

6

Auxiliary Commands and Functions

OUTLINE

- 6-1 Introduction □ 6-2 MONITOR Mode Functions □ 6-3 FORCE Mode Functions
- 6-4 PRINT Functions

OBJECTIVES

At the end of this chapter, you will be able to

- Explain how the MONITOR mode may be called up and used for ladder diagram analysis.
- Explain how the FORCE mode is used for PLC program testing and analysis.
- List the safety precautions required when using the FORCE mode.
- Explain how the PRINT mode is used to print out ladder diagrams.
- List and explain the other major types of PLC PRINT capabilities.

6-1 INTRODUCTION

Three important PLC functions deserve a separate chapter to cover their usefulness: the MONITOR mode, the FORCE/OVERRIDE function, and the various PRINT capabilities.

After a circuit is programmed into a PLC, its operation may be watched on screen in the MONITOR mode. The current flow from left to right as contacts open and close is indicated by a brightening of the screen pattern. Functions such as coils and timers also light up when they become energized. Other types of PLC models show the current flow by flashing lines and functions. Still others use a dotted pattern system. This chapter discusses the use of the MONITOR mode.

The second function to be covered in this chapter is the FORCE function. In some cases, this function may be looked upon as an override control. To use the FORCE function, first call up the contact, coil, or function to be controlled. Next, the cursor is moved to the function to be controlled. Then, the FORCE function key is depressed. Then, using the keyboard keys, the function under FORCE control may be turned on and off. The keyboard then overrides the status of the input from the outside system.

The third function to be discussed is the use of printouts to record information regarding a circuit and the status of the circuit parts. The most common printout is that of the ladder diagram. Other printouts are available on many other PLC models. These are for registers, timed status information, and other PLC equipment status.

6-2 MONITOR MODE FUNCTIONS

The MONITOR mode for ladder diagram operation is indicated on the screen in various ways. It may be indicated by a brightening of the pattern where voltage is passed through. In other cases it is indicated by the pattern changing to a dotted line or to a flashing effect. A large monitor that shows complete ladder lines normally uses the brightness enhancement effect. Smaller monitors showing a portion of a line use the other indicating systems. Figure 6-1 illustrates brightness enhancement for a standard, three-wire, motor-control, single-line ladder diagram. The figure shows the screen as the two inputs (stop and start) are energized and de-energized. The pattern changes allow us to watch the circuit operation.

The MONITOR function is especially useful for analyzing a large number of ladder lines. The MONITOR mode assists the operator in troubleshooting a large system that is malfunctioning. In some PLC models the screen is in MONITOR mode whenever it is in the EDIT mode; in other PLCs, the MONITOR mode must be called up separately.

Other system characteristics may be monitored in addition to the ladder diagram. These include register status (value), as well as individual coil and contact status. Other monitorable system parameters include a listing of the forced functions, which are discussed next. Some advanced PLC systems can also list the actual malfunctioning output devices for fast analysis.

FIGURE 6-1
MONITOR Mode Example

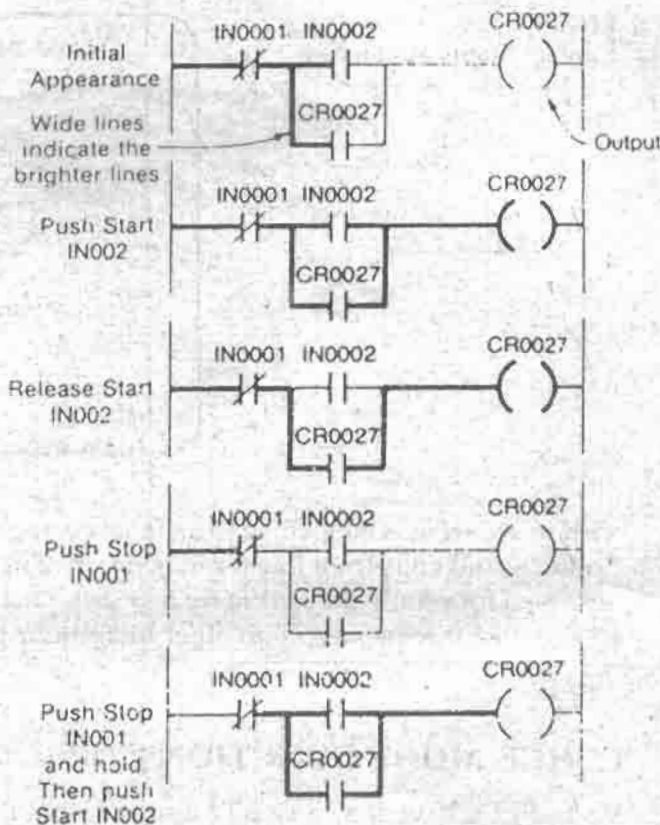


Figure 6-2 shows how the status of four holding registers would be shown. This figure shows the register values in binary; many PLCs give you a choice of which numbering system you want used for the printout: binary, decimal, hex, octal, or ASCII.

In most PLC systems, you may call up individual coils, contacts, or both on the screen. For example, if you are looking at or in the vicinity of line 32, you may

FIGURE 6-2
Individual Register Status
Display

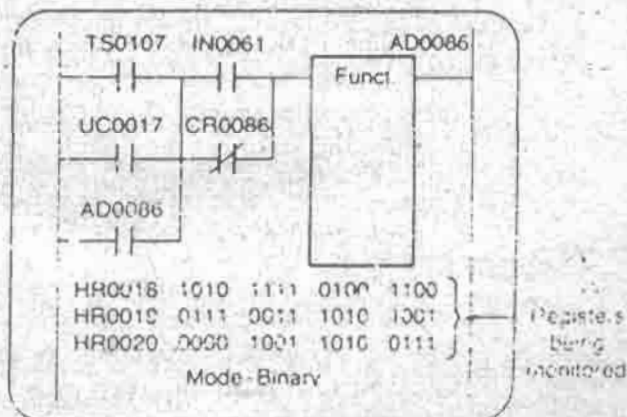
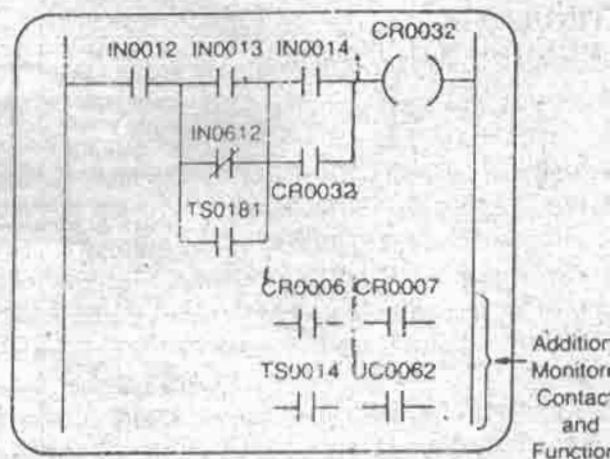


FIGURE 6-3
Contact Status Monitoring



wish to see what is happening to an input contact on line 6, which is off the screen. Contacts and coils from line 6 can be inserted in a blank space by themselves and observed for on-off status. Figure 6-3 shows how these individual contacts might appear on a screen along with other PLC information, such as the ladder diagram.

6-3

FORCE MODE FUNCTIONS

Many PLCs have the capability to carry out a FORCE function. The function is essentially an override control that enables the operator or programmer to operate the circuit from the program keyboard. The FORCE mode is useful but must be used with utmost caution in conjunction with a working process. Misuse of FORCE could lead to equipment damage and operator injury. FORCE is an override function. When turned on, it can lead to feeding the process program with incorrect information. If, for example, you were to force a safety interlock closed when the interlock is open, unsafe operation would result. It is best to use FORCE only for process malfunction troubleshooting, and then with great caution. It is, of course, useful for prerunning the process in the office to see how it works before hooking up to the actual process.

The FORCE procedure is normally carried out in the MONITOR mode. First, place the cursor over the contact, coil, or function you wish to force. Then carry out the specific keyboard procedures for forcing. Turning FORCE on changes the status of the contact or coil under the cursor. If it is a normally open contact, it will close (turn on). If it is a normally closed contact, it will open (turn off). If you force a coil or function, it will go on when forced, regardless of external commands in effect.

In most cases, forcing any contact of a relay, CR, will turn the relay coil on, as well as forcing all other contacts of that CR number. An example of a display showing a FORCE procedure is shown in figure 6-4. To remove the FORCE function, turn it off and then press the Clear key.

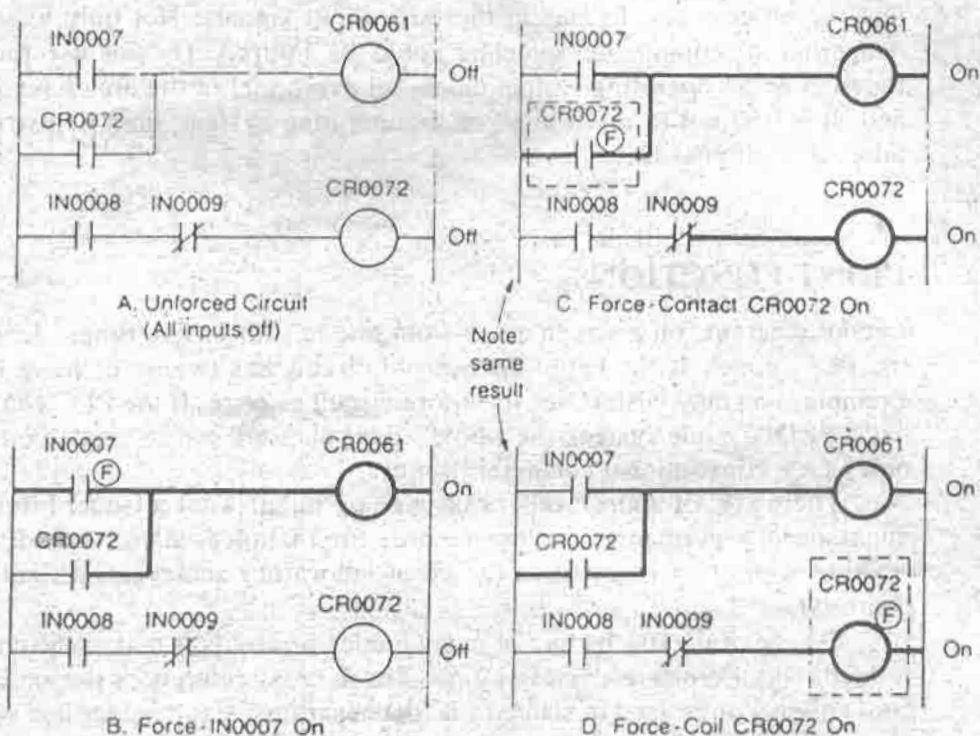


FIGURE 6-4
Force Procedure

The individual coils or contacts that are forced on may be left in the forced state permanently by entering them—usually by pressing Return. This permanent-entry procedure must be done carefully so as not to introduce a permanent unwanted change in an operational sequence.

There are certain limitations of the FORCE mode. Not all functions react like coils and contacts when forced. For coils and contacts, forcing a contact causes its coil and all of its other contacts to be forced at the same time. Many other functions work in the same manner, but not all. It is necessary to review the operating procedures of a particular PLC to see how each function responds to the FORCE command.

For example, in some PLCs, forcing the MASTER CONTROL RELAY (MCR) function does not have the same effect as officially turning the MCR function on through its normal operating ladder program. Forcing the MCR coil does not affect its function but does turn on its associated contacts.

The same special consideration can apply to the SKIP and DR/SEQUENCER functions. See your operating manual for individual FORCE function operational characteristics.

If an industrial process is in operation, it obviously would be undesirable to insert into it periodic false signals by hooking up a keyboard to the CPU control-

ling the process and forcing in the false input signals. Not only would this be dangerous to equipment, someone could be injured. Do not use the FORCE function on an operating system unless all personnel in the area have been notified. It is best not to use it at all on an operating system; limit its use to simulations, if at all possible.

6-4 PRINT FUNCTIONS

Ladder diagrams on a screen cover from one to four or five rungs, depending on the PLC model. If the entire operational circuit has twenty or more rungs, for example, you may wish to see the entire circuit at once. If the PLC you are using has a PRINT mode system, the whole ladder diagram can be printed out continuously on a conventional computer printer.

There are, of course, other reasons you might want a ladder printout. You might need a permanent written record, for instance. Also, in education and training, a printout is a written record of laboratory achievement (under proper controls).

One helpful extra feature of many ladder printouts is that each rung may be printed with a cross-reference system. These cross references are similar to the conventional ones used in standard ladder diagrams. Each ladder line with a coil or function is assigned a consecutive number. Then, on each line, a listing is printed of the other lines in which contacts from that line's coil or function occur.

Figure 6-5 is an illustration of a PLC ladder printout. The cross-reference system is included as numbers referencing other sections.

Other typical PRINT mode capabilities include register status, FORCE mode status, timing diagrams, input status, output status, and a listing of malfunctioning output devices. This section discusses only register status, FORCE mode status, and timing diagrams.

A register status printout is shown in figure 6-6. A user-friendly screen program lets you choose to have the status of the register, consecutive registers, or a number of nonconsecutive registers printed. In most cases, you may choose what numbering system you want the printout to display: binary, hex, octal, decimal, ASCII, or others, depending on your PLC model. The printout may be in hard copy form from the printer, or it may be printed on the monitor screen.

The status of any forced functions may also be printed out. If you have forgotten what forced contacts or functions remain in the ladder diagram, a FORCE listing printout will display them. If there are no forced contacts or coils, none will print out; otherwise, those in effect in the circuit will be printed out. Like the register status, the FORCE function listing may be put on a printer or printed on the screen.

Timing diagrams are available on many PLC printouts. In most, you first choose the time interval you wish to use, from tenths of a second to minutes. Next, you choose the item or items to be observed, such as registers or coils and contacts. The number of items viewed is limited by the PLC's program and printer

column width. Figure 6-7 illustrates the printouts for two registers being timed. Figure 6-8 shows five contacts (each with the same number as its coil) being timed. Both figures shown use a fixed, selected interval.

An alternative to fixed-time intervals is available. Exception time saves paper and the time that would be spent poring through a lot of data. Exception timing prints out only when one of the items being monitored changes status. Figure 6-9 shows how exception time works for the same registers and contacts shown in figures 6-7 and 6-8. The time of the status change is shown on the left of the printout.

Timing in intervals and by exception can be shown on the screen or printed on a printer.

EXERCISES

Obtain the operational manuals for one or more PLCs and review the operational procedures for MONITOR, FORCE, and PRINT. Answer the following questions:

1. Explain how the MONITOR function is made operational, how it works, and what data and functions may be observed.
2. Repeat exercise 1 for the FORCE function.
3. For the FORCE function, list how the force procedure affects each of the operational functions of the PLC, starting with contacts and coils.
4. Repeat exercise 1 for the PRINT function.

7

Creating Ladder Diagrams from Process-Control Descriptions

OUTLINE

7-1 Introduction □ 7-2 Ladder Diagrams and Sequence Listings □ 7-3 Large-Process Ladder Diagram Construction

OBJECTIVES

At the end of this chapter, you will be able to

- Create basic ladder diagrams from a sequence of operational steps.
- List the major steps in creating a PLC program for an industrial situation.
- Describe the content of each of these steps.

7-1 INTRODUCTION

Planning without action is a waste of time and money, and action without planning creates chaos. The purpose of this chapter is to outline some of the planning needed to create good, workable, safe PLC programs—without chaos.

You may want to omit this chapter for now if you work with preprogrammed PLC programs. You should include this chapter if you have to create your own programs, modify programs, or if you doubt the validity of the program you have.

This chapter is written in relay logic. The principles are readily converted to PLC programs, as was covered in chapter 5 for coils and contacts.

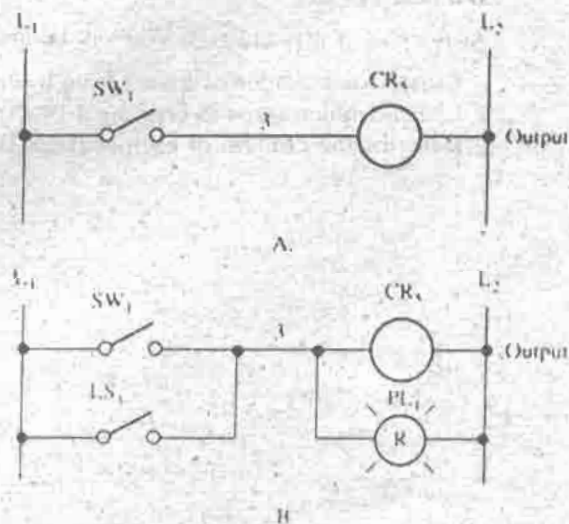
7-2 LADDER DIAGRAMS AND SEQUENCE LISTINGS

Ladder diagrams are the most commonly used diagrams for nonelectronic control circuits. They are sometimes called *elementary diagrams* or *line diagrams*. Sometimes they are considered a subtype of schematic diagrams. The term *ladder diagrams* is used in this text. Why are these diagrams called ladder diagrams? They look like a ladder in a way. You start at the top of the ladder and generally work your way down.

Two types of ladder diagrams are used in control systems: the *control ladder diagram* and the *power ladder diagram*. This section concentrates on control ladder diagrams, with only a fundamental explanation of the power ladder diagram.

Figure 7-1 shows two basic control ladder diagrams. The first one, A, is for a single switch that turns a relay output, CR₅, on and off. The second, B, is a single-function diagram with parallel lines for control and parallel lines for output. Either or both of two switches turn the output and a pilot light on.

FIGURE 7-1
Basic Control Ladder Diagrams



The control ladder diagram of figure 7-2 has two active functional lines. Some of the common practices for the format of control ladder diagrams are illustrated by this figure. Those practices are as follows:

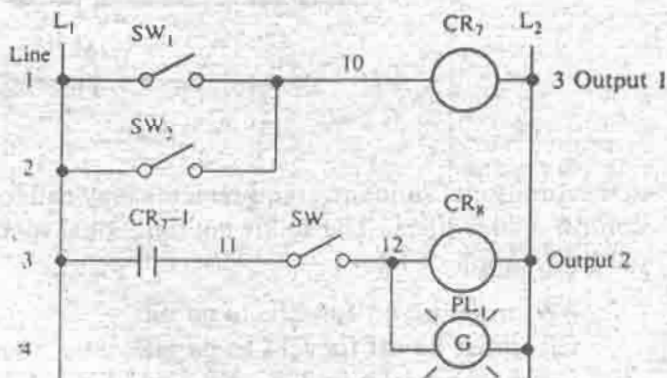
- All coils, pilot lights, and outputs are on the right.
- An input line can feed more than one output. If it does, the outputs are connected in parallel.
- Switches, contacts, and so on are inserted in the ladder line starting on the left.
- Switches, contacts, and so on may be multiple contacts in series, parallel, or series parallel.
- Lines are numbered consecutively downward on the left.
- Every connection node is given a unique identification number.
- Outputs can be identified by function on the right, in notes.
- A cross-identification system may be included on the right. The contacts associated with the line's coil or output are identified by line location. In figure 7-2 the 3 to the right of line 1 indicates that a normally open contact of relay CR₇ (the coil on line 1) is located on line 3. For a normally closed contact, the number would have an asterisk (*) next to it or a bar over it. Figure 7-5 uses the same system on two different lines.
- Relay contacts are identified by the relay coil number plus a consecutive sequence number. For example, we have included contact CR₇-1. If other relay CR₇ contacts were used, the next would be CR₇-2, and so on.

The control ladder diagram in figure 7-2 has an operating sequence as follows:

Straight-Through Sequence

All switches are open to start; both coils are off.
 Close SW₁, SW₂, or both; CR₇ is energized.
 On line 3, CR₇-1 closes, enabling line 3 (CR₈ is still off).
 Closing SW₃ energizes CR₈ and pilot light PL₁.
 Opening both SW₁ and SW₂ turns everything off.

FIGURE 7-2
Two-Function Control Ladder
Diagram



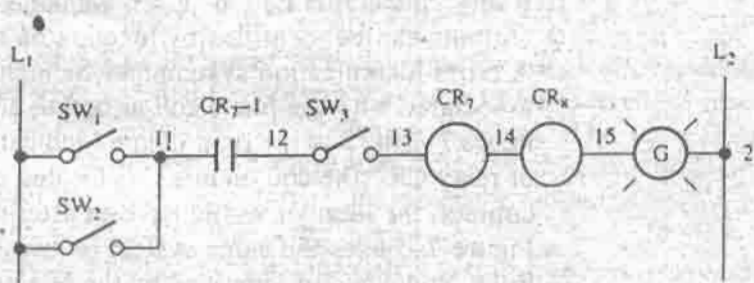
Alternative Possible Sequence

Initially turning on SW_3 causes nothing to energize.

Opening SW_3 when everything is on would turn off CR_8 and PL_1 only.
(Other sequence possibilities exist.)

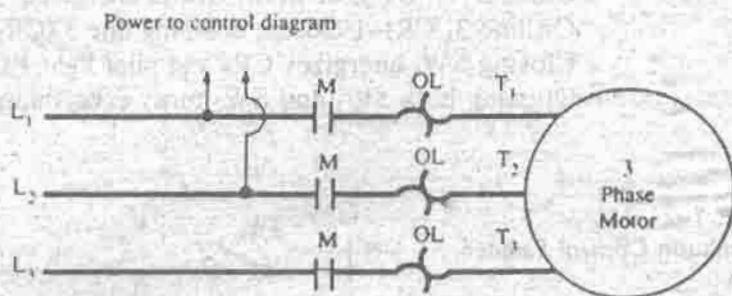
Figure 7-3 is an incorrect ladder diagram that contains the same components used in figure 7-2. Will this circuit work? No. First of all, if power could get to point 13, the outputs would not work. Each would have 1/3 control voltage across it. Relays would not pull in, and the light would glow dimly or not at all. But outputs will never go on anyway. If all switches are closed, no power gets through contact CR_7-1 . It cannot close until CR_7 is energized, which is impossible.

FIGURE 7-3
Incorrect Control Ladder Diagram for Figure 7-2



The operation of the power ladder diagram in figure 7-4 is straightforward. When the power contactor coil is energized, the power contacts close and power is applied to the motor or the load device. Note that the power ladder diagram wiring is shown by thicker lines, to differentiate its wire from control circuit lines.

FIGURE 7-4
Power Ladder Diagram



Additional sequence requirements may call for the construction of additional control ladder lines. The following functional modifications can be added to the ladder diagram of figure 7-2.

SW_4 must be on for CR_7 to go on.

CR_7 must be off for CR_8 to go on.

CR_6 is turned on by CR_7 , CR_8 , and SW_3 .

The extended ladder diagram is shown in figure 7-5. Note that there is a dotted line between the two SW_3 contacts. The dotted line indicates a common single switch with two contacts. (If SW_3 were on the left, only one contact would be needed to run lines 3, 4, and 5.)

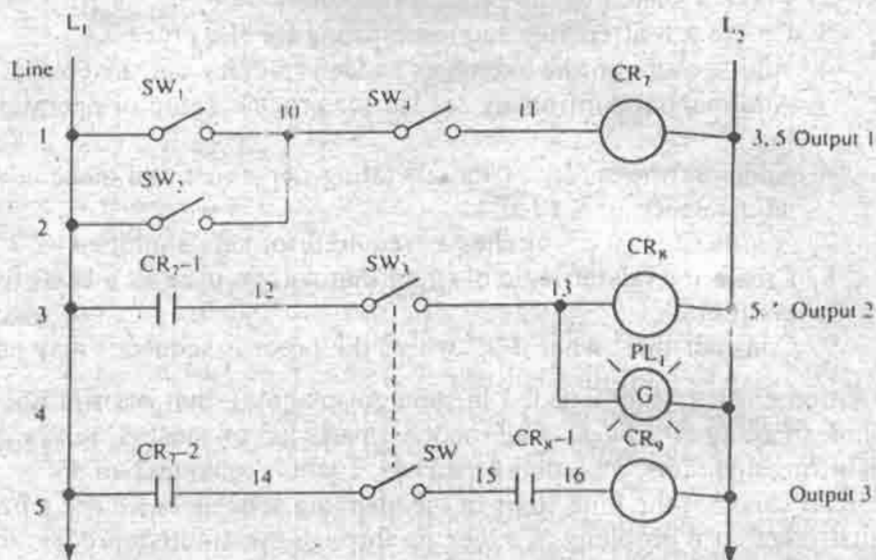


FIGURE 7-5
Extended Control Ladder Diagram for Figure 7-2

An added sequence of operation can be determined from an added ladder line. Such an added ladder line is shown in figure 7-6. The added sequence based on this additional line would be as follows: CR_7 or CR_8 or both, plus LS_{12} and CR_9 , turn on relay output CR_{10} .

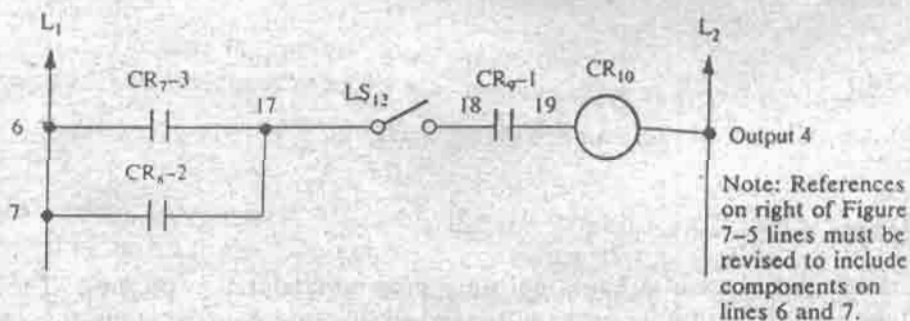


FIGURE 7-6
Added Line for Control Ladder Diagram of Figure 7-5

7-3 LARGE-PROCESS LADDER DIAGRAM CONSTRUCTION

Some of the steps in planning a program for a large process are

1. Define the process to be controlled.
2. Make a sketch of the process operation.
3. Create a written step sequence listing for the process.
4. Add sensors on the sketch as needed to carry out the control sequence.
5. Add manual controls as needed for process setup or operational checking.
6. Consider the safety of the operating personnel and make additions and adjustments as needed.
7. Add master stop switches as required for safe shutdown.
8. Create the ladder logic diagram that will be used as a basis for the PLC program.
9. Consider the "what if's" where the process sequence may go astray.

Some other steps needed in program planning that we will not cover are troubleshooting of process malfunctions, parts list of sensors, relays, and so on, and wiring diagrams, including terminals, conduit runs, and so on.

To illustrate the nine steps of the planning sequence, we use a fundamental industrial control problem. We then go through the creative process to illustrate each of the steps of the planning process.

Step 1

Define the problem.

We wish to set up a system for spray-painting parts. A part is to be placed on a mandrel. When the part is in place, the mandrel automatically raises the part into a hood. After the part rises and is in the hood, it is to have spray paint applied for a period of six seconds. At the end of the six seconds, the mandrel returns to the original position. The painted part is then removed from the mandrel by hand. (We assume for our illustration that the part dries very quickly.)

Step 2

Make a sketch of the process (figure 7-7).

Step 3

List the sequence of operational steps in as much detail as possible. The sequence steps should be double or triple spaced so that any omitted steps discovered later may be added. The following is a step sequence for this process.

1. Turn on paint pump and pneumatic air supply.
2. Turn system on. This requires extra pushbuttons separate from system

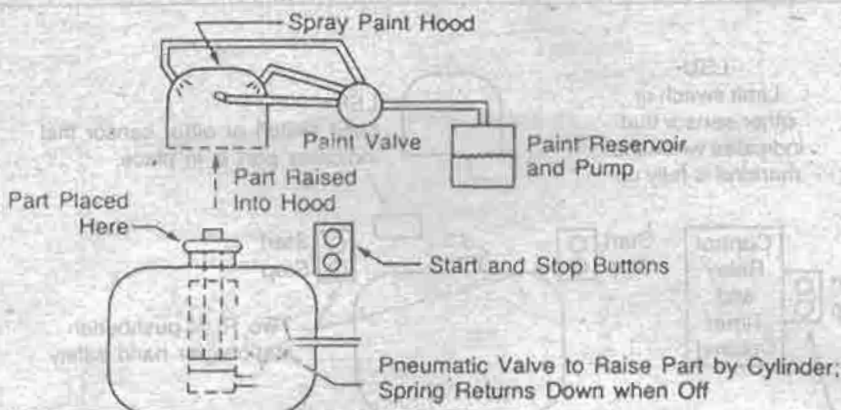


FIGURE 7-7
Sketch of the Spray Process System

3. Put part on mandrel. Sensor indicates part in place.
4. Push the system start button or buttons. Having to push two buttons (with both hands) reduces the possibility of the operator's hands being injured by the rising mandrel.
5. The mandrel is raised by a pneumatic cylinder energized by the opening of an electrically actuated air valve. The mandrel will return down by gravity and downward spring action when the valve is reopened. Note that when the mandrel rises, the part in the place sensor at the bottom becomes de-energized.
6. When the part reaches the top, it is held against a stop by the air pressure. A sensor indicates the part has reached the top.
7. A timer starts and runs for six seconds.
8. During the timing period of six seconds, paint is applied by the sprayer.
9. At the end of the six seconds, painting stops and the part lowers.
10. The up sensor is de-energized when the part leaves the top.
11. The part arrives at the bottom, re-energizing the part in the place sensor. (We assume that the part in the place sensor did not rise with the mandrel.)
12. The part is removed from the mandrel.
13. The system is reset so that we may start at step 3 again.

Step 4

Add sensors as required. Once we list the sequence, we find that sensors are needed in the machine to indicate process status. We need a sensor (LSP) to show that the part has been placed on the mandrel initially. We also need a sensor (LSU) to indicate when the mandrel is fully extended upward. Among other possible sensors that a process such as this might need is one to make sure the paint sprayer has paint and one to make sure the inserter's hand is out of the way. Depending on the process and the detail of control, there could be other sensors

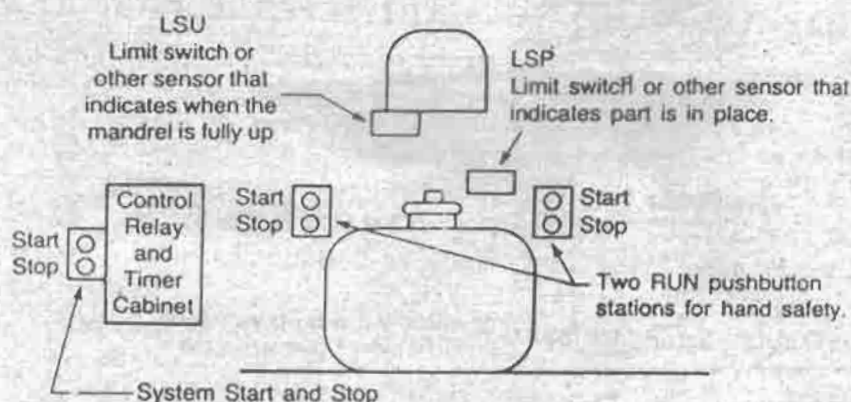


FIGURE 7-8
Sensor, Enclosures, and Pushbutton Locations

required, as well. Figure 7-8 includes the two basic sensors, LSP and LSU, and their locations. The figure also shows the enclosures needed, along with the locations of start and stop buttons.

Step 5

Add manual controls as needed: We may need a manual pushbutton to raise the mandrel to the top for setup purposes! The manual up position is needed when we set the spray-gun pressure for optimum paint coverage. We include pushbutton up (PBU) on our ladder diagram to accomplish this manual control.

Step 6

Consider the safety of the machine operator. One basic way to keep hands out of the process is to have two start buttons. Then both hands must be away from the work to depress both buttons (which works until the operator figures out how to use one knee and one hand). Other considerations, which we do not cover in detail here, might be operating a fan to disperse fumes during spraying, or perhaps a photoeye proximity-personnel-system-stop device.

Step 7

Add master stop switches as needed for operator safety. This may seem to be part of step six because both steps deal with operator safety. It is a continuation of the safety issue, but emergency stop switches are so important that they need special consideration as an additional step.

Step 8

Create the ladder logic diagram. The diagram created is to include the steps and considerations of the first seven steps. This is shown in figure 7-9 for our spraying example.

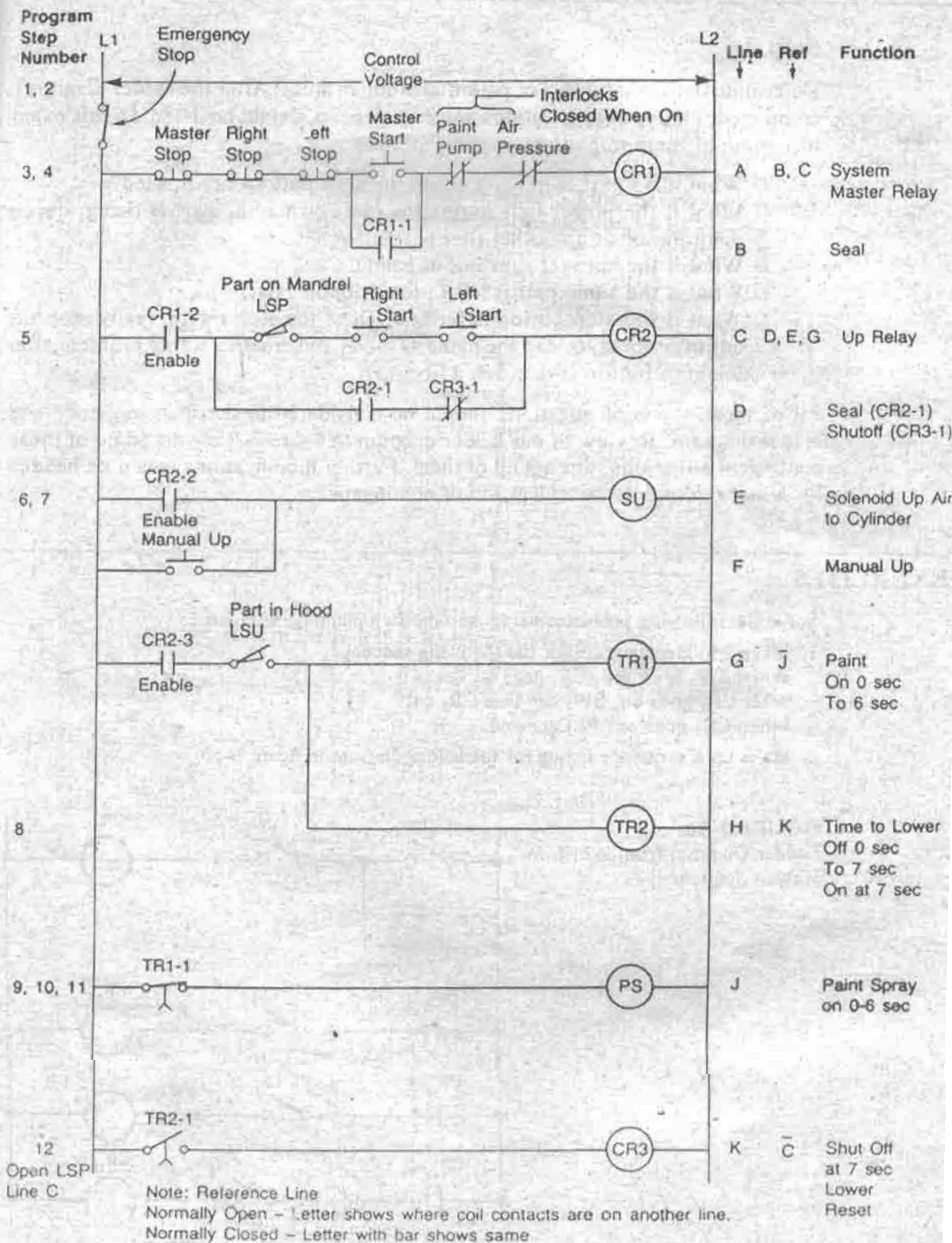


FIGURE 7-9

Step 9

Determine the "what if's," or potential problem areas. After the ladder diagram is completed, all possible situations and emergencies should be listed. In this example, some of them might be

- What if no part is in place when the start buttons are pushed?
- What if the power fails during the cycle, when the part is rising, during painting, or at any other time?
- What if the sprayer runs out of paint?
- What if the same part is left in for a double coat?
- What if the stop button is pushed? Does the stop button really stop the entire process, or can the mandrel move and create a safety problem after the stop button is depressed (it can)?

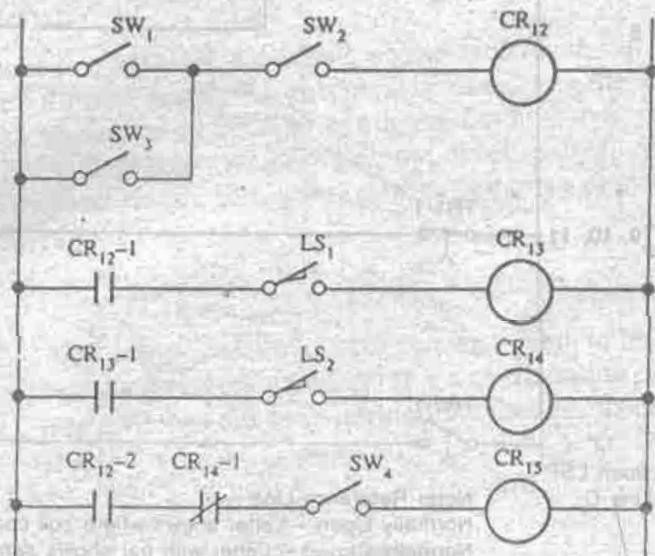
All of these types of questions should be considered in the final sequence and ladder diagram. Review of our ladder diagram in figure 7-9 covers some of these contingent situations, but not all of them. Further modifications would be needed for a more complete consideration of contingencies.

EXERCISES

Solve the following problems using the nine-step planning sequence:

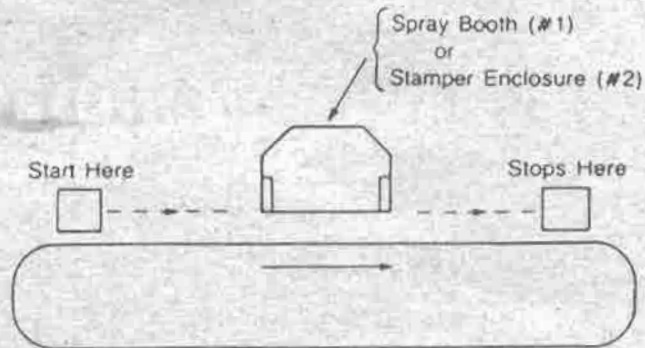
1. Make a ladder diagram for the following sequence:
When SW_1 is closed, CR_1 goes on.
After CR_1 goes on, SW_2 can turn CR_2 on.
When CR_2 goes on, PL_1 goes off.
2. Make up a sequence listing for the ladder diagram in figure 7-10.

FIGURE 7-10
Ladder Diagram from Which to
Make a Sequence



3. A part is placed on a conveyor. The part automatically moves down the conveyor. In the middle of the conveyor, the part goes through a two-foot-long painting section. The sprayer paints for the time the part is under the booth, during which time the conveyor does not stop. When the part reaches the end of the conveyor, the conveyor stops and the part is removed. Assume that only one part can be on the conveyor at one time. (*Hint*: Use one limit switch at the front of the booth and another at the end.) See figure 7-11.

FIGURE 7-11
Diagram for Exercises 3 and 4



4. Same as exercise 3 except that the part stops in the middle of the conveyor and is stamped, not painted, and then continues to the end of the conveyor.