

6 Sequential Applications

Chapter Topics:

- Function charts
- Simple ladder logic implementation of function charts
- Parallel operations

OBJECTIVES

Upon completion of this chapter, you will be able to:

- Draw a function chart, given the operational description of a sequential process
- Translate the function chart to ladder logic
- Handle pause and reset of the sequential operation

Scenario: Using a proximity sensor to detect material moving into and out of a station.

Commonly, only one sensor is used to detect the presence of material as it moves into a station, is processed, and moves out of the station. As an example, consider the problem of applying a label to each box as it travels on a conveyor, shown in Figure 6.1. A retro-reflective proximity sensor (PROX) is used to detect the presence of the box. Assume PROX turns **on** when the box is in the proper position to have the label applied. When the labeling station is started, the presence of a box must be detected, the label is applied (involving multiple steps), and then the operation is repeated. A chart of the steps of this process is shown in Figure 6.2. The process starts waiting for a box to be detected. When PROX turns **on**, then the machinery applies the label (multiple steps). When the labeling steps are finished, then the station waits for the next box. However, as depicted in Figure 6.2, the operation **does not work!** After applying the label, PROX remains **on**, (box still in

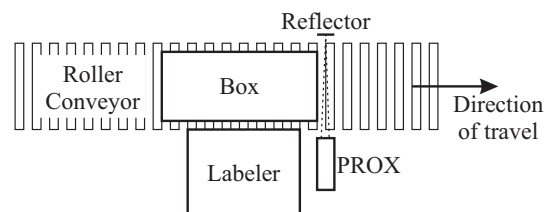


Figure 6.1. Labeling station.

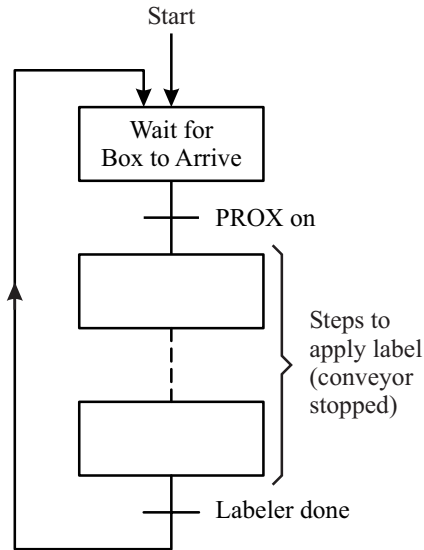


Figure 6.2. Chart of labeling station operation.

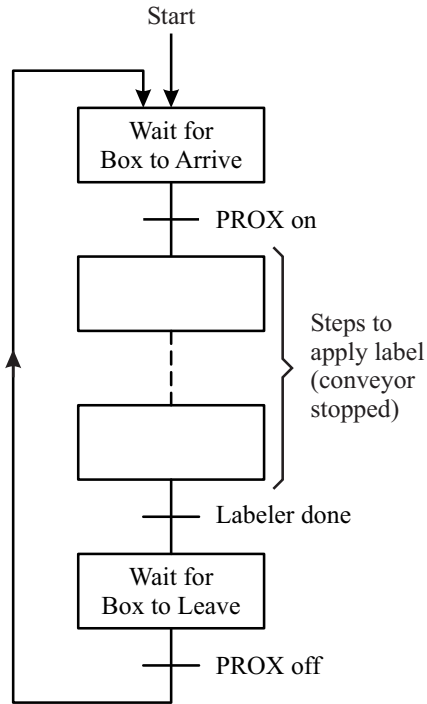


Figure 6.3. Corrected chart of labeling station operation.

station) and so the condition that indicates a new box (**PROX on**) is true. Therefore, a new label is applied to the box before it leaves the station. If left to run unattended, this station will continue to apply multiple labels to the first box that enters the station!

Solution: The station must detect that a labeled box has exited the station before detecting that a new box has entered. Therefore, a step must be added to wait for the box to leave the station, detecting **PROX is off**. The correct chart of this process is shown in Figure 6.3. The moral of this scenario is to remember that one must detect that a proximity sensor is first **off** before it can be detected to be **on**.

Design Tip

When one proximity sensor is used to sense material moving in/out, one must detect that the sensor is **off** before detecting the sensor is **on** (or vice versa).

6.1 INTRODUCTION

With the basic ladder logic contact, timer, and counter instructions, one is able to tackle more significant problems. This chapter introduces ladder logic program design for

sequential applications, a significant contribution of the text. More advanced techniques for sequential control are treated in Chapter 9.

The sequential design technique is based on describing the operation as a function chart and then translating the function chart to ladder logic code. The ladder logic primarily uses the basic contact and coil instructions. Timers and counters are used only when explicitly needed by the operation. The ability to pause and reset an operation is added to the basic sequential design. Operations with parallel steps and machine control involving manual and single-step modes are also considered. Since the design technique uses the set/reset instructions, the last section presents an alternate implementation using only the ordinary output coil that may be used for PLCs that do not have the set/reset coil instructions.

6.2 FUNCTION CHART

The basic tool used to design sequential control applications is the function chart. This method of describing sequential operations is described in the IEC 848 standard (IEC, 1988) and incorporated as one of the IEC 61131-3 languages (IEC, 1993). The form of the function chart described in this chapter is a simplified version of the IEC 61131-3 SFC (sequential function chart) language. The full IEC sequential function chart language is described in Chapter 14.

The general form of the function chart is shown in Figure 6.4. The function chart has the following major parts:

- Steps** of the sequential operation,
- Transition conditions** to move to next step
- Actions** of each step

The **initial step** is indicated by the double-line rectangle. The initial step is the initial state of the ladder logic when the PLC is first powered up or when the operator resets the operation. The **steps** of the operation are shown as rectangles on the left side of the diagram. Unless shown by an arrow, the progression of the steps proceeds from top to bottom. Each step rectangle contains a short description of what is happening during the step. To the left of the step rectangle is the variable/symbol/tag name of the step-in-progress coil (or bit) that is **on** when that step is active. The **transition condition** is shown as a horizontal bar between steps. If a step is active and the transition condition below that step becomes true, the step becomes inactive, and the next step becomes active. The stepwise flow continues until the bottom of the diagram. At the bottom, the sequencing may end, as indicated by a filled black circle within another circle, or it may repeat by going back to the first step. The **actions** associated with a step are shown in the rectangle to the right of the step. The actions are output(s) that are **on** when a step is active. Any outputs not listed are assumed to be **off**. However, the set/reset of outputs may be indicated. Any timer or counter active during a particular step is also listed as an action.

The function chart is prepared from the operational description of the system. Often, the hardest part about formulating the function chart is making a distinction between the transitions and the steps. Also, one must remember that physical outputs are actions associated with a step. In order to help in the recognition of the steps and transitions within an operational description, use the following definitions:

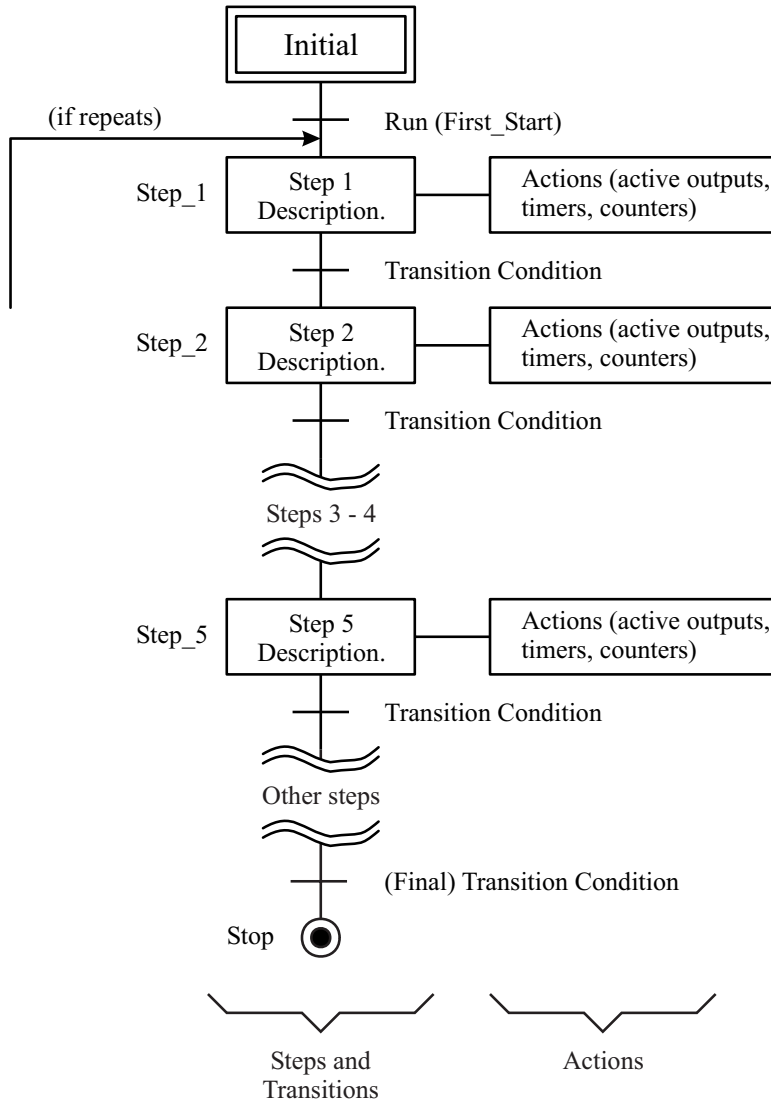


Figure 6.4. General function chart.

Step:

Operation spanning a length of time (however long or short).
The time period may be defined or undefined.

Transition:

Physical input device or internal coil turning **on** or **off**
— or —

Physical input device or internal coil being turned **on** or **off**

A transition condition is recognized when the narrative describes a physical input device or internal coil turning **on** or **off**. Alternatively, the end of a defined time period also

signals a transition to the next step. If the narrative describes a physical output being turned on/off, that is not a transition. A physical output is considered a step action and the turning on/off of a physical output is handled by a change in the active step. For example, if “Output1” is being turned on as the active step is changed from “Step1” to “Step2,” it is accomplished by **not** listing “Output1” as a “Step1” action and by listing it as a “Step2” action. Output1 is **not** a transition condition. The change in Output1 does not cause a change in the active step, but is a consequence of the change in the active step.

Design Tip

When constructing the function chart, remember that physical outputs **never** occur as part of the transition condition. Also, physical inputs are **never** an action.

These concepts are illustrated by the following example.

Example 6.1. Metal Shear Control. Design the function chart of the program to control the metal shear shown in Figure 6.5 and whose operation is described as:

The shear cuts a continuous length of steel strip. Two conveyors (driven by CONV1_MTR and CONV2_MTR) move the strip into position. Inductive proximity sensor PROX turns **on** to indicate that the strip is in position to be sheared. When the strip is in position, both conveyors should stop. A hydraulic cylinder (controlled by SHEAR_CYL_RET) is then retracted to move the shear down to cut the material. Limit switch DOWN_LS closes (turns **on**) when the shear is fully down. The cylinder is then extended to move the shear blade up. Limit switch UP_LS closes when the shear blade is fully up. Conveyor 2 (controlled by CONV2_MTR) is now turned **on** to move the cut sheet out of the station. The proximity sensor PROX turns **off** when the sheet has been moved out of the station. Both conveyors are now operated to move the strip into position, and the operation repeats.

Your program is not controlling conveyor 3, so assume it is always running.

The shear is controlled by SHEAR_CYL_RET, a single action linear hydraulic cylinder. Once SHEAR_CYL_RET is energized, the shear blade moves down to cut the material until a mechanical stop is reached and remains in the “down” position as long as power is applied (turned **on**). The shear blade moves up when power is removed (turned **off**).

Upon initial startup, no material is in the shear and the conveyors operate to bring the material into the shearing position (PROX turns **on**). The start switch should have no effect if the process is already running. If the stop switch is pressed at any time, the station operation should pause, except when the shear blade is moving. If the stop switch is pressed when the shear blade is moving, the blade movement must complete. When the start switch is pressed while the operation is paused, the station should resume the suspended step. When the station is paused, the conveyor drive motors should be shut off.

Assume the following physical input and physical outputs:

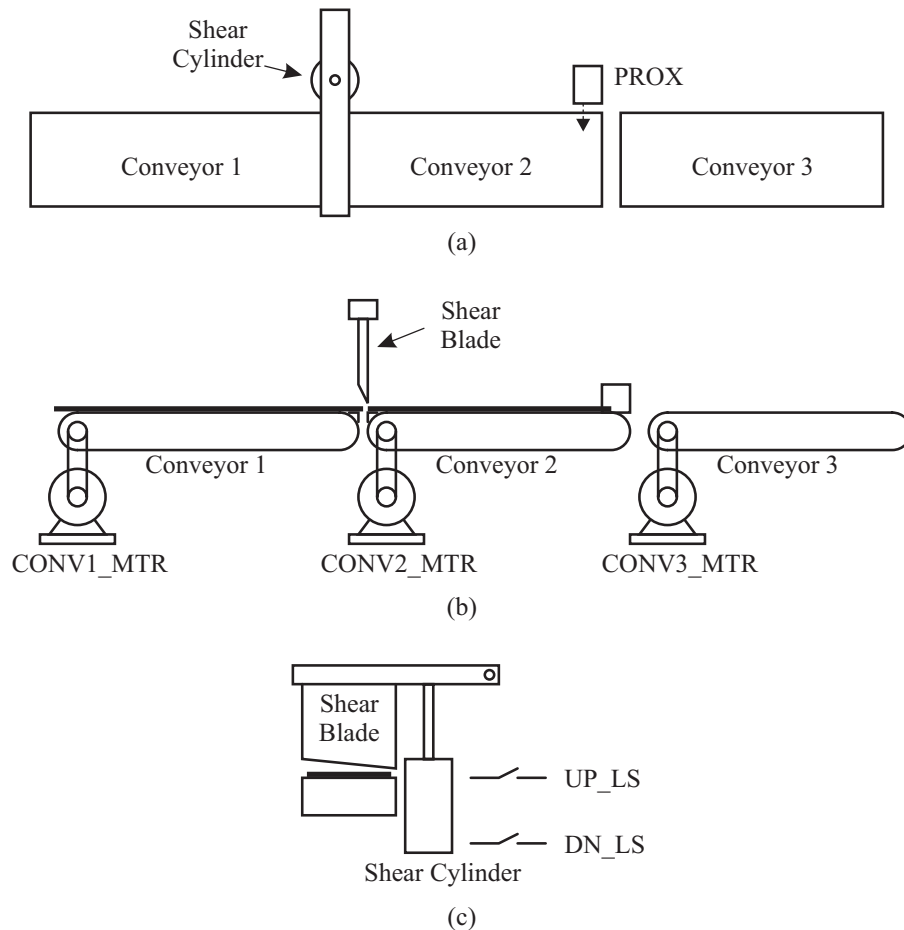


Figure 6.5. Metal shear: (a) top view; (b) front view; (c) side view.

<u>Variable</u>	<u>Description</u>
START_PB	Start push button, N. O., on when starting
STOP_PB	Stop push button, N. C., off when stopping
PROX	Proximity sensor, on when strip in shearing position
DOWN_LS	Limit switch, N. O., on (closed) when blade fully down
UP_LS	Limit switch, N. O., on (closed) when blade fully up
CONV1_MTR	Conveyor 1 control, on to move material on conveyor 1
CONV2_MTR	Conveyor 2 control, on to move material on conveyor 2
SHEAR_CYL_RET	Shear cylinder control, on to retract cylinder and move blade down

Solution. There are two main steps to develop the function chart:

1. Identify the steps and transition conditions.
2. Add step actions.

To identify the steps and transitions, the first paragraph of the process description is repeated, with the steps identified by the underlined phrases and the transition conditions identified by the *italicized phrases*. Often, it is easier to identify the first transition condition (signaled by an input sensor change) and then recognize the step before and the step after the transition condition. Also, many times the steps and transition conditions alternate during the narrative.

The shear cuts a continuous length of steel strip. Two conveyors (driven by CONV1_MTR and CONV2_MTR) move the strip into position. Inductive proximity sensor *PROX turns on* to indicate that the strip is in position to be sheared. When the strip is in position, both conveyors should stop. A hydraulic cylinder (controlled by SHEAR_CYL_RET) is then retracted to move the shear down to cut the material. Limit switch *DOWN_LS closes (turns on)* when the shear is fully down. The cylinder is then extended to move the shear blade up. Limit switch *UP_LS closes* when the shear blade is fully up. Conveyor 2 (controlled by CONV2_MTR) is now turned **on** to move the cut sheet out of the station. The proximity sensor *PROX turns off* when the sheet has been moved out of the station. Both conveyors are now be operated to move the strip into position, and the operation repeats.

Notice that the phrase "... both conveyors should stop." is not marked as a transition condition. This phrase describes a physical output being turned on/off and that will be handled by a change in the active step.

So, the steps and the transition conditions that indicate the end of each step are:

<u>Step</u>	<u>Transition Condition</u> (out of step)
Move strip into position	PROX on
Move shear down	DOWN_LS on
Move shear up	UP_LS on
Move cut sheet out	PROX off

These steps and the transition conditions between them are shown in Figure 6.6. The "off" state of PROX that signals the end of the fourth step is shown with the "/" in front of the variable name. The variable name of the step-in-progress bit for each step is also shown beside the step box. This particular operation repeats, indicated by the line from the fourth step back to the first step.

The next part of the function chart development is to add the actions to each step. Reading back through the metal shear narrative, the process actions for each step are:

<u>Step</u>	<u>Action</u>
Move strip into position	CONV1_MTR and CONV2_MTR
Move shear down	SHEAR_CYL_RET
Move shear up	
Move cut sheet out	CONV2_MTR

These actions are added to the steps and the transition conditions to form the function chart shown in Figure 6.7.

The part of the narrative that describes the operation pause is handled in the ladder logic code and is considered in the following section.

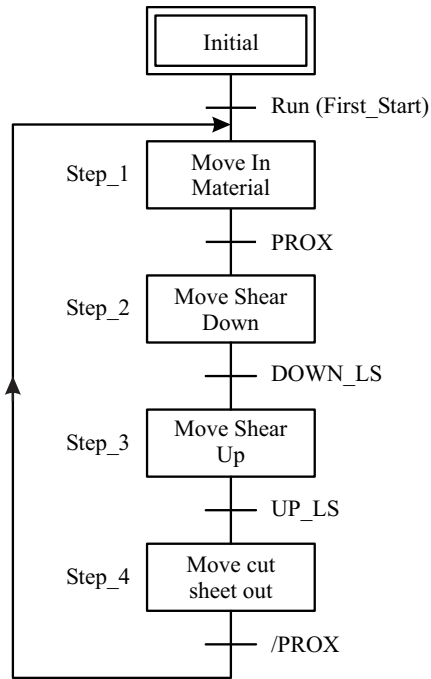


Figure 6.6. Steps and transitions for metal shear.

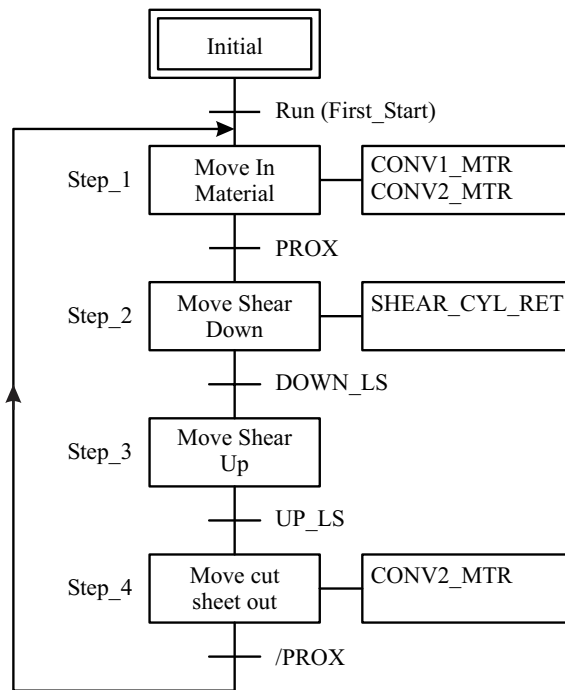


Figure 6.7. Function chart for metal shear.

6.3 IMPLEMENTING FUNCTION CHART IN LADDER LOGIC

Once a function chart has been developed, it needs to be implemented in ladder logic. There are multiple ways to accomplish this task. The design technique described in this chapter utilizes only the basic ladder logic instructions to implement the step and transition logic. Other methods are shown in Chapter 9.

The author calls this method the “cookie cutter” or “template-based” approach because the form of the ladder logic code is the same, regardless of the application. Also, this approach aids in debugging because the logic that handles the transitions and the logic that handles the step actions are distinct. The latter advantage is apparent when comparing this approach to the ad-hoc approach of section 9.5.

The code is broken into the following sections:

- Start/stop/pause of overall operation

- First start

- Transitions between steps

- Step actions

Each of these code templates is covered in detail and then applied to the metal shear of Example 6.1.

The start/stop/pause of the overall operation is handled as the rung in Figure 6.8, which is the same general format as the start/stop rung shown in section 2.7. An internal coil (variable) named Run controls the overall operation of the function chart. It will be used to turn **off** physical outputs that need to be **off** when pausing the operation. Occasionally, the Run may be used as part of a transition condition. The optional permissive conditions must be satisfied to allow the operation to be started or restarted after an abnormal condition. The optional lockout conditions cause the operation to pause or stop in addition to preventing a restart.

The “first start” transition condition causes the operation to be initiated when no steps are currently active. The ladder logic to generate First_Start is shown in Figure 6.9a. When the Run internal coil is turned **on** (start push button pressed) and no steps are active (Step_N is the last step), the First_Start internal coil is turned **on** and will be used as a transition condition into the first step. Alternatively, the first step (Step_1) can be set (latched) to start the operation (Figure 6.9b). START_PB could be used in place of Run in Figure 6.9, but if the run rung has permissive and/or lockout conditions, these conditions should also be repeated on the rung that starts the operation for the first time. As explained in section 2.7, a change to lockouts and permissives should affect only one rung.

Transitions between steps are handled as shown in Figure 6.10. The logic implements the transition condition below the step in the function chart, which is the transition condition

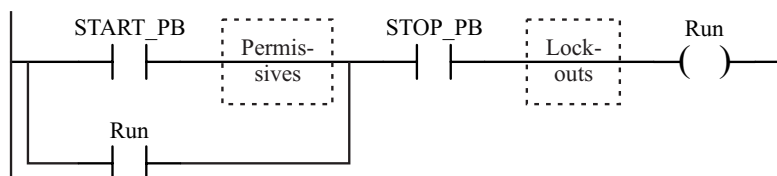


Figure 6.8. General start/stop/pause rung.

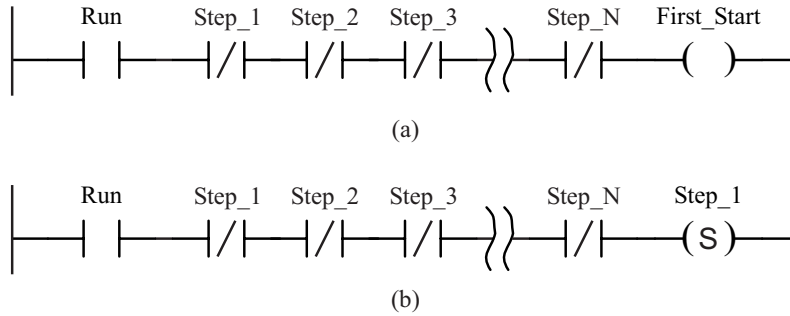


Figure 6.9. General first start rung: (a) First_Start internal coil; (b) set first step.

out of a step. When the current step is active (Current_Step is **on**) and the transition condition is true, then the step-in-progress bit of the next step is set and the step-in-progress-bit of the current step is reset. Thus, the next step becomes active and the current step becomes inactive.

If the PLC does not have set/reset or latch/unlatch instructions (e.g., Modicon 984 and Siemens TI-5x5) then an alternative approach must be used, as detailed in section 6.8.

The step-in-progress internal coils are used to control the step actions. The appropriate step-in-progress bits turn **on** the outputs and timers that are the step actions. The Run internal coil is also used as part of the condition for those actions that must be **off** when the operation is paused. For example, if the MOTOR_ON output should be **on** in steps 4 and 15 of the function chart (represented by Step_4 and Step_15), then the logic driving MOTOR_ON appears as shown in Figure 6.11. The Run internal coil turns **off** MOTOR_ON if step 4 or step 15 is active and the stop push button is pressed to pause the operation. When the operation is resumed (by pressing the start push button), then MOTOR_ON is reactivated. If the Run internal coil is omitted from the rung in Figure 6.11, then MOTOR_ON will remain **on** when the operation is paused when in step 4 or step 15.

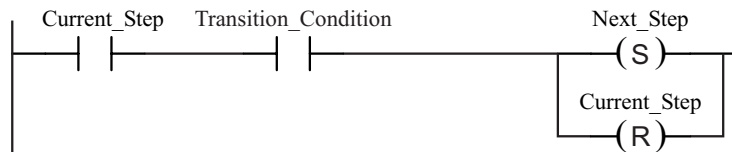


Figure 6.10. General transition between steps.

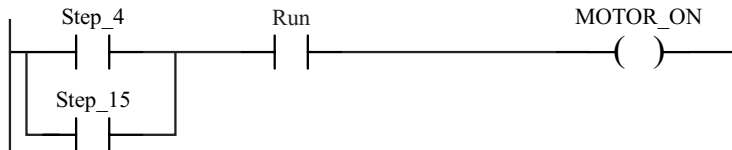


Figure 6.11. Example step action.

Note that in Figure 6.11, the Step_4 and Step_15 step-in-progress bits are in parallel, meaning that MOTOR_ON is an action in steps 4 and 15. The MOTOR_ON output is **off** for any other steps.

If the action associated with a step is a set/reset of an output, then the output coil of Figure 6.11 is replaced by a set or reset coil.

Design Tip

Repeating outputs is a common mistake when implementing a function chart where a particular output is the action for more than one step. Consider the output first and then the steps for which it is **on** to avoid repeating output instructions.

Example 6.2. Metal Shear Control. Use ladder logic to implement the metal shear operation described in Example 6.1.

The physical inputs and physical outputs are:

<u>Variable</u>	<u>Description</u>
START_PB	Start push button, N. O., on when starting
STOP_PB	Stop push button, N. C., off when stopping
PROX	Proximity sensor, on when strip in shearing position
DOWN_LS	Limit switch, N. O., on (closed) when blade fully down
UP_LS	Limit switch, N. O., on (closed) when blade fully up
CONV1_MTR	Conveyor 1 control, on to move material on conveyor 1
CONV2_MTR	Conveyor 2 control, on to move material on conveyor 2
SHEAR_CYL_RET	Shear cylinder control, on to retract cylinder and move blade down

The addresses associated with the variables:

<u>Variable</u>	<u>Modicon</u>	<u>PLC-5</u>	<u>ControlLogix</u>	<u>Siemens</u>	<u>GE Fanuc</u>
START_PB	100001	I:0/00	Local:1:I.Data.0	I0.0	%I1
STOP_PB	100002	I:0/01	Local:1:I.Data.1	I0.1	%I2
PROX	100003	I:0/02	Local:1:I.Data.2	I0.2	%I3
DOWN_LS	100004	I:0/03	Local:1:I.Data.3	I0.3	%I4
UP_LS	100005	I:0/04	Local:1:I.Data.4	I0.4	%I5
CONV1_MTR	000001	O:1/00	Local:2:O.Data.0	Q4.0	%Q1
CONV2_MTR	000002	O:1/01	Local:2:O.Data.1	Q4.1	%Q2
SHEAR_CYL_RET	000003	O:1/02	Local:2:O.Data.2	Q4.2	%Q3

Solution. The function chart for the shear operation is shown in Figure 6.7. Before developing the ladder logic code, the internal variables should be identified:

<u>Variable</u>	<u>Description</u>
Run	Indicates operation running
Step_1 to Step_4	Step-in-progress bits for steps

The addresses or data types associated with the variables:

<u>Variable</u>	<u>Modicon</u> <u>Data Type</u>	<u>PLC-5</u> <u>Addr.</u>	<u>ControlLogix</u> <u>Data Type</u>	<u>Siemens</u> <u>Addr.</u>	<u>GE Fanuc</u> <u>Addr.</u>
Run	BOOL	B3/0	BOOL	M0.0	%M0
Step_1 to	BOOL	B20/1	BOOL	M50.1	%M51
Step_4	BOOL	B20/4	BOOL	M50.4	%M54

The ladder logic code is broken into the following sections:

- Start/stop/pause of overall operation
- First start
- Transitions between steps
- Step actions

The IEC 61131-3 code for the metal shear, shown in Figure 6.12, is developed using the code templates shown in Figures 6.8 - 6.11. A rung comment is shown within a rectangle above the rung. The function of each rung is as follows:

1. Start/stop/pause of overall operation
2. First start (starting the operation for the very first time)
3. Transition from step 1 to step 2
4. Transition from step 2 to step 3
5. Transition from step 3 to step 4
6. Transition from step 4 to step 1
7. Control of conveyor 1 (an action for step 1)
8. Control of conveyor 2 (an action for steps 1 and 4)
9. Control of shear cylinder (an action for step 2)

The initial start of the operation is handled like Figure 6.9b. Note the use of the Run in rungs 7 and 8 to turn **off** the conveyors when the station is paused. Since the shear cylinder operation should not stop if the stop push button is pressed while it is moving, Run is not used as a condition in rung 9.

The CONV2_MTR output is an action for 2 steps, as shown in rung 8 of Figure 6.12. Note that if a particular output is an action for multiple steps, then the step-in-progress bits of each step are placed in parallel. When a particular output is the action for more than one step, novice programmers often repeat the outputs. If one did not consider the output first

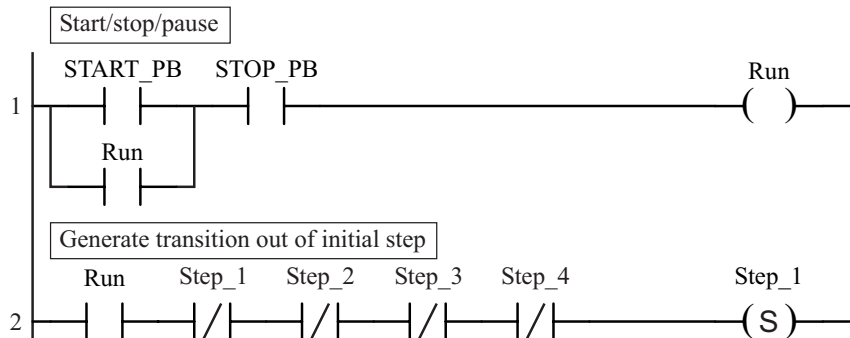


Figure 6.12. IEC ladder logic for metal shear. (continued)

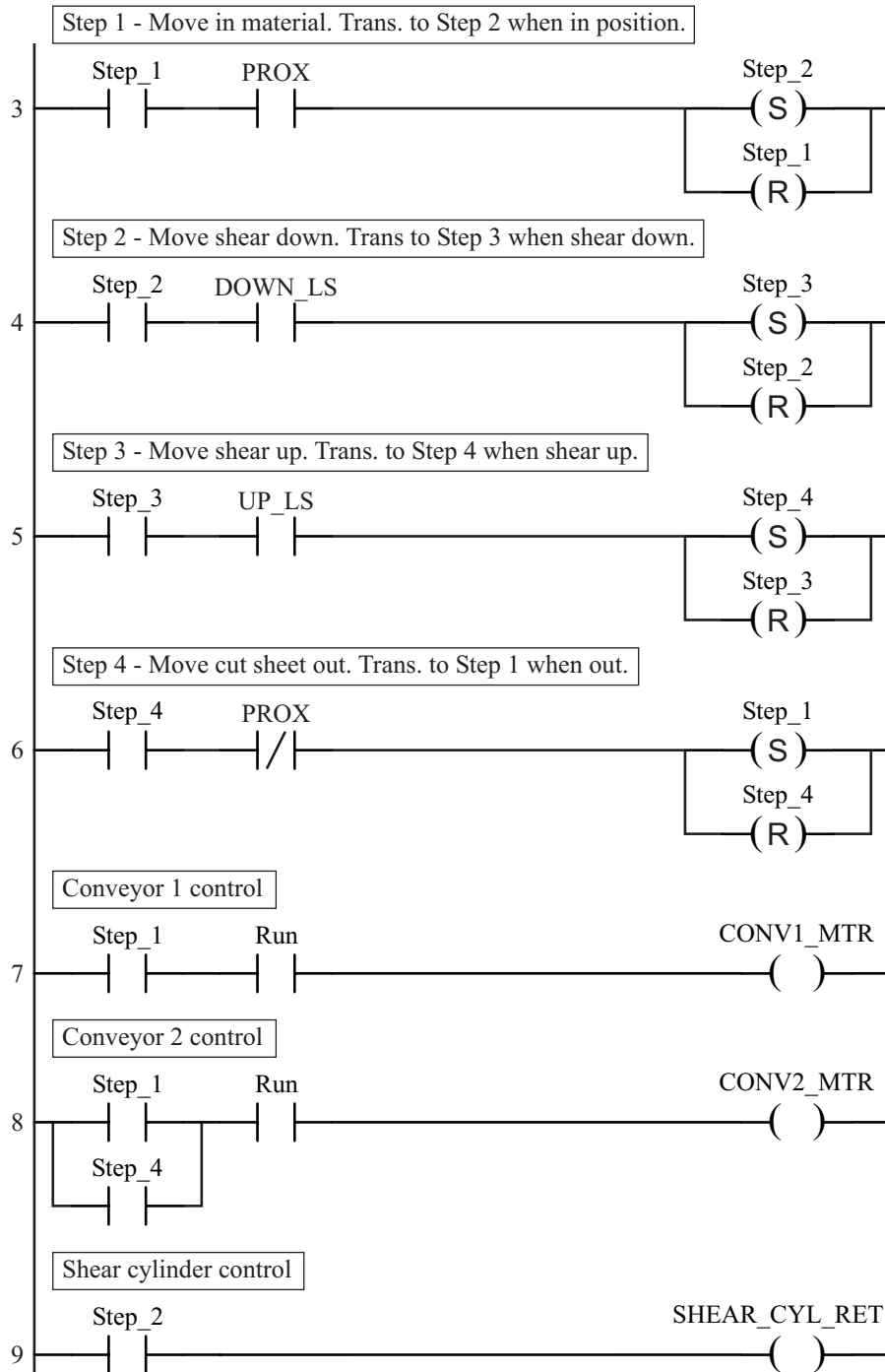


Figure 6.12. (continued)

and then steps for which it is **on** then the ladder logic driving the physical outputs for the shear may appear as in Figure 6.13. Rungs 8 and 10 both drive the CONV2_MTR output. What is the result? Since rung 10 is scanned after rung 8, the logic of rung 10 will override the logic of rung 8. Consequently, CONV2_MTR is never **on** in step 1, causing the material to jam as it is conveyed into position.

Depending on the particular PLC used to implement this example, the ladder logic will appear different from the ladder logic shown in Figure 6.12. If using Modicon Concept, the right power rail is absent and a circle encloses the set and reset instructions. The Allen-Bradley ControlLogix, PLC-5, and SLC-500 use latch/unlatch in place of the set/reset.

Example 6.2 does not have all of the features of a real application, but serves to illustrate the basic approach to implementing a function chart in ladder logic. The next example adds timers, counters, and reset to an application.

Example 6.3. Tub Loader Control. Design the function chart of the program to control the tub loader described below. Also, implement the control with ladder logic.

Figure 6.14 shows the layout of a parts tub loader machine. Parts are placed on the belt conveyor by a milling machine. The parts move down the conveyor and drop into the parts tub. Parts on the belt conveyor are detected by a photoelectric sensor, PE272, which is **off** as a part interrupts the beam. Assume PE272 detects the part as it falls into the tub. After 100 parts are deposited in the tub, the tub is moved out and a new, empty tub moves into position. To change the tub, the following operation must take place:

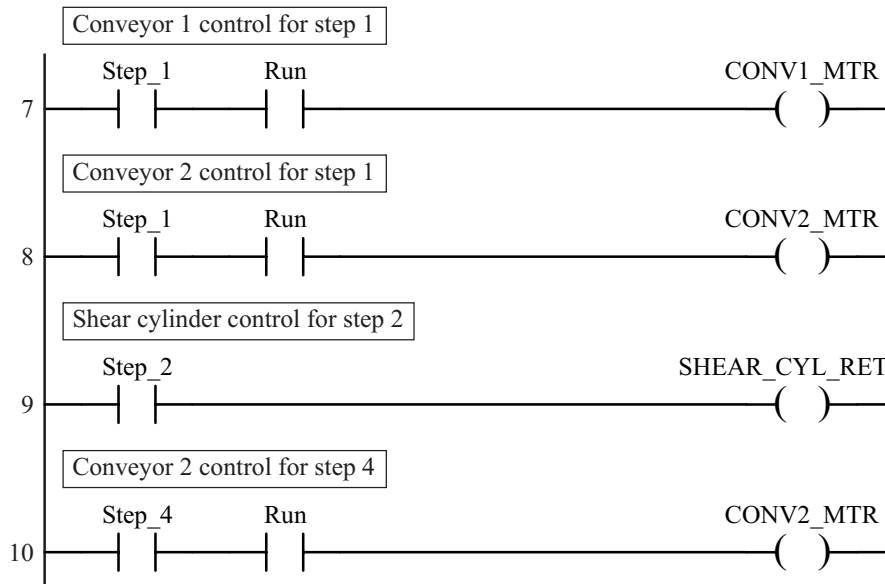


Figure 6.13. Incorrect output logic for metal shear.

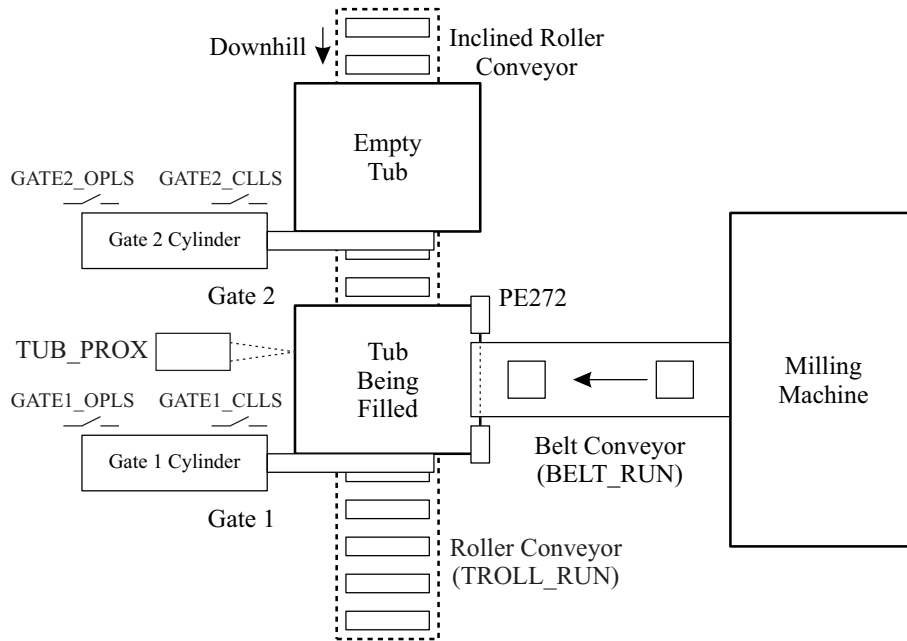


Figure 6.14. Parts tub loading station.

Open Gate 1 (GATE1_OPLS senses when open).

Hold Gate 1 open and wait for TUB_PROX to be **off** for 3 seconds to allow the full tub to be moved out of the loading station. Run the tub roller conveyor to move out the full tub.

Gate 1 is closed (GATE1_CLLS senses when closed).

Gate 2 is opened (GATE2_OPLS senses when open).

Hold Gate 2 open to allow an empty tub to move down a slight incline into the loading station. When the tub contacts the tub roller conveyor, the tub roller conveyor moves the tub into position. When TUB_PROX is **on** for 5 seconds, the tub is in position (front resting on Gate 1).

Gate 2 is closed (GATE2_CLLS senses when closed).

The TUB_PROX proximity sensor is **on** when the tub is present, though not necessarily in position. Hence, the delays ensure the empty tub has moved in and the full one has moved out.

While the tub is being changed, the belt conveyor motor must be stopped (BELT_RUN **off**) and an internal coil, Tub_Permissive, must be turned **off**. After a new tub is in position, BELT_RUN is turned **on**, the Tub_Permissive coil is turned **on**, and the counting of parts is resumed. The Tub_Permissive is used by the milling machine ladder logic. When Tub_Permissive is **on**, the machine produces parts.

The roller conveyor for the tubs has two sections. The section between the two gates and extending out of the station is powered and controlled by the

TROLL_RUN output. The roller conveyor section before Gate 1 is unpowered and inclined to allow new tubs to move into the station. In order to completely move the empty tub into the station, the powered section must be running.

Single-action pneumatic cylinders control Gate 1 and Gate 2. Once GATE1_RET is energized, gate 1 opens and remains in the open position as long as power is applied (turned **on**). The gate closes when power is removed (turned **off**). Limit switches GATE1_OPLS and GATE1_CLLS sense the open and closed positions, respectively. Similarly, GATE2_RET controls Gate 2. The GATE2_OPLS and GATE2_CLLS limit switches sense the position of Gate 2.

Single-speed motors drive the two conveyors. When BELT_RUN is **on**, the conveyor moves parts from the milling machine to the tub. When BELT_RUN is **off**, the conveyor is stopped. When TROLL_RUN is **on**, the powered section of the roller conveyor moves. When TROLL_RUN is **off**, the powered section of the roller conveyor is stopped.

There is an internal coil, Run, that is **on** when the operation is enabled. The Run internal coil is set by another part of the ladder logic. When the Run coil is **off**, the tub loading operation should be paused at the current step. When paused, do not advance to the next step. When the Run coil turns **on** while the operation is paused, the tub loader should resume the suspended step. When paused, both conveyors must be stopped, all counter and timer accumulator values must be retained, and the ladder logic program must remain in the step in which the Run coil changed from **on** to **off**. If the Run coil turns **off** when changing tubs, the pneumatic cylinder controls must continue to be activated, holding the gate open (otherwise, a tub may be damaged).

There is another internal coil, Reset, that when **on**, restarts the operation. The Reset internal coil is set by another part of the ladder logic. When Reset is **on**, internal counters and timers are reset and the internal state is set so that the ladder logic program assumes an empty tub is in position. The Reset internal coil must be ignored while Run is **on**.

Assume the following physical input, physical output, and internal coil assignments:

<u>Variable</u>	<u>Description</u>
PE272	Photoelectric sensor, off when part passes.
TUB_PROX	Proximity sensor, on (closed) when tub is present, though not necessarily in position to receive parts.
GATE1_OPLS	Limit switch, on (closed) when Gate 1 is open.
GATE1_CLLS	Limit switch, on (closed) when Gate 1 is closed.
GATE2_OPLS	Limit switch, on (closed) when Gate 2 is open.
GATE2_CLLS	Limit switch, on (closed) when Gate 2 is closed.
BELT_RUN	Belt conveyor control, on to run conveyor to move parts from milling machine to the parts tub.
TROLL_RUN	Powered roller conveyor control, on to run conveyor to move parts tub.
GATE1_RET	Gate 1 cylinder control, on to retract cylinder and open gate; off closes gate.
GATE2_RET	Gate 2 cylinder control, on to retract cylinder and open gate; off closes gate.

Run	Internal coil, on when loading enabled to operate (controlled by another part of the ladder logic).
Reset	Internal coil, on to reset tub loader operation (controlled by another part of the ladder logic).
Tub_Permissive	Internal coil, on when milling machine is permitted to run (controlled by this part of the ladder logic).

The addresses associated with the physical inputs and outputs are:

<u>Variable</u>	<u>Modicon</u>	<u>PLC-5</u>	<u>ControlLogix</u>	<u>Siemens</u>	<u>GE Fanuc</u>
PE272	100003	I:0/02	Local:1:I.Data.2	I0.2	%I3
TUB_PROX	100004	I:0/03	Local:1:I.Data.3	I0.3	%I4
GATE1_OPLS	100005	I:0/04	Local:1:I.Data.4	I0.4	%I5
GATE1_CLLS	100006	I:0/05	Local:1:I.Data.5	I0.5	%I6
GATE2_OPLS	100007	I:0/06	Local:1:I.Data.6	I0.6	%I7
GATE2_CLLS	100008	I:0/07	Local:1:I.Data.7	I0.7	%I8
BELT_RUN	000001	O:1/00	Local:2:O.Data.0	Q4.0	%Q1
TROLL_RUN	000002	O:1/01	Local:2:O.Data.1	Q4.1	%Q2
GATE1_RET	000003	O:1/02	Local:2:O.Data.2	Q4.2	%Q3
GATE2_RET	000004	O:1/03	Local:2:O.Data.3	Q4.3	%Q4

The addresses/data types associated with the internal variables are:

<u>Variable</u>	<u>Modicon</u>	<u>PLC-5</u>	<u>ControlLogix</u>	<u>Siemens</u>	<u>GE Fanuc</u>
<u>Data Type</u>	<u>Addr.</u>	<u>Data Type</u>	<u>Addr.</u>	<u>Addr.</u>	
Run	BOOL	B3/100	BOOL	M62.0	%M100
Reset	BOOL	B3/101	BOOL	M62.1	%M101
Tub_Permissive	BOOL	B3/102	BOOL	M62.2	%M102

Solution. This example introduces the following aspects of sequential problems:

- Using timers
- Using counters
- Using Run as part of the transition condition
- Reset of the operation

As illustrated in Example 6.1, there are two main steps to develop the function chart:

1. Identify the steps and transition conditions.
2. Add step actions.

To identify the steps and transitions, the first paragraph of the process description is repeated, with the steps identified by the underlined phrases and the transition conditions identified by the *italicized phrases*. As in example 6.1, many times it is easier to identify the first transition condition (signaled by an input sensor change) and then recognize the step before and the step after the transition condition. Often, the steps and transition conditions alternate during the narrative.

Figure 6.14 shows the layout of a parts tub loader machine. Parts are placed on the belt conveyor by a milling machine. The parts move down the conveyor and drop into the parts tub. Parts on the belt conveyor are detected by a photoelectric sensor, PE272, which is **off** as a part interrupts the beam. Assume PE272 detects the part as it falls into the tub. After *100 parts are deposited* in the tub, the tub is

moved out and a new, empty tub moves into position. To change the tub, the following operation must take place:

Open Gate 1 (*GATE1_OPLS* senses when open).

Hold Gate 1 open and wait for *TUB_PROX* to be **off** for 3 seconds to allow the full tub to be moved out of the loading station. Run the tub roller conveyor to move out the full tub.

Gate 1 is closed (*GATE1_CLLS* senses when closed).

Gate 2 is opened (*GATE2_OPLS* senses when open).

Hold Gate 2 open to allow an empty tub to move down a slight incline into the loading station. When the tub contacts the tub roller conveyor, the tub roller conveyor moves the tub into position. When *TUB_PROX* is **on** for 5 seconds, the tub is in position (front resting on Gate 1).

Gate 2 is closed (*GATE2_CLLS* senses when closed).

Since the timer accumulator values must be retained when paused, retentive timers must be used for the time delays. Also, the Run coil must be one of the conditions that controls the timer.

The sentence, “When paused, do not advance to the next step.” normally means that the internal Run coil is part of the transition condition. However, since retentive timers are used for the transition out of the steps holding the gates open, the Run coil is not needed for these steps. One could argue that the Run coil is not needed for the transitions out of the other steps since the conveyors are stopped when paused, but for the purposes of the example, the Run coil is used.

So, the steps and the transition conditions that indicate the end of each step are:

<u>Step</u>	<u>Transition Condition</u> (out of step)
Parts into tub	Part_Ctr done (100 parts detected) and Run
Open Gate 1	GATE1_OPLS on and Run
Hold Gate 1 open	G1_Hold_Tmr done (TUB_PROX off for 3 sec.)
Close Gate 1	GATE1_CLLS on and Run
Open Gate 2	GATE2_OPLS on and Run
Hold Gate 2 open	G2_Hold_Tmr done (TUB_PROX on for 5 sec.)
Close Gate 2	GATE2_CLLS on and Run

The next part of the function chart development is to add the actions to each step. Reading back through the tub loader narrative, the process actions for each step are:

<u>Step</u>	<u>Actions</u>
Parts into tub	BELT_RUN and Tub_Permissive and Part_Ctr (counts 100 parts with /PE272)
Open Gate 1	GATE1_RET
Hold Gate 1 open	GATE1_RET and TROLL_RUN and G1_Hold_Tmr (3 sec.)
Close Gate 1	
Open Gate 2	GATE2_RET
Hold Gate 2 open	GATE2_RET and TROLL_RUN and G2_Hold_Tmr (5 sec.)
Close Gate 2	

The function chart for the tub loader is shown in Figure 6.15. This particular operation repeats, indicated by a line from the last step back to the first step. Before developing the ladder logic code, the internal variables should be identified:

The addresses or data types associated with the variables:

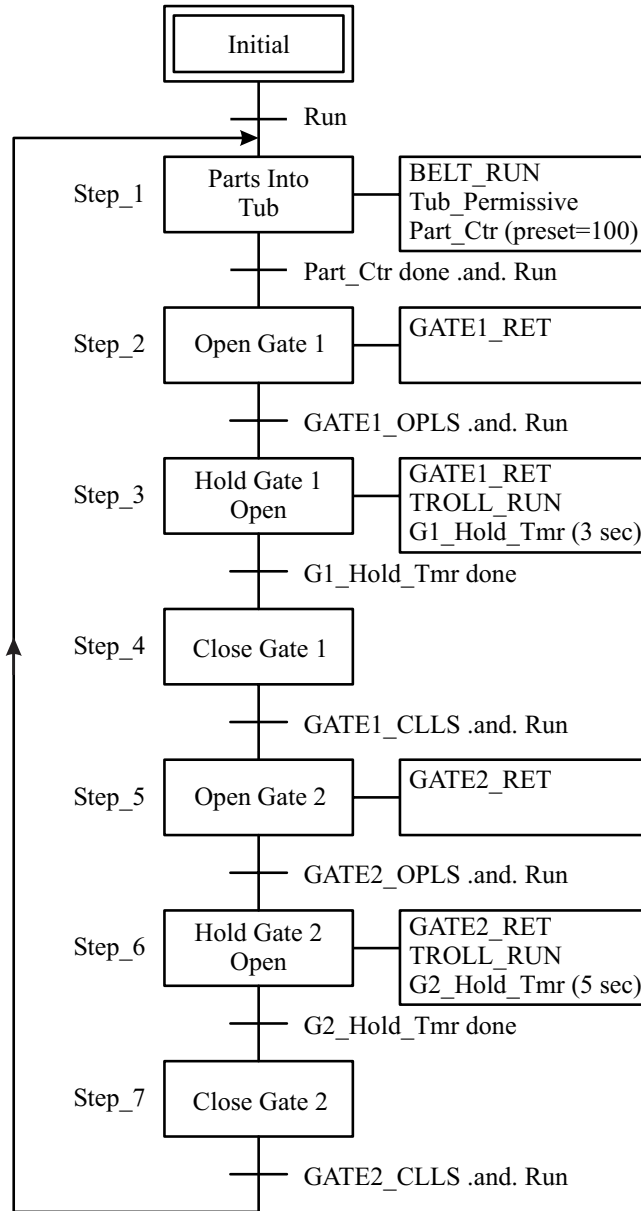


Figure 6.15. Function chart for parts tub loader.

<u>Variable</u>	<u>Modicon</u> <u>Data Type</u>	<u>PLC-5</u> <u>Addr.</u>	<u>ControlLogix</u> <u>Data Type</u>	<u>Siemens</u> <u>Data Type</u>	<u>GE Fanuc</u> <u>Addr.</u>
Step_1 to	BOOL	B20/1	BOOL	M50.1	%M51
Step_7	BOOL	B20/7	BOOL	M50.7	%M57
Int_Reset	BOOL	B20/8	BOOL	M51.0	%M58
Ctr_Done	n/a	n/a	n/a	n/a	%M59
Part_Ctr	n/a	C5:1	COUNTER	DB2	%R101
G1_Hold_Tmr	n/a	T4:1	TIMER	T1	%R104
G2_Hold_Tmr	n/a	T4:2	TIMER	T2	%R107

The ladder logic code is broken into the following sections:

- Start/stop/pause of overall operation
- First start
- Transitions between steps
- Step actions

Since the timers and counters are shown as actions, they may be placed with the rungs that drive the physical outputs. However, since they are also part of the transitions, they may also be placed with the rungs handling the transitions. The author favors the latter approach since the transition condition is more likely to be changed.

The Modicon Concept IEC 61131-3 code for the tub loader, shown in Figure 6.16, is developed using the code templates shown earlier in this chapter. A rung comment is shown within a rectangle above the rung. The function of each rung is as follows:

1. First start (starting the operation for the very first time)
2. Transition from step 1 to step 2 and counting parts
3. Transition from step 2 to step 3
4. Transition from step 3 to step 4 and delay tub prox. off
5. Transition from step 4 to step 5
6. Transition from step 5 to step 6
7. Transition from step 6 to step 7 and delay tub prox. on
8. Transition from step 7 to step 1
9. Control of belt conveyor (an action for step 1)
10. Control of roller conveyor (an action for steps 3 and 6)
11. Control of gate 1 cylinder (an action for steps 2 and 3)
12. Control of gate 2 cylinder (an action for steps 5 and 6)
13. Control of Tub_Permissive (an action for step 1)
14. Reset of steps

Since Modicon Concept does not define a retentive on-delay timer, one must be constructed as outlined in Chapter 5. On rungs 4 and 7 a non-retentive TON timer generates a “tick” every 0.1 seconds which is counted. The counter provides the retentive function. The Run internal coil is part of the input condition for each retentive timer, thus pausing the timer when the station operation is paused.

The reset condition for each counter must also be defined. Two situations must be considered: normal operation and operator-initiated reset. For this solution, the next step is used to normally reset each counter. The operator-initiated reset turns on the Int_Reset internal coil to reset the counters. For example, the counter used to count parts in step 1 is reset when the operation is in step 2 or when Int_Reset is on (Figure 6.16, rung 2).

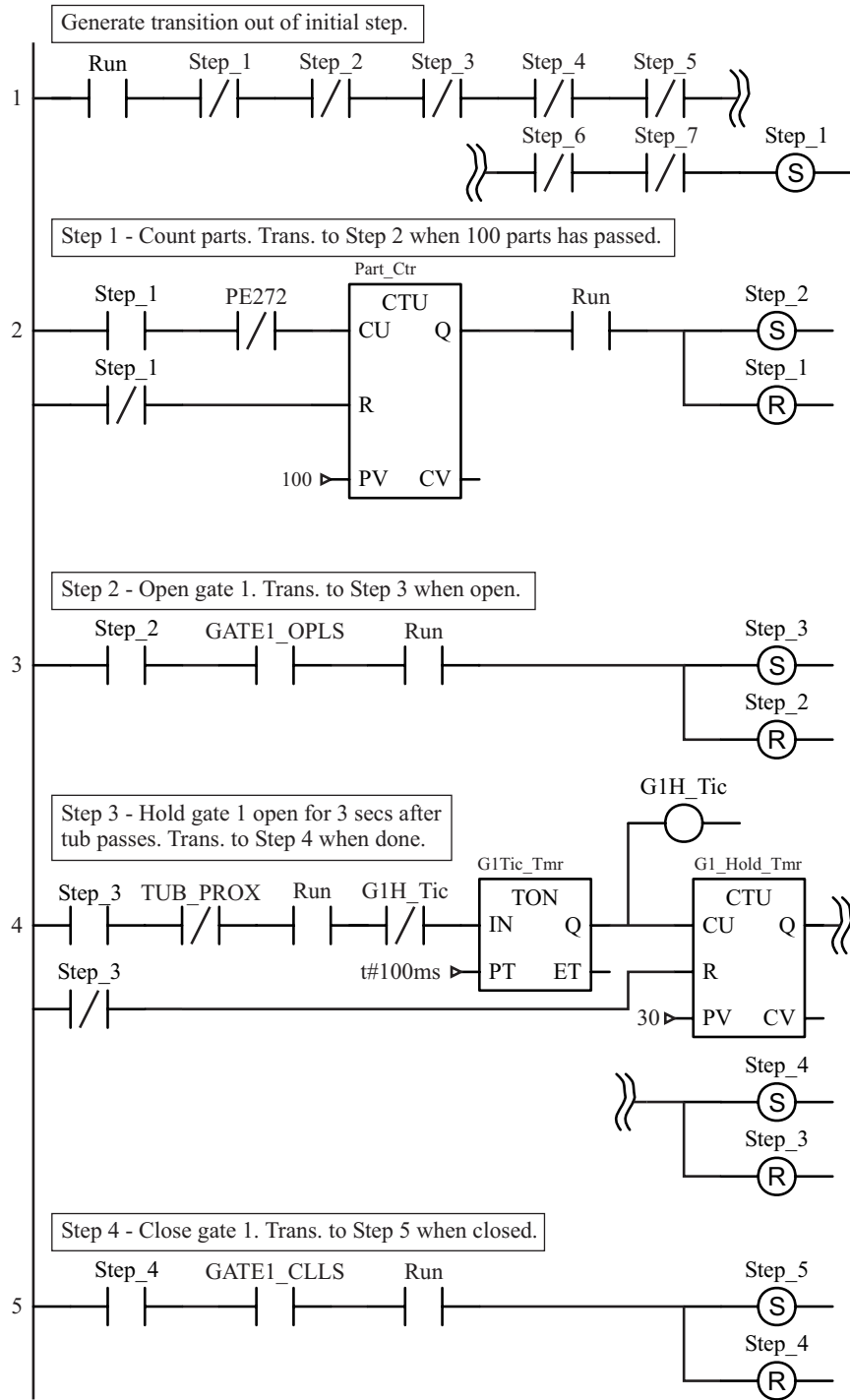


Figure 6.16. Modicon Concept ladder logic for tub loader. (continued)

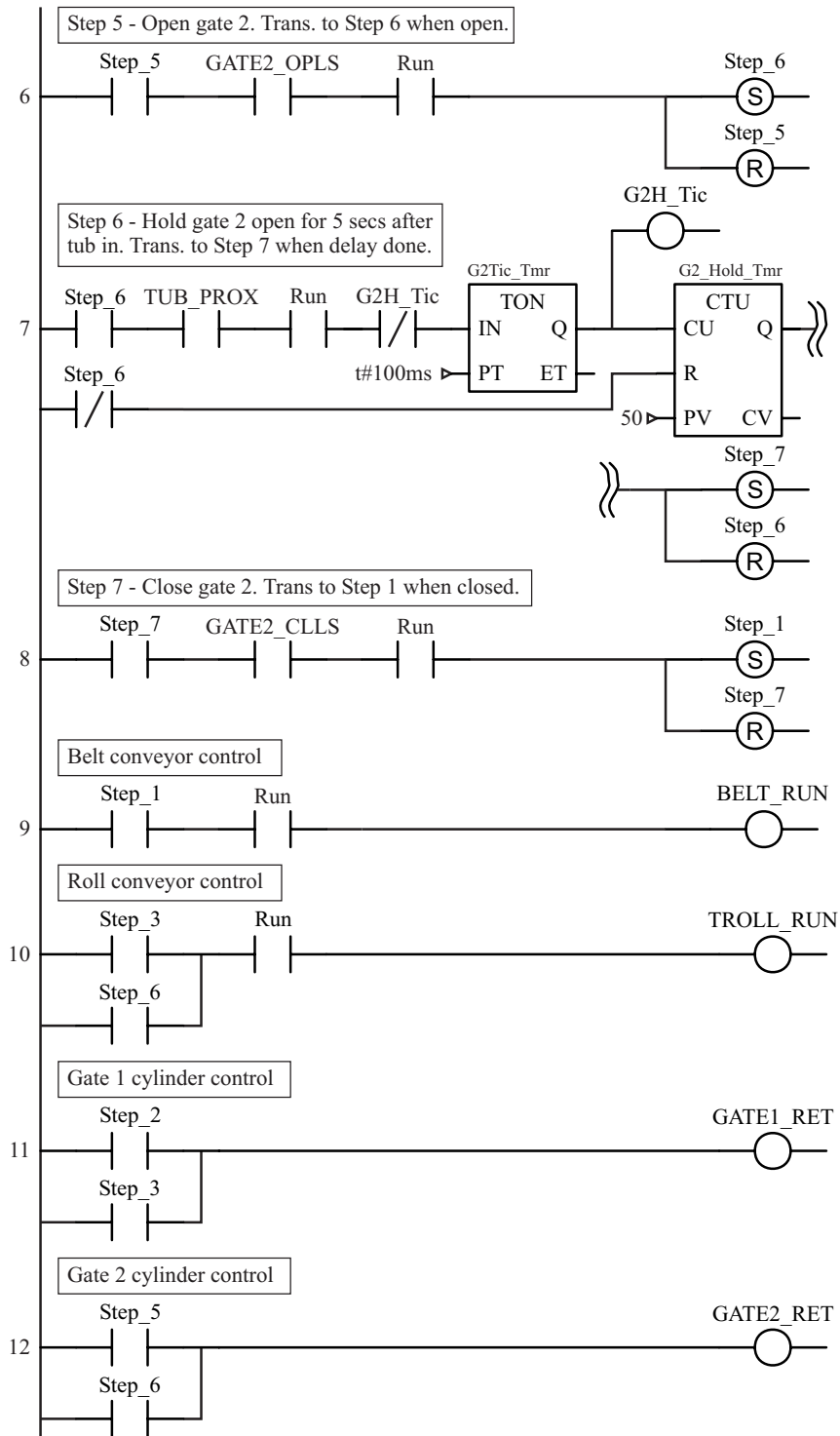


Figure 6.16. (continued)

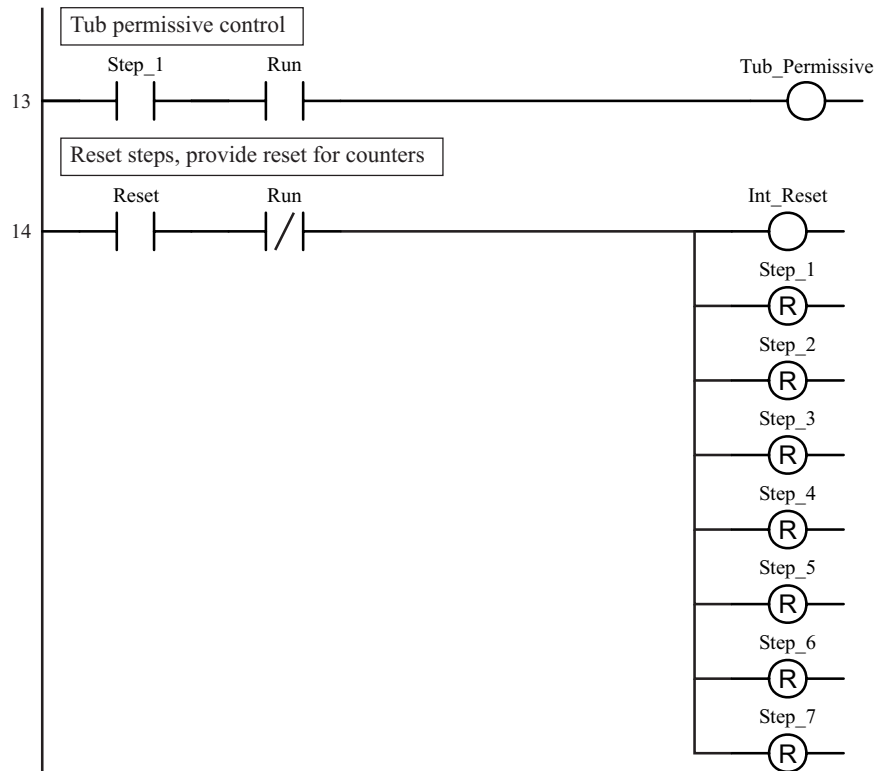


Figure 6.16. (continued)

When the reset push button is pressed while the station is paused, the Int_Reset coil is turned on (to reset the counters) and all step-in-progress coils are reset. This action effectively places the station operation in the initial state.

The Allen-Bradley PLC-5 code for the tub loader appears in Figure 6.17. Besides the use of latch/unlatch in place of set/reset, the only real difference is in the timers and counters. Timers and counters are output instructions, and so no logic can appear in series to the right of these instructions. Therefore, a parallel branch is used to handle the transition to the next step (Figure 6.17, rungs 2, 4, and 7). These parallel branches can be programmed as two rungs. However, in keeping with the convention that timers and counters remain with the transition condition, they are combined on a single rung. As with the IEC 61131-3 code, the Run internal coil is part of the input condition for each retentive timer, thus pausing the timer when the station operation is paused.

The counters and retentive timers are normally reset during the transition to the next step. For example, the Part_Ctr counter used in step 1 to count parts is reset during the transition from step 1 to step 2 (Figure 6.17, rung 3). The reset of retentive timers and counters as a result of an operator-initiated reset is handled on the same rung as the reset of all step-in-progress coils (Figure 6.17, rung 14).

The Allen-Bradley ControlLogix ladder logic code is nearly identical to the PLC-5 code in Figure 6.17. The only differences are:

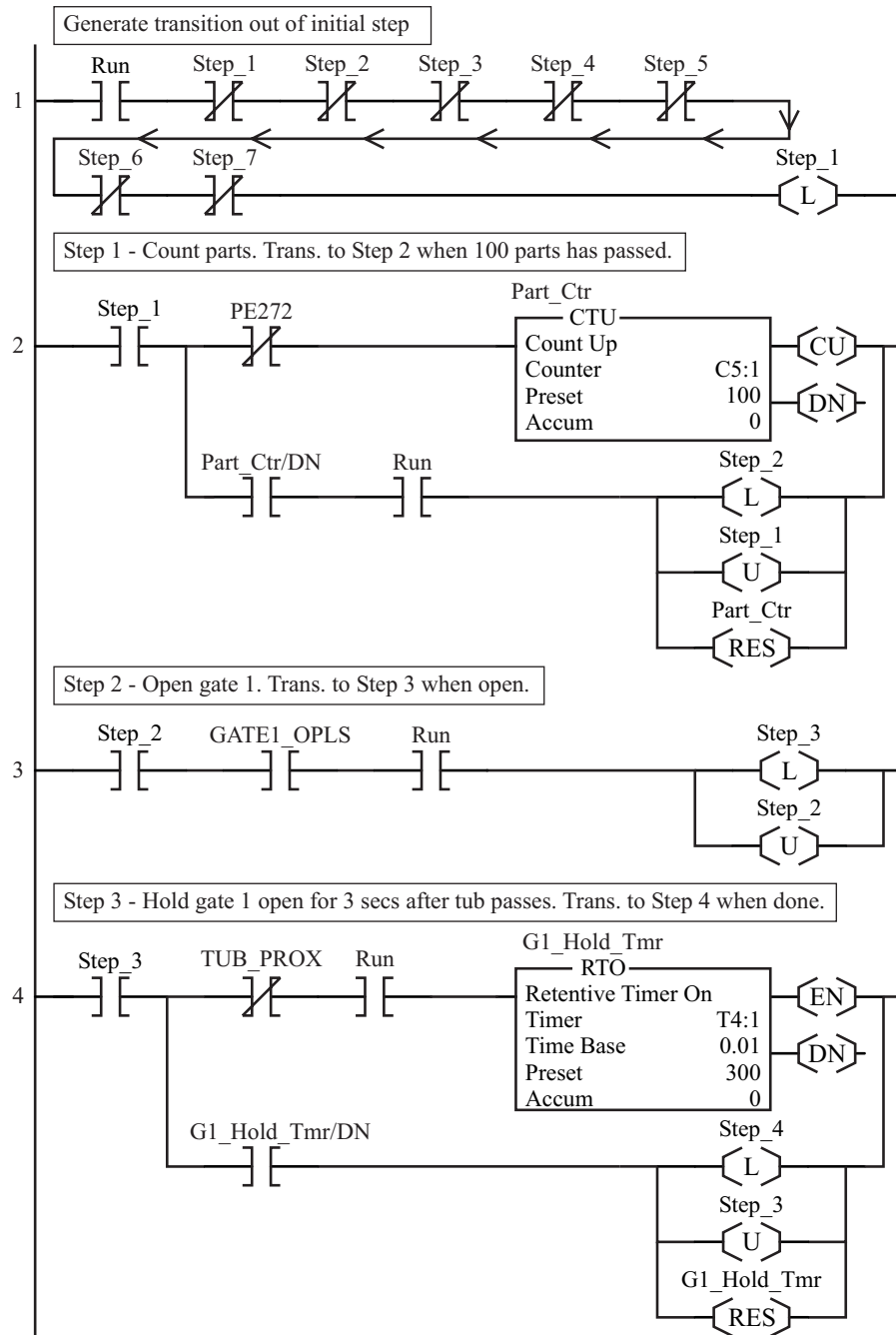


Figure 6.17. Allen-Bradley PLC-5 ladder logic for tub loader. (continued)

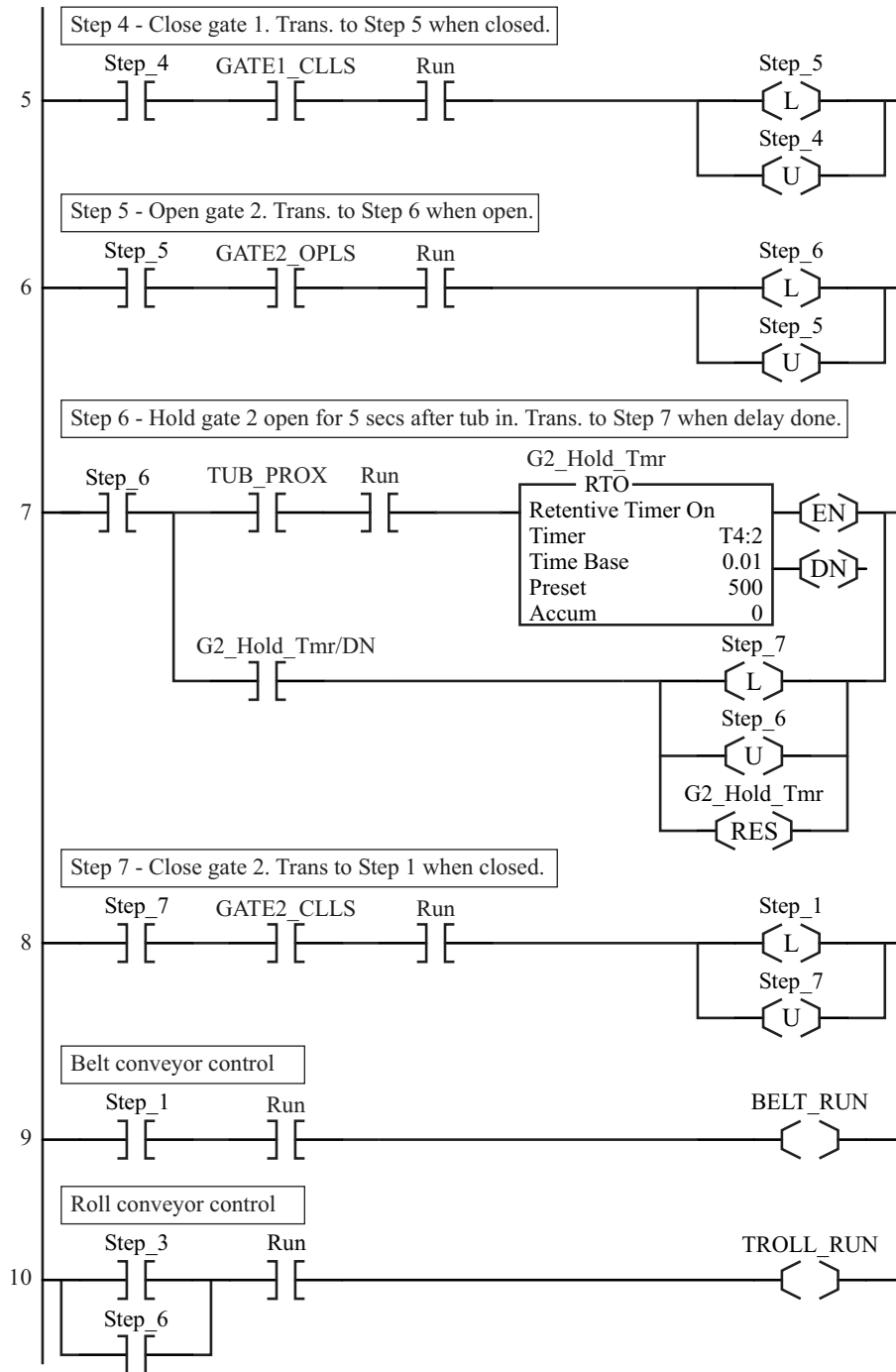


Figure 6.17. (continued)

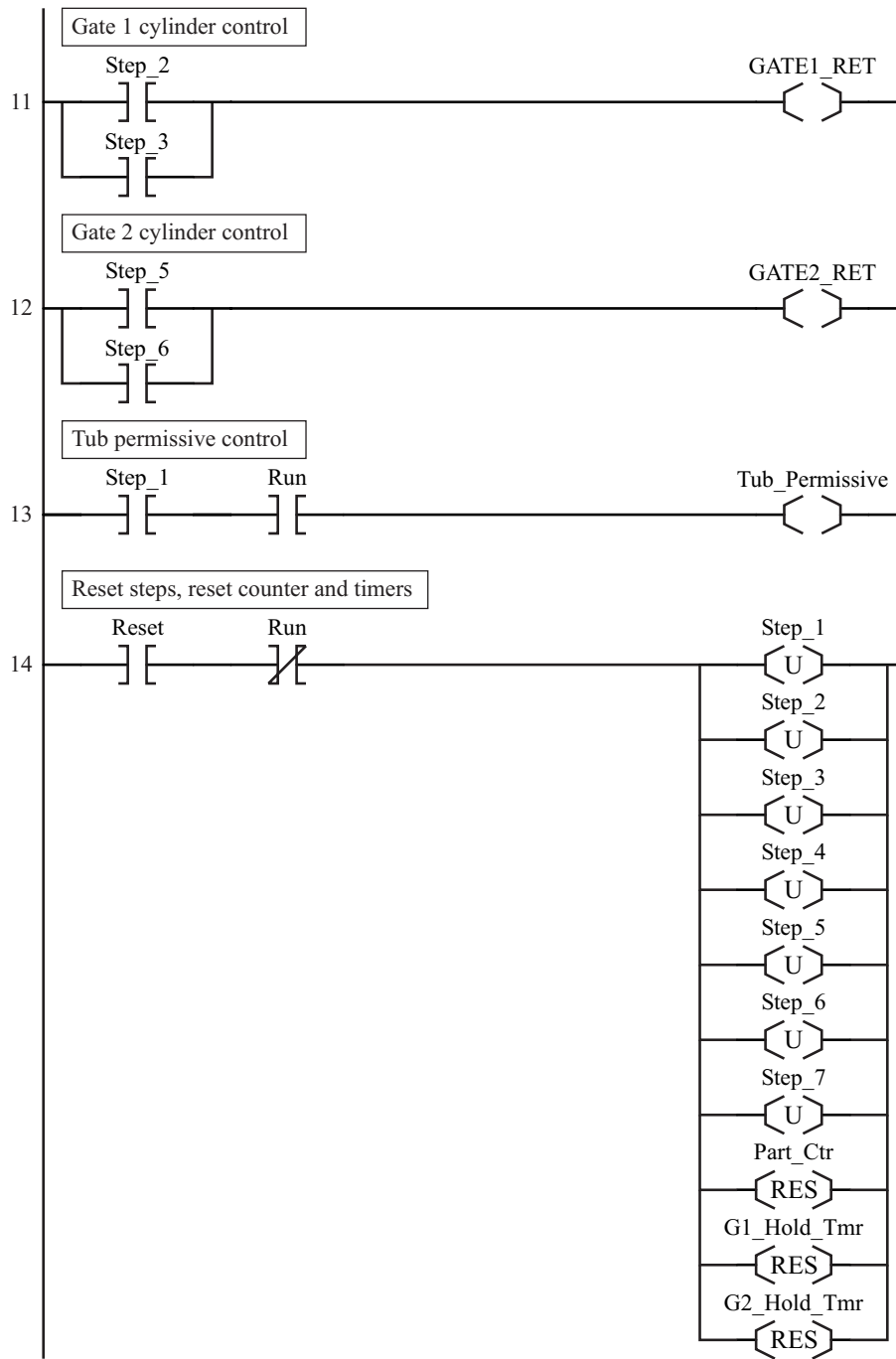


Figure 6.17. (continued)

1. The "Part_Ctr" tag appears in the Counter field of the CTU instruction in rung 3, replacing the address in the PLC-5 CTU instruction.
2. For the timers (rungs 5 and 8), the "Time Base" field is absent and the Preset value is multiplied by 10 (ControlLogix time base is 1 ms). Also, the timer tag appears in the Timer field of the RTO instruction, replacing the address in the PLC-5 RTO instruction.

The Siemens S7 ladder logic code (Figure 6.18) looks most similar to the Modicon PLC. The only differences are in the retentive timers and the counter. The S_ODTS retentive on-delay timer block is used in place of an IEC-compatible TON and CTU as in the Modicon PLC. Also note the use of the "Part_Ctr".Q contact on the ENO output of the counter. Since the CTU block Q output can only connect to a variable, this method allows one to place the "Run" contact in series with the Q output and to control the set and reset coils without starting a new network.

The GE Fanuc ladder logic is shown in Figure 6.19 and is similar to the Modicon and S7 ladder logic. Since the output of the counter in rung 3 cannot connect to a contact, an extra internal coil and rung must be added to accommodate the specification that the operation cannot advance to the next step when paused.

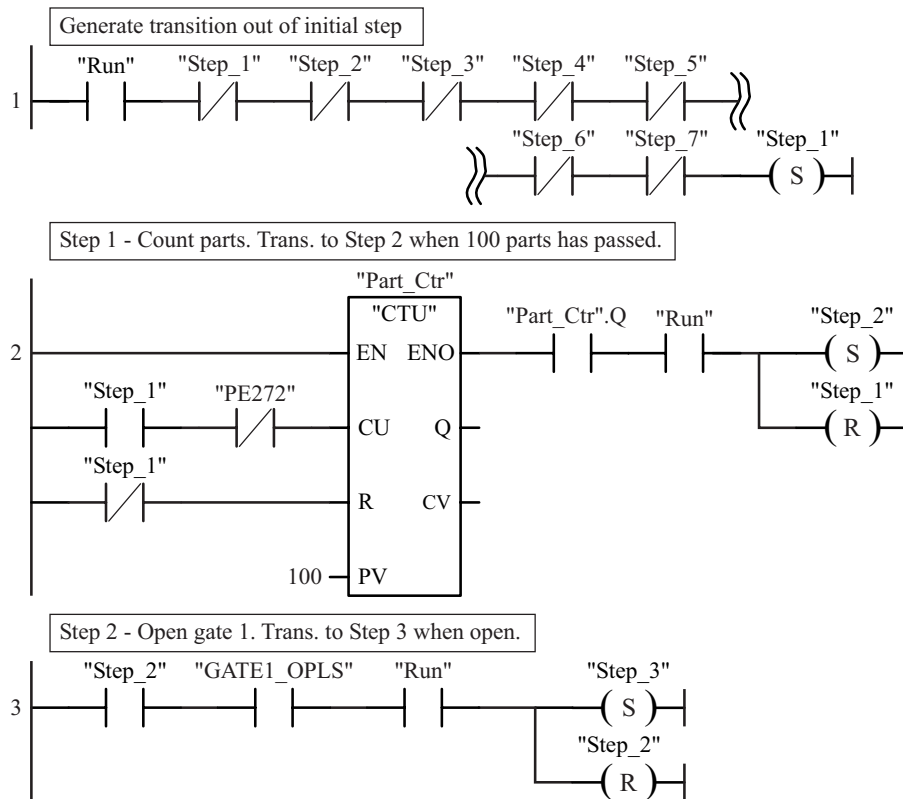


Figure 6.18. Siemens S7 ladder logic code for tub loader. (continued)

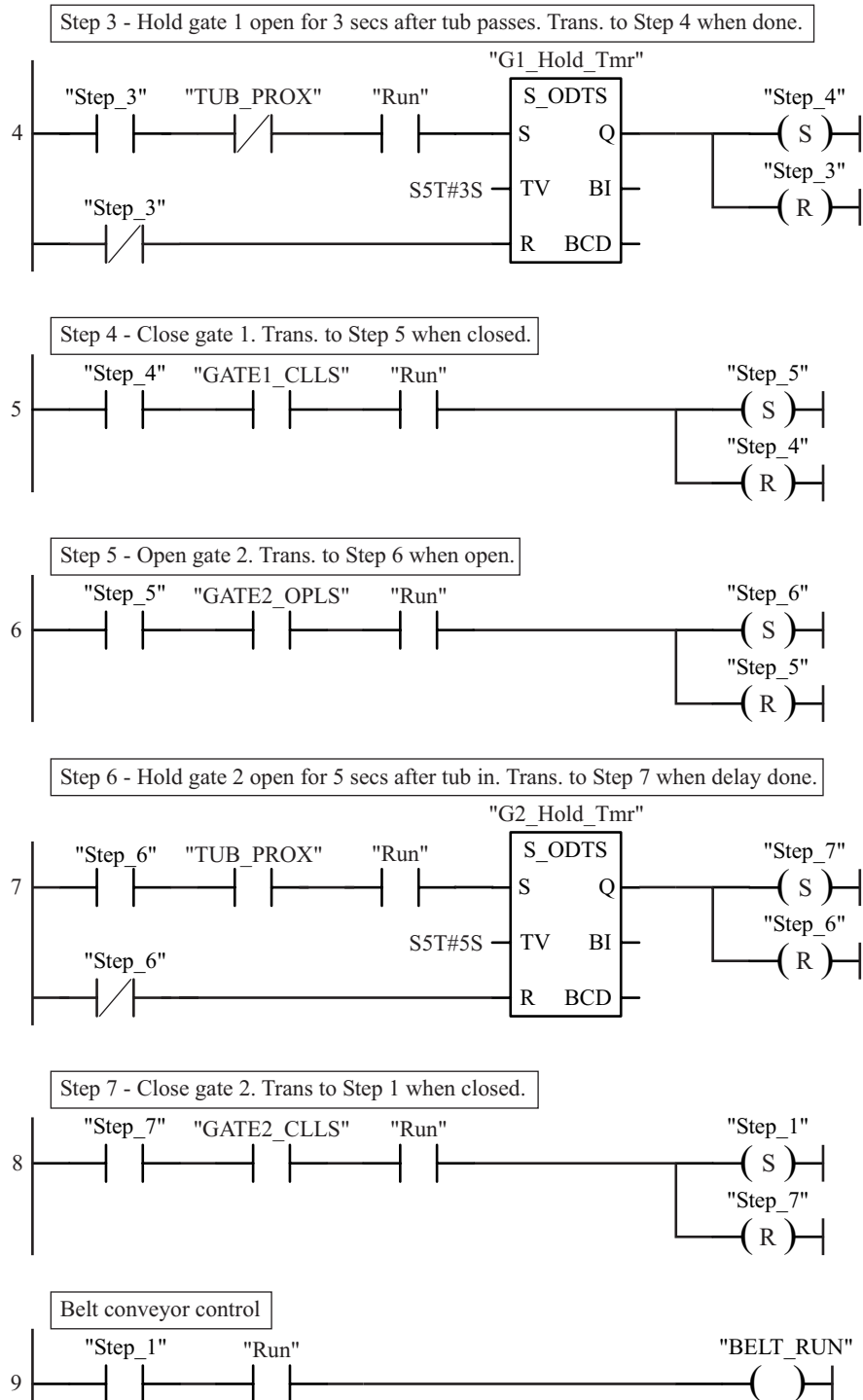


Figure 6.18. (continued)

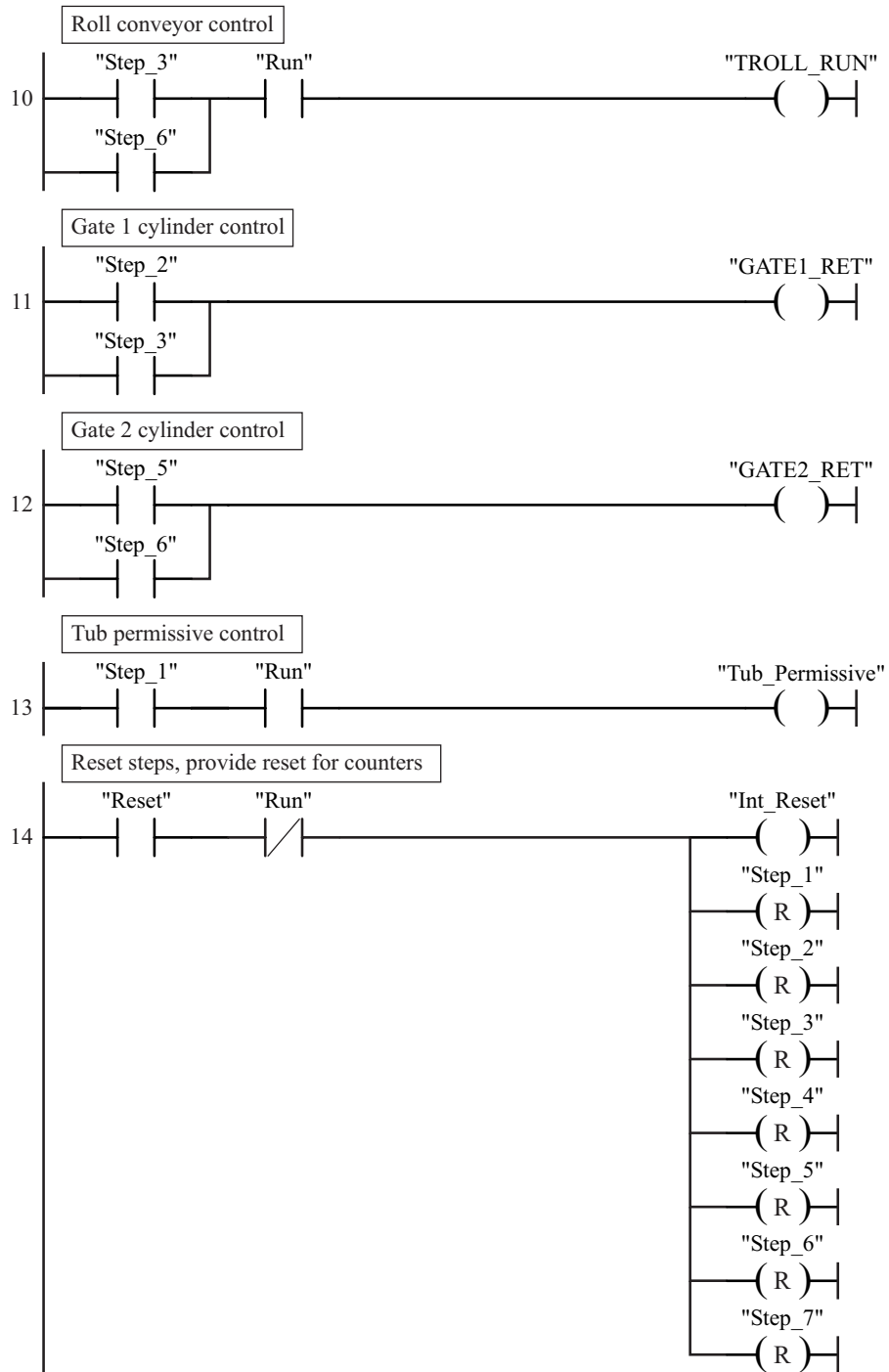


Figure 6.18. (continued)

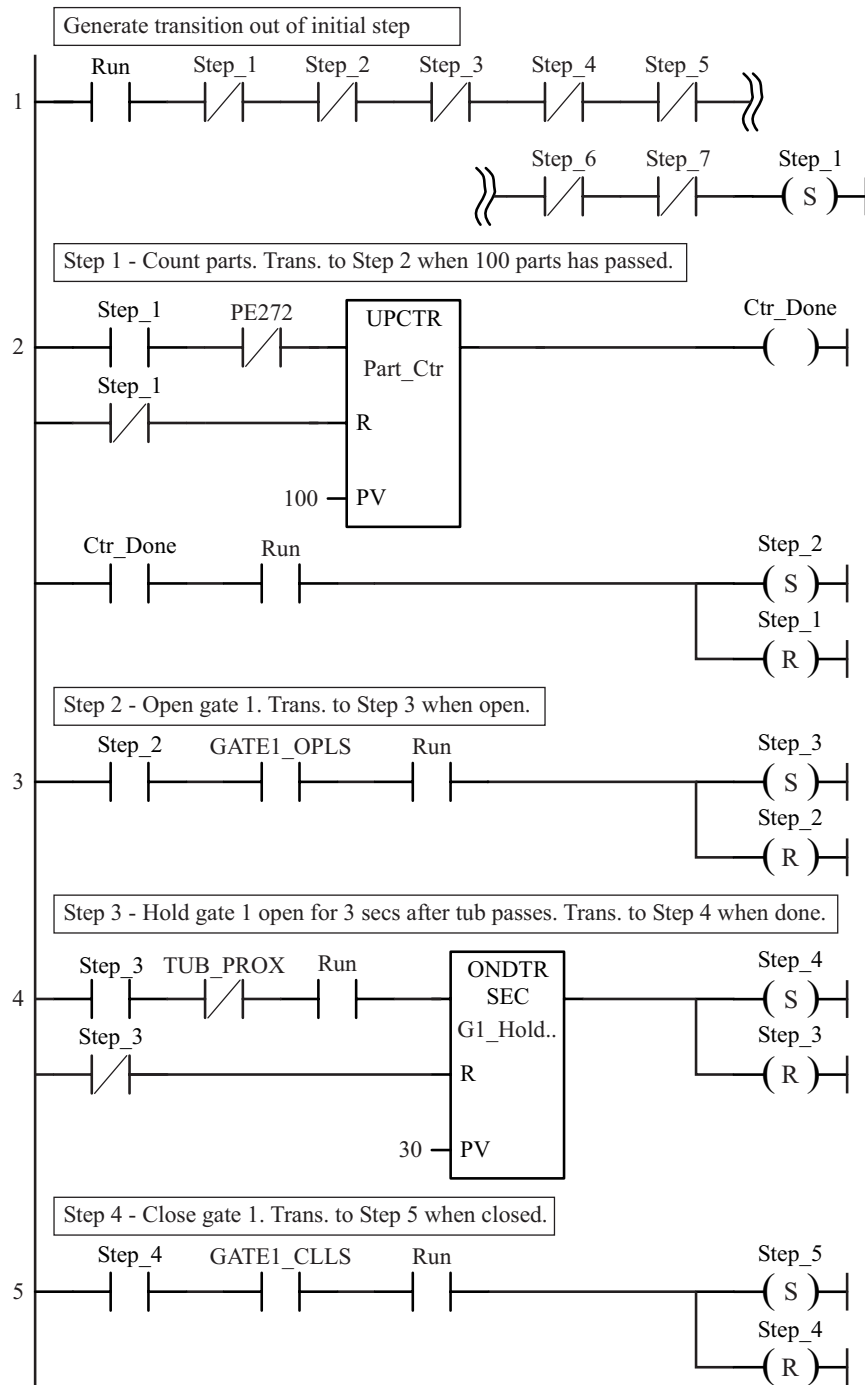


Figure 6.19. GE Fanuc ladder logic code for tub loader. (continued)

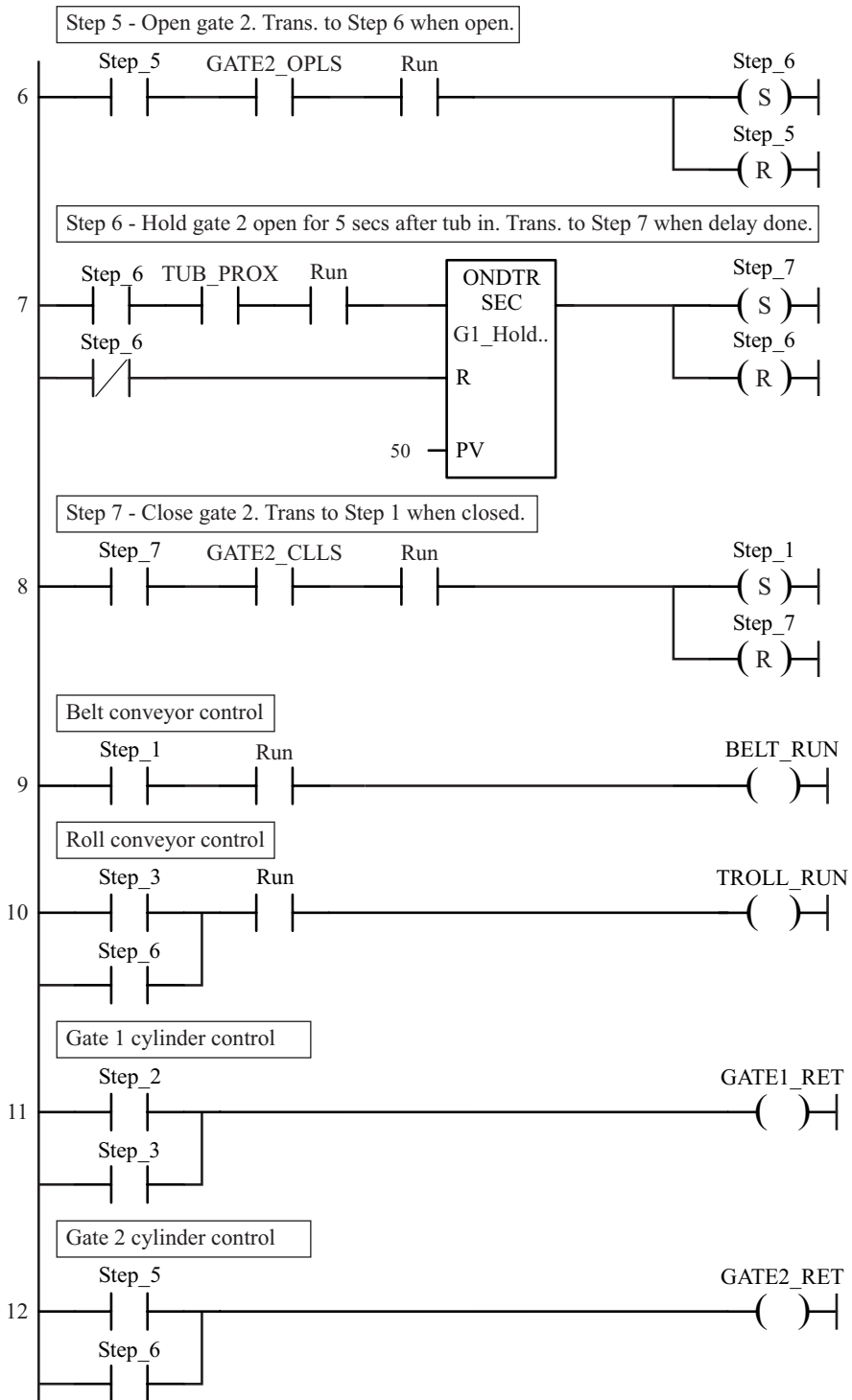


Figure 6.19. (continued)

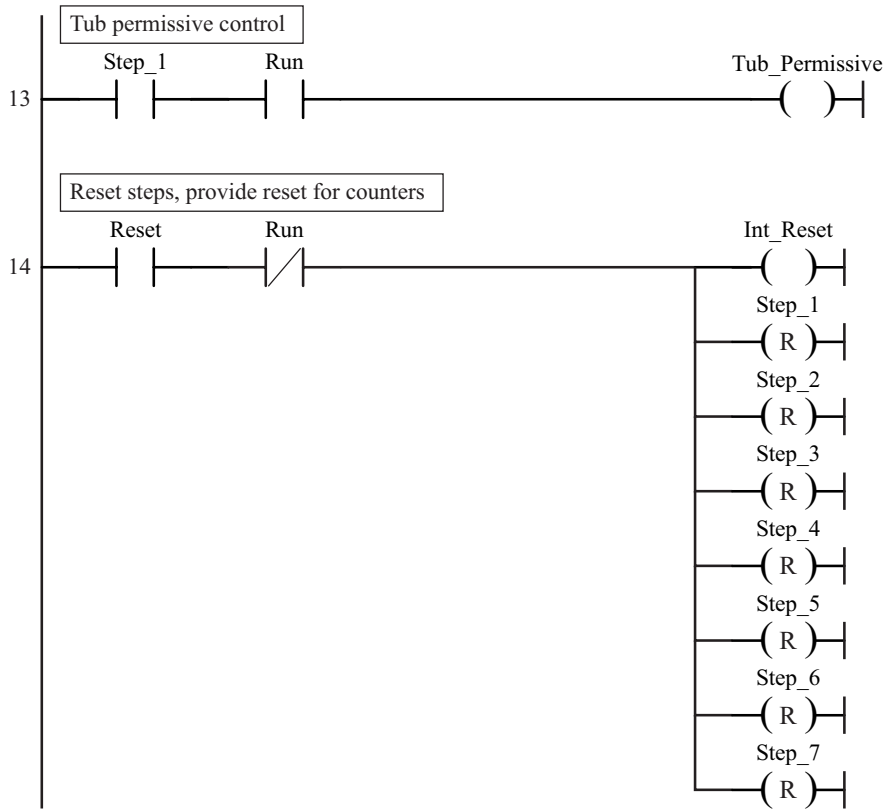


Figure 6.19. (continued)

6.4 COMPLICATED RESET OPERATION

Example 6.3 has most of the features of a real application. The next example illustrates a problem in which the reset operation is more complicated than in the previous example.

Example 6.4. Engine Inverter Station Control. Design the function chart of the program to control the following station that inverts (turns over) gasoline engine assemblies and implement the control with ladder logic.

Figure 6.20 shows the layout of a station that inverts gasoline engine assemblies riding on a pallet as they come down the conveyor. This station is only one in a series of stations along this conveyor. Implement ladder logic for this station only. The conveyor is controlled by another PLC, so assume it is always moving. This particular line is asynchronous, that is, each station processes assemblies at its own speed and does not coordinate its operation with any other station. Because this is an asynchronous line, the station contains two capturing mechanisms (engaging hooks) that control access to the station and allow pallets to queue up before the station.