, some conditions where an output needs to remain on even after the conditions that provided the output are no longer true. For example, if separate start and stop buttons are used, you would not want to hold the start button for the duration of the activation. In this event, an instruction with a retentive operation is desired.

These instructions are considered to be latching and are described in Figure 87. The OTL and OTU instructions are always used in pairs with the same bit address since both instructions modify the same bit.

Instruction	Abbreviation	Symbol
Output latch	OTL	-(L)-
Output unlatch	OTU	-(U)-

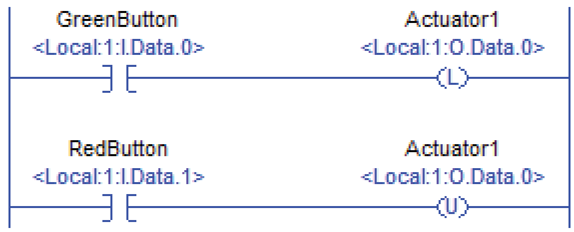


Figure 87. Associated OTL and OUT instructions triggered by two inputs.

Output Latch instruction

The **Output Latch instruction** (OTL) sets the addressed bit to logic state 1 when the rung containing the OTL is true. After, the bit remains at logic state 1, regardless of the current OTL rung conditions, until it is set to logic state 0 by the associated OTU instruction.

Output Unlatch instruction

The **Output Unlatch instruction** (OTU) sets its addressed bit to 0 when the rung containing the OTU is true. Thereafter, the bit remains at logic state 0 regardless of the current OTU rung conditions, until it is set to logic state 1 by the associated OTL instruction.

Table 3 summarizes the logic state operation of the latching instructions.

Table 3. Latching instructions operation.

Instruction	Previous state of bit O:0/0	Rung condition	New state of bit O:0/1
OTL	0	True	1
		False	0
	1	True	1
		False	1
OTU	1	True	0
		False	1
	0	True	0
		False	0

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up and connections
  Real application option. Simulated application option.
- Checking the I/O configuration
- Inserting the logic
  Rung 0 (clamp indicator). Rung 1 (clamp extend control – X3). Rung 2 (stamp extend control – X1 latch / X2 unlatch). Rung 3 (stamp retract control – X2 latch / X1 unlatch).
- Running the PLC and HMI projects
- Testing the application
- End of the procedure

PROCEDURE

Set up and connections

In this exercise, you will complete a program that controls a clamp and stamp application. The program will use a push-button to clamp and another one to stamp a fictive sheet of metal. The logic will only permit stamping if the workpiece is clamped first. You can either connect the real application to the trainer or use the version that is simulated on the HMI and shown in Figure 88.

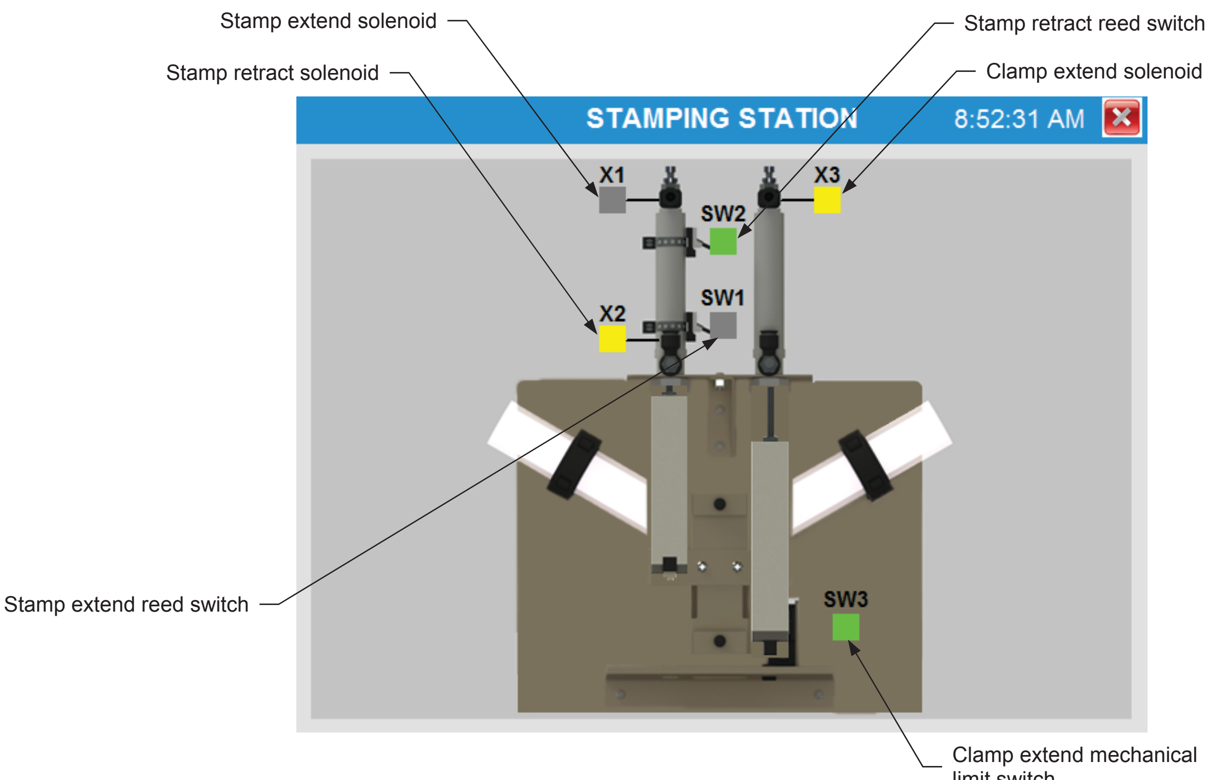


Figure 88. HMI application.

Green squares indicate actuated sensors. Yellow squares show energized actuators. Gray squares indicate that the state of the sensor or actuator is off.

The clamp cylinder retracts when X3 is not actuated. This is because it is a spring-return valve.

Real application option

1. Connect the equipment as shown in Figure 89 and Figure 90. The tags used in this exercise are shown in Figure 91. Adjust the air pressure between 200 kPa and 275 kPa (30 psi and 40 psi).

To avoid air leaking from the connectors, make sure that plastic tubes are cut clean and inserted deep enough into the connectors. Plastic tubes are removed by pressing the release button towards the body of the connector before pulling out the tubing.

Make sure with the students that no fault is inserted to the training system.

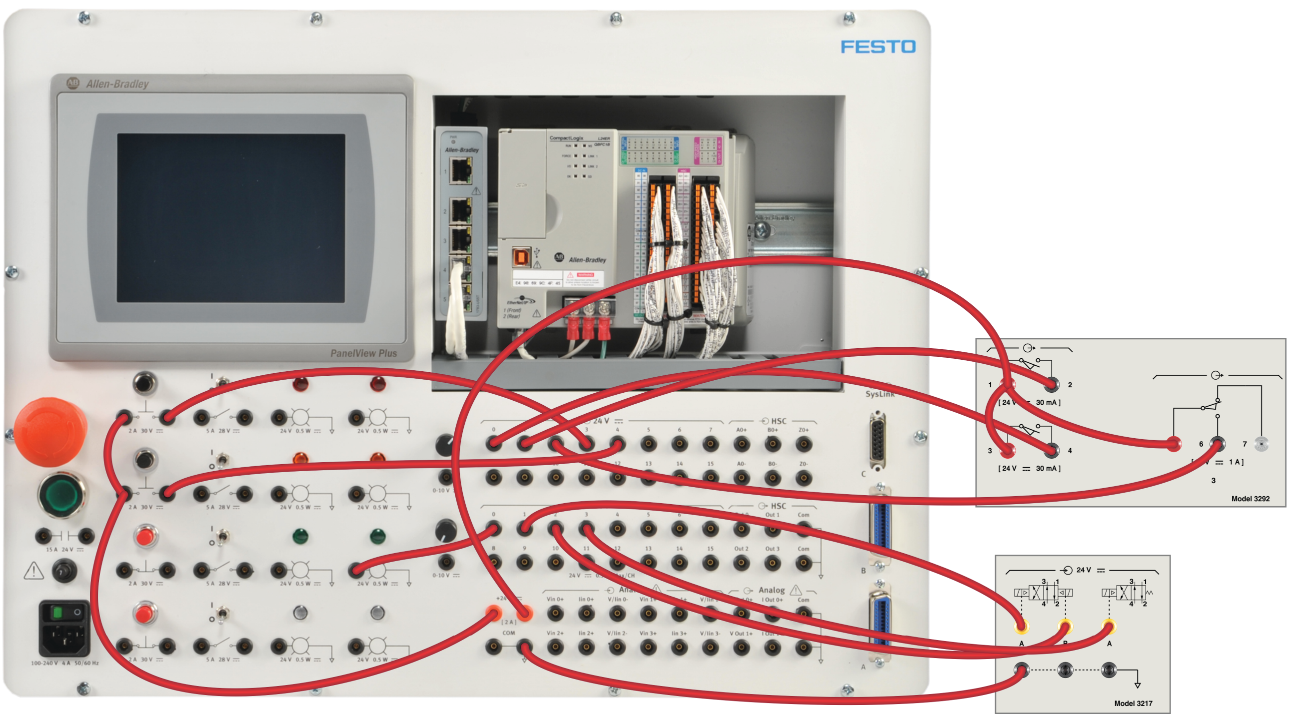


Figure 89. Clamp and stamp setup (real application).

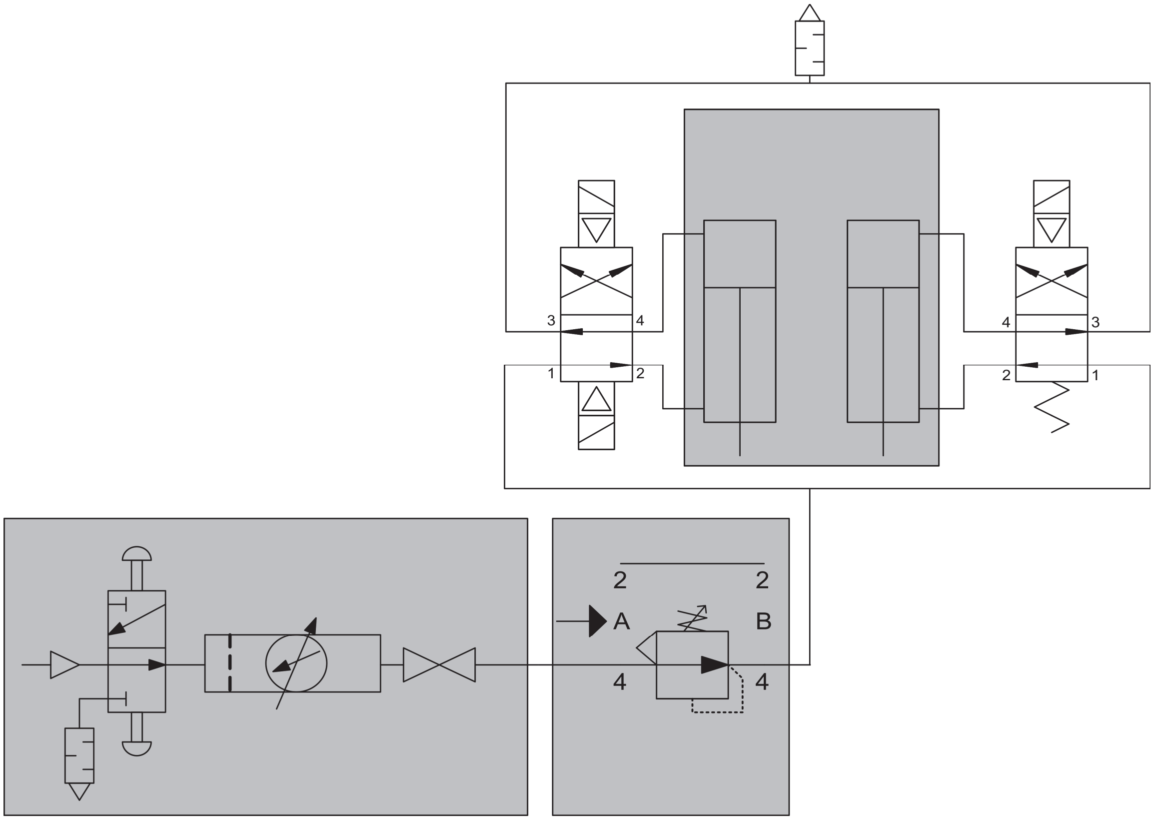


Figure 90. Pneumatic connections.

Name	Alias For	Base Tag	Data Type	Description
⊞-TmrOffX3			TIMER	Timer X3 - Simulation that X3 is retracting
SW1	Local:1:I.Data.0	Local:1:I.Data.0	BOOL	Stamp cylinder extend reed switch
SW2	Local:1:I.Data.1	Local:1:I.Data.1	BOOL	Stamp cylinder retract reed switch
SW3	Local:1:I.Data.2	Local:1:I.Data.2	BOOL	Clamp cylinder extend limit switch
PB1	Local:1:I.Data.3	Local:1:I.Data.3	BOOL	Clamp NO push button
PB2	Local:1:I.Data.4	Local:1:I.Data.4	BOOL	Stamp NO push button
L1	Local:1:O.Data.0	Local:1:O.Data.0	BOOL	Clamp indicator(Light)
X1	Local:1:O.Data.1	Local:1:O.Data.1	BOOL	Stamp cylinder extend (DCV1A)
X2	Local:1:O.Data.2	Local:1:O.Data.2	BOOL	Stamp cylinder retract (DCV1B)
X3	Local:1:O.Data.3	Local:1:O.Data.3	BOOL	Clamp cylinder extend (DCV2A)

Figure 91. Tags and connections for Exercise 2 (real application).

2. Open the *Ex2_Real_Student* project in Logix Designer (Figure 92).

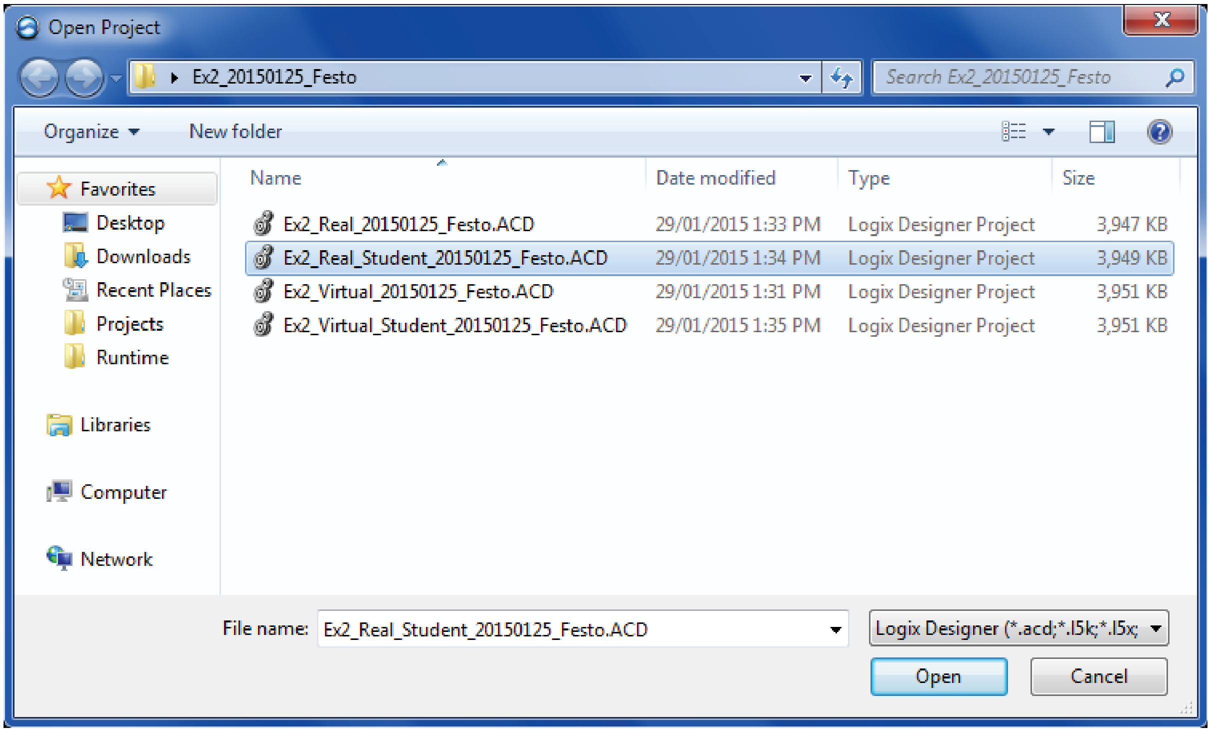


Figure 92. Opening the *Ex2_Real_Student* Logix Designer project.

3. Open the *Controller Tags* window. Click the *Edit Tags* tab and fill out the *Name* and *Alias For* columns according to Figure 91. That way, you will have all the necessary tags when writing the logic.

Suggestion: You can remove tags from the version given to the students.

Simulated application option

1. Connect the equipment as shown in Figure 93. The tags used in this exercise are shown in Figure 94.

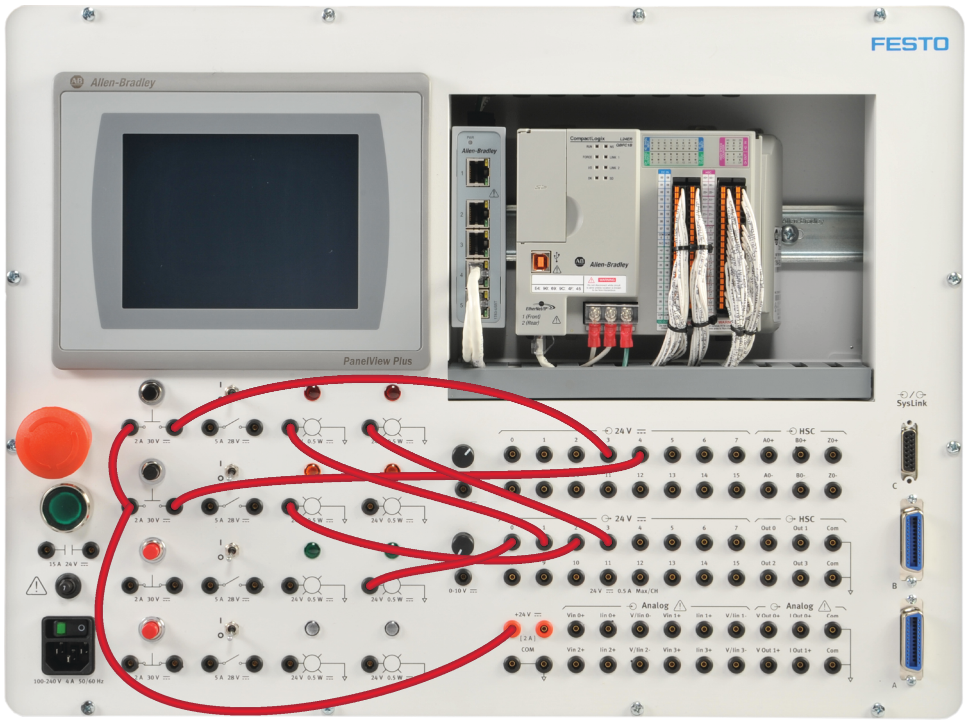


Figure 93. Clamp and stamp setup (virtual application).

Name	Alias For	Base Tag	Data Type	Description
SW1			BOOL	Stamp cylinder extend reed switch
SW2			BOOL	Stamp cylinder retract reed switch
SW3			BOOL	Clamp cylinder extend limit switch
+-TmrOffX3			TIMER	Timer X3 - retract simulation
+-TmrOnSW3			TIMER	Timer SW3 - SW3 simulation
+-TmrSW1			TIMER	Timer SW1 - SW1 simulation
+-TmrSW2			TIMER	Timer SW2 - SW2 simulation
PB1	Local:1:I.Data.3	Local:1:I.Data.3	BOOL	Clamp NO push-button
PB2	Local:1:I.Data.4	Local:1:I.Data.4	BOOL	Stamp NO push button
L1	Local:1:O.Data.0	Local:1:O.Data.0	BOOL	Clamp indicator (Light)
X1	Local:1:O.Data.1	Local:1:O.Data.1	BOOL	Stamp cylinder extend (DCV1A)
X2	Local:1:O.Data.2	Local:1:O.Data.2	BOOL	Stamp cylinder retract (DCV1B)
X3	Local:1:O.Data.3	Local:1:O.Data.3	BOOL	Clamp cylinder extend (DCV2A)

Figure 94. Tags and connections for Exercise 2 (virtual application).

2. Open the *Ex2_Virtual_Student* project in Logix Designer (Figure 95).

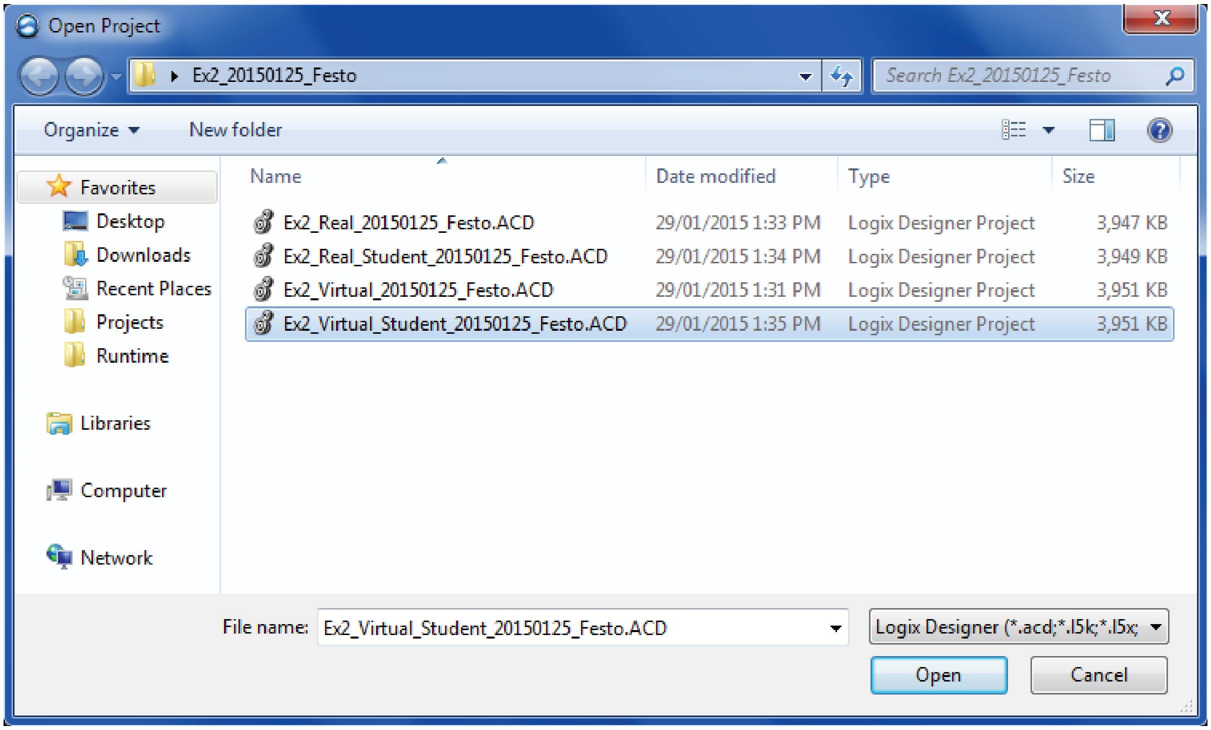


Figure 95. Opening the *Ex2_Virtual_Student* Logix Designer project.

3. Open the *Controller Tags* window. Click the *Edit Tags* tab and verify that the *Name* and *Alias For* columns are as shown in Figure 94. Make some edits if necessary. That way, you will have all the necessary tags when writing the logic.

Suggestion: You can remove tags from the version given to the students.

Checking the I/O configuration

4. In the *Controller Organizer* window, expand the *I/O Configuration* to reveal how the controller is organized (Figure 96).

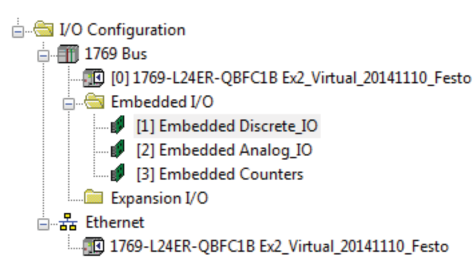


Figure 96. I/O configuration.

5. What is the controller model that is configured for this project?

1769-L24ER-QBFC1B

6. Double-click *Discrete_IO* to open the module properties. How is the module *Type* described (*General* tab)?

"Embedded 16 Point 24 V DC Sink/Source Input /16 Point 24V DC Source Output"

7. What is the default Requested Packet Interval (RPI)?

20 ms

8. Click *Cancel* to close the properties window.

Inserting the logic

In this section, we will create a ladder routine and insert four lines of code.

9. In the *Controller Organizer*, we see that there is one program, *MainProgram,* in the continuous task *MainTask* (Figure 97). In this program, there are two routines at this time:

   - **MainRoutine.** The sole purpose of this routine is to call the other routines.
   - **LD02_Reserved.** This routine induces time delays between cylinder displacements, when the (virtual) valve solenoids are actuated. This provides for a more realistic result on the touch screen.

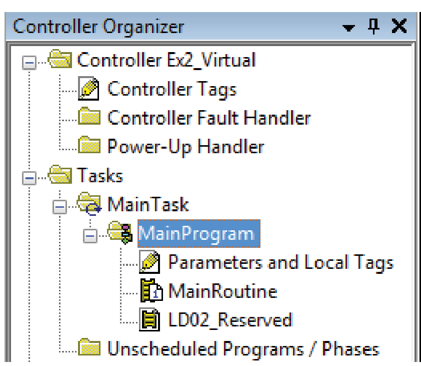


Figure 97. MainProgram and Routines (virtual version).

10. Right-click *MainProgram* and select *Add ► New Routine.* Enter the information found in Figure 98 to create a new ladder routine called *LD01_StampingStation*.

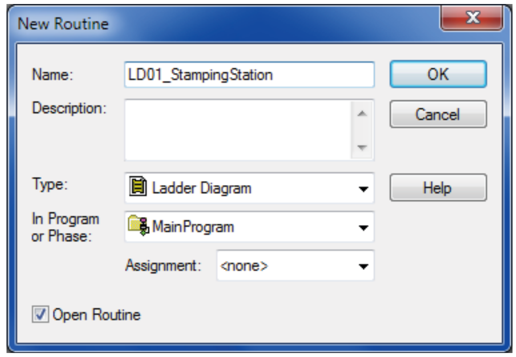


Figure 98. New ladder routine.

Rung 0 (clamp indicator)

11. Open the newly created routine *LD01* (Figure 99). We see that there are two rungs already: the *(End)* rung that is not editable, and rung *0*.

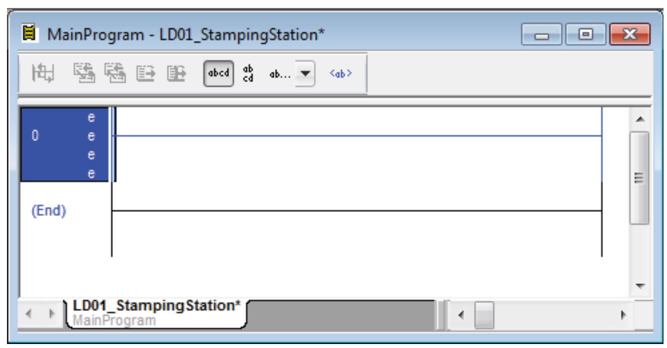


Figure 99. Empty routine.

12. Let us start by having an indicator light turn on whenever the mechanical limit switch at the bottom of the clamp cylinder is actuated. To do so, you will need an Examine On (XIC) and an Output Energize (OTE) instruction. First, add the Examine On instruction by clicking the symbol while rung 0 is selected (Figure 100).

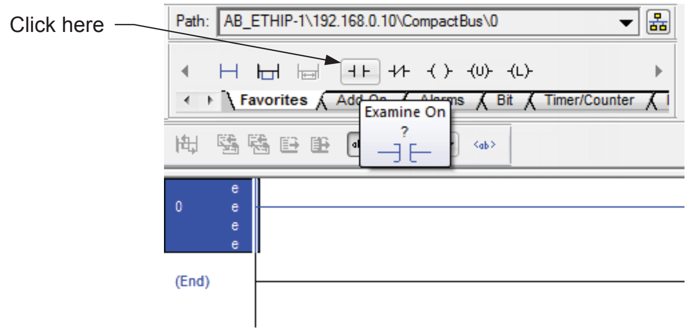


Figure 100. Adding an Examine On (XIC) instruction.

13. Double-click the question mark (Figure 101). This gives you access to a list of available tags. Select the alias tag that pertains to the mechanical switch (SW3).

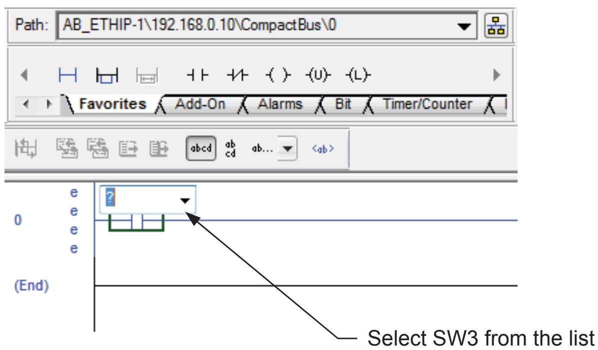


Figure 101. Assigning a tag to the instruction.

14. Drag and drop an Output Energize (OTE) instruction as shown in Figure 102.

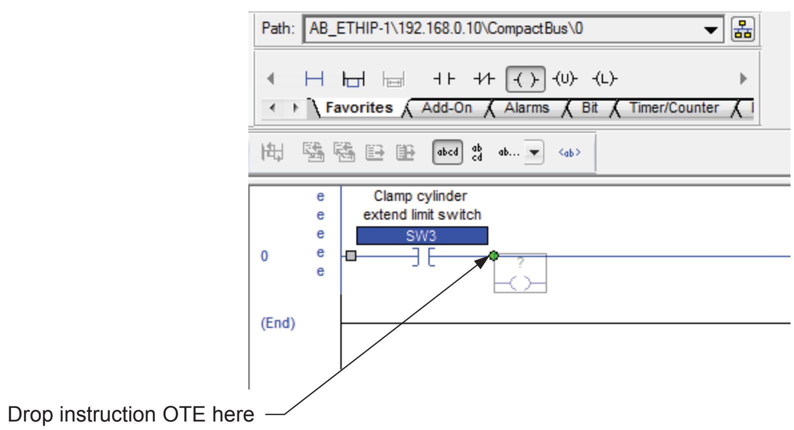


Figure 102. Adding an Output Energize instruction.

15. Assign the alias tag of the indicator light (L1) to the OTE instruction (Figure 103).

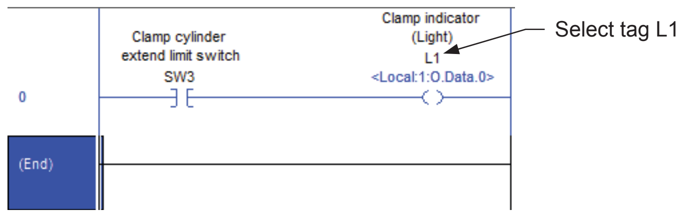


Figure 103. Assigning tag L1 to the instruction.

Rung 1 (clamp extend control – X3)

16. Insert a rung. One way to do so is by clicking the corresponding icon in the *Language Element* menu (Figure 104).

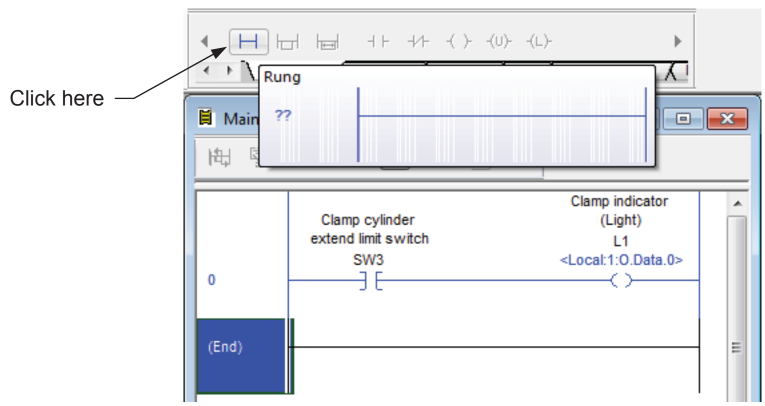


Figure 104. Adding a rung.

17. Enter the logic for this rung according to Figure 105. Figure 106 shows where to go to add a branch. X3 (clamp cylinder solenoid) energizes if one of these two conditions is fulfilled:

- PB1 (NO clamp push-button) is pressed, or
- SW2 (stamp retract switch) is **not** actuated **and** X3 (valve solenoid) is currently actuated.

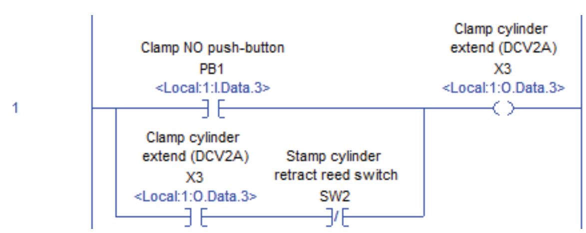


Figure 105. Rung 1 (clamp extend).

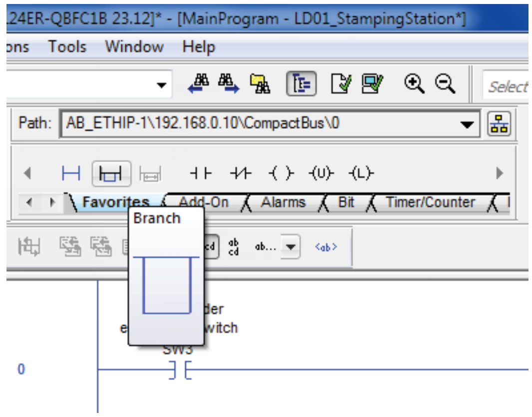


Figure 106. Adding a branch.

Rung 2 (stamp extend control – X1 latch / X2 unlatch)

18. Insert another rung. This time, right-click the existing rung 1 and select *Add Rung* (Figure 107).

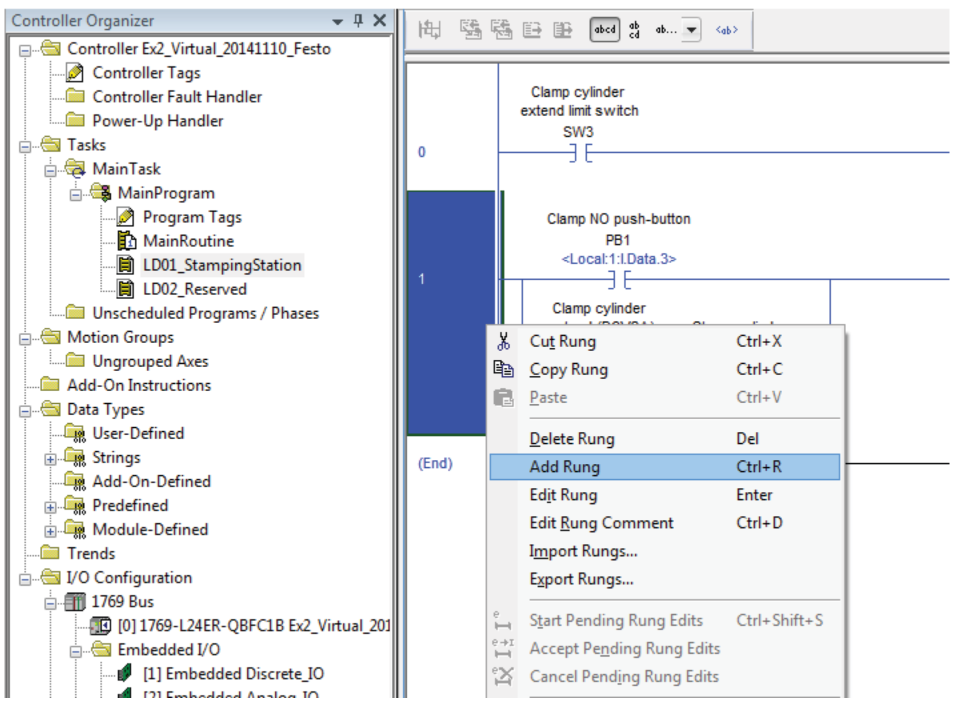


Figure 107. Adding a rung (right-click).

19. Enter the logic for this rung according to Figure 108. You will need latch (L) and unlatch (U) instructions. X1 will latch and X2 will unlatch if **all** of these four conditions exist simultaneously:

- PB2 is pressed
- SW1 (stamp extend switch) is **not** actuated
- SW2 (stamp retract switch) is actuated
- SW3 (clamp extend switch) is actuated

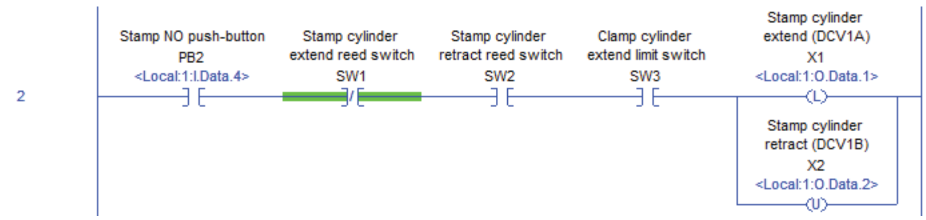


Figure 108. Rung 2 (stamp extend).

Rung 3 (stamp retract control – X2 latch / X1 unlatch)

20. Insert one last rung.

21. Enter the logic for this rung according to Figure 109. X2 will latch and X1 will unlatch if **all** of these four conditions exist simultaneously:

- PB2 is **not** pressed
- SW1 (stamp extend switch) is actuated
- SW2 (stamp retract switch) is **not** actuated
- SW3 (clamp extend switch) is actuated

In parallel to these conditions, add an *Examine On* instruction linked to the first scan bit (simply type "*S:FS*" above the instruction). This forces the system to start with the stamping cylinder retracted.

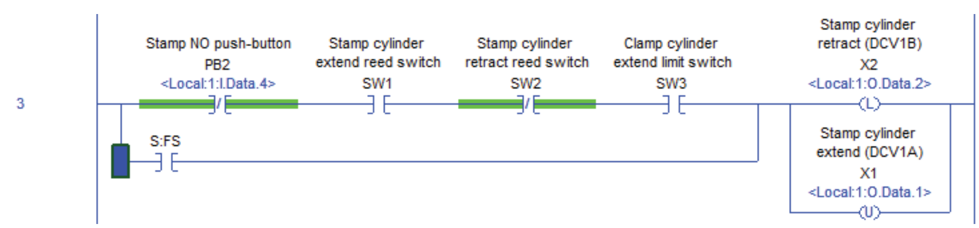


Figure 109. Rung 3 (stamp retract).

22. Save your program under a new name (*File* ▶ *Save As…*) as shown in Figure 110.

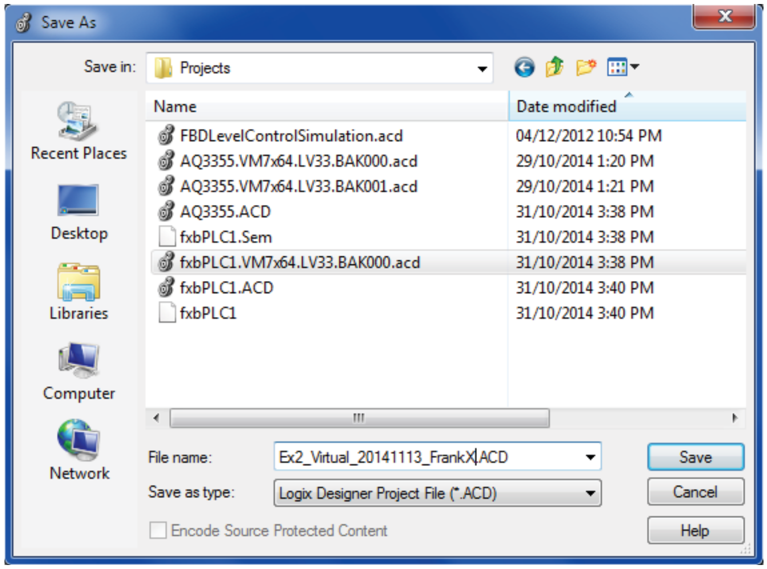


Figure 110. Saving the file under a different name.

Running the PLC and HMI projects

23. Now that your program is entered and saved, it is time to download it to the PLC. Providing that your network is properly configured (see Exercise 1), open the *Communications* menu and select *Download (*Figure 111*)*.

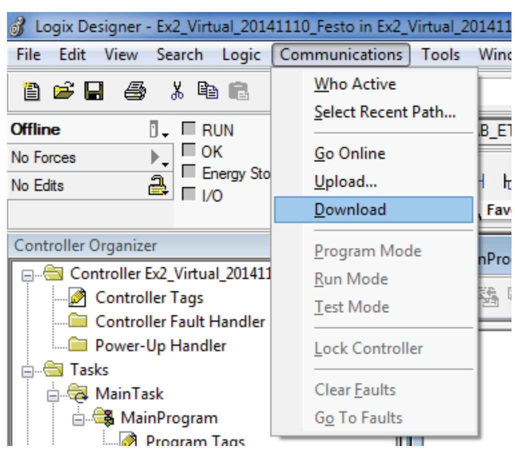


Figure 111. Download.

24. Put the controller mode to *(Remote) Run*.

25. If necessary, transfer the HMI program (.mer) to the touch screen using *ME Transfer Utility*, a *FactoryTalk View Studio* tool (Figure 112).

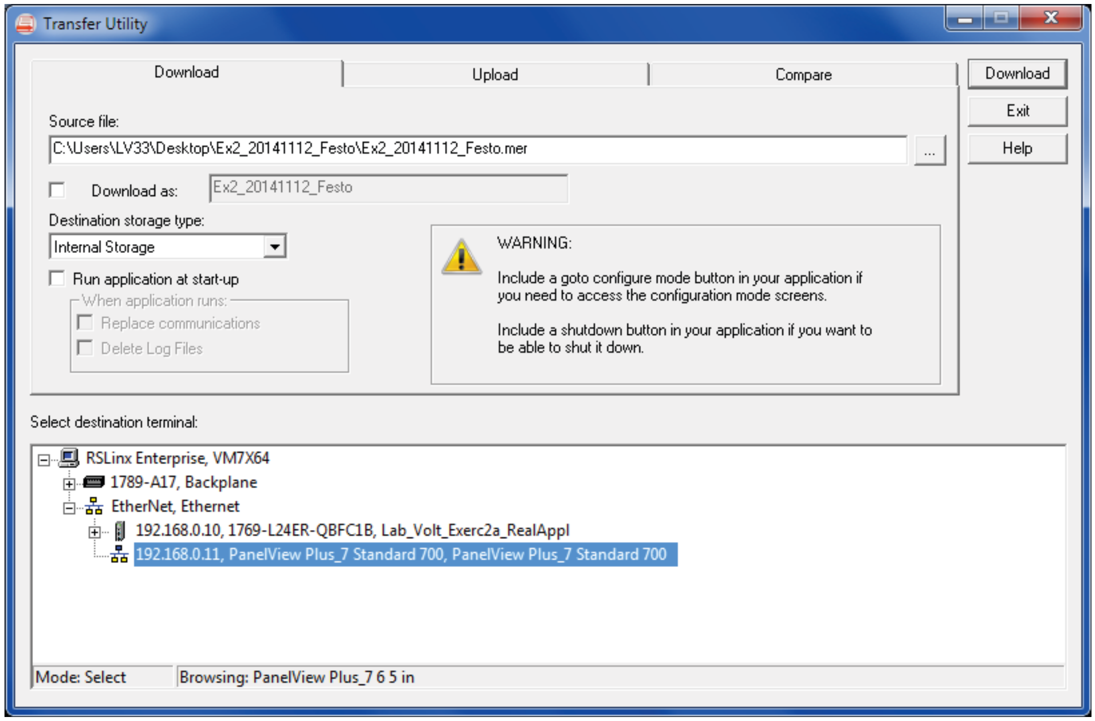


Figure 112. Transferring the .MER to the touch screen.

You may have to open the archived project, modify it, and create a new runtime application if the PLC address or the version of the touch screen is different.

26. Load and run the HMI program on the touch screen. The program should resemble Figure 113. If errors show up on the screen, check connectivity with the PLC and verify the tags you used in the PLC program.

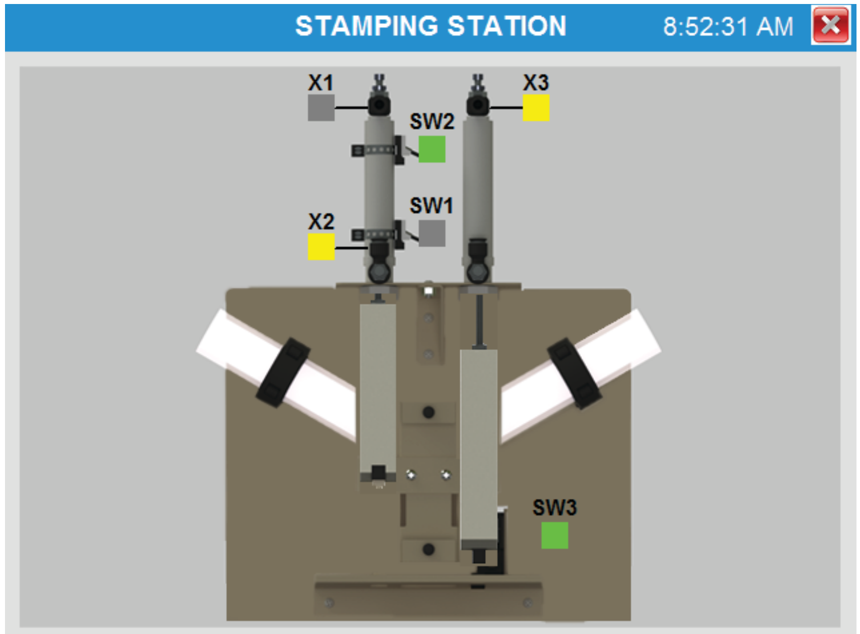


Figure 113. Running the HMI program.

Testing the application

27. Push the green button under the red emergency button on the trainer to activate the PLC outputs. Using the push-buttons, verify that the program operates as expected.

Test	Yes	No
Pressing PB1 extends the clamp cylinder.		
Output 0 (light) energizes when the clamp cylinder is extended.		
Pressing PB2 extends the stamp cylinder **ONLY** if the clamp cylinder is fully extended.		
The clamp cylinder cannot retract if the stamp cylinder is extended.		
The stamp cylinder retracts if PB2 is released.		

28. If you answered "No" to any of the preceding questions, please revise your project, make some modifications, and download it again to the PLC.

End of the procedure

29. Turn off the trainer, disconnect the leads, and clean the work surface.

CONCLUSION

In this exercise, you opened an incomplete PLC project and you made sure that the tags were correct. Then you created a ladder routine to control the logic of the application, using bit instructions. Finally, you transferred and ran your program and tested it with a physical or simulated clamp and stamp application.

REVIEW QUESTIONS

1. What is the Requested Packet Interval (RPI)?

   This parameter specifies the rate at which the input and output values are updated.

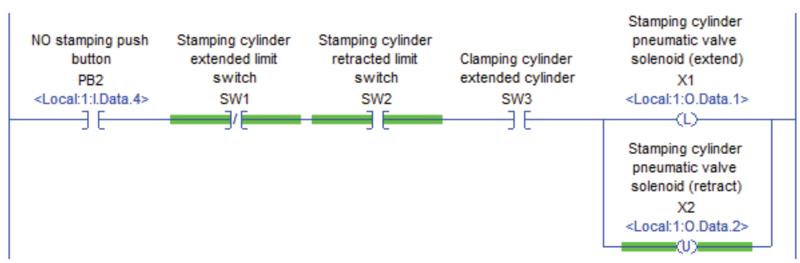
2. Which output instruction changes status along with the rung status?

   Output Energize (OTE)

3. Which output instruction sets the addressed bit to 0 when the rung containing the instruction is true?

   Output Unlatch (OUT)

4. What are the conditions necessary to unlatch X2?



Rung for Question 4 and Question 5.

   PB2=1
   SW1=0
   SW2=1
   SW3=1

5. In the previous figure, what happens simultaneously when X2 is unlatched?

   X1 is latched.

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