Chapter 5

Creating Relay Logic Diagrams

Chapter Outline

5.1 Introduction
5.2 Relay Logic Diagrams
5.3 Rules for Drawing Relay Logic Diagrams
5.4 Creating Relay Logic Diagrams for Industrial Control Circuits

Technical Terms

relay logic diagram
PLC ladder logic diagram (ladder diagram)
rails
rung
relay coil
contact

Learning Objectives

After completing this chapter, you will be able to:

- Use symbols to represent different types of input and output devices.
- Create relay logic diagrams using the standard relay logic rules.
- Place comments on relay logic devices using the standard rules.
- Create relay logic circuits for process and industrial control problems.

5.1 Introduction

A relay logic diagram illustrates the method by which an industrial control system operates. There are standard rules that should be followed when creating relay logic diagrams. Several standard symbols or legends are used to draw relay logic circuits.

In this chapter, you will learn the correct method of drawing relay logic diagrams. Finally, you will learn how to draw relay logic circuits for a control problem.

5.2 Relay Logic Diagrams

Relay logic diagrams are created to show the logical relationship between devices. Relay logic diagrams are sometimes called *elementary diagrams*, *line diagrams*, or *relay ladder logic (RLL)*. In this chapter, we will use the term *relay logic diagram* to describe the ladder logic diagram.

Relay logic diagram: Diagram that shows the logical relationships between devices.

PLC ladder logic diagram (ladder diagram): The program loaded into the programmable logic controller. This program defines the operation to be performed by the PLC.

Rails: Two vertical lines labeled L1 and L2 that connect the rungs of a PLC diagram.

Rung: Horizontal line in a relay logic diagram that has input devices and an output device.

Relay coil: Device that, when energized, opens associated normally closed contacts and closes normally open contacts.

Contact: Device that opens and closes corresponding to the state of its associated relay coil. A normally open contact is closed when its relay coil is energized. A normally closed contact is opened when its relay coil is energized.

Relay logic diagrams are very important because they show the symbols for different input and output devices. The first step in creating a program for a PLC is creating the relay logic diagram. After the relay logic diagram is drawn, it is then converted to a ***PLC ladder logic diagram***, often called a *ladder diagram*. The ladder diagram is used to program the programmable logic controller (PLC). The program defines the operations to be performed by the PLC.

Figure 5-1 displays a simple example of a relay logic diagram that uses two normally open switches (SW1 and LS1) and one normally open pushbutton (PB1). Three discrete input devices are connected in series with a motor starter.

Typically, 120 VAC, 24 VDC, or 12 VDC will be the voltage between the two ***rails***, labeled L1 and L2 in the figure. In general, L1 represents the supply terminal and L2 represents the common terminal.

Current in the relay logic circuit of Figure 5-1 can flow to the electric motor or motor starter when all three input devices are closed. Current to the motor causes the motor to turn on. Each row in the relay logic diagram is called a ***rung***. A relay ladder diagram can have more than one row.

Figure 5-2 illustrates how a ***relay coil*** and ***contacts*** are used in a relay ladder logic diagram to control a solenoid. When pushbutton one (PB1) is pressed, the relay coil (CR) is energized and causes contacts CR-1 and CR-2 to close. Closed CR-1 contact seals or locks the coil CR so that it stays energized. Closed CR-2 causes the solenoid to be energized. When the normally closed (NC) limit switch (LS1) is opened, the relay coil is turned off, and contacts CR-1 and CR-2 are opened. Opening the CR-2 contact disables the solenoid (SOL).

Note that CR represents the coil and CR-1 and CR-2 represents the contacts associated with the coil labeled CR. The CR1 and CR2 labels are used if there is more than one coil in the relay logic diagram. Then, the contact will be referred to as CR1-1, CR1-2, CR2-1, CR2-2, and so on. Numbers on the right-hand side of rung 1 in Figure 5-2 show that

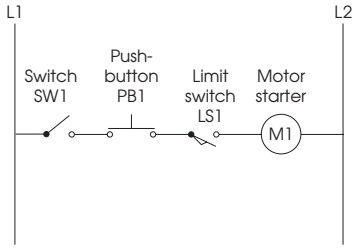

Figure 5-1. A simple relay logic diagram.

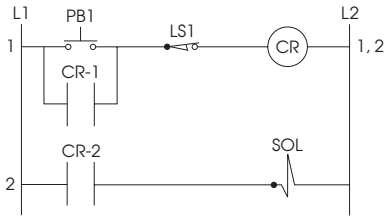

Figure 5-2. Use of a relay coil and contacts in a relay logic diagram.

there are normally open (NO) contacts on rung 1 and 2 that are related to CR-1. A bar underneath a number indicates the contact is normally closed (NC).

A relay logic circuit can have several relay coils and contacts. **Figure 5-3** displays two relay coils and four contacts. When the relay coil CR1 is energized, the normally open contact CR1-2 closes energizing CR2, and the normally closed contact CR1-1 opens turning off the red pilot light. When the relay coil CR2 is energized, the

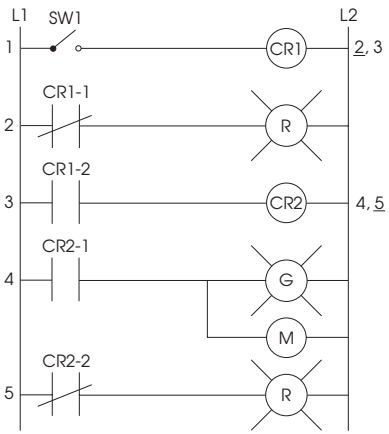

Figure 5-3. Relay coils and their associated contacts. The state of the contacts depends on the energized state of the coil.

normally open contact CR2-1 closes, turning on the green pilot light and energizing the motor. The normally closed contact CR2-2 opens, turning off the red pilot light.

Figure 5-4 displays a relay logic circuit that has two relay coils and five contacts. Note that contacts associated with a relay coil can be normally open, normally closed, or a combination of both. In Figure 5-4, numbers 2, 3, and 4 on the right-hand side of rung 1 specifies that there are normally open (NO) contacts with the same addresses as coil CR1 in rungs 2, 3, and 4. Numbers 4 with a bar on the bottom and 5 on the right-hand side of rung 3 specifies that there are normally closed (NC) and a normally open (NO) contacts with the same addresses as coil CR2 in rungs 4 and 5.

When the start switch in Figure 5-4 is closed, coil CR1 is energized. Then, three CR1 contacts close. The closing of the first contact CR1-1 turns on the green light. If the limit switch is closed, the closing of the second contact CR1-2 turns on the motor and the red pilot light. When the limit switch is open, the motor will not run and the red light will not turn on.

5.3 Rules for Drawing Relay Logic Diagrams

Nine rules are accepted as standard in the control industry for creating relay logic diagrams. It is important you learn these rules since creating a relay ladder diagram is your first step in programming a PLC.

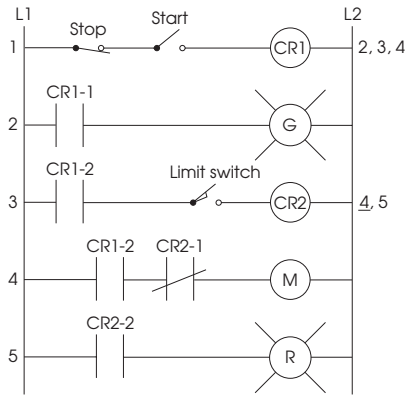

Figure 5-4. Several relay coils and contacts can be present in a relay logic diagram.

Rule 1. Input devices are placed near the left corner of the rung. This means that switches, pushbuttons, and contacts are placed near the left corner of each rung. **Figure 5-5** displays a correct relay logic diagram in which two switches, one pushbutton, and one motor are placed in the first rung. In this example, we must close switch one (SW1) and two (SW2) and press the normally open pushbutton (PB1) to turn the motor on.

Rule 2. One (and only one) output is placed near the right corner of the rung. This means that one output device such as a motor, a pilot light, or a relay coil must be placed near the right corner of the rung. Figure 5-5 displays a correct relay logic diagram in which the motor is placed near the right corner of the first rung. **Figure 5-6** displays an incorrect relay logic diagram in which the output is in the middle of the rung.

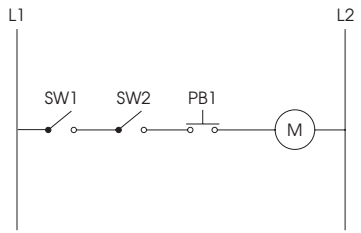

Figure 5-5. Correct relay logic diagram. Input devices are placed on the left side and the output device is on the far right.

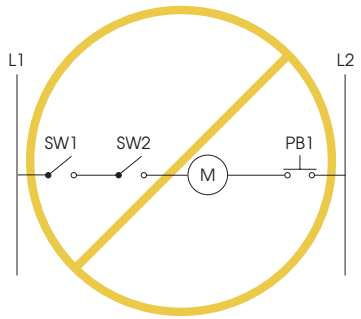

Figure 5-6. An incorrect relay logic diagram. The motor, which is an output device, must be placed on the right side.

Rule 3. Input devices can be connected in series, parallel, or a combination of series and parallel. **Figure 5-7** displays five input devices connected in a combination of series and parallel. In this example, when switch one (SW1), switch two (SW2), and pushbutton one (PB1) are closed, the motor turns on. Also, when switch one (SW1), switch three (SW3), and limit switch one (LS1) are closed, the motor turns on. Either or both combinations turn the motor on.

Rule 4. Output devices *cannot* be connected in series. Only parallel output devices can be placed in a rung. Compare the incorrect relay logic diagram displayed in **Figure 5-8,** to the correct relay logic diagram displayed in **Figure 5-9.**

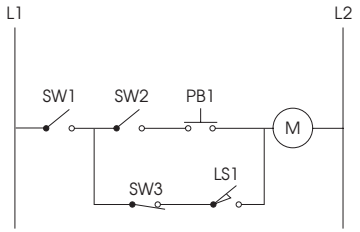

Figure 5-7. Combination of series and parallel input devices in a rung.

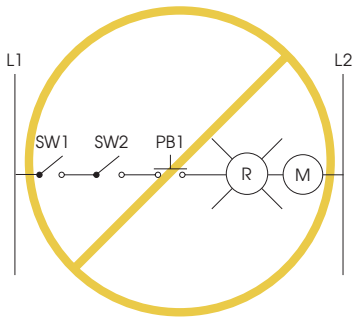

Figure 5-8. An incorrect relay logic diagram. Output devices cannot be placed in series.

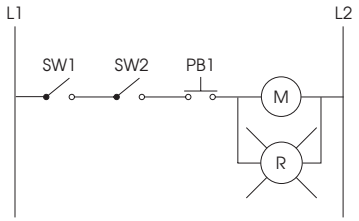

Figure 5-9. A correct relay logic diagram in which output devices are in parallel.

The relay logic diagram in Figure 5-9 illustrates that if both switch one (SW1) and switch two (SW2) are closed, pressing pushbutton one (PB1) will turn on the motor and the red pilot light.

Rule 5. While input devices can be represented multiple times in the relay logic diagram, each output device can only be represented once in the diagram. Compare the incorrect relay logic diagram displayed in **Figure 5-10** to the correct relay logic diagram displayed in **Figure 5-11.** Notice how the diagram from Figure 5-11 has been redrawn so that the input switches have been placed in parallel. Thus, the output devices are drawn only once. Switch one (SW1) still appears twice, but this is acceptable because it is an input device.

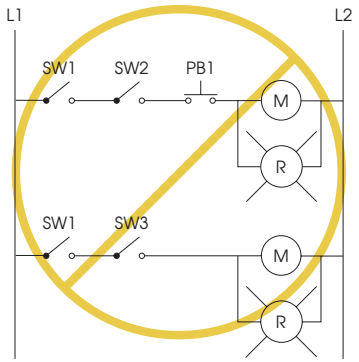

Figure 5-10. An incorrect relay logic diagram. Each output symbol can be used only once.

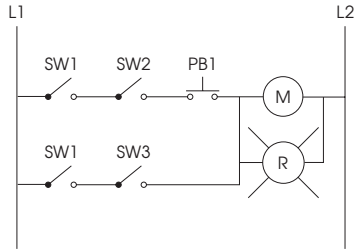

Figure 5-11. A correct relay logic diagram. Only one output device symbol is used for each output displayed.

Figure 5-11 illustrates that both the motor and the red light can be turned on under two conditions: closing switch one (SW1), switch two (SW2), and pushbutton one (PB1) or closing switch one (SW1) and switch three (SW3).

Rule 6. All the input and output devices must be placed horizontally. This means that no vertically positioned input or output devices are allowed in a relay logic diagram. Compare the incorrect relay logic diagram displayed in **Figure 5-12** to the correct relay logic diagram displayed in **Figure 5-13.**

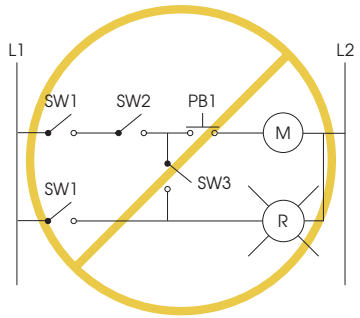

Figure 5-12. An incorrect relay logic diagram. Switch three (SW3) must be placed horizontally.

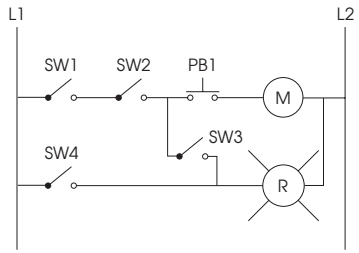

Figure 5-13. A correct relay logic diagram. Input and output devices are placed horizontally.

The relay logic in Figure 5-13 illustrates that when switch one (SW1), switch two (SW2), and switch three (SW3) are closed the red pilot light turns on. Also, closing switch four (SW4) alone turns on the red pilot light. If SW1, SW2, and PB1 are closed, the motor runs.

Rule 7. Current in the relay logic diagram must flow from left to right. **Figure 5-14** displays a correct and an incorrect control process flow. When SW1, SW2, and SW4 are closed, the red light turns on. Also, when the normally closed pushbutton two (PB2) is not open, SW3 and SW4 must be closed to turn on the red light. Finally, if SW3 and SW5 are closed, the red pilot light turns on.

The motor operates under two conditions: when SW1, SW2, and PB1 are closed and when SW3, PB2, and PB1 are closed.

Rule 8. Diagrams must be numbered and commented correctly. Rung numbers are placed on the left side of each rung. The instruction

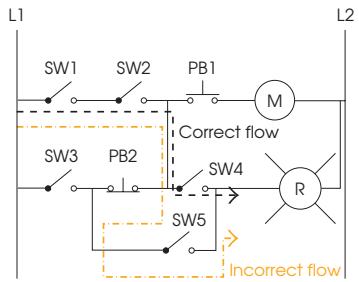

Figure 5-14. Flow process must be from left to right.

symbols and comments are placed above the instruction. Rung comments are placed on the right side of each rung.

Figure 5-15 displays a relay logic diagram with comments. When normally closed PB1 is closed, the green light turns on. Then, closing SW1 turns on motor one (M1), and closing SW2 turns on motor two (M2).

Rule 9. The location of each contact associated with a coil can be recorded by the right-hand rail near the coil. In **Figure 5-16,** the normally closed contact in rung 2 and the normally open contacts in rungs 1 and 3 are associated with M1.

If normally closed PB1 is closed, then pressing normally open PB2 energizes coil M1. When coil M1 is energized, the normally open

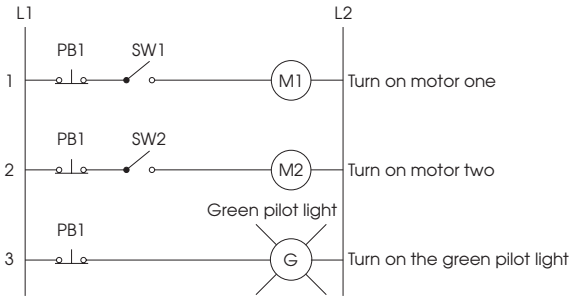

Figure 5-15. Placing rung numbers by the left rail and comments and contact location by the right rail.

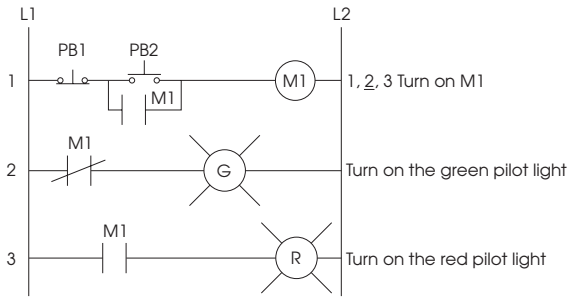

Figure 5-16. Illustrates how to place comments in the relay logic diagram to identify contacts' locations.

contact M1 in rung 1 closes to seal or lock the motor operation. Normally closed contact M1 in rung 2 opens to turn off the green pilot light. Normally open contact M1 in rung 3 closes to turn on the red pilot light.

5.4 Creating Relay Logic Diagrams for Industrial Control Circuits

Two steps must be completed to draw a relay logic diagram of an industrial control system. In step one, clearly define the control problem. This may involve drawing a schematic diagram of the system setup and discussing the problem with production and maintenance engineers and technicians. In step two, review and follow the nine relay logic diagram rules discussed in previous sections. This will allow you to draw the relay logic diagram. The following examples should be used as a guide to familiarize you with creating relay logic diagrams.

Example 5-1

Follow the two steps required to draw the relay logic diagram of the following motor control problem.

Step 1: Define the problem.

A motor can operate in continuous run mode or in temporary run mode also called *jog mode*. Therefore, in a motor control system, we need one stop pushbutton and two run pushbuttons. One pushbutton is for the continuous run mode of operation. The second one is for the temporary run mode of operation. The pushbutton for the continuous run mode of operation is labeled "start." The pushbutton for the temporary run mode of operation is labeled "jog." If we press the jog pushbutton, the motor will run as long as we are pressing the jog pushbutton, which is equivalent to closing a normally open switch. If we press the start pushbutton, the motor will start running continuously until we press the stop pushbutton. The red pilot light is on whenever the motor is operating.

Step 2: Draw the relay logic diagram.

Figure 5-17 displays the relay logic diagram of the motor control system. The stop pushbutton is a normally closed pushbutton. When the normally open start pushbutton is closed, the relay coil CR1 energizes. The normally open contact CR1 closes and seals or locks the relay coil. Therefore, the relay coil is energized as long as the normally closed stop pushbutton is closed. The normally open contact CR1 closes and turns the motor and red pilot light on. This is the continuous run mode of operation for the motor.

With the motor off, pressing the normally open jog pushbutton turns on the motor and the red pilot light. Whenever the jog pushbutton is released, the motor and the red pilot light turn off. Therefore, this represents the jog or temporary run mode of operation.

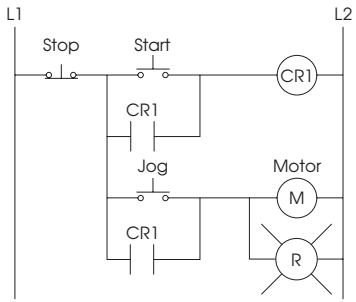

Figure 5-17. Press the start pushbutton for running the motor continuously. Press the jog pushbutton for running the motor temporarily.

Example 5-2

Follow the two steps required to draw the relay logic diagram of the following motor control problem.

Step 1: Define the problem.

In a motor control system, one master stop pushbutton (Stop_PB) is available for stopping the operation at any time. If the temperature switch (TSW) is closed, pressing the red pushbutton (Red_PB) will turn on both motors one (M1) and two (M2). If TSW is open, pressing Red_PB will only turn on M2. If TSW is closed and the green pushbutton (Green_PB) is pressed once, M1 will run. Closing the temperature switch turns on the white pilot light.

Step 2: Draw the relay logic diagram.

Figure 5-18 displays the relay logic diagram of the circuit described in the first step. The normally closed stop pushbutton (Stop_PB) is the master stop pushbutton. If we press the normally open red pushbutton (Red_PB), motor two (M2) turns on. If the normally open temperature switch (TSW) is closed, then pressing the Red_PB will also turn on motor one (M1). Also, when TSW is closed, pressing the green pushbutton (Green_PB) will only turn on M1. When TSW is closed, the white pilot light (White_PLT) turns on.

Example 5-3

Follow the two steps required to draw the relay logic diagram of the following motor control problem.

Step 1: Define the problem.

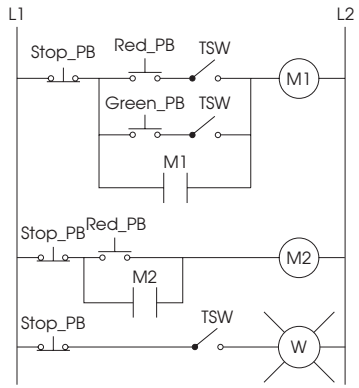

Figure 5-18. Close the temperature switch to turn on the white pilot light. Then, press the red pushbutton to turn on both motors. Press the green pushbutton to turn on only motor one (M1). Open the temperature switch and then press the red pushbutton to turn on only motor two (M2).

One motor and one pilot light are to be controlled in a control circuit. Use two start pushbuttons and two stop pushbuttons. Pressing any one of the start pushbuttons must turn on the motor. Pressing any one of the two stop pushbuttons must stop the motor operation. When the motor is running, the pilot light must be on.

Step 2: Draw the relay logic diagram.

Figure 5-19 displays the relay logic diagram of the circuit described in the first step. If we press either the green pushbutton (Green_PB)

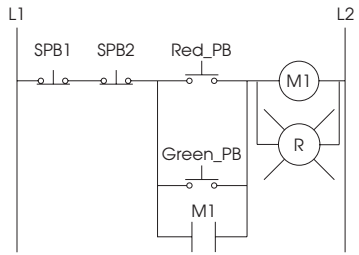

Figure 5-19. Press either the green pushbutton (PB4) or the red pushbutton (PB3) to turn on the motor. Press either one of the stop pushbuttons to turn off the motor.

or the red pushbutton (Red_PB), the motor will operate. When the motor is running, the contact M1 closes and seals or locks the circuit. Pressing either stop pushbutton one (SPB1) or the stop pushbutton two (SPB2) breaks the current path and turns off the motor. When the motor is in operation, the red pilot light (Red_PLT) is on.

Summary

- Relay logic diagrams show the logical relationship between system components.
- Relay logic diagrams are created using the following nine standard relay logic rules:
- Rule 1. Input devices are placed near the left corner of the rung.
- Rule 2. One (and only one) output is placed near the right corner of the rung.
- Rule 3. Input devices can be connected in series, parallel, or a combination of series and parallel.
- Rule 4. Output devices *cannot* be connected in series.
- Rule 5. Each output device can only be represented once in the diagram.
- Rule 6. All the input and output devices must be placed horizontally.
- Rule 7. Current in the relay logic diagram must flow from left to right.
- Rule 8. Diagrams must be numbered and commented correctly.
- Rule 9. The location of each contact associated with a coil can be recorded by the right-hand rail near the coil.

Review Questions

1. How many input devices can you place in series in one rung in a relay logic diagram?
2. How many output devices can you place in series in one rung in a relay logic diagram?
3. What type of device must you place as a last device on a rung of a relay logic diagram?
4. Can the same input or output device be used more than one time in a relay logic diagram?

5. Draw the relay logic diagram for a circuit that operates as follows:
   A. The main switch (MSW) is the emergency stop switch, which is normally closed.
   B. When the red pushbutton (PBR) is pressed, the red pilot light and motor one (M1) are energized. They will stay on until MSW is opened.
   C. When the green pushbutton (PBG) is closed, both white and green pilot lights turn on, and motor one (M1) and motor two (M2) will run. They will stay on until MSW is opened.
6. Draw the relay logic diagram for a circuit that operates as follows:
   A. The main switch (MSW) is the emergency stop switch, which is normally closed.
   B. When the red pushbutton (PBR) is pressed, the red pilot light turns on and stays on until MSW is opened.
   C. When the green pushbutton (PBG) is pressed, white and green pilot lights turn on and stay on until MSW is opened.
7. Draw the relay logic diagram for a circuit that operates as follows:
   A. When switch one (SW1) is closed, the green pilot light turns on.
   B. When switch two (SW2) is closed, the yellow pilot light turns on.
   C. When both SW1 and SW2 are closed, the green and yellow pilot lights turn off, and the red and white pilot lights turn on.

Relay logic diagrams are created using the following nine standard relay logic rules:

- Rule 1. Input devices are placed near the left corner of the rung.
- Rule 2. One (and only one) output is placed near the tight corner of the rung.
- Rule 3. Input devices can be connected in series, parallel, or a combination of series and parallel.
- Rule 4. Output devices *cannot* be connected in series.
- Rule 5. Each output device can only be represented once in the diagram.
- Rule 6. All the input and output devices must be place horizontally.
- Rule 7. Current in the relay logic diagram must flow from left to right.
- Rule 8. Diagrams must be numbered and commented correctly.
- Rule 9. The location of each contact associated with a coil can be recorded by the right-hand rail near the coil.

Standard relay logic rules for creating relay logic diagrams.