CHAPTER 13

Designing Systems

This chapter considers the way programs are designed and how they and a PLC system can be tested and faults found. This involves consideration of both the hardware and the software.

13.1 Program Development

Whatever the language in which a program is to be written, a systematic approach to the problem can improve the chance of high-quality programs being generated in as short a time as possible. A systematic design technique is likely to involve the following steps:

1. A definition of what is required, with the inputs and outputs specified.
2. A definition of the algorithm to be used. An algorithm is a step-by-step sequence that defines a method of solving the problem. This can often be shown by a flowchart or can be written in pseudocode, which involves the use of the words BEGIN, DO, END, IF-THEN-ELSE, and WHILE-DO.
3. The algorithm is then translated into instructions that can be input to the PLC. Because programs are often very long and can end up difficult to write as a long single block and are even more difficult to later follow for fault finding and maintenance, it is advisable to break the program down into areas that are then further subdivided until manageably sized blocks of program occur. This technique is termed *top-down design*.
4. The program is then tested and debugged.
5. The program is documented so that any person using or having to modify the program at a later date understands how the program works.

13.1.1 Flowcharts and Pseudocode

Figure 13.1a shows the symbols used in flowcharts. Each step of an algorithm is represented by one or more of these symbols and linked by lines to represent the program flow (Figure 13.1b). Pseudocode is a way of describing the steps in an algorithm in an informal way.

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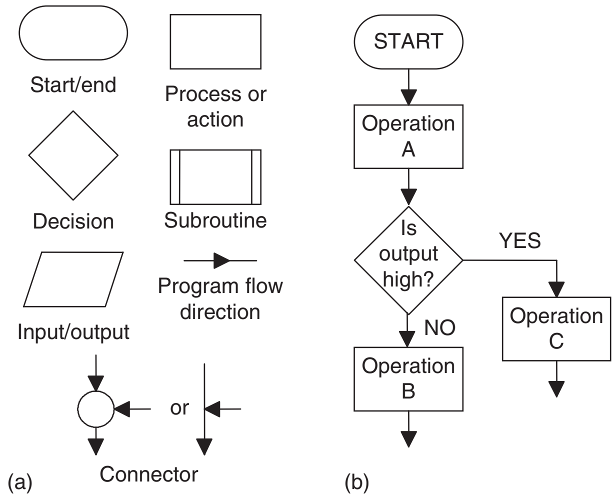

Figure 13.1: (a) Flowchart symbols, and (b) example of a simple flowchart.

Consider how the following program operations can be represented by flowcharts and pseudocode and then programmed using ladder and sequential function chart programming:

- *Sequential*. Consider a sequence in which event A has to be followed by event B. Figure 13.2a shows how this can be represented by a flowchart. In pseudocode this is written as:

```
BEGIN A
    DO A
END A
BEGIN B
    DO B
END B
```

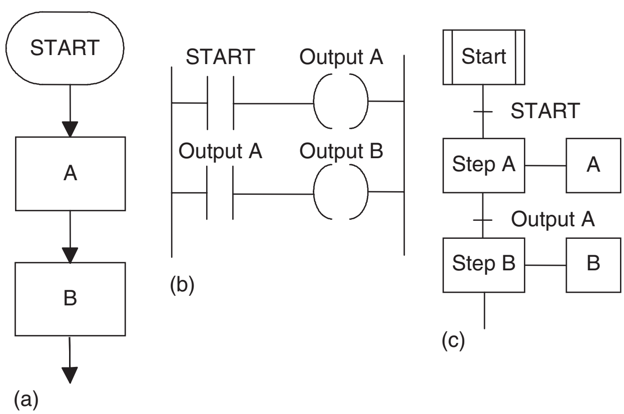

Figure 13.2: Sequence.

A sequence can be translated into a ladder program in the way shown in Figure 13.2b. When the start input occurs, output A happens. When action A happens, it operates the output A relay and results in output B occurring. Figure 13.2c shows the sequential function chart representation of a sequence.

- *Conditional*. Figure 13.3a shows the flowchart for when A or B is to happen if a particular condition X being YES or NO occurs. The pseudocode to describe this situation involves the words IF-THEN-ELSE-ENDIF.

```
IF X
THEN
    BEGIN A
    DO A
    END A
```

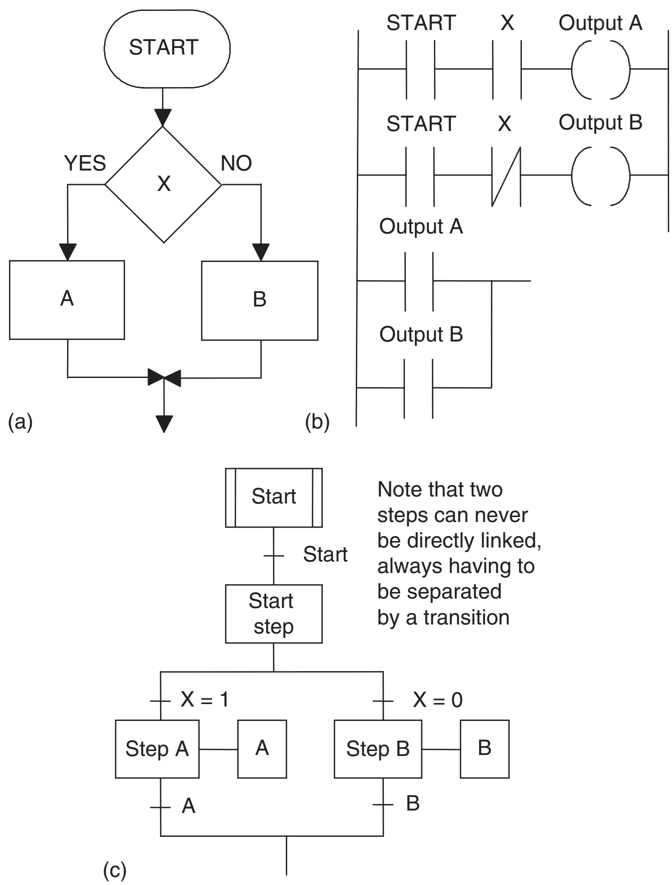

Figure 13.3: ***Conditional.***

```
ELSE
    BEGIN B
    DO B
    END B
ENDIF X
```

Such a condition can be represented by the ladder diagram shown in Figure 13.3b. When the start input occurs, the output will be A if there is an input to X; otherwise the output is B. Figure 13.3c shows the sequential function chart for such selective branching.

- *Looping.* A *loop* is a repetition of some element of a program that is repeated as long as some condition prevails. Figure 13.4a shows how this repetition can be represented by a flowchart. As long as condition X is realized, sequence A followed by B occurs and is repeated. When X is no longer realized, the program continues and the looping through A and B ceases. In pseudocode, this can be represented using the words WHILE-DO-ENDWHILE:

```
WHILE X
    BEGIN A
    DO A
    END A
    BEGIN B
    DO B
    END B
ENDWHILE X
```

Figure 13.4b shows how this idea can be represented by a ladder diagram with an internal relay. Figure 13.4c shows the sequential flowchart.

Where a loop has to be repeated a particular number of times, a counter can be used, receiving an input pulse each time a loop occurs and switching out of the loop sequence when the required number of loops has been completed (Figure 13.5).

13.2 Safe Systems

Modern safety legislation charges employers with duties that include making the workplace safe and free of risks to health, ensuring that plant and machinery are safe and that safe systems of work are established and followed. There is thus a need to assess the risks in the workplace. This means looking for hazards, that is, anything that can cause harm, deciding who might be harmed and how, evaluating the risks that somebody will be harmed by a hazard and whether existing precautions are adequate or whether more needs to be done to reduce the chance of harm occurring, recording the findings, and reviewing and revising the assessment, if necessary.

Thus, for example, issues such as emergency stops and access doors on equipment need to be considered, the risks assessed, and safe systems then designed. With regard to access

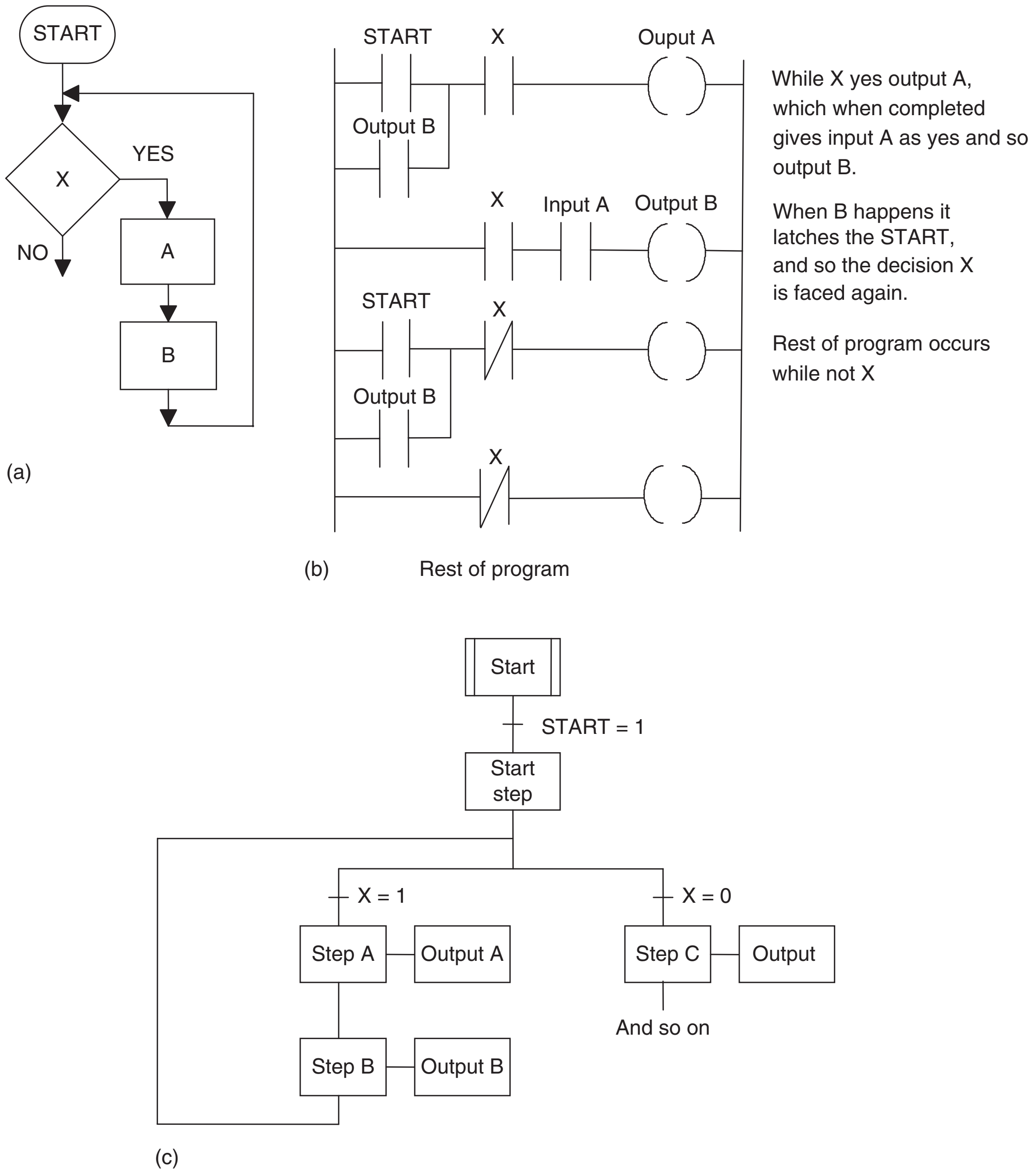

Figure 13.4: Looping.

doors on equipment, switch contacts can be used on such doors so that the system is stopped if the doors are not correctly guarding equipment.

An important standard is IEC 61508: Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems. The standard is in seven parts, as follows: Part 1: General requirements; Part 2: Requirements for E/E/PE safety-related

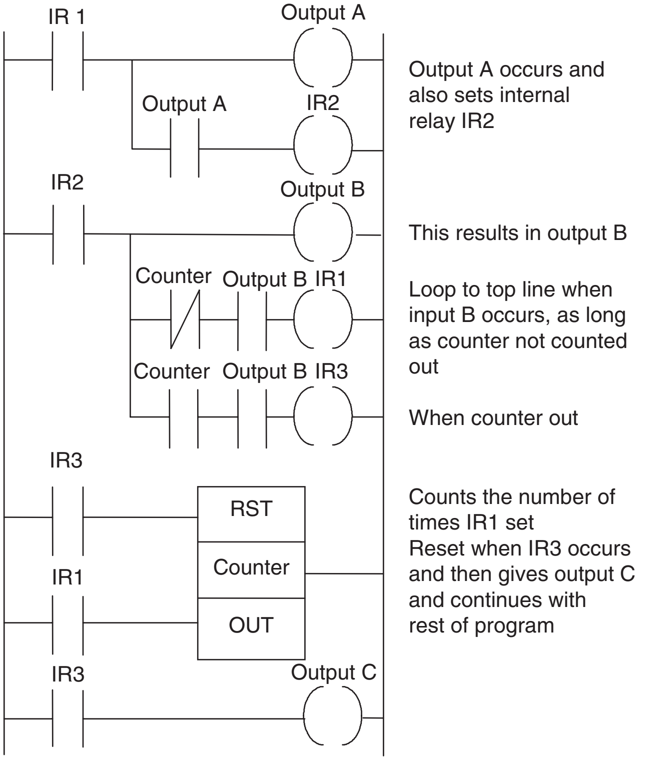

Figure 13.5: Looping.

systems; Part 3: Software requirements; Part 4: Definitions and abbreviations; Part 5: Examples of methods for the determination of safety integrity levels; Part 6: Guidelines on the application of IEC 61508-2 and IEC 61508-3; and Part 7: Overview of techniques and measures. To provide functional safety of a machine or plant, the safety-related protective or control system must function correctly, and when a failure occurs it must operate so that the plant or machine is brought into a safe shutdown state.

13.2.1 PLC Systems and Safety

Safety must be a priority in the design of a PLC system. Thus, emergency stop buttons and safety guard switches must be hardwired and not depend on the PLC software for implementation, so that, in a situation where there is a failure of the stop switch or PLC, the system is automatically safe. The system must be *fail-safe*. Thus if failure occurs, the outputs must revert to a fail-safe mode so that no harm can come to anyone. For example, the guards on a machine must not be open or be capable of being opened if the PLC fails.

With a PLC system, a stop signal can be provided by a switch as shown in Figure 13.6. This arrangement is unsafe as an emergency stop because if there is a fault and the switch

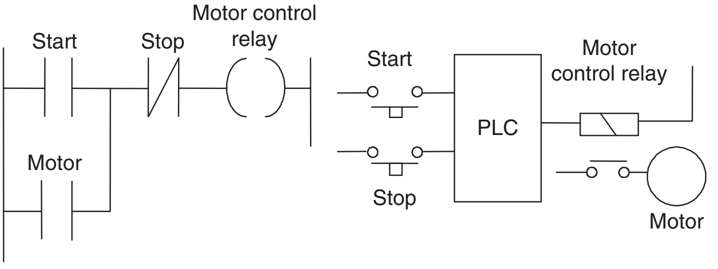

Figure 13.6: An unsafe stop system.

cannot be operated, then no stop signal can be provided. Thus to start we momentarily close the push-button start switch and the motor control internal relay then latches this closure and the output remains on. To stop we have to momentarily open the stop switch; this unlatches the start switch. However, if the stop switch cannot be operated, we cannot stop the system. What we require is a system that will still stop if a failure occurs in the stop switch.

We can achieve this by the arrangement shown in Figure 13.7. The program has the stop switch as open contacts. However, because the hardwired stop switch has normally closed contacts, the program has the signal to close the program contacts. Pressing the stop switch opens the program contacts and stops the system.

For a safe emergency stop system, we need one that will provide a stop signal if there is a fault and the switch cannot be operated. Because there might be problems with a PLC, we also need the emergency stop to operate independently of the PLC. Putting the emergency stop in the input to the PLC gives an unsafe system (Figure 13.8).

Figure 13.9 shows a safer system where the emergency stop switch is hardwired in the output. Pressing the emergency stop button switch stops, say, a running motor. When we release the stop button, the motor will not restart again, because the internal relay contacts have come unlatched.

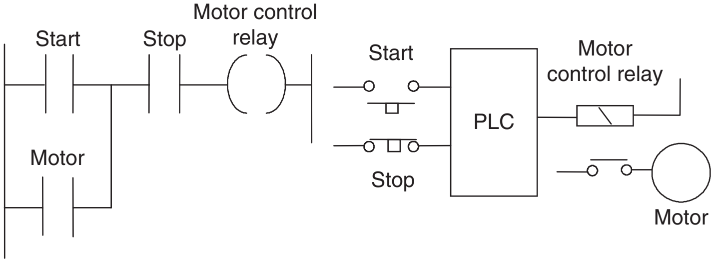

Figure 13.7: A safer stop system.

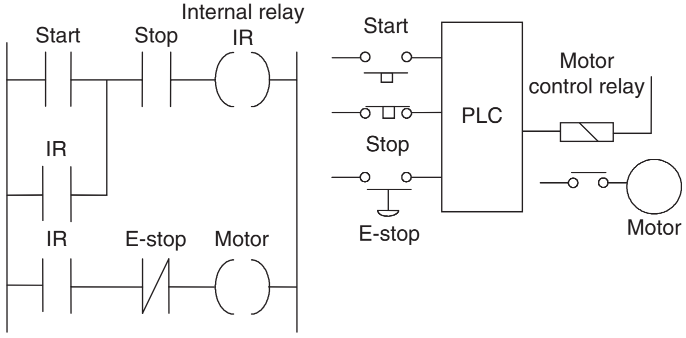

Figure 13.8: An unsafe emergency stop system.

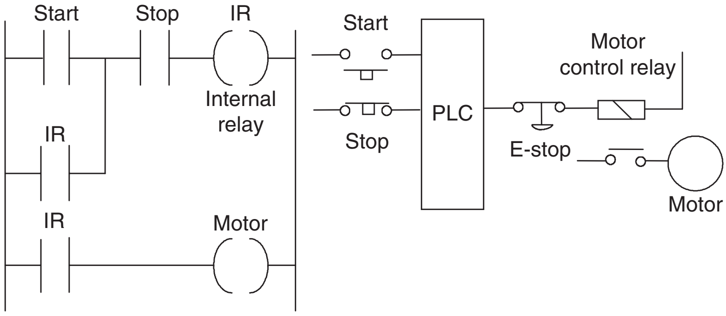

Figure 13.9: A safer emergency stop system.

13.2.2 Emergency Stop Relays

Emergency stop relays are widely used for emergency stop arrangements, such as the PNOZ p1p from Pilz GmbH & Co. This device has LEDs for indicating the status of input and output circuits, the reset circuit and power supply, and faults. However, the base unit can be connected via an interface module so that its status can be read by a PLC. This interface isolates the output from the emergency stop relay from the signal conditioning and input to the PLC by means of optoisolators (refer back to Figure 1.8). Thus, though the emergency stop operates independently of the PLC, it can provide signals that a PLC can use to, say, initiate safe closing-down procedures. Figure 13.10 illustrates this idea.

A simple emergency stop relay in which operation of the emergency stop button breaks the control circuit to the relay, causing it to deenergize and switch off the power (Figure 13.11a), has the problem that if the relay contacts weld together, the emergency stop will not operate. This can be overcome using a dual-channel mode of operation in which there are two normally closed contacts in series and both are broken by the action of the relay deenergizing (Figure 13.11b). Safety can be increased yet further if three contacts in

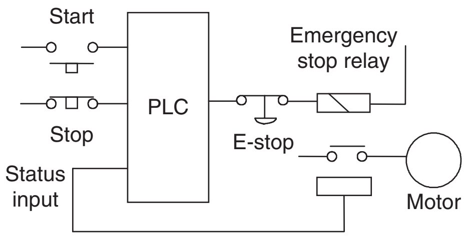

Figure 13.10: Emergency stop relay providing feedback of status.

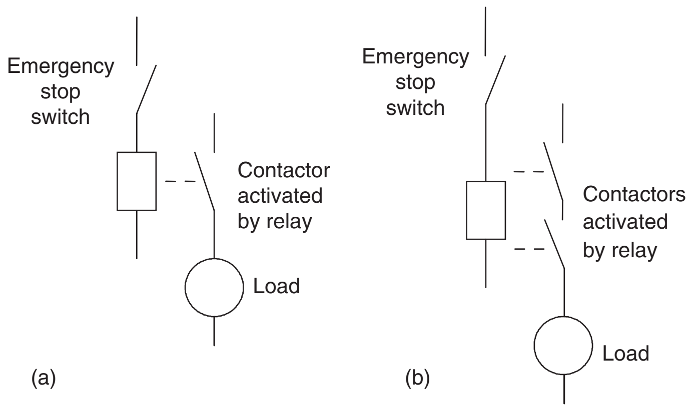

Figure 13.11: Emergency stop relay: (a) single-channel mode, and (b) dual-channel mode.

series are used, one using normally closed contacts and the others normally open contacts. Then one set of contacts has to be deenergized and the other two energized.

13.2.3 Safety Functions

In designing control systems, it is essential that personnel are prevented from coming into contact with machinery while it is active. This might involve:

- *Two-handed engaging* so that both hands must be on switches all the time and the machine will switch off if only one of the switches is being engaged.
- *Protective door monitoring* to prevent access to a machine while it is operating. This can be achieved by the use of safety interlocks such as doors and gates. Limit switches positioned on door and gate latches can be used so that when the door or gate is unlatched, the limit switch is opened and closes down the machinery. However, it is relatively simple for operatives to defeat such limit switches by sticking a device such as a screwdriver in the contacts to force a machine to operate. More sophisticated safety interlocks have thus been devised, such as proximity switches and key locks.

- *Light curtains* to prevent any person getting close to machinery. A danger zone, such as a packaging machine, can use infrared beams to protect people from getting too close. If a light beam is broken, it immediately triggers a safe shutdown command.
- *Safety mats* are another way of detecting when someone is too close to a machine. They are placed round a machine and when someone steps on the mat, a contact is closed, causing the machine to stop.
- *Emergency stop relays*, to enable machinery to be stopped in the event of an emergency (see Section 13.2.2).

Thus a safe-operating system for a work cell might use gated entry systems, such as guards on machines that activate stop relays if they are not in place, light curtains, and emergency stop relays.

13.2.4 Safety PLCs

Safety PLCs are specially designed to enable safety functions to be realized. In a safety PLC there can be two or three microprocessors that perform exactly the same logic, check against each other, and give outputs only if there is agreement. An example of such a PLC is the SIMATIC S5-95F. This is a two-channel system with two identical subsystems that communicate with each other via a fiber-optic cable link. The inputs from the sensors are fed simultaneously to both subsystems. During operation, data is passed between the two subsystems via the fiber-optic cable. They operate in synchronism with the same program and compare input and output signals, the results of logic operations, counters, and the like, and automatically go into a safe-stop condition if there are different outputs or internal faults or failures. For safety-related digital outputs, actuators are switched on or off from both subsystems. This means that one subsystem alone can shut down equipment.

13.3 Commissioning

Commissioning of a PLC system involves:

1. Checking that all the cable connections between the PLC and the plant being controlled are complete, safe, to the required specification, and meet local standards.
2. Checking that the incoming power supply matches the voltage setting for which the PLC is set.
3. Checking that all protective devices are set to their appropriate trip settings.
4. Checking that emergency stop buttons work.
5. Checking that all input/output devices are connected to the correct input/output points and giving the correct signals.
6. Loading and testing the software.

13.3.1 Testing Inputs and Outputs

Input devices, such as switches, can be manipulated to give the open and closed contact conditions and the corresponding LED on the input module observed. It should be illuminated when the input is closed and not illuminated when it is open. Failure of an LED to illuminate could be because the input device is not correctly operating, there are incorrect wiring connections to the input module, the input device is not correctly powered, or the LED or input module is defective. For output devices that can be safely started, push buttons might have been installed so that each output could be tested.

Another method that can be used to test inputs and outputs is *forcing*. This involves software, rather than mechanical switching on or off, being used with instructions from the programming panel to turn off or on inputs/outputs. To do this, a PLC has to be switched into the forcing or monitor mode by perhaps pressing a key marked FORCE or selecting that mode on a screen display. For example, Figure 13.12 shows the keystrokes that might be used, along with the resulting screen display, to force the output Y005 into the on state. Figure 13.13 shows the keys for the forcing an input X001 into a closed state. Thus if an input is forced and the input LED comes on, we can check that the consequential action of that input being on occurs.

13.3.2 Testing Software

Most PLCs contain some software-checking program. This checks through the installed program for incorrect device addresses and provides a list on a screen or as a printout of all the input/output points used, counter and timer settings, and so on, with any errors detected. For example, there might be a message that an output address is being used more than once in a program, a timer or counter is being used without a preset value, a counter is being used without a reset, or the like.

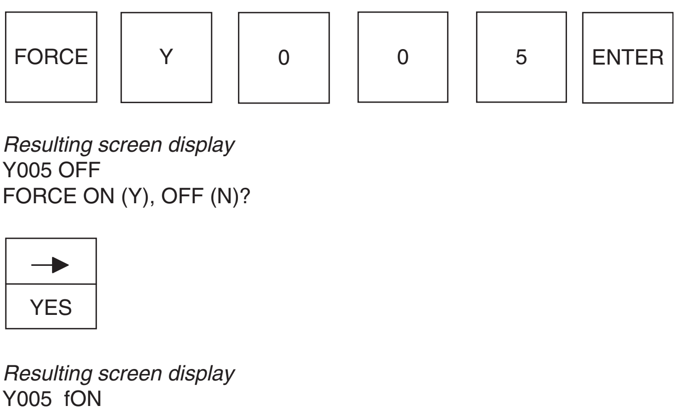

Figure 13.12: Forcing an output.

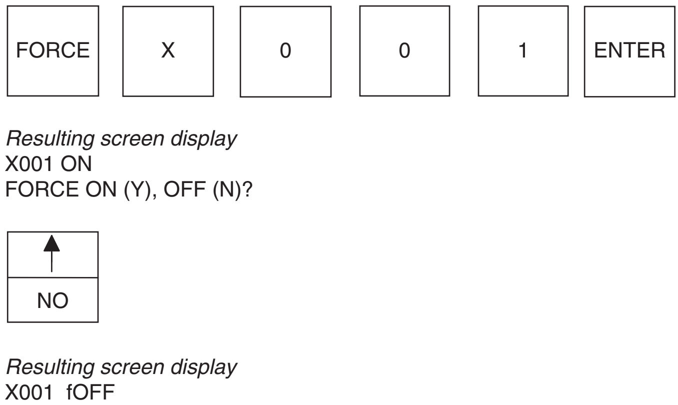

Figure 13.13: Forcing an input.

13.3.3 Simulation

Many PLCs are fitted with a simulation unit that reads and writes information directly into the input/output memory and so simulates the actions of the inputs and outputs. The installed program can thus be run and inputs and outputs simulated so that they, and all preset values, can be checked. To carry out this type of operation, the terminal has to be placed in the correct mode. For Mitsubishi this is termed the *monitor mode*, for Siemens the *test mode*, and for Telemecanique the *debug mode*.

With a Mitsubishi in monitor mode, Figure 13.14 shows how inputs appear when open and closed and how output looks when not energized and energized. The display shows a selected part of the ladder program and what happens as the program proceeds. Thus at some stage in a program the screen might appear in the form shown in Figure 13.15a. For rung 12, with inputs to X400, X401, and X402 but not M100, there is no output from Y430. For rung 13, the timer T450 contacts are closed, the display at the bottom of the screen indicating that there is no time left to run on T450. Because Y430 is not energized, the Y430 contacts are open, so there is no output from Y431. If we now force an input to M100, the screen display changes to that shown in Figure 13.5b. Now Y430, and consequently Y431, come on.

13.4 Fault Finding

With any PLC-controlled plant, by far the greater percentage of faults are likely to be with sensors, actuators, and wiring rather than within the PLC itself. Of the faults within

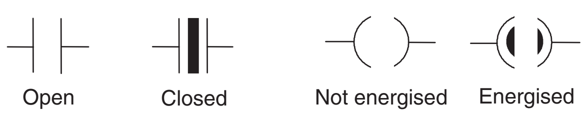

Figure 13.14: Monitor mode symbols.

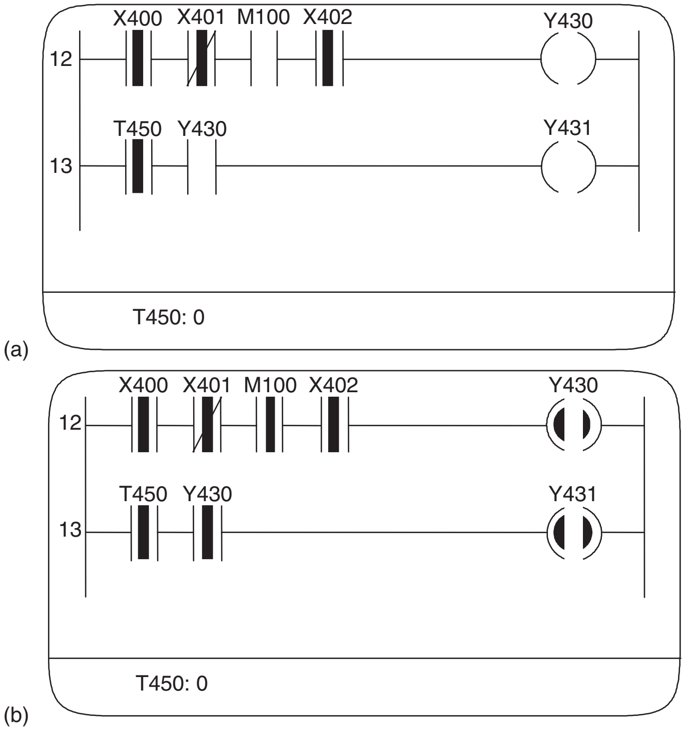

Figure 13.15: Ladder program monitoring.

the PLC, most are likely to be in the input/output channels or power supply rather than in the CPU.

As an illustration of a fault, consider a single output device failing to turn on, even though the output LED is on. If testing of the PLC output voltage indicates that it is normal, the fault might be a wiring fault or a device fault. If checking of the voltage at the device indicates the voltage there is normal, the fault is the device. As another illustration, consider all the inputs failing. This might be as a result of a short circuit or earth fault with an input. A possible procedure to isolate the fault is to disconnect the inputs one by one until the faulty input is isolated. An example of another fault is if the entire system stops. This might be a result of a power failure, someone switching off the power supply, or a circuit breaker tripping.

Many PLCs provide built-in fault analysis procedures that carry out self-testing and display fault codes, possibly with a brief message that can be translated by looking up the code in a list, which gives the source of the fault and possible methods of recovery. For example, the fault code may indicate that the source of the fault is in a particular module, with the method of recovery given as “Replace that module” or, perhaps, “Switch the power off and then on.”

13.4.1 Fault Detection Techniques

The following are some common fault detection techniques:

- *Timing checks*. The term *watchdog* is used for a timing check that is carried out by the PLC to check that some function has been carried out within the normal time. If the function is not carried out within the normal time, a fault is assumed to have occurred and the watchdog timer trips, setting off an alarm and perhaps closing down the PLC. As part of the internal diagnostics of PLCs, watchdog timers are used to detect faults. The watchdog timer is preset to a time slightly longer than the scan time would normally be. It is then set at the beginning of each program scan and, if the cycle time is normal, it does not time out and is reset at the end of a cycle, ready for the next cycle. However, if the cycle time is longer than it would normally be, the watchdog timer times out and indicates that the system has a fault.

  Within a program, additional ladder rungs are often included so that when a function starts, a timer is started. If the function is completed before the time runs out, the program continues, but if not, the program uses the jump command to move to a special set of rungs, which triggers an alarm and perhaps stops the system. Figure 13.16 shows an example of a watchdog timer that might be used with the movement of a piston in a cylinder. When the start switch is closed, the solenoid of a valve is energized and causes the piston in the cylinder to start moving. It also starts the timer. When the piston is fully extended, it opens a limit switch and stops the timer. If the time taken for the piston to move and switch off the timer is greater than the preset value used for the timer, the timer sets off the alarm.

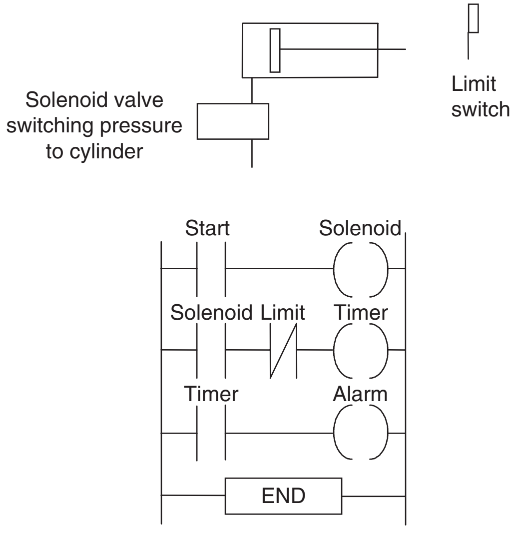

Figure 13.16: Watchdog timer.

- *Last output set*. This technique involves the use of status lamps to indicate the last output that has been set during a process that has come to a halt. Such lamps are built into the program so that as each output occurs, a lamp comes on. The lamps that are on thus indicate which outputs are occurring. The program has to be designed to turn off previous status lamps and turn on a new status lamp as each new output is turned on. Figure 13.17 illustrates this concept.

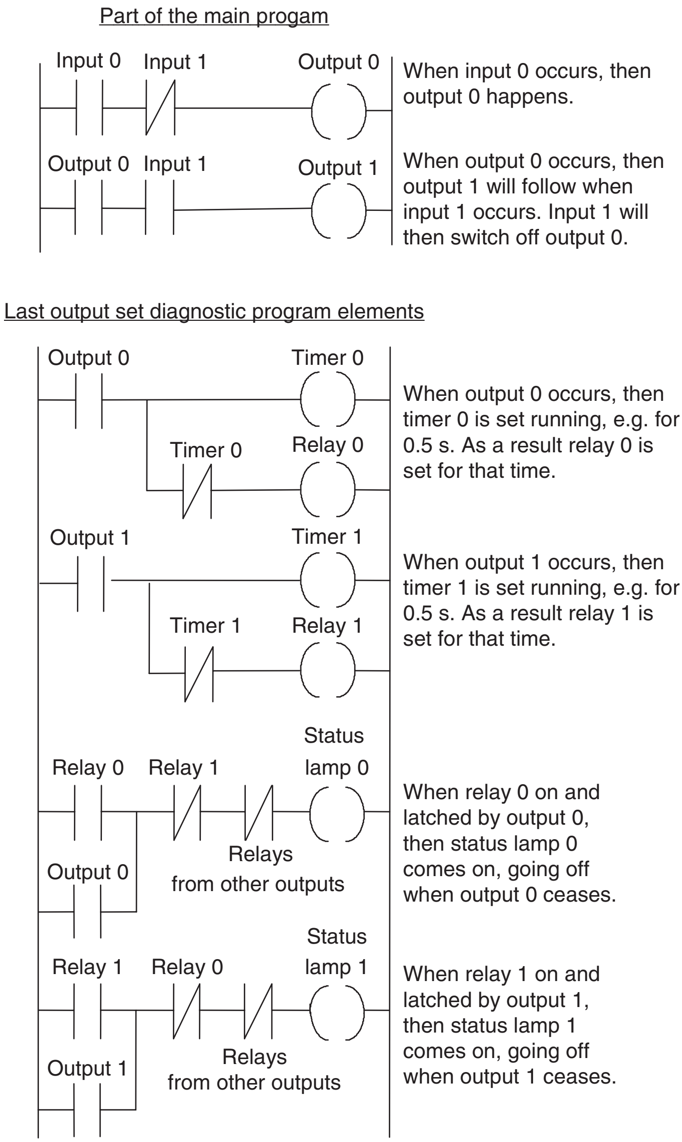

Figure 13.17: Last output set diagnostic program.

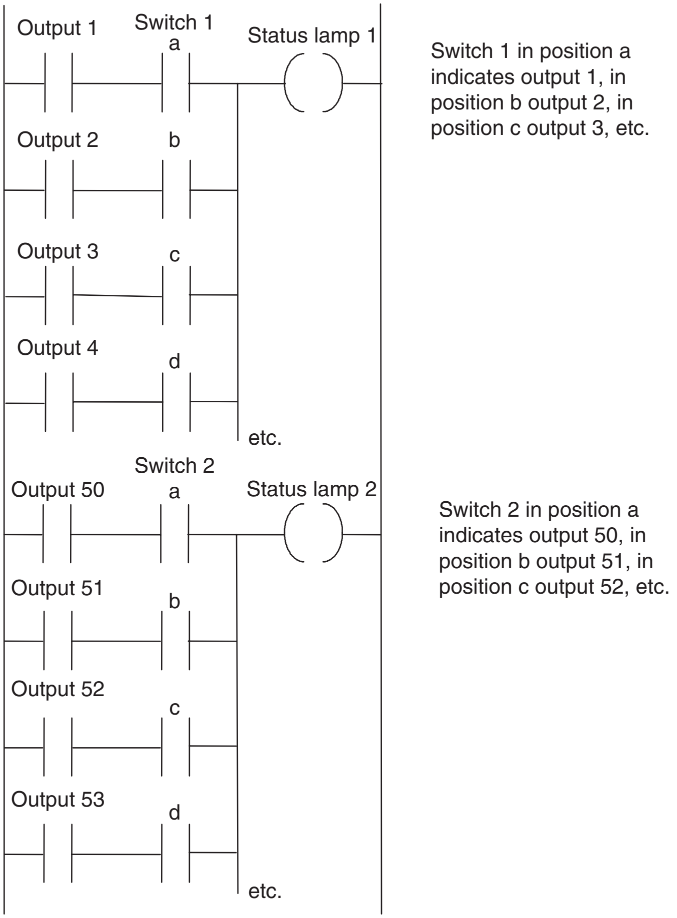

Figure 13.18: Single status lamp for a group of outputs.

Such a technique can be cumbersome in a large system with many outputs. In such a case, the outputs might be grouped into sets and a status lamp used for each set. A selector switch can then be used within a group to select each output in turn to determine whether it is on. Figure 13.18 illustrates this idea.

As an illustration of the use of this program to indicate which action occurred last, Figure 13.19 shows the program that might be used with a pneumatic system operating cylinders in a sequence. The program indicates at which point in the sequence a fault occurred, such as a piston sticking, and would be added to the main program used to sequence the cylinders. Each of the cylinder movements has a light-emitting diode associated with it, with the last cylinder movement indicated by its LED being illuminated.

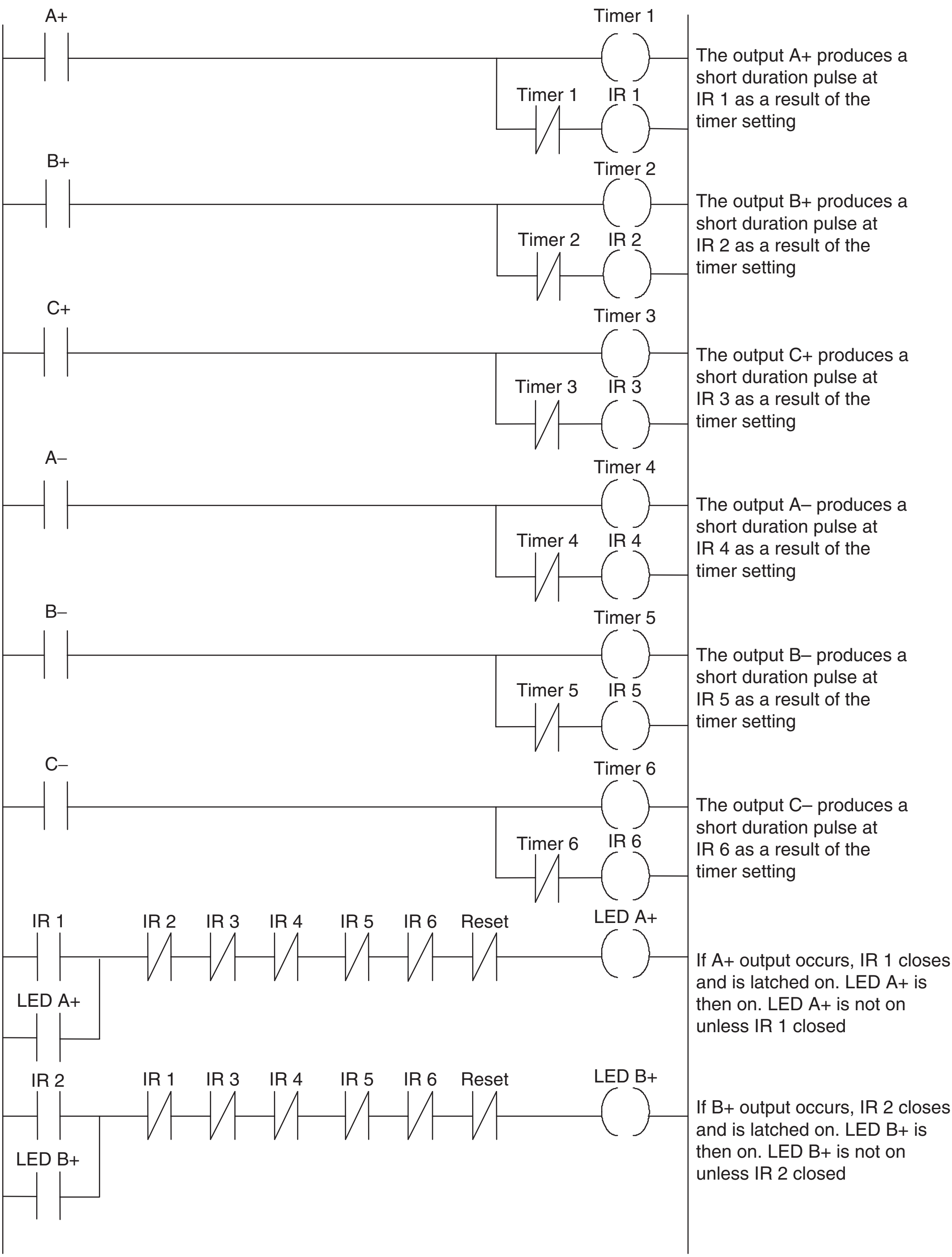

Figure 13.19: Diagnostic program for last cylinder action.

(*Continued*)

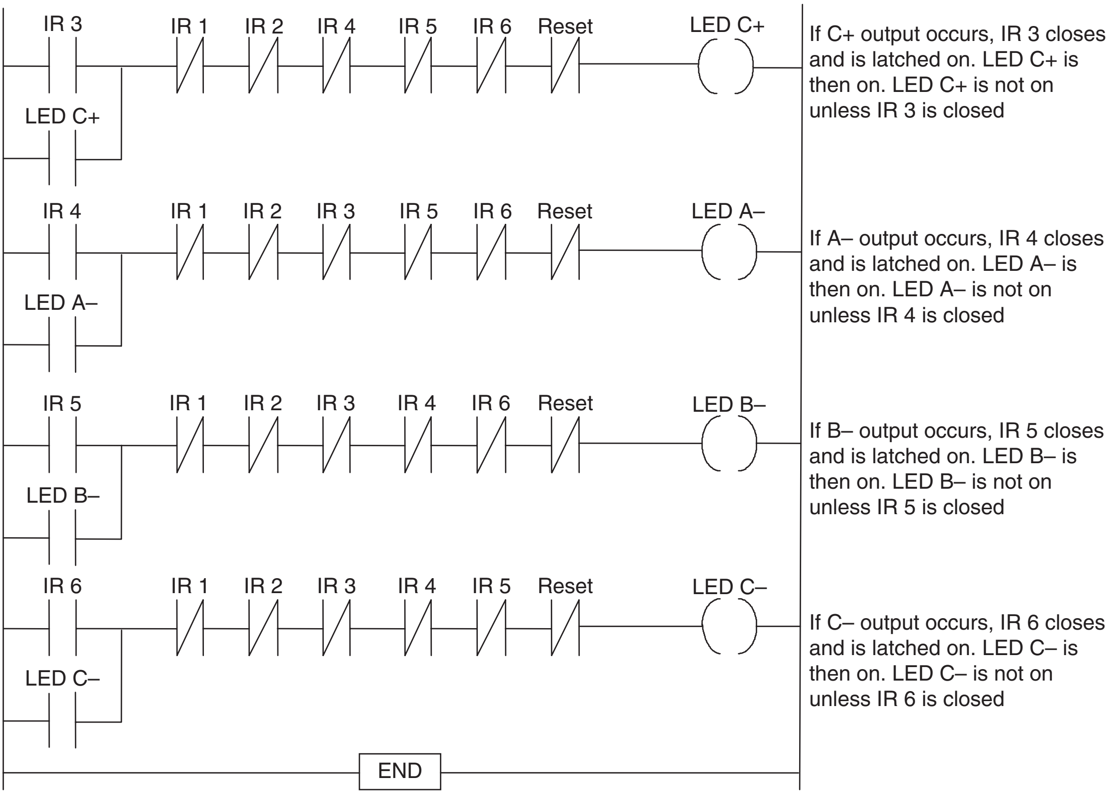

Figure 13.19—Cont'd

- *Replication*. Where there is concern regarding safety in the case of a fault developing, checks may be constantly used to detect faults. One technique is replication checks, which involve duplicating, that is, replicating, the PLC system. This could mean that the system repeats every operation twice and, if it gets the same result, it is assumed that there is no fault. This procedure can detect transient faults. A more expensive alternative is to have duplicate PLC systems and compare the results given by the two systems. In the absence of a fault, the two results should be the same.
- *Expected value checks*. Software errors can be detected by checking whether an expected value is obtained when a specific input occurs. If the expected value is not obtained, a fault is assumed to be occurring.

13.4.2 Program Storage

Applications programs may be loaded into battery-backed RAM in a PLC. A failure of the battery supply means a complete loss of the stored programs. An alternative to storing applications programs in battery-backed RAM is to use EPROM. This form of memory is secure against the loss of power. Against the possibility of memory failure occurring in the PLC and loss of the stored application program, a backup copy of each application program should be kept. If the program has been developed using a computer, the backup may be on a CD or a hard disk. Otherwise the backup may be on an EPROM cartridge. The program can then again be downloaded into the PLC without it having to be rewritten.

13.5 System Documentation

The documentation is the main guide used by everyday users, including for troubleshooting and fault finding with PLCs. It thus needs to be complete and in a form that is easy to follow. The documentation for a PLC installation should include the following:

- A description of the plant
- Specification of the control requirements
- Details of the programmable logic controller
- Electrical installation diagrams
- Lists of all input and output connections
- Application program with full commentary on what it is achieving
- Software backups
- Operating manual, including details of all start up and shut down procedures and alarms

13.5.1 Example of an Industrial Program

The following is an example of the way a program might appear for a real plant controlled by an Allen-Bradley PLC5; I am grateful to Andrew Parr for supplying it. It illustrates the way a program file is documented to aid in clarification and the safety and fault indication procedures that are used. Note that the right-hand power rail has been omitted, which is allowable in IEC 1131-3.

The program is one of about 40 program files in the complete program, each file controlling one area of operation and separated by a page break from the next file. The file that follows controls a bundle-cutting band saw and involves motor controls, desk lamps, and a small state transition sequence.

Note the rung cross-references, such as [38], below B3/497 in rung 2. These are used to show that B3/497 originates, for example, in rung 38 in the current program file. Also note that all instructions are tagged with descriptions and the file is broken down into page sections. The software allows you to go straight to a function via the page titles.

All the motor starter rungs work in the same way. The PLC energizes the contactor and then one second later looks for the auxiliary relay (labeled as Aux in the program file) coming back to say the contactor has energized. If there is a fault that causes the contactor to deenergize, such as a loss of supply, or a trip or open circuit coil, it causes the PLC to signal a fault and deenergize the contactor output so that the machine does not spring into life when the fault is cleared.

The saw normally sits raised clear of the bundle. To cut the bundle, the blade motor has to be started and the lower push-button pressed (at rung 8). The saw falls under gravity at a fast or slow speed that is set by hydraulic valves. To raise the saw, a hydraulic pump is started to pump oil into the saw support cylinders. At any time the saw can be raised, such as to clear swarf, to what is termed the *pause state*. Otherwise, cutting continues until the bottom limit is reached. The saw then is raised to the top limit for the next bundle. A cut can be aborted by pressing the raise button for two seconds. While a bundle is being cut, it is held by clamp solenoids.

The final three rungs of the program set the length to be cut. There are two photocells about 20 mm apart on a moveable carriage. These are positioned at the required length. The operator runs the bundle in until the first is blocked and the second is clear. These control the long/correct/short desk lamps.

```
                              Bundle Cutting Saw
                          ***Saw Cutting...Saw Motor
                               Stacking Machine
File #14 Saw Proj: FLATS3        Page:00001                 21:08 12/05/02
-----------------------------------------------------------------------------
  | Saw_Motor
  |  Tripped    Saw_Motor   Saw_ESR                          Saw_Motor
  | 1=Tripped  Start_Fault  Healthy                          Available
  |   I:032        B3        I:031                              B3
0 +-----]/[-----------]/[---------] [-----------------------------( )-----------
  |     10        517         17                               516
  |               [2]
  |                                         Saw_Blade
  |   Saw_Motor    Saw_Motor  Saw_Motor  Tension_LS     Saw_Motor
  |    Start_PB     Stop_PB   Available   1=Healthy     Contactor
  |     I:030        I:030       B3        I:032          O:034             >
1 +--+----]  [--------+---]  [---------] [---------] [----------+----( )------------------>
  |  |    00        |    01       516       03         |    10              >
  |  |              |             [0]                  |
  |  |Saw_Motor     |                                  |
  |  |Contactor     |                                  |
  |  |  O:034       |                                  |
  |  +----]  [------+                                  +------------------------
  |      [1]
  |                                        <------------------------------+----------
  |                                         Saw_Motor                     |
  |                                         Start_Motor                   |
  |                                         +-- TON ---------------+      |
  |                                         + Timer On Delay       +-(EN)---+
  |                                         | Timer:      T4:109   |
  |                                         | Base (SEC): 0.01     +-(DN)
  |                                         | Preset:        100   |
  |                                         | Accum:           0   |
  |                                         +----------------------+
  |
  |  Saw_Motor     Saw_Motor   Saw_Alarms                            Saw_Motor
  | Start_Fault   Running_Aux    Accept                              Start_Fault
  |   T4:109         I:032         B3                                   B3
2 +-+----]  [-----------]/[----+------]/[-----------------------------------( )-------
  | |   DN            11       |     497                                   517
  | |   [1]                    |     [38]
  | |Saw_Motor                 |
  | |    B3                    |
  | +----]  [------------------+
  |     517
  |     [2]
  |
```

```
                              Bundle Cutting Saw
                                ...Coolant Pump
                               Stacking Machine
File #14 Saw Proj: FLATS3        Page:00002                       21:08 12/05/02
--------------------------------------------------------------------------------
    |Coolant_Pump  Coolant_Pump  Saw_ESR                          Coolant_Pump
    | 1=Tripped     Start_Fault  Healthy                            Available
    |   I:032          B3        I:031                                 B3
  3 +------]/[-----------]/[-----------] [-----------------------------( )---
    |    12          519          17                                  518
    |                [6]                  Test_Run
    |Coolant_Pump                        Coolant_Pump
    |Select_SW      OneShot               TOF_Timer
    |   I:030         B3                  +--TOF---------------+
  4 +-----] [----------]ONS[-------------+ Timer Off Delay    +--(EN)------
    |    02          520                  |Timer:      T4:110 |
    |                                     |Base (SEC):   1.0  +--(DN)
    |                                     |Preset:          4 |
    |                                     |Accum:           4 |
    |                                     +--------------------+
    |Coolant_Pump  Saw_Motor             Coolant_Pump
    |Select_SW     Running_Aux            Contactor
    |    I:030        I:032                O:034
  5 +--+----] [----------] [------+--------+--------( )----------------+---------
    |  |   02          11         |        |        11                |
    |  |Test_Run                  |        |Coolant_Pump              |
    |  |Coolant_Pump              |        |Start_Fault               |
    |  |TOF_Timer                 |        |TON Timer                 |
    |  |T4:110                    |        |+--TON -------------+     |
    |  +----] [-------------------+        ++Timer On Delay    +-(EN)-+
    |     DN                                |Timer:     T4:111|
    |     [4]                               |Base (SEC): 0.01+---(DN)
    |                                       |Preset:       100|
    |                                       |Accum:          0|
    |Coolant Pump                           +------------------+
    |Start_Fault  Coolant_Pump  Saw_Alarms                      Coolant_Pump
    |TON_Timer    Running_Aux   Accept                          Start_Fault
    |   T4:111       I:032        B3                               B3
  6 +--+-----] [---------] [------+----]/[--------------------------( )---
    |  |    DN         13         |   497                            519
    |  |    [5]                   |   [38]
    |  |Coolant_Pump              |
    |  |Start_Fault               |
    |  |     B3                   |
    |  +----] [-------------------+
    |    [6]519
    |
    | Saw_Motor   Coolant_Pump                                  Saw_Motor &
    | Running_Aux Running_Aux                                   Coolant_OK
    |   I:032        I:032                                          B3
  7 +------] [----+-------] [------+--------------------------------( )---
    |    11       |     13         |                               496
    |             |Coolant_Pump    |
    |             |Select_SW       |
    |             +------]/[-------+
    |                  02
```

```
                    Bundle Cutting Saw
                     ...Coolant Pump
                     Stacking Machine
File #14 Saw Proj: FLATS3      Page:00003              21:08 12/05/02
-----------------------------------------------------------------------------
Blank page for future modification
```

```
                                  Bundle Cutting Saw
                          ...Saw Cut Sequence...Transitions
                                   Stacking Machine
File #14 Saw Proj: FLATS3        Page:00004                    21:08 12/05/02
------------------------------------------------------------------------------
    |
    |State_0                                  Saw_Hyd    Saw_Blade
    |Ready_for Saw_Motor_& Saw_Hyd_Pump Permit_SW Tension_LS Saw_Lower  Trans_A
    |Start     Coolant_OK  Healthy      1=Permit  1=Healthy PushButton Seq_Start
    |    B3         B3          B3          I:031      I:032      I:030      B3
  8 +----] [----------] [----------] [-----------] [----------] [----------] [--------( )----
    |   500        496         499          14         03         04        506
    |  [15]        [7]        [24]
    |
    |                                                                     Trans_B
    | State_1       Saw                                                  Cut_Done
    | Cutting     End_Cut_LS                                             or_Fault
    |    B3          I:032                                                   B3
  9 +----] [------+------] [----+-----------------------------------------( )----
    |   501    |       00     |                                             507
    |  [16]    |              |
    |          |Saw_Motor_&   |
    |          | Coolant_OK   |
    |          |     B3       |
    |          +------]/[-----+
    |                 496
    |                 [7]
    |
    | State_2
    | Raise_to    Saw_Top_LS                                          Trans_C
    | Top_Limit   Struck_TON                                          At_Top_LS
    |    B3         T4:112                                                B3
 10 +----] [------------] [-------------------------------------------( )----
    |   502          DN                                                  508
    |  [17]         [20]
    |
    | State_1     Saw_Raise                                           Trans_D
    | Cutting     Pushbutton                                          Pause_Req
    |    B3          I:030                                                B3
 11 +----] [------------] [-------------------------------------------( )----
    |   501          03                                                  509
    |  [16]
    |
    | State_3     Saw_Lower                                           Trans_E
    | Paused      Pushbutton                                          Pause_End
    |    B3          I:030                                                B3
 12 +----] [------------] [-------------------------------------------( )---
    |   503          04                                                  510
    |  [18]
    |
    |
```

```
                           Bundle Cutting Saw
                    ...Saw Cut Sequence...Transitions
                             Stacking Machine
File #14 Saw Proj: FLATS3       Page:00005                 21:08 12/05/02
--------------------------------------------------------------------------
  |
  |              Raise_PB                                       Trans_F
  | State_3     Raise_to_Top                                   Pause_End
  | Paused       TON_Timer                                     Go_To_Top
  |    B3         T4:108                                           B3
13 +-----] [------+--------] [--------+---------------------------( )-------
  |   503        |     DN        |                                511
  |   [18]       |    [19]       |
  |              |  Saw_Motor_&  |
  |              |  Coolant_OK   |
  |              |     B3        |
  |              +--------]/[--------+
  |                   496
  |                   [7]
  |                                                               Trans_G
  | State_3     Saw_Top_LS                                     Hit_Top_LS
  | Paused      Struck_TON                                    While_Paused
  |    B3        T4:112                                            B3
14 +-----] [------------] [---------------------------------------( )-------
  |   503          DN                                              495
  |   [18]        [20]
  |
  |
```

```
                              Bundle Cutting Saw
                                  ...States
                               Stacking Machine
File #14 Saw Proj: FLATS3        Page:00006                     21:08 12/05/02
-----------------------------------------------------------------------------
   |
   |          State_2                                              State_0
   | State_1  Raise_to  State_3                                    Ready_for
   | Cutting  Top_Limit Paused                                      Start
   |   B3        B3       B3                                          B3
15 +----]/[--------]/[--------]/[------------------------------------( )----
   |   501       502      503                                         500
   |  [16]      [17]     [18]
   |
   |                 Trans_B
   |    Trans_A      Cut_Done  Trans_D   Saw_ESR                     State_1
   |    Seq_Start    or_Fault  Pause_Req Healthy                     Cutting
   |       B3           B3        B3      I:031                         B3
16 +-+-----] [-----+----]/[-------]/[-------] [-----------------------( )----
   | |    506      |   507       509       17                          501
   | |    [8]      |   [9]      [11]
   | |  Trans_E    |
   | |  Pause_End  |
   | |    B3       |
   | +-----] [-----+
   | |    510      |
   | |   [12]      |
   | |  State_1    |
   | |  Cutting    |
   | |    B3       |
   | +----] [------+
   |      501
   |     [16]
   |
   |     Trans_B                                                     State_2
   |     Cut_Done     Trans_C    Saw_ESR                             Raise_to
   |     or_Fault     At_Top_LS  Healthy                             Top_Limit
   |       B3            B3       I:031                                 B3
17 +--+-----] [-----+-----]/[--------] [------------------------------( )----
   | |    507      |    508         17                                 502
   | |    [9]      |   [10]
   | |  Trans_F    |
   | |  Pause_End  |
   | |  Go_To_Top  |
   | |    B3       |
   | +-----] [-----+
   | |    511      |
   | |   [13]      |
   | |  State_2    |
   | |  Raise_to   |
   | |  Top_Limit  |
   | |    B3       |
   | +-----] [-----+
   |      502
   |     [17]
```

```
                                Bundle Cutting Saw
                                    ...States
                                 Stacking Machine
File #14 Saw Proj: FLATS3           Page:00007                     21:08 12/05/02
------------------------------------------------------------------------------------
   |
   |                                Trans_F      Trans_G
   |  Trans_D     Trans_E     Pause_End    Hit_Top_LS    Saw_ESR          State_3
   | Pause_Req   Pause_End   Go_To_Top   While_Paused   Healthy           Paused
   |    B3          B3          B3           B3          I:031              B3
18 +-+--] [-----+-----]/[----------]/[------------]/[----------] [---------------( )----
   | |  509     |    510         511          495          17                503
   | | [11]     |
   | |State_3   |
   | | Paused   |
   | |  B3      |
   | +--] [----+
   |    503
   |   [18]
   |
   |
```

```
                              Bundle Cutting Saw
                                 .... .Timers
                               Stacking Machine
File #14 Saw Proj: FLATS3         Page:00008                     21:08 12/05/02
-------------------------------------------------------------------------------
   |
   |If Raise PB is pressed for more than 2 secs go right to top limit switch
   |
   |                                                   Raise_PB
   |   State_3    Saw_Raise                           Raise_to_Top
   |    Paused    PushButton                           TON_Timer
   |     B3         I:030                          +--TON--------------+
19 +-------] [-----------] [-----------------------+Timer On Delay     +--(EN)------
   |     503         03                            |Timer:     T4:108 |
   |                                               |Base (SEC): 0.01  +--(DN)
   |                                               |Preset:       200 |
   |                                               |Accum:          0 |
   |                                               +-------------------+
   |T4:112 ensures saw carriage goes past top limit to help avoid creeping
   |off the top position
   |
   |Saw_Top_LS                                    Saw_Top_LS
   | 1=Struck                                     Struck_TON
   |   I:032                                   +---TON----------------+
20 +----] [--------------------------------------+ + Time On Delay     + --(EN)---+---
   |    01                                     | | Timer:     T4:112 |          |
   |                                           | | Base (SEC): 0.01  +---(DN)   |
   |                                           | | Preset:       100 |          |
   |                                           | | Accum:        101 |          |
   |                                           | +-------------------+          |
   |                                           |Saw_Top_LS                      |
   |                                           |Struck_TOF                      |
   |                                           | 1=At_Top                       |
   |                                           |+--TOF----------------+         |
   |                                           ++ Timer Off Delay    +----(EN)--+
   |                                            | Timer:     T4:113 |
   |                                            | Base (SEC): 0.01  +----(DN)
   |                                            | Preset:       300 |
   |                                            | Accum:          0 |
   |                                            +-------------------+
   |
   |Permissive for bundle delivery/despatch
   |  Saw_Top_LS                                                    Saw_Not
   |   1=Struck                                                    Operating
   |    I:032                                                          B3
21 +-+----] [--------+-------------------------------------------------( )---
   | |    01         |                                                 524
   | |  Saw_Hyd      |
   | |Permit_SW      |
   | | 1=Permit      |
   | |   I:031       |
   | +----]/[--------+
   |      14
   |
```

```
                          Bundle Cutting Saw
                  .... .Solenoids and Hydraulic Pump
                          Stacking Machine
File #14 Saw Proj: FLATS3       Page:00009              21:08 12/05/02
--------------------------------------------------------------------------
    |The saw lowers at slow or fast speed under gravity.
    |It is raised by starting the pump which drives the saw up to the top
    |limit or for a time for a pause.
    |
    |             State_0
    | Saw_Lower   Ready_for                                  Saw_Lower
    |PushButton     Start                                    Fast_SOV
    |  I:030         B3                                       O:033
 22 +----] [-------+-----] [-----+--------------------------------( )------
    |    04        |    500      |                               11
    |              |    [15]     |
    |              |  State_1    |
    |              |  Cutting    |
    |              |    B3       |
    |              +-----] [-----+
    |  State_1          501                                  Saw_Lower
    |  Cutting          [16]                                  Healthy
    |    B3                                                   O:033
 23 +----] [------------------------------------------------------( )------
    |   501                                                    10
    |
    |Saw_Hyd_Pump  Saw_Hyd_Pump                             Saw_Hyd_Pump
    |  1=Tripped   Start_Fault                                 Healthy
    |   I:032         B3                                        B3
 24 +----]/[-----------]/[------------------------------------( )-----
    |    14          498                                       499
    |                [26]
    |  Saw_Raise                          Saw_Lower  Saw_Lower
    |  PushButton                         Slow_SOV   Fast_SOV
    |    I:030                             O:033      O:033       >
 25 +-+-----] [-------------------------+-------]/[---------]/[------------>
    | |     03                          |     10         11        >
    | | State_2                         |    [23]       [22]
    | | Raise_to                        |
    | | Top_Limit                       |
    | |     B3                          |
    | +-----] [-------------------------+
    | |    502                          |
    | |    [17]                         |
    | | State_0                Saw_Hyd  |
    | | Ready_for Saw_Top_LS  Permit_SW |
    | | Start     Struck_TON  1=Permit  |
    | |    B3       T4:112     I:031    |
    | +-----] [---------]/[---------] [---------+
    |     500        DN        14
    |    [15]       [20]
    |             Saw_Hyd_Pump  Saw_ESR   Saw_Hyd-Pump
    |                Healthy    Healthy    Contactor
    |             <    B3        I:031       O:034
    |             <-----] [---------] [-----+------( )--------------+-----
    |             <                         >                      >
    |
```

```
                           Bundle Cutting Saw
                   .... .Solenoids and Hydraulic Pump
                             Stacking Machine
File #14 Saw Proj: FLATS3        Page:00010                 21:08 12/05/02
-------------------------------------------------------------------------------
   |                 <                       >                        >
   |                 <       499     17      |     12                 |
   |                                         |                        |
   |                                         | Saw_Hyd_Pump           |
   |                                         | Start_Fault            |
   |                                         | TON_Timer              |
   |                                         |+--- TON------------- + |
   |                                         ++Timer On Delay   +-(EN)-+
   |                                          |Timer:     T4:114|
   |                                          |Base (SEC): 0.01+-(DN)
   |                                          |Preset:       100|
   |                                          |Accum:          0|
   |                                          + ----------------+
   |
   | Saw_Hyd_Pump
   | Start_Fault  Saw_Hyd_Pump    Saw_Alarms                     Saw_Hyd_Pump
   |  TON_Timer   Running_Aux      Accept                        Start_Fault
   |    T4:114       I:032           B3                              B3
26 +-+-----] [------------]/[-------+------]/[-----------------------( )-------
   | |     DN          15           |   497                          498
   | |    [25]                      |   [38]
   | |Saw_Hyd_Pump                  |
   | | Start_Fault                  |
   | |     B3                       |
   | +-----] [----------------------+
   |      498
   |      [26]
   |
```

```
                                  Bundle Cutting Saw
                                 ...Blade Tensioning
                                  Stacking Machine
File #14 Saw Proj: FLATS3        Page:00011                       21:08 12/05/02
--------------------------------------------------------------------------------
   |Saw tension is changed via two hydraulic soleniods.
   |The TOF timer on the pump reduces start commands on the pump.
   |
   |Saw_Tension
   |Motor_Tripped TensionPump   Saw_ESR                           Tension_Pump
   | 1=Tripped    Start_Fault   Healthy                             Available
   |    I:032         B3         I:031                                  B3
27 +-----]/[-----------]/[-------------]  [--------------------------------( )--------
   |     05          513          17                                    512
   |                 [30]
   |Saw_Tension     TensionPump                        TensionPump
   |Increase_PB     Available                          Run_Cmd_TOF
   |    I:030           B3                             +---TOF-----------+
28 +-+--]  [----------+-----]  [-----------------------+Timer Off Delay+--(EN)------
   | |  02            |    512                         |Timer:   T4:115|
   | |                |    [27]                        |Base (SEC): 1.0+--(DN)
   | | Saw_Tension    |                                |Preset:        5|
   | | Decrease_PB    |                                |Accum:         5|
   | |    I:030       |                                +-----------------+
   | +-----]  [-------+
   |      06
   | Tension_Pump                                Tension_Pump
   | Run_Cmd_TOF                                   Contactor
   |    T4:115                                       O:034
29+ ------]  [-----------------------------------+------( )------------------------+-------
   |      DN                                     |      13                         |
   |                                             |Tension_Pump                     |
   |                                             | Start_Fault                     |
   |                                             |  TON Timer                      |
   |                                             |+--TON---------------+           |
   |                                             ++ Timer On Delay     +---(EN)-+
   |                                              | Timer:     T4:116  |
   |                                              | Base (SEC): 0.01   +---(DN)
   |                                              | Preset:       100  |
   |                                              | Accum:          0  |
   |                                              +--------------------+
   | Tension_Pump
   |  Start_Fault  Saw_Tension    Saw_Alarms                        Tension_Pump
   |   TON_Timer    Pump_Aux       Accept                            Start_Fault
   |    T4:116       I:032           B3                                   B3
30 +-+----]  [-----------]/[------+------]/[-------------------------------( )--------
   | |    DN          06          |    497                               513
   | |   [29]                     |   [38]
   | |Tension_Pump                |
   | |Start_Fault                 |
   | |     B3                     |
   | +-----]  [-------------------+
   |      513
   |      [6]
```

```
                              Bundle Cutting Saw
                              ...Blade Tensioning
                               Stacking Machine
File #14 Saw Proj: FLATS3        Page:00012                    21:08 12/05/02
-----------------------------------------------------------------------------
  |
  |Saw_Tension     Saw_Tension                                   Saw_Tension
  |Increase_PB     Decrease_SOV                                  Increase_SOV
  |   I:030           O:033                                         O:033
31+----] [-----------------]/[-------------------------------------------( )-----
  |    05              13                                              12
  |                   [32]
  |
  |Saw_Tension     Saw_Tension                                   Saw_Tension
  |Decrease_PB     Increase_SOV                                  Decrease_SOV
  |   I:030           O:033                                         O:033
32+----] [-----------------]/[-------------------------------------------( )-----
  |    06              12                                              13
  |                   [31]
  |
```

```
                              Bundle Cutting Saw
                                ...Saw Clamps
                              Stacking Machine
File #14 Saw Proj: FLATS3         Page:00013                   21:08 12/05/02
-----------------------------------------------------------------------------
    |T4:118 & 119 operate the clamp/unclamp solenoids for a fixed time.
    |
    |   Saw_Clamp  Saw_Unclamp  Saw_Unclamp      Saw_Clamp  Saw_Clamp
    |   PushButon   Solenoid    PushButton       TON_Timer   Solenoid
    |     I:034      O:006        I:034           T4:118      O:006
 33 +-+-----] [------+----]/[-----------]/[---------+--------]/[---------( )-------+----
    | |     00       |   14          01            |        DN         13          |
    | |              |  [34]                       |       [33]                    |
    | |  Saw_Clamp   |                             |                               |
    | |   Solenoid   |                             |Saw_Clamp                      |
    | |    O:006     |                             |TON_Timer                      |
    | +------] [-----+                             |+--TON-------------+           |
    |         13                                   ++Timer On Delay    +--(EN)-+
    |        [33]                                   |Timer:    T4:118|
    |                                               |Base (SEC): 1.0+--(DN)
    |                                               |Preset:        2|
    |                                               |Accum:         0|
    |                                               +------------------+
    |
    |   Saw_UnClamp  Saw_Clamp    Saw_Clamp    Saw_UnClamp  Saw_UnClamp
    |    PushButton   Solenoid    PushButton    TON_Timer     Solenoid
    |      I:034       O:006        I:034        T4:119        O:006
 34 +-+-------] [------+----]/[-----------]/[--------+--------]/[---------( )--------+---
    | |       01       |   13          00            |        DN         14          |
    | |                |  [33]                       |       [34]                    |
    | | Saw_UnClamp    |                             |                               |
    | |  Solenoid      |                             |Saw_UnClamp                    |
    | |   O.006        |                             |TON_Timer                      |
    | +------] [-------+                             | +--TON-------------+          |
    |       14                                       ++Timer On Delay    +---(EN)-+
    |      [34]                                      | Timer:    T4:119|
    |                                                | Base (SEC): 1.0+--(DN)
    |                                                | Preset:        2|
    |                                                | Accum:         0|
    |                                                +-------------------+
    |
    |  Saw_Clamp                                                 Saw_Clamps
    |  Solenoid                                                  Last_Clamped
    |    O.006                                                       B3
 35 +------] [-----------------------------------------------------(L)----------
    |      13                                                        488
    |     [33]
    |
    | Saw_UnClamp                                                  Saw_Clamps
    | Solenoid                                                     Last_Clamped
    |   O.006                                                          B3
 36 +------] [-------------------------------------------------------(U)---------
    |      14                                                          488
    |     [34]
    |
```

```
                         Bundle Cutting Saw
                           ...Saw Clamps
                         Stacking Machine
File #14 Saw Proj: FLATS3      Page:00014              21:08 12/05/02
------------------------------------------------------------------------
  |
  |                                                        Saw_Clamp
  |  Saw_Clamps                                          Loading_Valve
  |   Solenoid                                             Required
  |    0.006                                                  B3
37+-+----] [-------+--------------------------------------------( )-----
  | |     13       |                                          481
  | |    [33]      |
  | |Saw_UnClamp   |
  | |Solenoid      |
  | |    O:006     |
  | +-----] [-------+
  |       14
  |      [34]
  |
  |Disch_Desk
  | Lamp_Test                                              Saw_Alarms
  |PushButton                                                Accept
  |   I:031                                                     B3
38+------] [----------------------------------------------------( )------
  |     12                                                      497
  |
  |
```

```
                              Bundle Cutting Saw
                              ...Saw Desk Lamps
                              Stacking Machine
File #14 Saw Proj: FLATS3       Page:00015                       21:08 12/05/02
------------------------------------------------------------------------------
   |     Saw_ESR                                                  Saw_Intlock
   |     Healthy                                                  Healthy_Lamp
   |      I:031                                                     O:030
39 +--+----] [--------+------------------------------------------------( )-------
   |  |     17        |                                                 00
   |  | Disch_Desk    |
   |  |  Lamp_Test    |
   |  | PushButton    |
   |  |    I:031      |
   |  +-----] [-------+
   |        12
   |
   |     Saw_ESR                                                  Saw_Intlock
   |     Healthy                                                   Fault_Lamp
   |      I:031                                                     O:030
40 +--+----]/[--------+------------------------------------------------( )-------
   |  |     17        |                                                 01
   |  | Disch_Desk    |
   |  |  Lamp_Test    |
   |  | PushButton    |
   |  |    I:031      |
   |  +-----] [-------+
   |        12
   |
   |  Saw_Hyd_Pump                                                Saw_Hyd_Pump
   |     Healthy                                                  Healthy_Lamp
   |       B3                                                       O:030
41 +--+----] [--------+------------------------------------------------( )-------
   |  |    499        |                                                 02
   |  |    [24]       |
   |  | Disch_Desk    |
   |  |  Lamp_Test    |
   |  | PushButton    |
   |  |    I:031      |
   |  +-----] [-------+
   |        12
   |
   |  Saw_Hyd_Pump                                                Saw_Hyd_Pump
   |     Healthy                                                  Running_Lamp
   |      I:032                                                     O:030
42 +--+----] [--------+------------------------------------------------( )-------
   |  |     15        |                                                 03
   |  | Disch_Desk    |
   |  |  Lamp_Test    |
   |  | PushButton    |
   |  |    I:031      |
   |  +-----] [-------+
   |        12
   |
```

```
                                Bundle Cutting Saw
                                ...Saw Desk Lamps
                                Stacking Machine
File #14 Saw Proj: FLATS3          Page:00016                    21:08 12/05/02
-------------------------------------------------------------------------------
   |                                                                 Saw_Motor
   |   Saw_Motor                                                      Healthy
   |   Available                                                     Desk_Lamp
   |      B3                                                          O:030
43 +--+----] [--------+-------------------------------------------------( )-------
   |  |    516        |                                                 04
   |  |    [0]        |
   |  | Disch_Desk    |
   |  | Lamp_Test     |
   |  | PushButton    |
   |  |   I:031       |
   |  +-----] [-------+
   |        12
   |                                                                Saw_Motor
   |   Saw_motor                                                    Saw_Intlock
   |  Running_Aux                                                   Desk_Lamp
   |     I:032                                                        O:030
44 +--+----] [--------+-------------------------------------------------( )-------
   |  |     11        |                                                 05
   |  | Disch_Desk    |
   |  | Lamp_Test     |
   |  | PushButton    |
   |  |   I:031       |
   |  +-----] [-------+
   |        12
   |
   |  Coolant_Pump                                                   Coolant_Pump
   |   Available                                                     Healthy_Lamp
   |      B3                                                          O:030
45 +--+----] [--------+-------------------------------------------------( )-------
   |  |    518        |                                                 06
   |  |    [3]        |
   |  | Disch_Desk    |
   |  | Lamp_Test     |
   |  | PushButton    |
   |  |   I:031       |
   |  +-----] [-------+
   |        12
   |
   |  Coolant_Pump                                                   Saw_Hyd_Pump
   |  Running_Aux                                                    Running_Lamp
   |     I:032                                                        O:030
46 +--+----] [--------+-------------------------------------------------( )-------
   |  |     13        |                                                 07
   |  | Disch_Desk    |
   |  | Lamp_Test     |
   |  | PushButton    |
   |  |   I:031       |
   |  +-----] [-------+
   |        12
   |
```

```
                              Bundle Cutting Saw
                              ...Saw Desk Lamps
                              Stacking Machine
File #14 Saw Proj: FLATS3        Page:00017                    21:08 12/05/02
------------------------------------------------------------------------------
   | Saw_Top_LS                                                   Saw_at_Top
   |  1=Struck                                                    Desk_Lamp
   |   I:032                                                        O:030
47 +-+----] [-------+-------------------------------------------------( )--------
   | |   01         |                                                  10
   | |Disch_Desk    |
   | |Lamp_Test     |
   | |Push Button   |
   | |  I:031       |
   | +-----] [------+
   |       12
   | Saw_Hyd_Pump   State_3                                       Saw_Raising
   | Running_Aux     Passed                                        Desk_Lamp
   |   I:032          B3                                             O:030
48 +-+----] [--------------]/[-------+------------------------------------( )--------
   | |   15          503             |                                   11
   | | State_3       [18]            |
   | | Paused      Fast_Flash        |
   | |   B3           B3             |
   | +----] [--------------] [-------+
   | |   503          14             |
   | |  [18]        [2:34]           |
   | |Disch_Desk                     |
   | |Lamp_Test                      |
   | |Push Button                    |
   | |  I:031                        |
   | +----] [------------------------+
   |      12
   |  Saw_Lower     State_3                                      Saw_Lowering
   |  Slow_SOV       Passed                                        Desk_Lamp
   |   O:033          B3                                             O:030
49 +-+----] [--------------]/[-------+------------------------------------( )--------
   | |   10          503             |                                   12
   | |  [23]         [18]            |
   | |Saw_Lower     State_3          |
   | |Fast_SOV       Paused          |
   | |  O:033         B3             |
   | +----] [--------------]/[-------+
   | |   11          503             |
   | |  [22]         [18]            |
   | | State_3                       |
   | | Paused      Fast_Flash        |
   | |   B3           B3             |
   | +----] [--------------] [-------+
   | |   503          14             |
   | |  [18]        [2:34]           |
   | |Disch_Desk                     |
   | |Lamp_Test                      |
   | |Push_Button                    |
   | |  I:031                        |
   | +----] [------------------------+
   |      12
```

```
                              Bundle Cutting Saw
                              ...Saw Desk Lamps
                               Stacking Machine
File #14 Saw Proj: FLATS3        Page:00018                    21:08 12/05/02
-----------------------------------------------------------------------------
   |   State_2
   |   Raise_to                                                     End_Cut
   |   Top_Limit                                                   Desk_Lamp
   |       B3                                                        O:030
50 +-+----] [-------+-----------------------------------------------( )------
   | |    502       |                                                 13
   | |   [17]       |
   | | Disch_Desk   |
   | | Lamp_Test    |
   | | PushButton   |
   | |    I:031     |
   | +-----] [------+
   |        12
   |   Saw_Blade                                                   Saw_Blade
   |  Tension_LS                                                  Tension_OK
   |   1=Healthy                                                   Desk_Lamp
   |     I:032                                                       O:030
51 +-+----] [-------+-----------------------------------------------( )------
   | |     03       |                                                 14
   | | Disch_Desk   |
   | | Lamp_Test    |
   | | PushButton   |
   | |    I:031     |
   | +-----] [------+
   |        12                                                   Tension_Pump
   |  Saw_Tension                                                   Running
   |    Pump_Aux                                                   Desk_Lamp
   |     I:030                                                       O:030
52 +-+----] [-------+-----------------------------------------------( )------
   | |     06       |                                                 15
   | | Disch_Desk   |
   | | Lamp_Test    |
   | | PushButton   |
   | |    I:031     |
   | +-----] [------+
   |        12                                                       Bundle
   |  Saw_Clamps                                                    Clamped
   |  Last_Clamped                                                 Desk_Lamp
   |       B3                                                        O:031
53 +-+----] [-------+-----------------------------------------------( )------
   | |    488       |                                                 10
   | |   [36]       |
   | | Disch_Desk   |
   | | Lamp_Test    |
   | | PushButton   |
   | |    I:031     |
   | +-----] [------+
   |        12
```

```
                                    Bundle Cutting Saw
                                    ...Saw Desk Lamps
                                    Stacking Machine
File #14 Saw Proj: FLATS3          Page:00019                      21:08 12/05/02
------------------------------------------------------------------------------
    |                                                                  Bundle
    |   Saw_Clamps                                                   UnClamped
    |    Raised_LS                                                   Desk_Lamp
    |      O:034                                                       O:031
54 +--+----] [------------------------- +------------------------------( )----
    |  |     10                          |                               11
    |  |                                 |
    |  |                                 |
    |  |Saw_Clamps                       |
    |  |Last_Clamped                     |
    |  |      B3                         |
    |  +------]/[------------------------+
    |  |     488                         |
    |  |     [36]                        |
    |  |                                 |
    |  |Saw_Unclamp                      |
    |  |  Solenoid        Fast_Flash     |
    |  |   O:006             B3          |
    |  +------] [---------------] [------+
    |  |     14              14          |
    |  |     [34]           [2:34]       |
    |  |Disch_Desk                       |
    |  |Lamp_Test                        |
    |  |Push_Button                      |
    |  |    I:031                        |
    |  +------] [------------------------+
    |        12
    |
```

```
                                 Bundle Cutting Saw
                       ...Saw Cutting Length Lamps (from PECs)
                                  Stacking Machine
File #14 Saw Proj: FLATS3        Page:00020                      21:08 12/05/02
-----------------------------------------------------------------------------
   |
   | PECs (photocells) operate at +/- 10 mm from set length
   |
   | West_Saw_Cut       East_Saw_Cut
   | Photocell          Photocell                                  Length_Short
   | 1=Mat_Present      1-Mat_Present                                Desk_Lamp
   |     I:054              I:054                                      O:031
55 +--+----]/[----------------]/[------- +---------------------------------( )-------
   |  |     01               02         |                               13
   |  |                                 |
   |  | Disch_Desk                      |
   |  | Lamp_Test                       |
   |  | PushButton                      |
   |  |     I:031                       |
   |  +-----] [-------------------------+
   |         12
   |
   | West_Saw_Cut       East_Saw_Cut
   | Photocell          Photocell                                Length_Correct
   | 1=Mat_Present      1-Mat_Present                                Desk_Lamp
   |     I:054              I:054                                      O:031
56 +--+----] [----------------]/[------- +---------------------------------( )-------
   |  |     01               02         |                               14
   |  |                                 |
   |  | Disch_Desk                      |
   |  | Lamp_Test                       |
   |  | PushButton                      |
   |  |     I:031                       |
   |  +-----] [-------------------------+
   |         12
   |
   | West_Saw_Cut       East_Saw_Cut
   | Photocell          Photocell                                   Length_Long
   | 1=Mat_Present      1-Mat_Present                                Desk_Lamp
   |     I:054              I:054                                      O:031
57 +--+----] [----------------] [------- +---------------------------------( )-------
   |  |     01               02         |                               15
   |  |                                 |
   |  | Disch_Desk                      |
   |  | Lamp_Test                       |
   |  | PushButton                      |
   |  |     I:031                       |
   |  +-----] [-------------------------+
   |         12
   |
   |
58 +-------------------------------------------------------------------[END]-----
   |
   |
```

Summary

A systematic approach to the writing of programs can improve the chances of high-quality programs being generated in as short a time as possible. This is likely to involve the following: a definition of what is required, a definition of the algorithm to be used, translation of the algorithm into instructions for the PLC, testing and debugging of the program, and documentation to ensure that any person using the program can understand how it works.

Modern safety legislation charges employers with duties that include making the workplace safe and without risks to health and ensuring that plant and machinery are safe and that safe systems of work are set and followed. An important standard relevant to PLCs is IEC 61508: Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems. Emergency stop buttons and safety guard switches must be hardwired and not depend on the PLC software for implementation so that, in the situation where there is a failure of the stop switch or PLC, the system is automatically safe. The system must be fail-safe. This can involve two-handed engaging, protective door monitoring, light curtains, safety mats, and emergency stop relays.

Commissioning of a PLC system involves checking that all the cable connections between the PLC and the plant being controlled are complete, safe, and to the required specification and local standards, checking that the incoming power supply matches the voltage setting for which the PLC is set, checking that all protective devices are set to their appropriate trip settings, checking that emergency stop buttons work, checking that all input/output devices are connected to the correct input/output points and giving the correct signals, loading the software, and testing the software. Fault detection techniques include watchdog timing checks, indicators to show last output set, replication, and expected value checks.

The documentation for a PLC installation should include a description of the plant, specification of the control requirements, details of the programmable logic controller, electrical installation diagrams, lists of all input and output connections, the application program with full commentary on what it is achieving, software backups, and an operating manual, including details of all startup and shutdown procedures and alarms.

Problems

Questions 1 through 7 have four answer options: A, B, C, or D. Choose the correct answer from the answer options.

1. The ladder program elements given in Figure 13.20 can be described by a basic algorithm of the type:

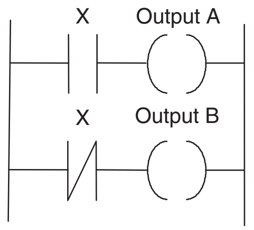

Figure 13.20: Program elements for Problem 1.

A. DO-THEN-DO-ENDDO
B. IF-THEN-ELSE-ENDIF
C. WHILE-DO-ENDWHILE
D. Not described by A, B, or C

2. *Decide whether each of these statements is true (T) or false (F).* The term *forcing,* when applied to a PLC input/output, means using a program to:
(i) Turn on or off inputs/outputs.
(ii) Check that all inputs/outputs give correct responses when selected.
A. (i) T (ii) T
B. (i) T (ii) F
C. (i) F (ii) T
D. (i) F (ii) F

3. *Decide whether each of these statements is true (T) or false (F).* The term *watchdog,* when applied to a PLC, means a checking mechanism that:
(i) Excessive currents are not occurring.
(ii) Functions are carried out within prescribed time limits.
A. (i) T (ii) T
B. (i) T (ii) F
C. (i) F (ii) T
D. (i) F (ii) F

4. *Decide whether each of these statements is true (T) or false (F).* When a PLC is in monitor/test/debug mode, it:
(i) Enables the operation of a program to be simulated.
(ii) Carries out a fault check.
A. (i) T (ii) T
B. (i) T (ii) F
C. (i) F (ii) T
D. (i) F (ii) F

Figure 13.21: Symbol for Problem 5.

5. When a PLC is in monitor/test/debug mode and the symbol shown in Figure 13.21 occurs, it means that an input is:
   A. Defective
   B. Correctly operating
   C. On
   D. Off
6. *Decide whether each of these statements is true (T) or false (F).* Failure of an input sensor or its wiring, rather than failure of an LED or in the PLC input channel, will show as:
   (i) The input LED not coming on.
   (ii) Forcing of that input, making the input LED come on.
   A. (i) T (ii) T
   B. (i) T (ii) F
   C. (i) F (ii) T
   D. (i) F (ii) F
7. A single output device fails to turn on when the output LED is on. The voltage at the output is tested and found normal, but the voltage at the device is found to be absent. The fault is:
   A. Faulty wiring
   B. A faulty output device
   C. A fault in the PLC
   D. A fault in the program
8. Explain how, using forcing, the failure of an input sensor or its wiring can be detected.
9. Suggest possible causes of a complete stoppage of the control operation and the PLC with the power-on lamp off.
10. Suggest possible causes of an output LED being on but the output device failing to turn on.
11. Devise a timing watchdog program to be used to switch off a machine if faults occur in any of the systems controlling its actions.

12. Design the program for a pneumatic system for control by a PLC with the cylinder sequence A+, B+, B–, A– and an LED indicating, in the presence of a fault such as a sticking cylinder, at which point in the cycle the fault occurred. Explain the action of all elements in the system.

Lookup Tasks

13. Look up the safety standard IEC61508. You will also find summaries of the main implications of it on the Web.

14. Find out details of light curtain systems that are commercially available.

15. Find out details of electronic safety relays that are commercially available.