Chapter 11 USE OF STATE DIAGRAMS

State Diagrams

The question is "What did Delaware. She wore a brand New Jersey, What did Missi sip? She sipped a Minne sota. Where has Oregon, boy? If you wan Al-ask-a. She went to pay her Texas." Wait a minute. We are confusing this poor PLC student. Wrong 'state'.

This chapter introduces the subject of state diagrams and how they play a part in PLC programming. Many of the more complicated problems in control involve state diagrams. This chapter will discuss some examples of state diagrams and their use in control. In Chapters 12 and 13, additional examples of state diagrams will be discussed as well as the programming choices accompanying those problems.

The process below is used to fill the wagon at lower right. An operator starts the silo emptying by pushing the start button. The conveyor starts and the slider gate opens. If the operator stops the system by pushing the stop button, the slider closes followed by a time delay of 30 seconds or enough time for the belt to empty of material. Then the conveyor stops running. If the E-stop or emergency stop button is pushed, the slider closes and the conveyor stops running immediately.

Several conditions that may cause a problem with the filling station including the prox switch which monitors the conveyor belt. If the prox switch does not change state while the conveyor is running, this signifies a broken belt or tripped motor starter for M1, the conveyor motor. Failure will cause the conveyor belt to turn off and the system to stop.

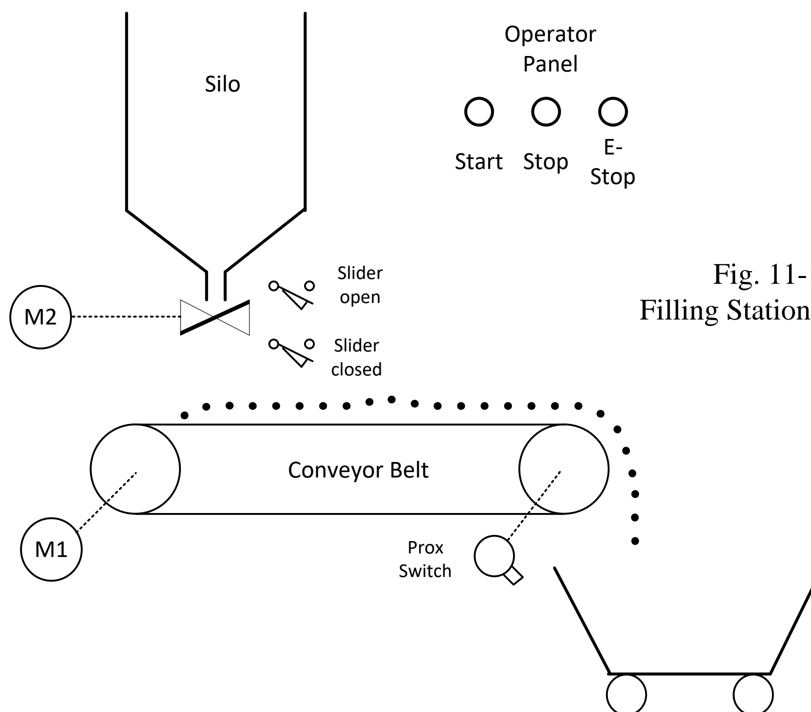


Fig. 11-1a
Filling Station Process

Failure of the slider to open or close after directing the slider in the appropriate direction is also to be detected. If this occurs, the operator is to be notified via an alarm and the conveyor belt is to continue running if failed open but stop if failed closed.

The system needs an initial state usually referenced as "home". The home position of this system is conveyor belt off and slider closed.

Using a State Diagram (or State Graph), the filling station may be defined as below:

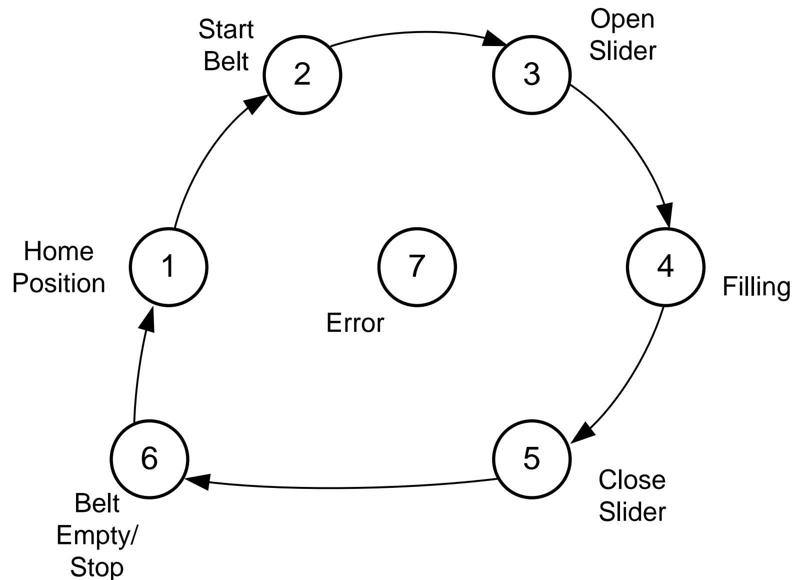


Fig. 11-1b Filling Station State Diagram

The home position requires certain conditions be met before advancing to a next step. This step implies a switch or switches be added to place the machine in this state. Usually, these additional switches are added to a screen on an HMI (human-machine-interface).

A number of conditions exist that cause errors. These include slider open and slider closed at the same time. This condition cannot occur and one of the two sensors is reporting a bad signal. An error state also occurs if the conveyor is running and the prox signal doesn't change state over a period of time. An error would also occur if the slider was directed to open and the open sensor does not change to on in a reasonable time. A similar error would occur if the slider was directed to close and the closed sensor was not energized.

In some systems, the error state is divided into multiple error states if the action resulting is different and the state following the error is different. In this system, an error shuts down the conveyor and closes the slider. The system is then expected to be homed and started normally. An I/O table must be generated to complete the definition of the system before programming commences. The I/O Assignment Table would be similar to the following:

Input Assignments:

Sensor	Function/State	Signal	I/O
Start Button	Starting		
Stop Button	Stopping		
Prox Switch	On-off		
Slider open ls	Slider is open		
Slider closed ls	Slider is closed		
E-stop Button	Emergency stopping		

Output Assignments:

Actuator	Function/State	Signal	I/O
M1 run	Conveyor motor		
M2 open	Open slider		
M2 close	Close slider		

The conveyor and filling station is **not** a good example of a program needing a state diagram. It is not necessary many times to create a state diagram and then implement a control program. In control programs such as the one to control this process, a state diagram may be used to help develop a program but may be not be of enough use to help. Not all processes require a state diagram.

The Pneumatic Cylinder and State Diagrams:

State diagrams are useful in applications using movement especially with pneumatic cylinders and processes requiring movement. A pneumatic cylinder is shown below.

Fig. 11-2
Pneumatic
Cylinder

How an air cylinder works is shown in the diagrams below. An air cylinder moves one of two ways, by single acting or double acting cylinder and air. Looking inside the single acting cylinder we find a spring pushing the cylinder to the left and air pushing the cylinder to the right.

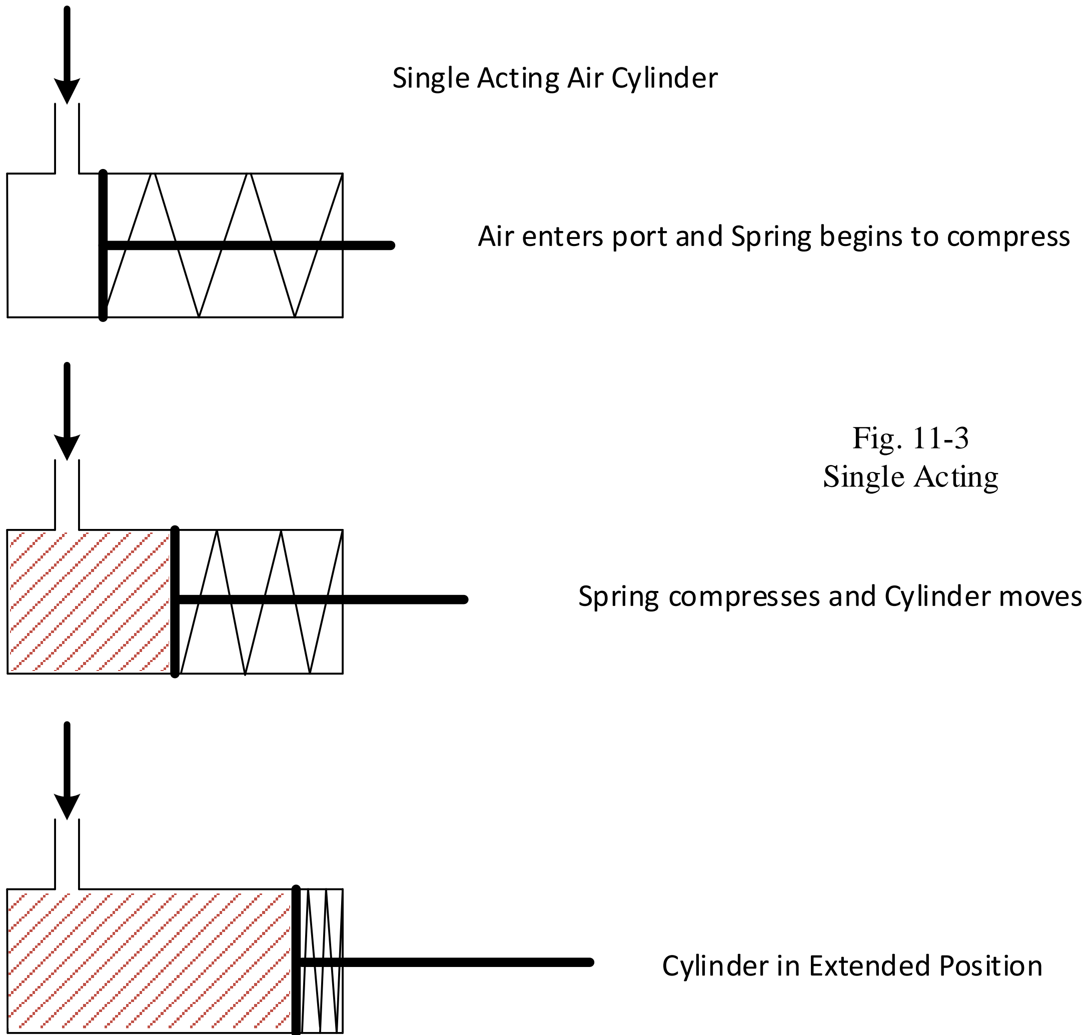


Fig. 11-3
Single Acting

A double acting cylinder is pictured on the next page. The left to right movement and right to left movement is shown with air movement. Air is controlled through valves. There is no spring.

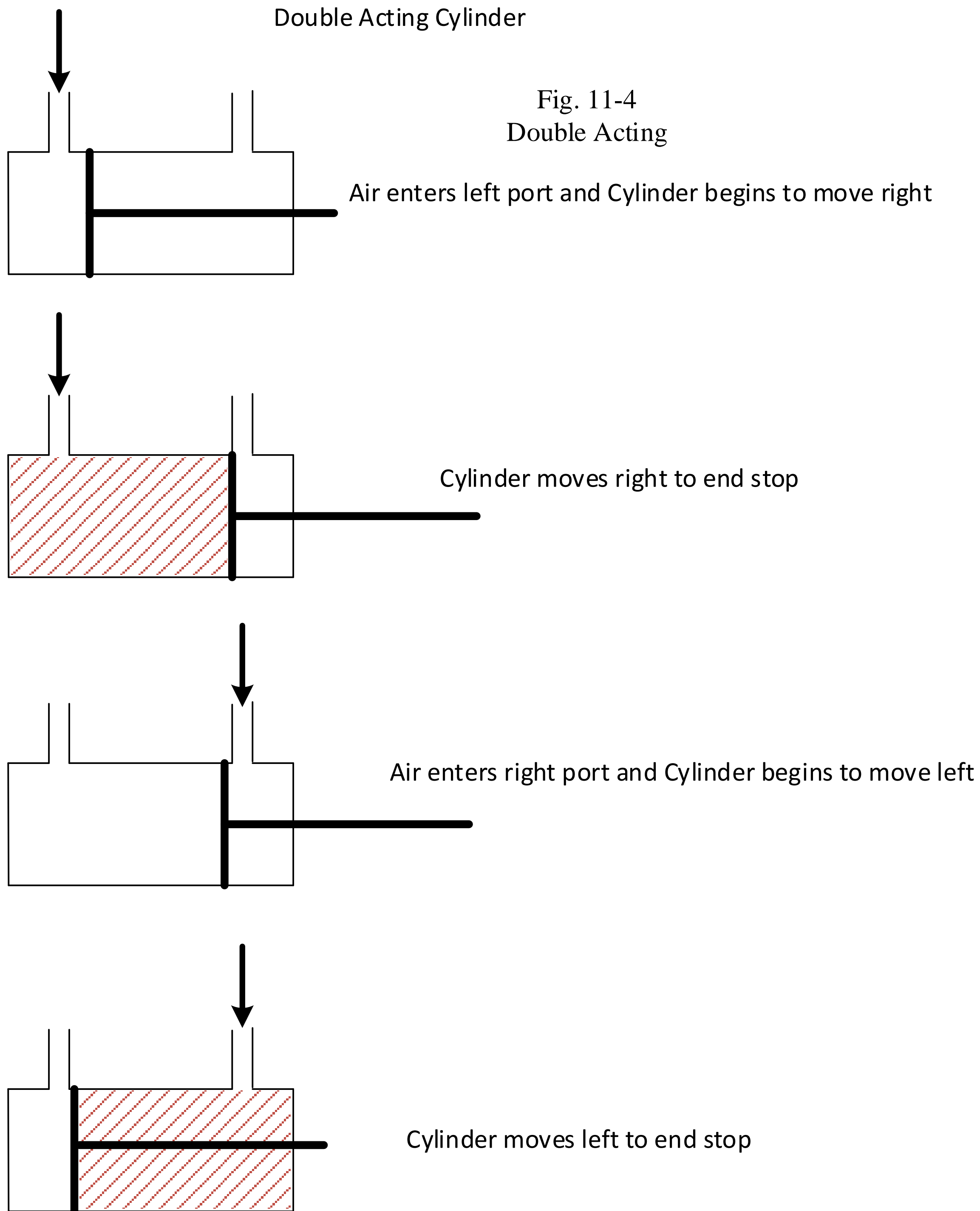


Fig. 11-4
Double Acting

The position of the cylinder is verified in both the closed and open position by reading the metal cylinder with proximity switches. Movement continues in both cases until there is a physical stop the cylinder encounters. There are only two valid positions and both are at end of travel.

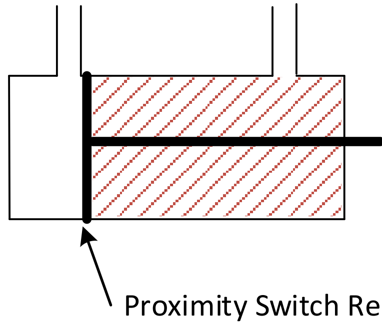
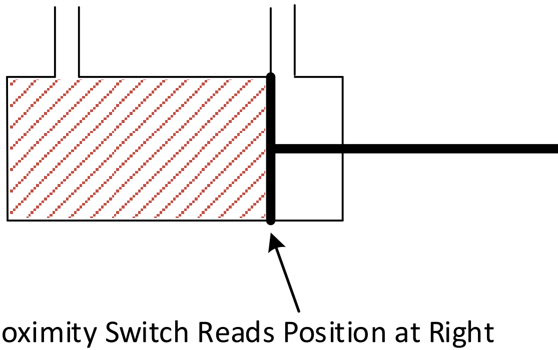


Fig. 11-5
Sensing End of Travel



Both cylinders have similar state diagrams with states shown below. The state diagram below represents the cylinder and its movements very well.

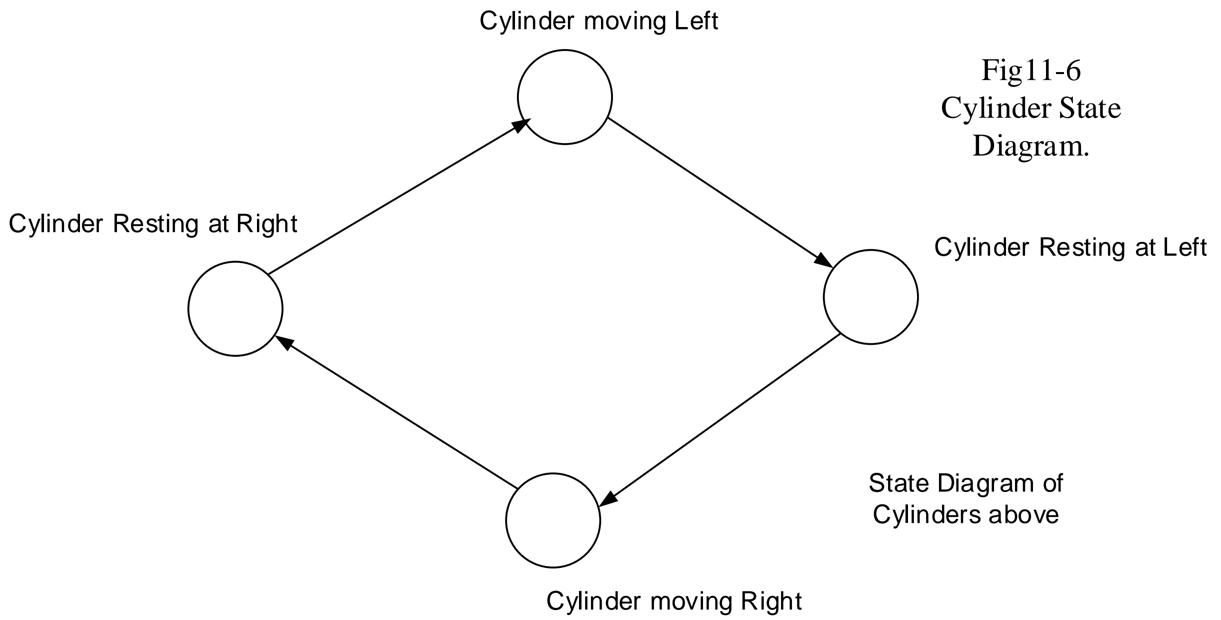


Fig11-6
Cylinder State
Diagram.

Many systems need a home or initial state from which to start. After switching into a mode on the HMI to send the system to a homed position, the home position of the machine must be achieved for proper action. If a slide gate is open, it must be closed. This can also be done via an auto/manual switch on the HMI. In manual, individual devices can be turned on or off or gates moved to a desired position without interference from an automated sequence. For example, in a manual mode, the slide gate referenced above can be opened or closed with an open and close pushbutton from the HMI. These buttons should be added to the sensor table and assigned internal bit addresses.

The programming language type must be selected. While some prefer a language similar to the State Diagram, most prefer the PLC's LAD (Ladder) or FBD (Function Block Diagram) language.

In the state diagram below, the error step may be jumped to from various steps and then a move is allowed to an initial state of 1 or a home state. The rules for error or the logic causing the jump to step 7 are usually included in the box and may be stated in a number of different formats. It is best to include a written description of the logic to jump from state to state.

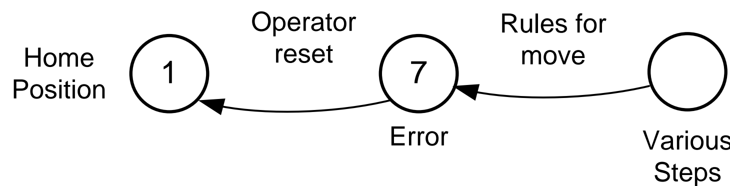


Fig. 11-7 Filling Station Error Recovery

Finding 2's Complement - A Simple State Diagram

The logic for converting a number to the 2's complement is shown below. This logic can be explained by a simple State Diagram. In this example, state 1 = M0.0 off and state 2 = M0.0 on. The word being examined is M2, M3 and the result resides in M4, M5.

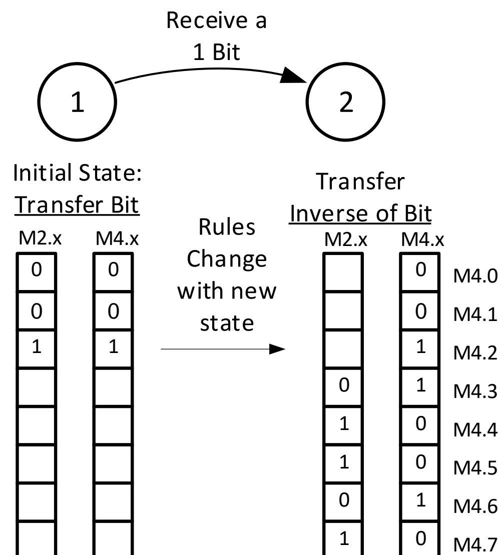


Fig. 11-8a Two's Complement

The algorithm can be viewed above but the program is found here. In it, the 'twoscomp' bit is set to '0' and the program begins. When the first '1' is found in the original number, that bit is transferred to the twos complement word but the state is changed by setting the 'twoscomp' bit. The state is now set to flip the original bit and place the flipped bit in the twos complement number. This algorithm depends on this simple flip bit from our state diagram to work.

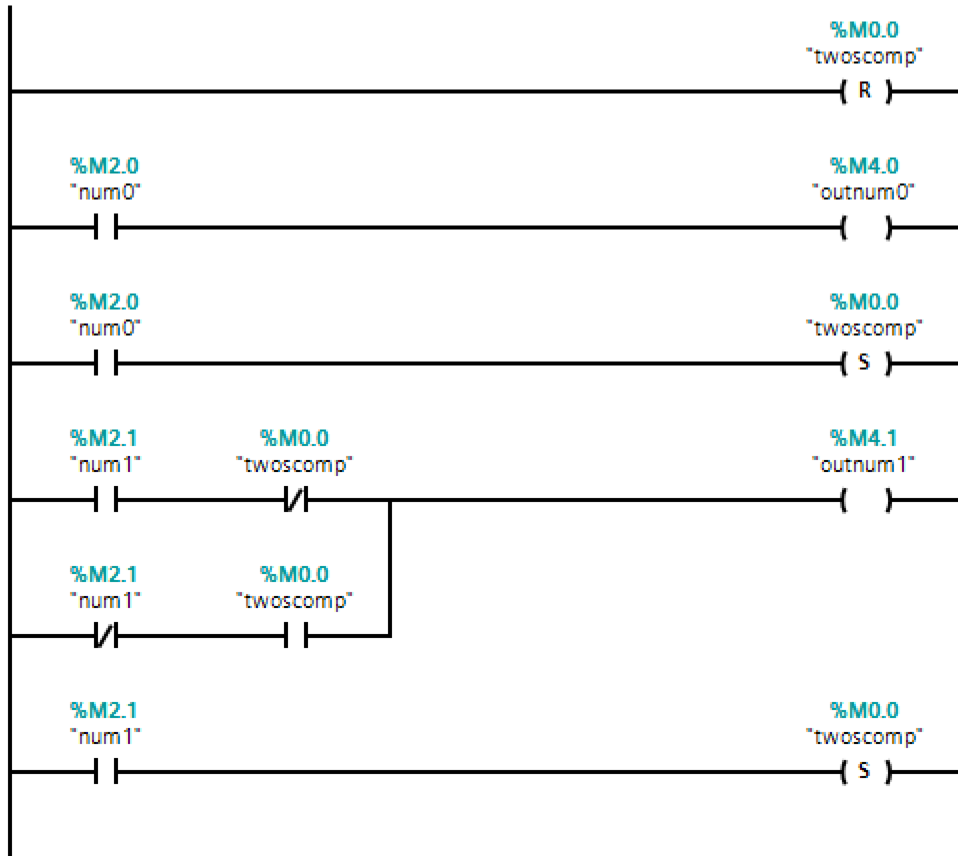


Fig. 11-8b Code for Two's Complement

Conveyor Two State System – A Simple State Diagram

State table analysis of the Conveyor Program below shows two states: #1 (loading) or #2 (off-loading).

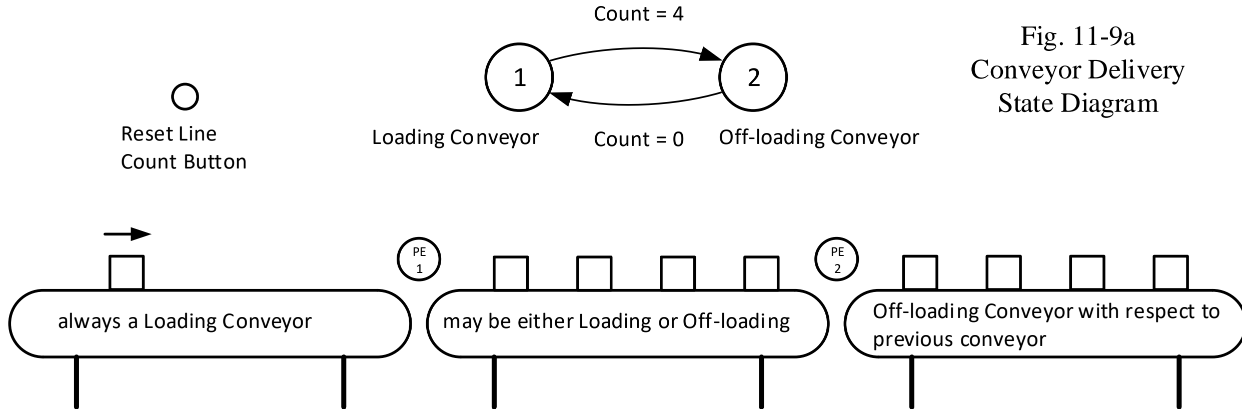


Fig. 11-9a
Conveyor Delivery
State Diagram

Boxes fill one at a time on the short conveyor at left, accumulate on the middle conveyor until 4 boxes are in place. Then the middle conveyor turns on automatically to off-load the boxes to the third conveyor.

The middle conveyor is programmed to switch from an accumulating or loading conveyor to an off-loading conveyor. Logic for this switch is developed in the network below. The memory bit 'Offload' energizes when the count is done ('QU' turns on). Internal logic acts in a manner similar to a switch controlled by a human. The state changes to off-loading and the middle conveyor turns on to transport boxes off the conveyor and then change back to an accumulating conveyor, switching from state 1 to 2 and back to 1 again.

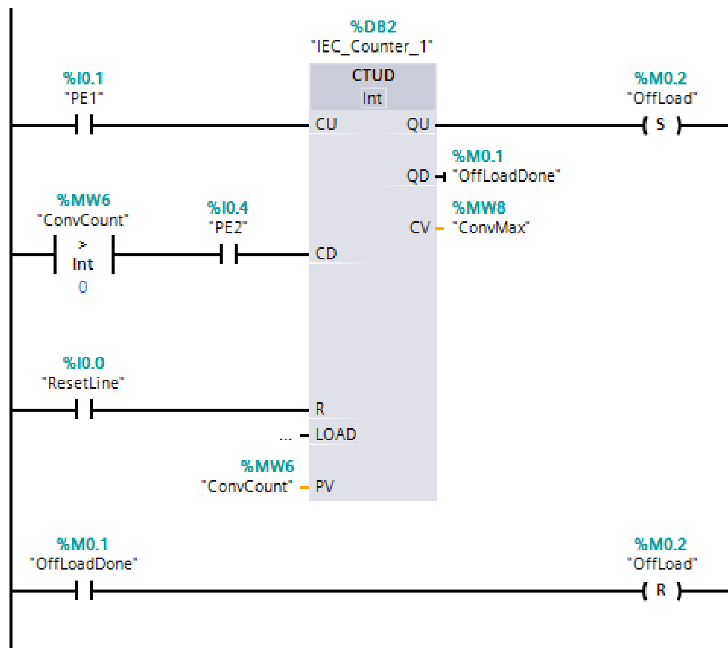


Fig. 9b
Program for
Load/Offload
Conveyor System

Another consideration when programming moving lines with boxes is "What happens if a person accidentally removes a box from the conveyor at the wrong time or moves his hand or foot in front of the photo-eye incrementing the counter accidentally (or not accidentally)?" What if a bird or big bee flies in front of the sensor giving a false count of the number of boxes? Counters must have a mechanism to reset the state affecting the overall operation of the conveyor. Reset buttons must be strategically placed so as not to be overused but to provide a means of resetting the line if the line is cleared of boxes.

The reset button should only be used by an operator if normal operation of the line has been interrupted and the line is not responding properly. Then the operator resets the counters and seal circuits. In coordination with reset of logic, boxes must also be removed from the conveyors. This may prove to be a cumbersome task. This is signified in the state diagram by moving to an initial state or a reset state.

When control of a process requires internal switching logic, the programmer must build switches through the use of memory logic. The logic is described as sequential logic in that the logic moves sequentially from one section to another section. If logic is developed remembering the sequential nature of the process, then a more organized program can be achieved.

State Table Analysis of 'Simon Says' Sequential Game

A later chapter will discuss the implementation of a number of sequential games including "Simon Says" and "WhackaMole". The Simon game is the same game played years ago by your parents or possibly your grandparents. A state diagram of the Simon game could be represented as follows:

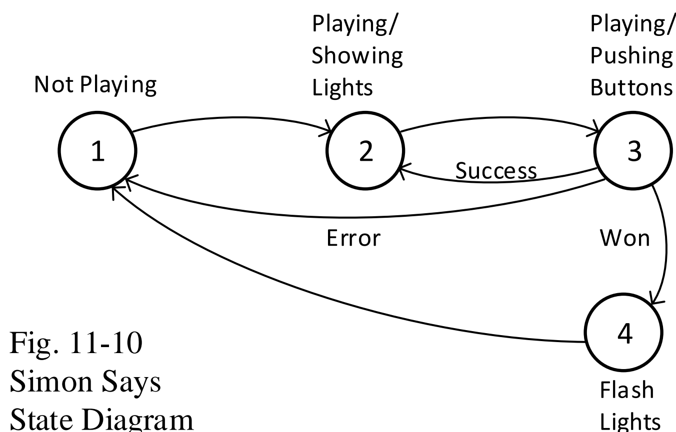


Fig. 11-10
Simon Says
State Diagram

The Simon game will be further discussed and programmed in a later chapter.

In general, while the number of states doesn't need to match the number of coils used in a program, the minimum number of coils used matches the number of flip-flop's in a state table. For instance, if there are 2 states, 1 coil is necessary (either on or off). For three or four states, 2 coils are necessary (off-off, off-on, on-off, on-on). For five to eight states, 3 coils are required. For 9 to 16 states, 4 coils are required, etc. Use of a minimum number of coils for representation

of states may not prove to be the most effective programming style. A number of different programming techniques will be discussed in this chapter and next and will give the programmer various ideas as to how best implement a state diagram from a sequential process.

Sets and Venn Diagrams

Use of sets and Venn diagrams may help the programmer visualize a sequential program. For example, the sets of "Simon Says" are found below. They are Not *Game Being Played* and *Game Being Played*. Subsets of *Game Being Played* are *Show Lights* and *Push Buttons*. A final state is shown at right if the player wins – *Flash Lights*. To begin a program by designing a Venn diagram is usually not required. However, as the program is written, the programmer may find the use of Venn diagrams a good tool in describing the logic or in visualizing the various states present in the process.

Sets of the program Simon Says:

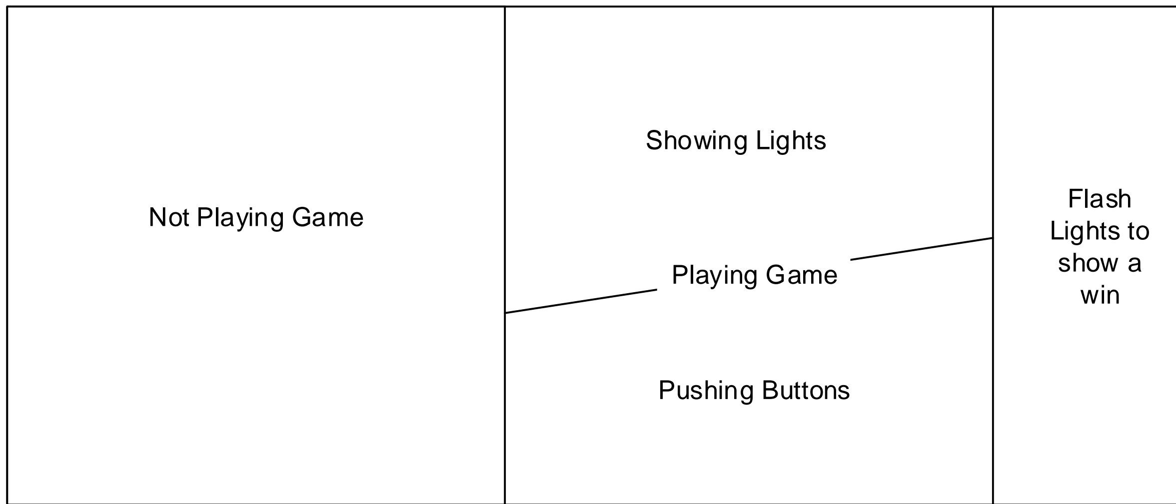


Fig. 11-11 Venn Diagram of Simon-Says Game

Sequential Function Charts

An alternative to state diagrams using ladder logic is the programming language referred to as Sequential Function Charts (SFC). SFC is a graphical approach to state development and program organization. Steps, actions and transitions are the three primary components of a typical SFC. Each step is similar to a state or unit of logic organized to accomplish a particular control task. An action defines an aspect of the task and a transition provides the means to move from task to task. Logic internal to each step, transition or action is programmed in Ladder logic or other programming language. SFC's graphical layout offers the program developer an overview for creating small islands (states) of logic and linking them together with transitions.

Two primary types of flows are allowed in the SFC diagram, sequential and parallel. With sequential flow, the program executes step 1 repeatedly until all conditions are satisfied for the transition to take place to move to step 2. Each step is evaluated until satisfied and then flow moves on. In a parallel configuration, branches may be configured as simultaneous or selection. In a selection branch, only one branch is executed at a time. The active branch is determined by the transition. With a simultaneous branch, all branches may be executed simultaneously. Transition occurs in a simultaneous branch when one of the active steps satisfies conditions to continue. The following figure shows a selection branch. Step one is executed until completion. Then step two executes. Only one step is allowed to execute at a time. Other steps are missed this time.

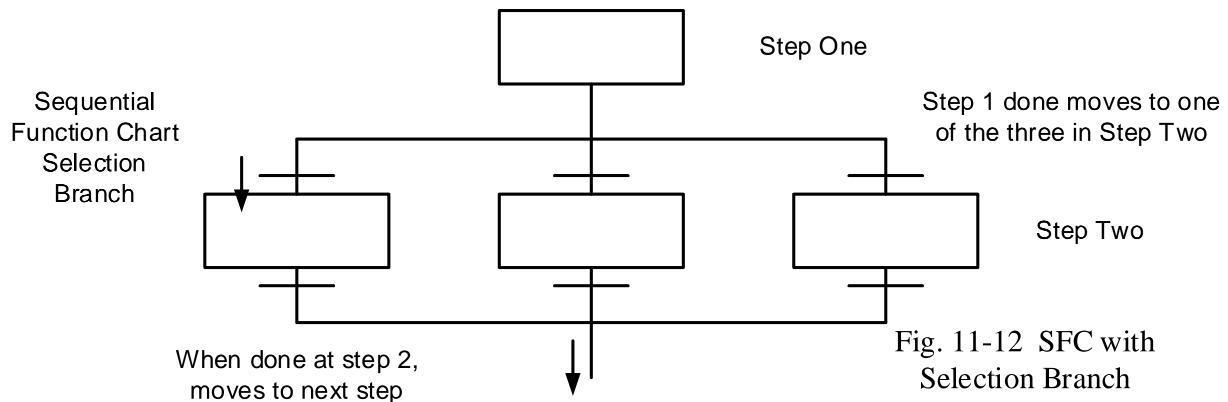


Fig. 11-12 SFC with Selection Branch

As mentioned before, with a simultaneous branch, all branches may be executed simultaneously. Transition occurs in a simultaneous branch when one of the active steps satisfies conditions to continue. The figure below shows a simultaneous branch with step one occurring and then one or more of the steps of step two turning on. Any of these steps in step two can cause a transition to later logic.

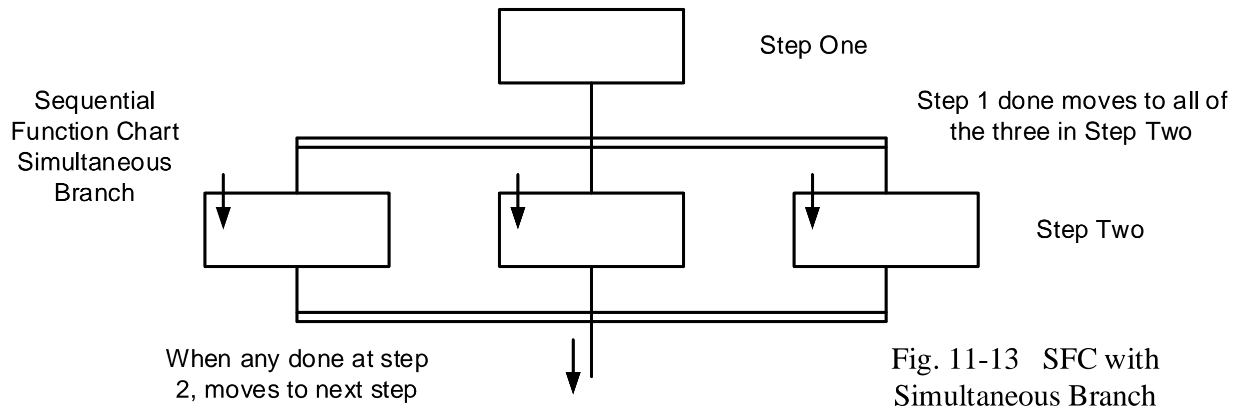


Fig. 11-13 SFC with Simultaneous Branch

Logic that is active is highlighted so a programmer can visually confirm the program step or steps being executed. Steps may be sub-divided into actions with a number of actions occurring sequentially during the step.

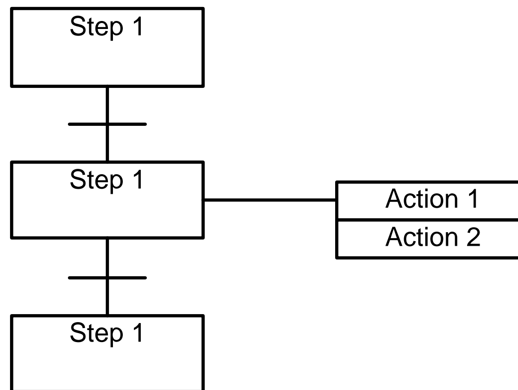


Fig. 11-14 Steps Subdivided into Actions

Showing logic that is active in highlighted form is a very powerful method to show the flow of logic in a sequential process. Sequential Function Charts may be useful in developing sequential logic especially when advantages such as highlighting are considered. Remember that each box in the Sequential Function Chart may be reduced to a number of rungs of ladder logic or other language. SFC overall is a very powerful organizing tool.

State diagrams and Sequential Function Charts are two of many different tools used by programmers to control a sequential process. A number of other tools have been discussed as well. Scientists, especially mathematicians, have used a variety of very sophisticated tools to generalize sequential problems. While it is not the purpose of this text to thoroughly explain these tools, it is appropriate to mention two different tools used to discuss sequential processes.

First is Finite State Machines or FSM. FSM may be defined as “model of behavior composed of states, transitions and actions.” Transitions and actions may be defined:

> “A transition indicates a state change and is described by a condition that would need to be fulfilled to enable the transition. An action is a description of an activity that is to be performed at a given moment.”

FSM may be used in “linguistics, computer science, philosophy, biology, mathematics, and logic.” Of course, the PLC programmer is interested in using FSM for logic in developing a program.

Another tool for solving of sophisticated sequential problems is the Petri net. The Petri net may be described as:

"A **Petri net** (also known as a **place/transition net** or **P/T net**) is one of several mathematical representations of discrete distributed systems." Petri nets were first introduced by Carl Adam Petry in 1962 from his PhD dissertation. An example of a Petry net diagram follows:

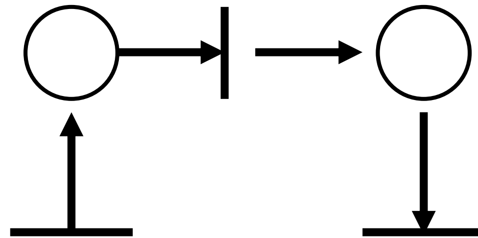


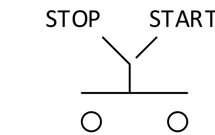
Fig. 11-15 Petri Net Example

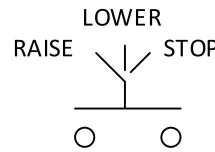
Back to Reality - Combinational Modes

External switches many times determine the mode of the machine and establish the need for states. These form a class of devices referred to as combinational modes. Combinational modes include switches such as:

Stop-Start
Forward-Reverse
Open-Close
On-Off
Raise-Lower
Up-Down
Fast-Slow-Stop
Forward-Reverse-Stop
Open-Close-Stop
Raise-Lower-Stop
Up-Down-Stop-Off-On
Hand-Auto
Hand-Step-Auto
Hand-SemiAuto-Auto
Manual-Auto
Manual-SemiAuto-Auto
High-Low
Summer-Winter
Summer-Off-Winter
High-Off-Low

TYPICAL SWITCHES





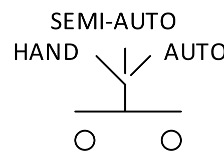


Fig. 11-16 Various Selector Switches

This list could be continued for many pages. This is but a sampling of the types of mode switches used for control of machines.

One of the most commonly used mode switches is: **Auxiliary-Off-Run-Start**

If you don't recognize this switch, think about what happens next time you start your car.

Typical switches that are two-position are wired to only one of the two positions.

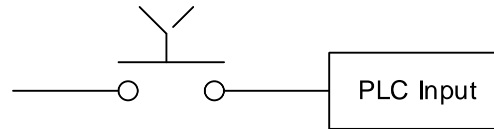


Fig. 11-17a Generic Selector Switch

If one mode is chosen, then the normally open contact is used. If the other mode is chosen, then the normally closed contact is used. For instance, if the switch above was used with the switch labeled High-Low, then High would refer to the input on and Low would refer to the input off.

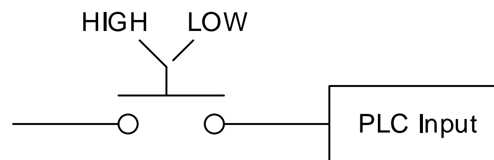


Fig. 11-17b Selector Switch with Tag

To summarize this section about switches, if a switch is needed but there is no switch planned for the panel or HMI screen, the program will need a memory circuit and probably a state diagram to replace the switch.

When switches are available, state definitions are not necessary, or at least not for the decisions made in coordination with the switches. On the other hand, if a switch is needed and none is available, one must determine if a state is necessary (and if coil conditions are required) that are derived from a state diagram.

It is possible to develop a number of state diagram programs without ever realizing that a state diagram is at the core of the program. The idea that a switch may be used instead of a state diagram may seem an oversimplification but the idea of using the idea of a potential switch to define the states of a system and then plan a method to automatically generate those states is a powerful method to plan a state diagram and write the ensuing program.

Scan-Dependent Code used in State Diagrams

Many times a state diagram can be programmed using a simple programming technique that uses scan-dependent code. Not all PLC logic can be replicated with relays since the PLC is sequential in nature and follows a scan from top to bottom of a program.

Rungs are solved sequentially starting at rung 0 and proceeding through the entire program

finishing with the end statement. As the rungs are solved, outputs are written from the coil or other output function to the appropriate table. The output is written from the program to the output as the rung is executed. The output is written to the card usually at the end of the scan. (Some processors write outputs asynchronously to the scan and therefore are not as predictable as to exactly when the output will be written to the output device. Both procedures of writing an output at the end of a scan and writing to the output asynchronously are valid procedures.

Use of scan-dependent code is necessary at times to accomplish a function or step from state in a program. To save a variable in a particular mode so that the variable may be used when the mode is turned off is a useful tool and is used in many programs.

Addressing States by Using Scan-Dependent Code - Climbing the Ladder

The following is a program to turn on three conveyors either automatically or manually. This program is used to demonstrate a common scan-dependent programming technique referenced here as "climb-the-ladder".

In this problem, a system of conveyors is to be programmed with each conveyor running independently. No integration of the conveyors into a state diagram is to be considered. Each conveyor has various start and stop conditions. The start conditions can be found parallel to the seal contact and the stop conditions can be found in series with the start logic. Logic for one of three motors is shown below (typical for all three):

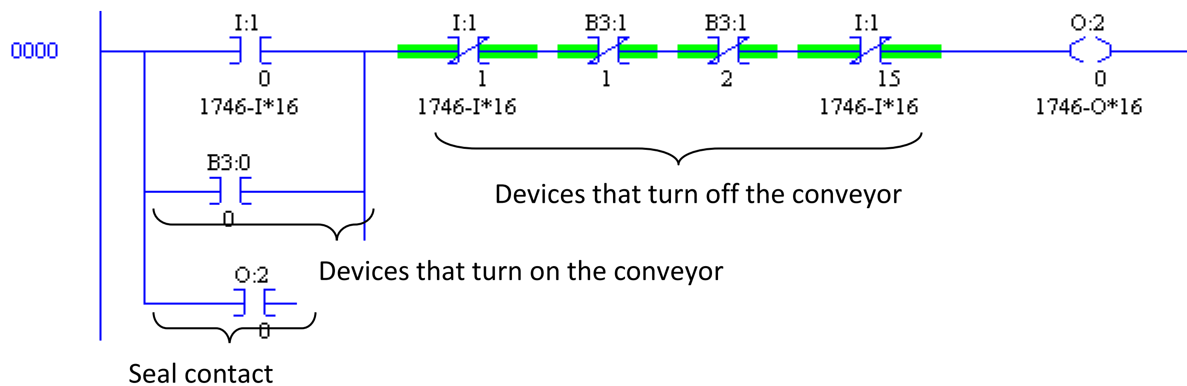


Fig. 11-18 Original Conveyor Circuit before Modifications

As long as all that is necessary to run the process is the independent start and stop contacts, all is well. However, what if the request is made that the emergency stop (let's say I:1/15 is the e-stop) shuts down all three or any that were running. Then in addition, a circuit is to be added to restart those motors previously running. To do this easily requires programming that is commonly referred to as climbing the ladder, an application of scan-dependent code and the state diagram shown below. A new state *'Off, Ready to Start'* is added to the state diagram and a new set of seal circuits is added to the logic. This is done during the scan that the emergency stop shuts down the output rungs with the new logic located **just prior** the output rungs. They are shown as follows:

Logic setting State 3 for each of the three conveyors

Now we can turn off the conveyor with the emergency stop switch

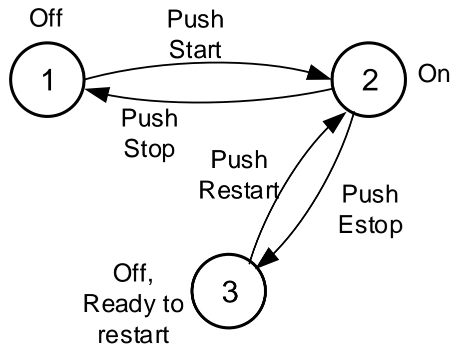


Fig. 11-19 State Diagram for Program Above

Notice that the three rungs added are not yet compiled since the stop or contact that turns the rung off is not yet known. Do not worry about not defining these contacts since there is time to add them later. The three coils B3:2/0, 2/1, and 2/2 are turned on the scan that the emergency stop is first turned on. These three coils remember the status of the three motors and save their status prior to the emergency stop turning the motors off. An annotation would read “Motor 1 Running Prior to E-Stop Shutdown”. Next, at an operator’s request, the system is to start back up with the motors that were previously running turning back on. Notice how this is done.

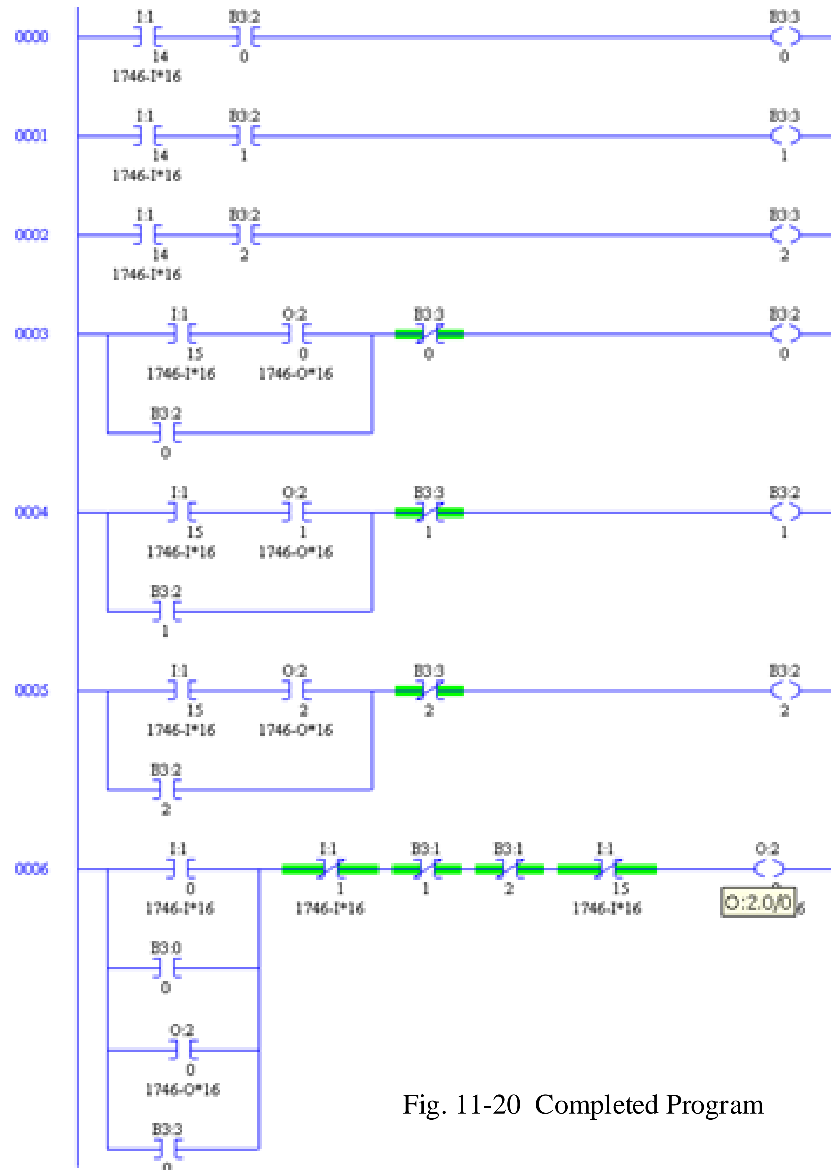
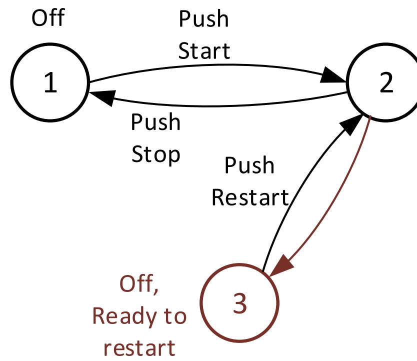


Fig. 11-20 Completed Program

Rungs 000-002 contain logic to turn on the motors previously on before the emergency stop was pushed. With the reset I:1/14, logic is developed to turn on the motor that was remembered in B3:2/0 through B3:2/2. The internal coil B3:3/0 turns on if B3:2/0 was energized, turns off the seal circuit containing B3:2/0 and then restarts the motor seal circuit with B3:2/0 in the start portion of the circuit.

For instance, if the emergency button is pushed while O:2/0 is on alone, B3:2/0 turns on and seals just prior to O:2/0 turning off. Since B3:2/0 is now on, when I:1/14 is pushed signaling a restart of the conveyors that were on when the emergency stop was pushed, B3:3/0 turns on and turns off the seal circuit B3:2/0. B3:3/0 then turns on the seal circuit for O:2/0. Even though B3:3/0 is on for only one scan, it can be counted on to turn off B3:2/0 and turn on O:2/0. The following diagram shows a sequence in which the E-Stop button is energized sending the conveyor to the “off” state (state 3) instead of the state 1 “off” state. When a reset button is pushed, the state diagram signals a restart of the conveyor(s) that had previously been turned off

due to the e-stop but not if stopped from other commands.



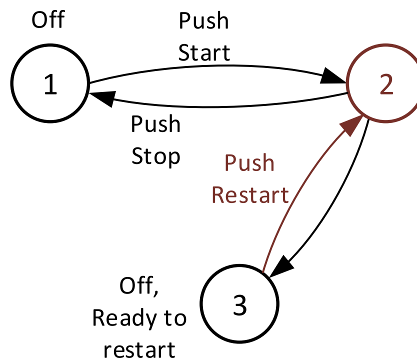
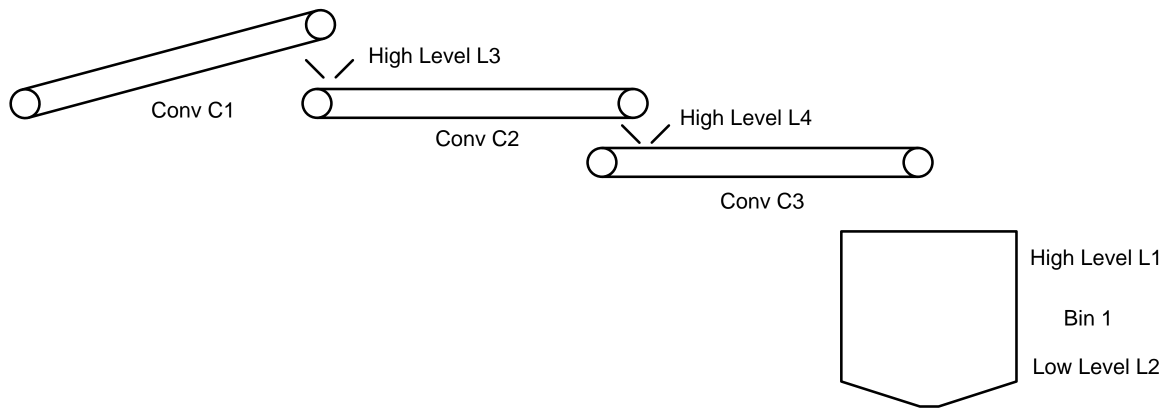


Fig. 11-21 State Diagrams for Completed Program

The example shows a scan-dependent program used to set and reset coils that are set by events to do specific tasks. This is an example of a simple state diagram being used to define a set of conditions and a programming technique that has been used with PLC programs extensively to simplify relay logic and perform state logic.

Revisit Three Conveyors to Bin

The problem of control of a number of conveyors usually involves interlocking of the conveyors so that a problem of back-up of product does not occur. If speed switches are introduced, they should be programmed to turn off the conveyor attached to the zero- speed switch if the switch is not active when the motor is told to turn on. The project below uses level switches to turn on and off the prior conveyor if high level is achieved with each of three hoppers.



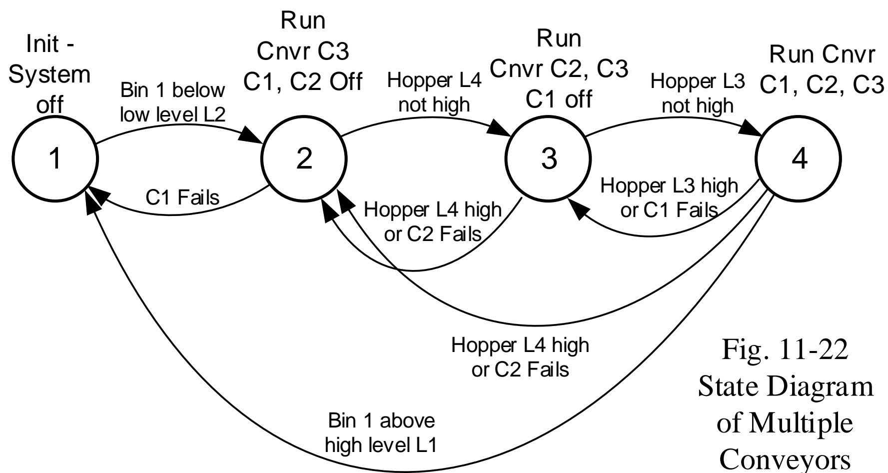


Fig. 11-22 State Diagram of Multiple Conveyors

Picture the conveyors conveying coal over a long distance. State diagrams may help here to describe this process. The design may be accomplished without the designer ever considering state diagrams but they help the description of what is really going on with the system.

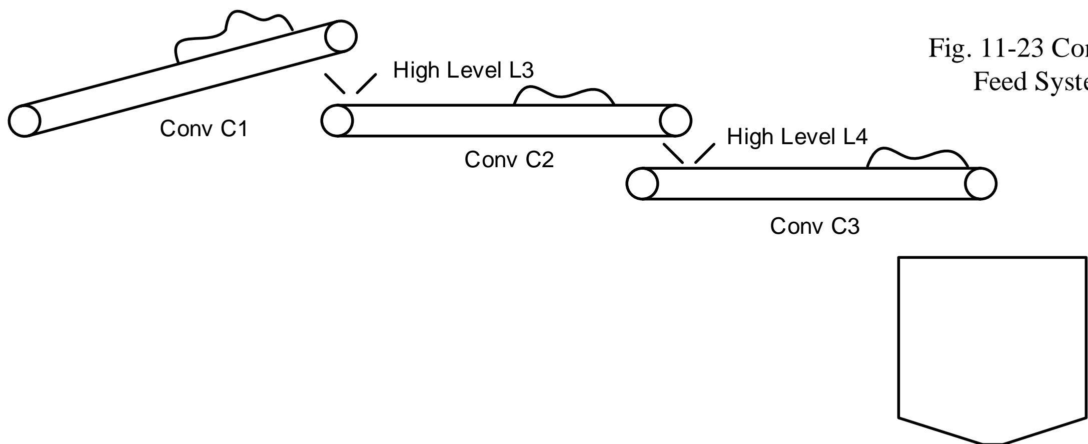


Fig. 11-23 Conveyor Feed System

The Electronic Safe – Definitely a State Diagram

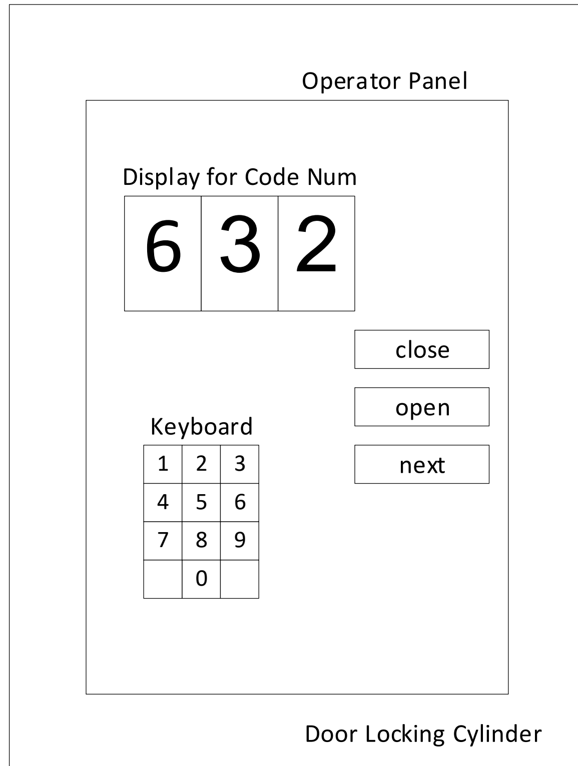


Fig. 11-24
Electronic Safe
Operator Panel

Description of the locking mechanism of the electronic safe:

- There must be typed in 3 code numbers, each consisting of 3 digits;
- A digit typed in at the keyboard arises at the least significant place in the display; the other digits already present on the display are shifted left
- Numbers to be compared to the three code numbers are stored in storage locations in PLC
- Each code number must be confirmed by pushing the 'next' button
- After pushing the 'open' button, the three numbers are compared with the code numbers stored in the storage locations.
- If the code numbers are equal, then the door is opened. Otherwise, the opening algorithm is blocked for 10 minutes.
- Pushing 'close' resets the display to 000, clears all input numbers and restarts the algorithm and locks the door.

This design is very dependent on a good state diagram to complete. The conveyor system did not require a state diagram for most experienced programmers to understand or build. The safe, on the other hand, does. The state diagram on the next page, if followed, will lead the programmer through the steps necessary to implement a program for unlocking and re-locking the safe successfully. With no state diagram, the experienced programmer may succeed in implementing the program but not as easily and the subsequent maintenance of the program will be more difficult without it. Saving the document of the state diagram is necessary since it is not carried along with the PLC program as part of the documentation. Its inclusion in a project

document is strongly recommended.

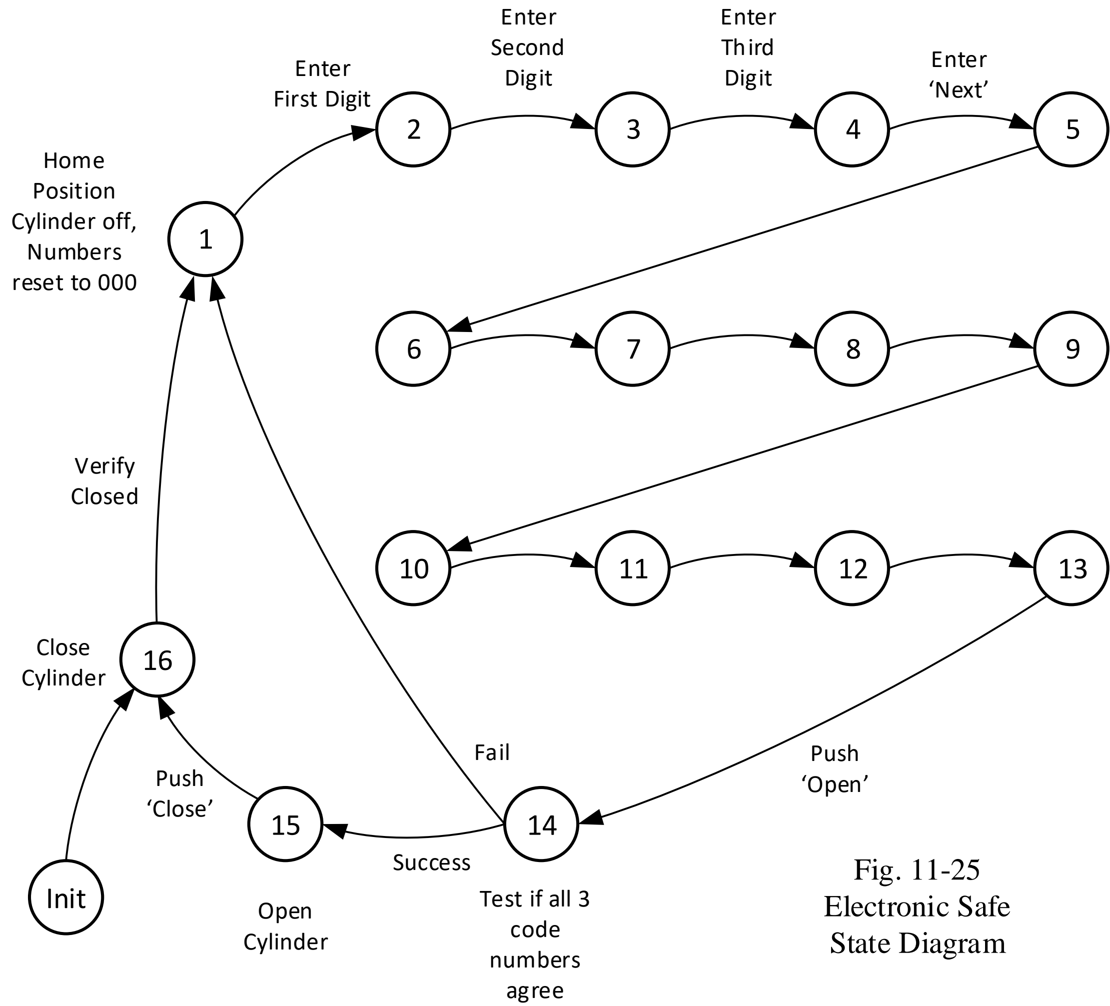


Fig. 11-25
Electronic Safe
State Diagram

Component Parts Feed Mechanism – High Need for State Diagram

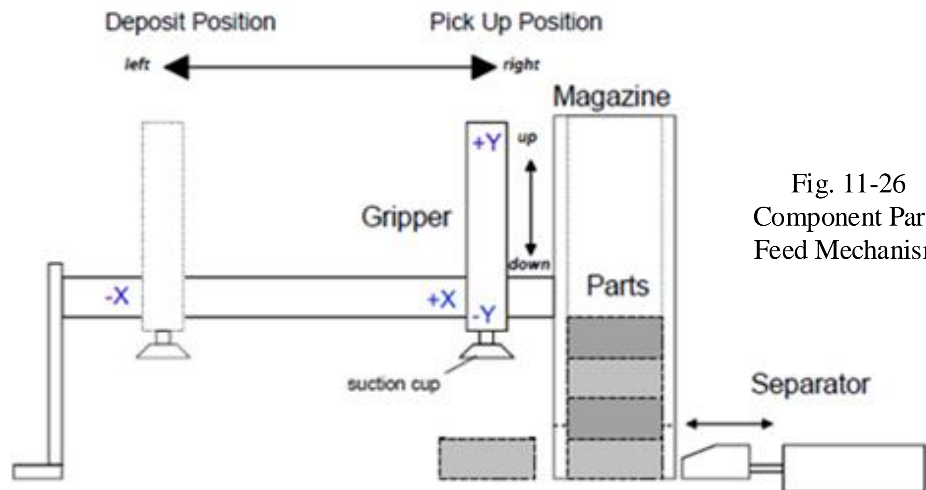


Fig. 11-26
Component Parts
Feed Mechanism

General Description:

A magazine is housing cylindrical parts (disks). A slide (separator) pushes out one disk to a "pick up position" where a gripper picks up the disk and places the disk to the "deposit position". The component feeder is running as long as disks are available.

Operating modes

Either the Software HMI or discrete switches are used to run the feeder in different operating modes. Switch S1 is used for changing the operating modes:

1 - Manual
2 - Homing
3 – Automatic

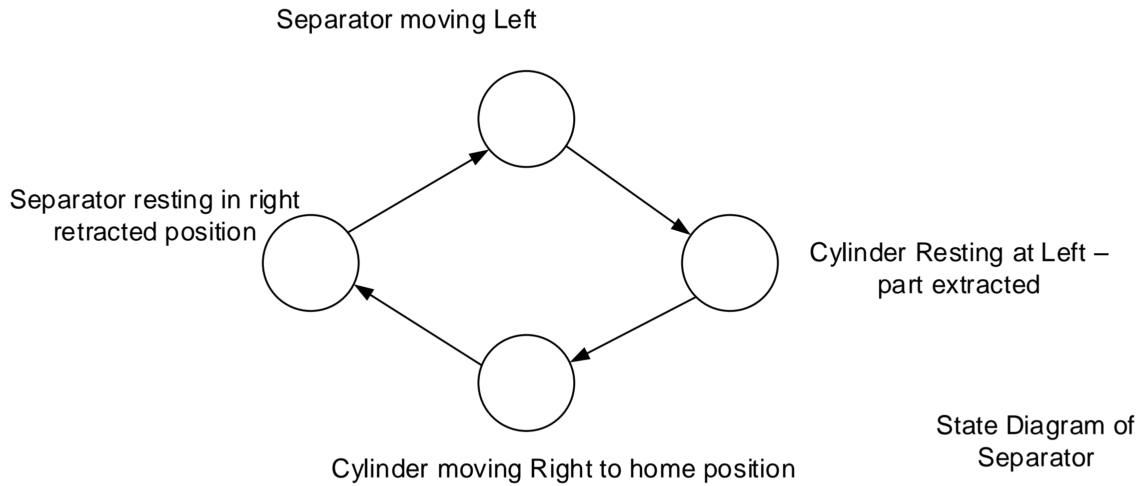
Homing cycle:

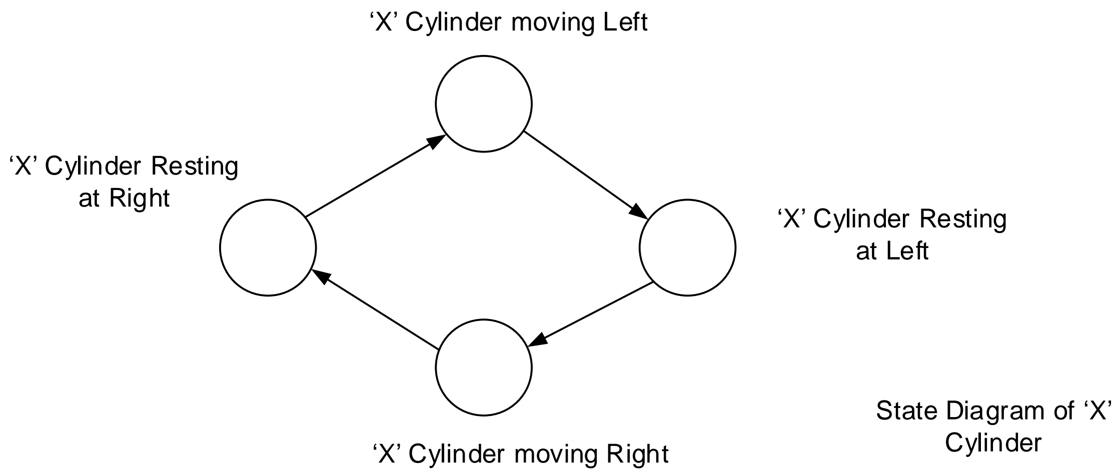
Before starting any automatic cycle, the feeder must be set up in its initial or homing position (Switch S1 to "Home" and press button "Start"). The homing cycle ends if the feeder has reached its homing position. The homing cycle stops after finishing the ongoing step if:

1 – "Stop" – pressed or if "Start" is pressed again
2 – If "Single Step" is activated by a selector switch. The feeder then steps forward one step in homing cycle each time the "Start" button is pressed.

The homing cycle resets if switch S1 is turned on. The ongoing operation then stops immediately.

Below are the three state diagrams for the cylinders in the machine. The state diagrams are not linked but information from one is used in other diagrams. Notice the linkage.





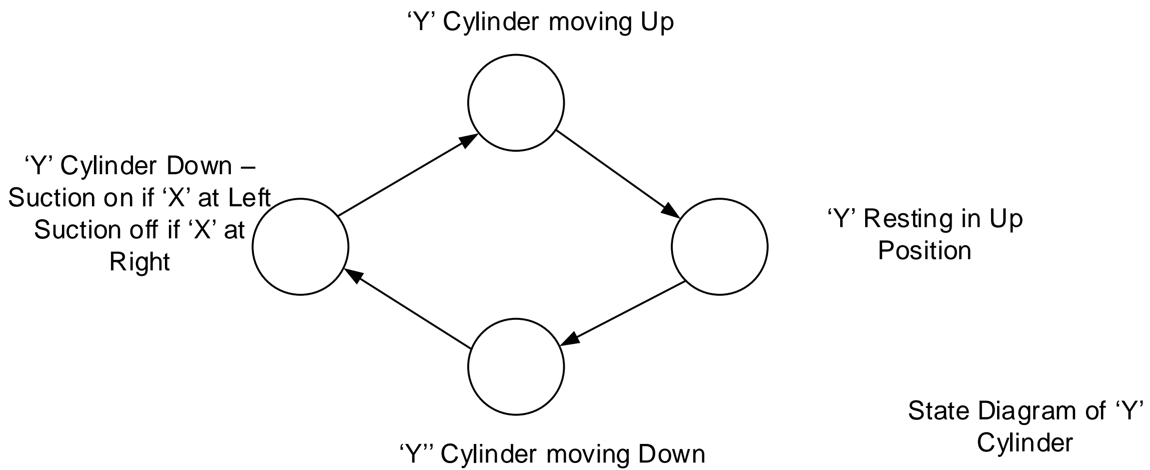


Fig. 11-27 Three Cylinder State Diagrams

Manual Mode

In Manual mode, every actuator should be activated by pressing the appropriate button. The manual mode position of S1 shall also serve to allow filling up the magazine with cylindrical parts. Filling up the magazine should not be registered if the button is not switched to manual mode when the magazine is being filled.

The actuator is locked in case of a wrong operation (e.g. the gripper can't be moved from left to right if the gripper is not in its UP position. All manual operations must be reset, if switch S1 is switched over to any other operating mode.

Automatic Mode

By setting switch S1 to "Automatic" and pressing "Start", the automatic cycle is started. A start may only occur if the feeder is in its homed position. The automatic cycle ends in home position if the magazine is empty.

The automatic cycle stops after the actual step if:

1 – "Stop" button is pressed; automatic cycle resumes if "Start" is pressed again.

2 – If "Single Step" is activated. Feeder steps forward one step in automatic cycle every time "Start" is pressed again.

The automatic cycle resets immediately if S1 is moved to any other operating mode. The ongoing operation then stops immediately. Starting automatic cycle again is only possible after the feeder has been brought into its homing position (either in manual mode or with the help of homing operation mode).

Interlocking Conditions which must be implemented first for security reasons:

Separator forth: gripper is	no part must be below gripper and NOT (x-axis in pick up position and not up)
Gripper down:	separator is back and x-axis in one of its end positions
X-Axis move left:	gripper is up and NOT ("x-axis move right" activated)
X-Axis move right:	gripper is up and NOT ("x-axis move left" activated)
Suction on:	--

A new programming language SFC (Sequential Function Chart) is used to combine the three state diagrams above in one continuous program. The state diagrams could be combined as well but for now, we will use the SFC diagram as a substitute.

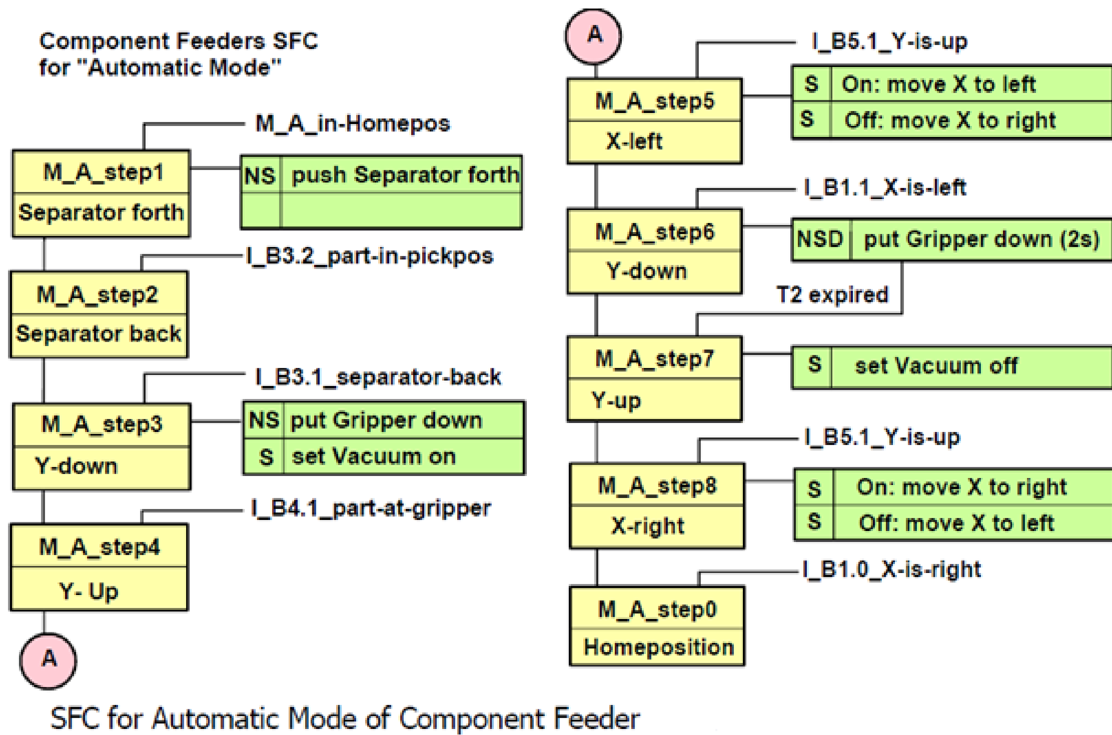
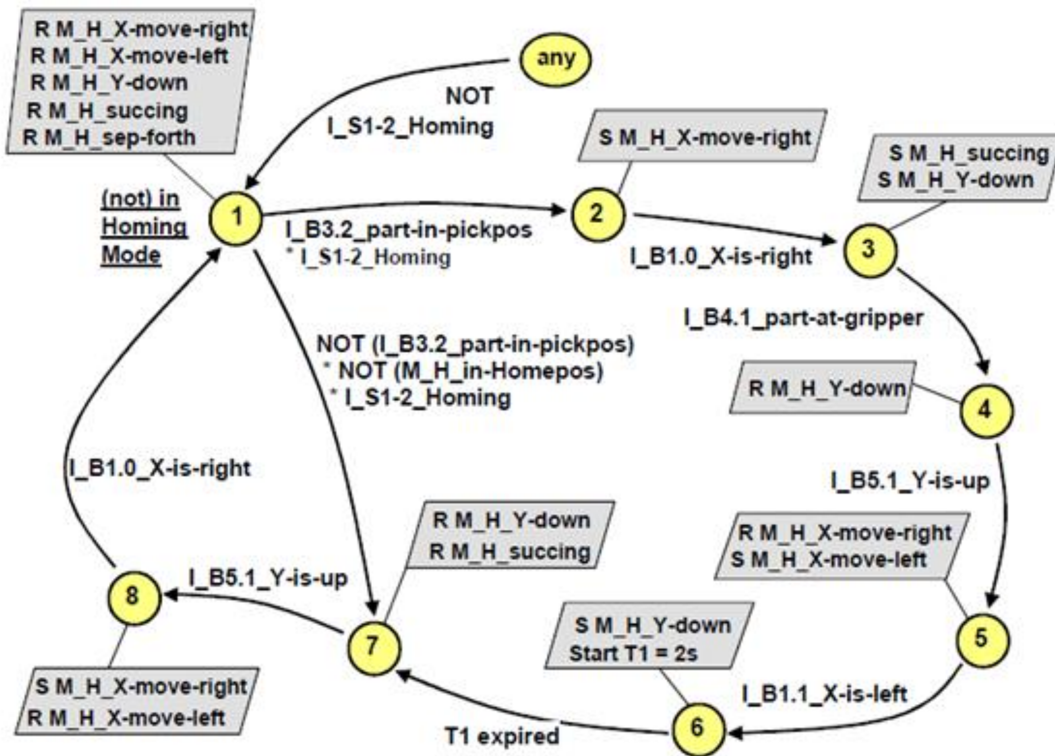


Fig. 11-28 SFC for Component Feeder

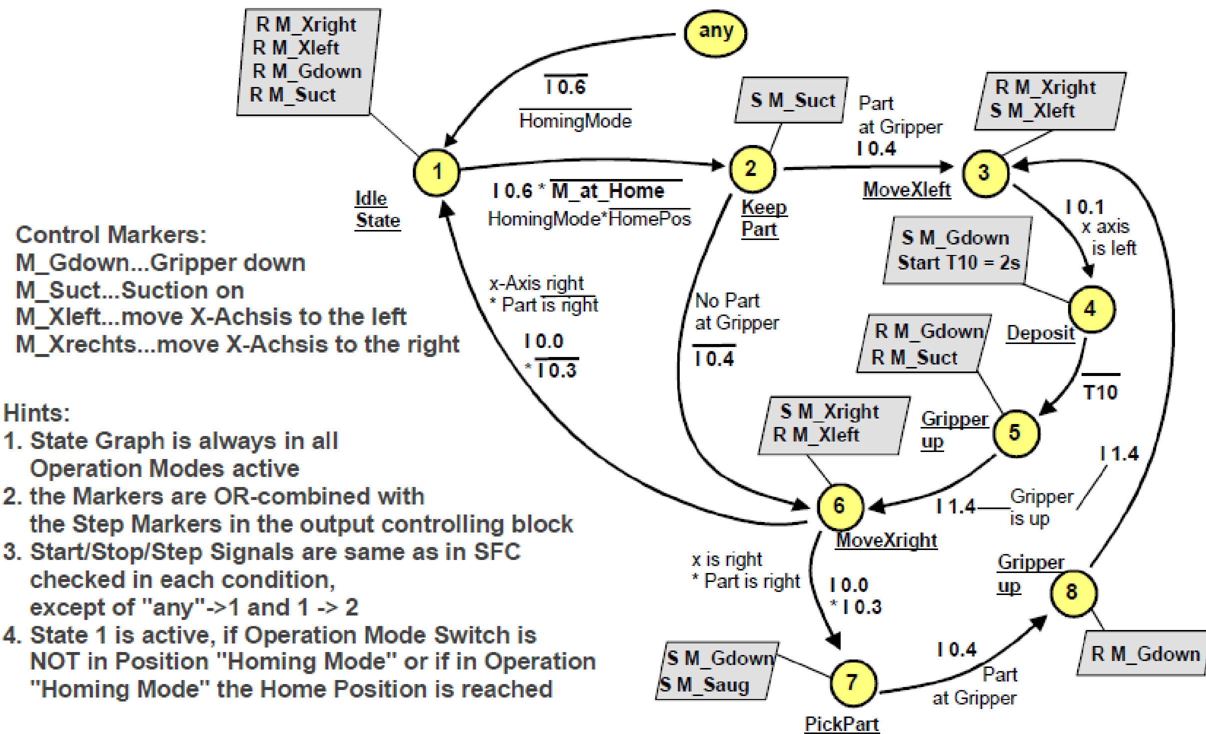
The Sequential Function Chart above shows the steps and gives the sequence of flow of logic. If one were to rely on this program, there is a reason to worry about the logic in that the logic performed in steps not currently active are not accessed or executed except in the step currently active. If there were a condition about which safety is a concern, then this logic must be replicated in each step, thus multiplying the complexity of the logic. Also, if this logic is changed, then it would need to change in all locations, not just one.

Thus, logic that is common to all steps must be located outside the step logic. This adds a level of complexity in that one must now determine whether to include logic that is only involved in the step or common to all steps. Most logic will probably end up being placed in the common logic area, in effect, negating the original concept of Sequential Function Chart or SFC logic.

Shown on the next page are the state graphs or state diagram for the component feeder. The first is somewhat simpler diagram that does not take into account an event that may drop down parts while in the homing mode. The second diagram answers this problem and prevents parts from dropping down while in homing mode.



State Graph controlling Homing Mode of Component Feeder



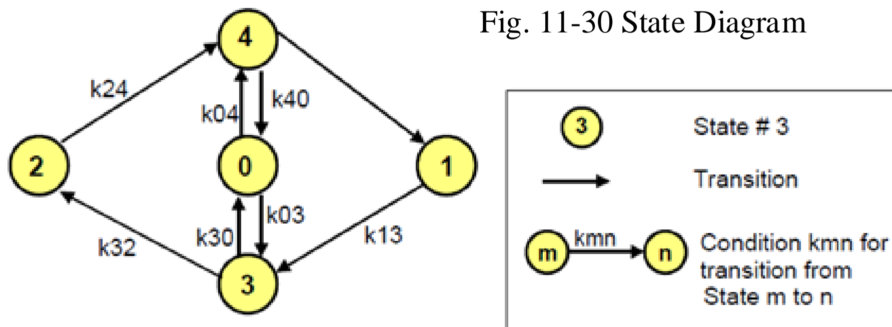
Alternative State Graph prevents dropping down parts from Gripper in Homing Mode

Fig. 11-29 State Diagrams for Various Parts of Component Feeder

State Diagrams Defined

State Diagrams have its origin in computer science. There are many advantages to State Diagrams although they are not established in a national or international standard. They are similar to Sequential Function Charts in that it describes a technical process or a functional element of a machine tool in terms of states and transitions. The following figure shows a typical state diagram with transition arrows and rules for traversing from state to state:

Fig. 11-30 State Diagram



At any time in a State Diagram, just one state can be active. State Diagrams may have branches and loops and allow alternate ways of stepping through the graph. To go from one state to another, there must be a transition between the two states; the original state must be active and the transition must be fulfilled.

The next figure shows a Functional Element (a rivet device) and gives a functional description of the control task with the help of a flow chart. There are two ways to construct a State Diagram. We can just model the functioning according to the task description or we can build a real model of all functional elements and combine them.

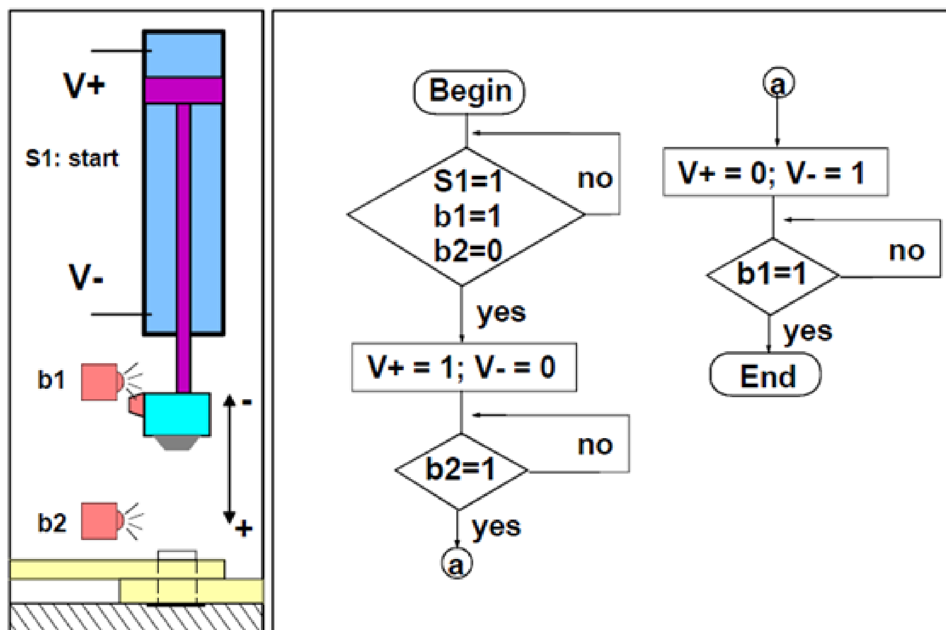


Fig. 11-31 - Riviter

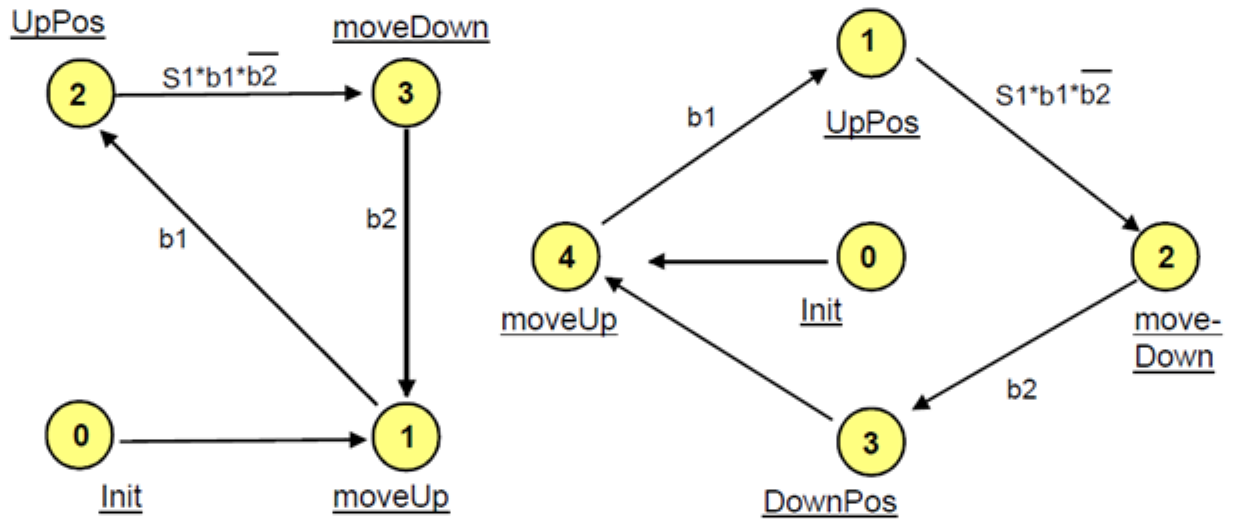


Fig. 11-32 Model of a Rivet Device (a) according to task description (b) according to the physical device

The cylinder should press the rivet for 2 sec. in the down position. Which of the two models best describes the physical process? Since the down position is time-dependent only, it is usually not considered a state. It is up to the user which state diagram is preferred but usually time-dependent only states are not necessary and may be combined in other states.

If there were two cylinders used in an operation, we could use either the task description or the physical device description to describe the state diagram for the process. The task is to look at the cylinder state graphs separately and then together to determine an optimal description of the process. If this can be done, a program can be written from the combined state diagram of the two independent cylinder state diagrams. The two cylinders below are described separately. The clamping cylinder can be described in the following State Diagram:

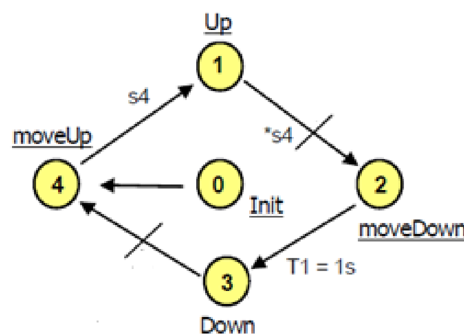


Fig. 11-33 First of Two Cylinder State Diagrams

The feed cylinder can be described in the following State Diagram:

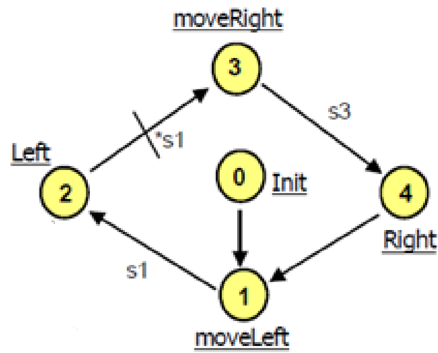


Fig. 11-34 Second of Two Cylinder State Diagrams

Or we can start with a combined State Diagram combining the two:

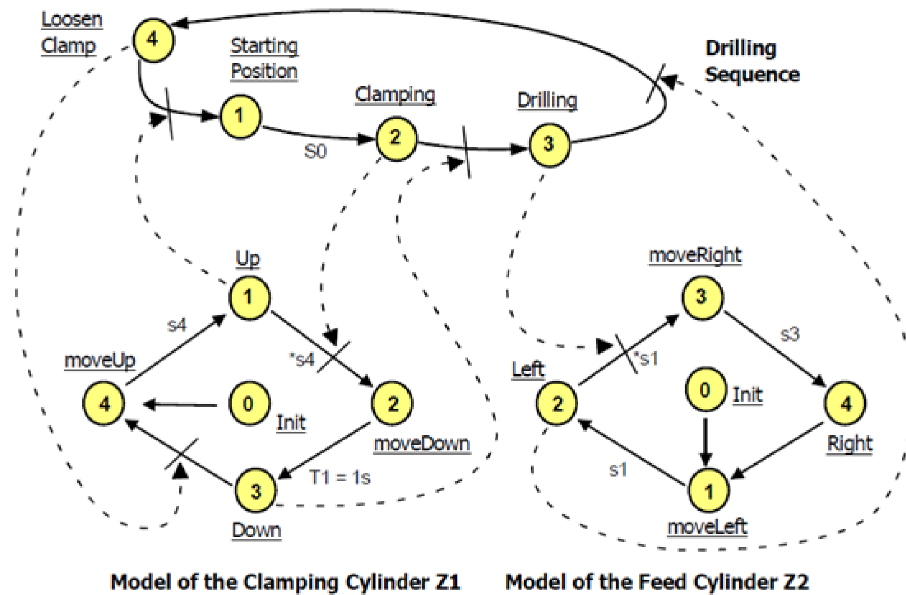


Fig. 11-35 Combined Two Cylinder State Diagrams

Run off Graphs consist of separate State Diagrams that are combined to show process actions in several areas at once:

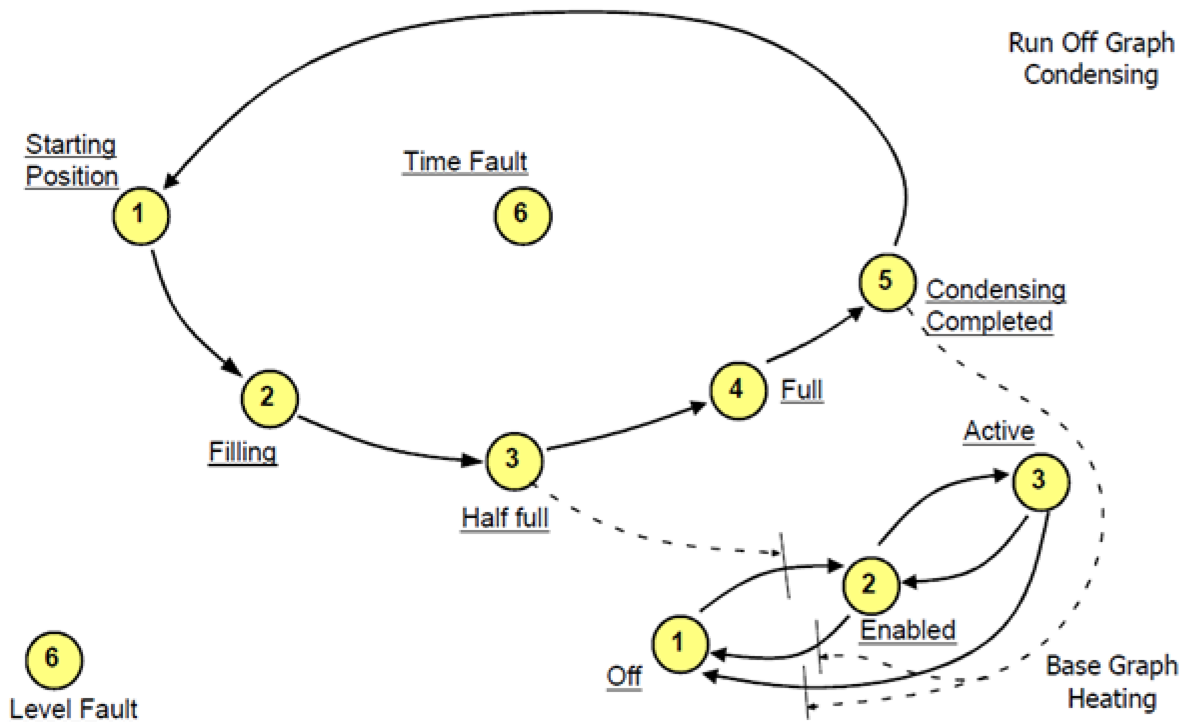


Fig. 11-36 - State Diagram for Juice Condenser discussed in earlier chapter

Introduction to Sequencers

Sequencers and sequential circuits are the result of the digital circuit state diagram. A machine or a process may be identified as a sequential circuit that indexes from step to step usually only in the forward direction. Decrementing back through the order of the steps **is not tolerated** in the design of most sequencers. If steps are identifiable and inputs can be defined allowing the process to advance from step to step and outputs change state from step to step, then a sequencer is advised.

Sequencers are divided into three general categories in the PLC. They may be relay-based, counter-based or sequencers using the SQx instruction set. Each will be discussed and examples given.

Sequencers may also be linked together giving a combined control scheme in which various sequencers hand off control between sequencers. Each sequencer is responsible for its actions and interfaces with other sequencers when a product or part is handed between the sequencers.

Multiple sequencers may also save programming code if various sequential programs are similar but not identical. This involves a type of subroutine control that uses a variety of step numbers to allow some programs to act during each step.

Relay-based sequencers are preferred since they are easier to read and understand by the maintenance electrician. With an increase in complexity, the counter-based sequencer is preferred. Counter-based sequencers are more easily changed and tolerate a greater number of steps than relay-based sequencers. If a large number of inputs and outputs are required in the sequencer, the choice leans more toward the SQx instructions. Timers may be used to add a time delay between steps. Examples of the use of timers in the sequencer are given.

Example of Sequencer - Simple Robot

A robotic arm that uses pneumatic solenoids is a candidate for sequential programming. The example below shows the steps in a sequence to successfully move a product from one position to another using a simple robotic arm.

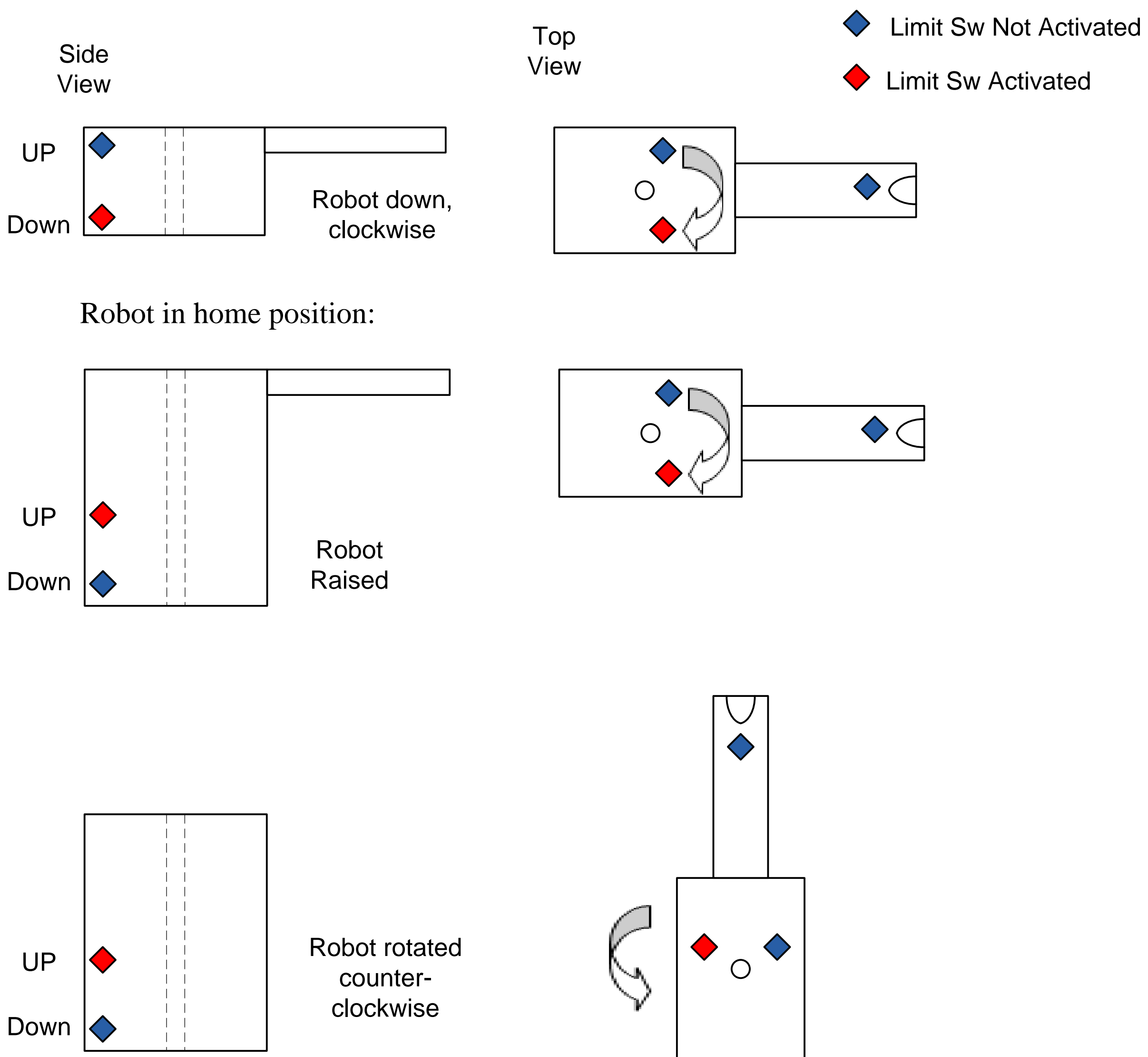


Fig. 11-37a Simple Robotic Sequencer

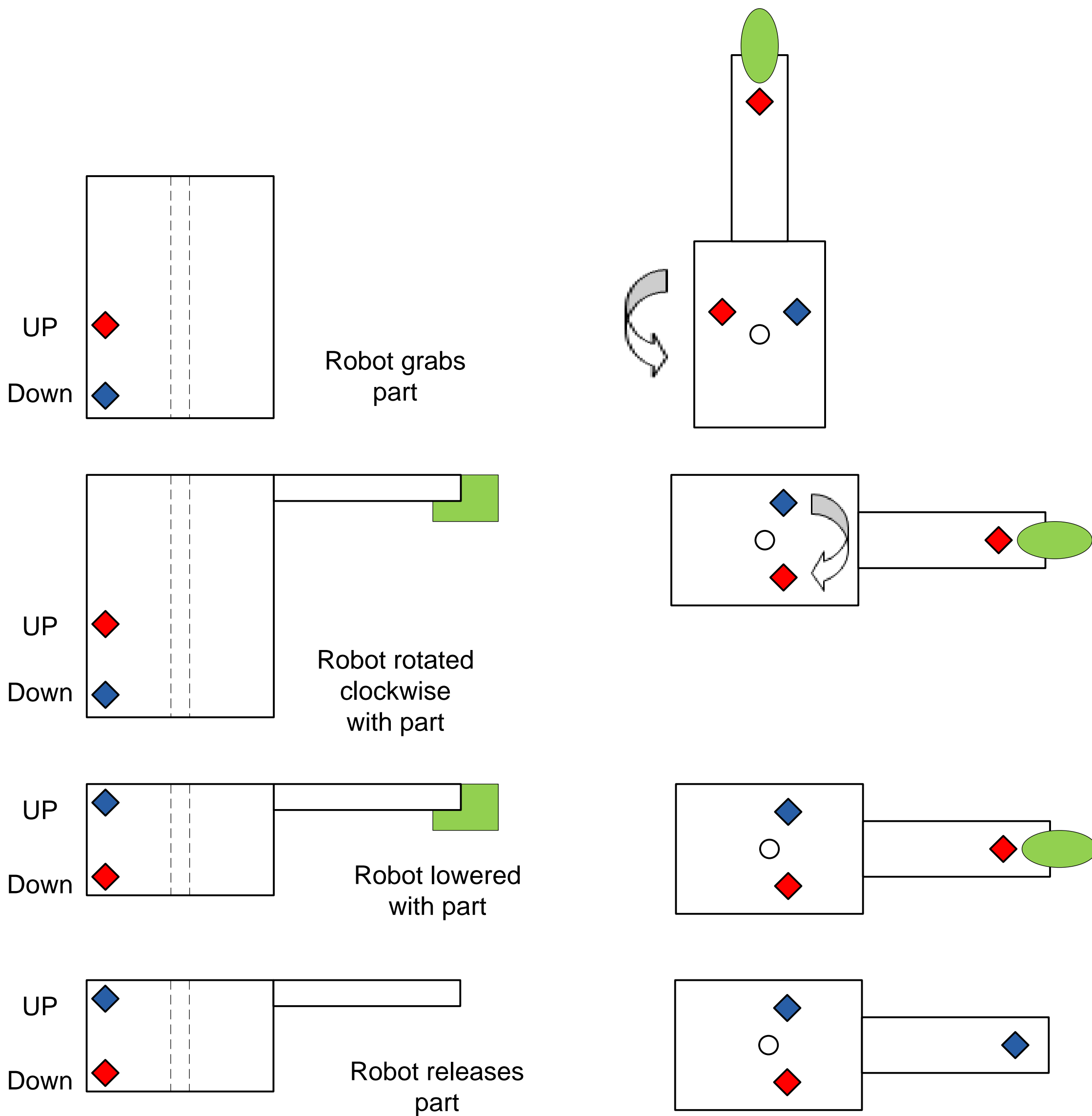


Fig. 11-37b Simple Robotic Sequencer (cont)

The operation of the robot can be summarized in the following table:

Step	Position	Required to Proceed	Solenoid to Proceed
1	Down, rotated cw	Start cycle pb	Raise
2	Up, rotated cw	Up l/s	Rotate cw
3	Up, rotated ccw	Ccw l/s	Grabber in
4	Up, rotated ccw	Part present	Rotate cw
5	Up, rotated cw	Cw l/s	Lower
6	Down, rotated cw	Cw l/s	Grabber out
7	Down, rotated cw	Done	

Next, an assignment of inputs and outputs for the functions is generated:

Address	Function
I:0/0	Start cycle push button
I:0/1	Robot down l/s
I:0/2	Robot up limit switch
I:0/3	Robot CW limit switch
I:0/4	Robot CCW limit switch
I:0/5	Part present limit switch
O:0/0	Raise robot solenoid
O:0/1	Rotate ccw solenoid
O:0/2	Rotate cw solenoid
O:0/3	Release part
O:0/4	Grab part

Home position is used for initialization of the program. It is:

Address	Function	State
I:0/1	Robot down limit switch	On
I:0/2	Robot up limit switch	Off
I:0/3	Robot CW limit switch	On
I:0/4	Robot CCW limit switch	Off
I:0/5	Part present limit switch	Off

Homing is a separate program from the sequence program that attempts to move the machine to the state of “home”. This is the position that the sequential program is looking for to move from state 0 to state 1. The homing program and sequence program share the same output rungs turning on and off outputs to control movement to accomplish their various tasks. The task of the homing program is to satisfy the states of all permissive contacts in rung 0 of the program.

The state diagram is on the next page. It follows the one-way flow of the sequential program allowing only flow in one direction. The progression follows step-by-step with an easy decision at the end of each step allowing the program to move to a set next step.

In most instances, only one input must be satisfied to move to a next step with a short time delay at the end of the step to allow the robot a short amount of time to settle before moving on.

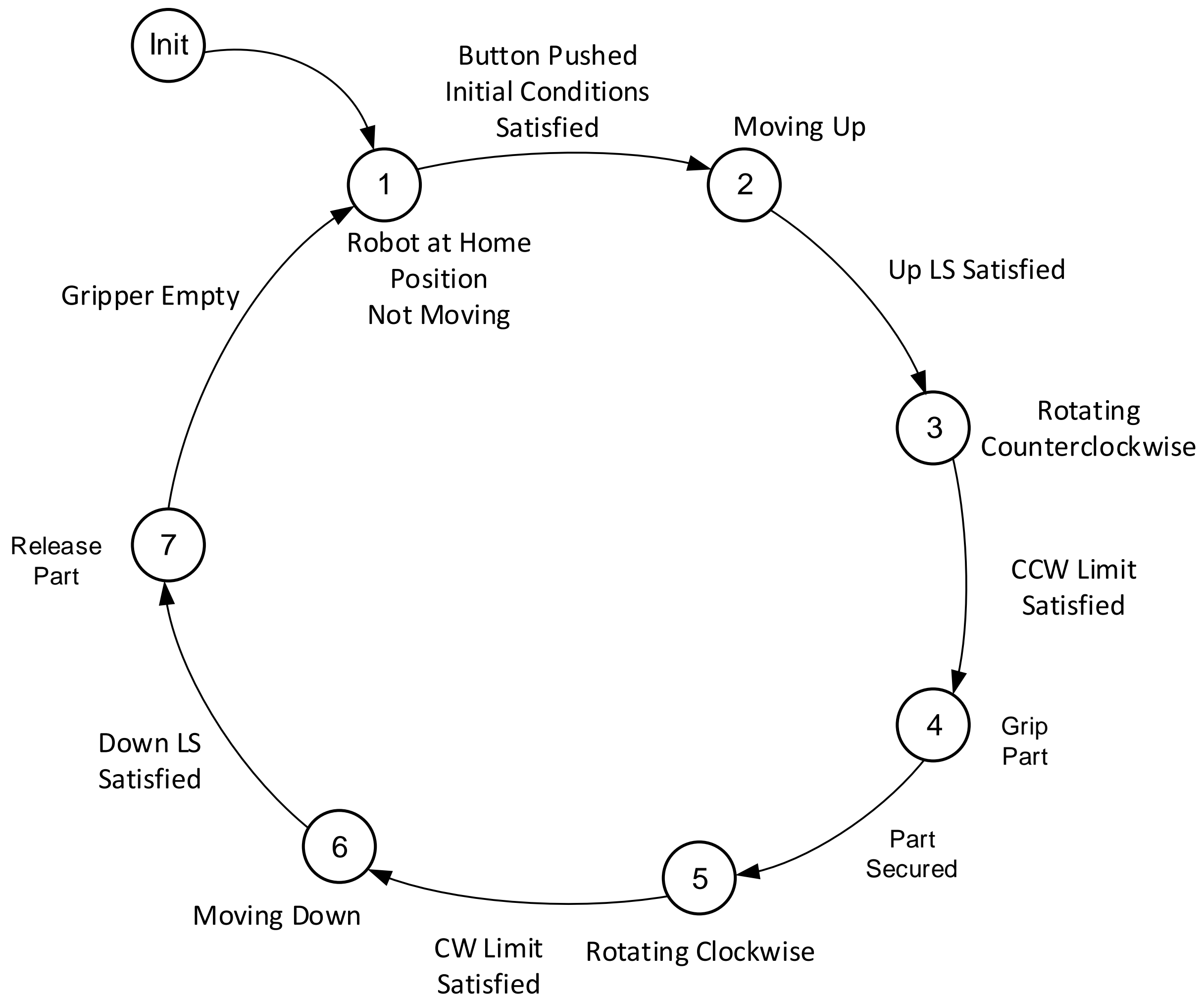


Fig. 11-37c State Diagram for Simple Robot

In the riveter example, if a machine is not resting in a position, the position is not classified as a step. The program shown below uses only one rung of logic for each step and it seems clearer for each step to correlate to a rung of logic.

Homing may be necessary as a separate state diagram. The homing portion may include a number of state diagrams depending on what state the machine is in at the time a homing request is made.

Ladder Program for Robot Sequencer

To program the sequencer using relay ladder logic, start with an initialization rung and then program rungs that depend on the prior rung plus an output to set the next rung.

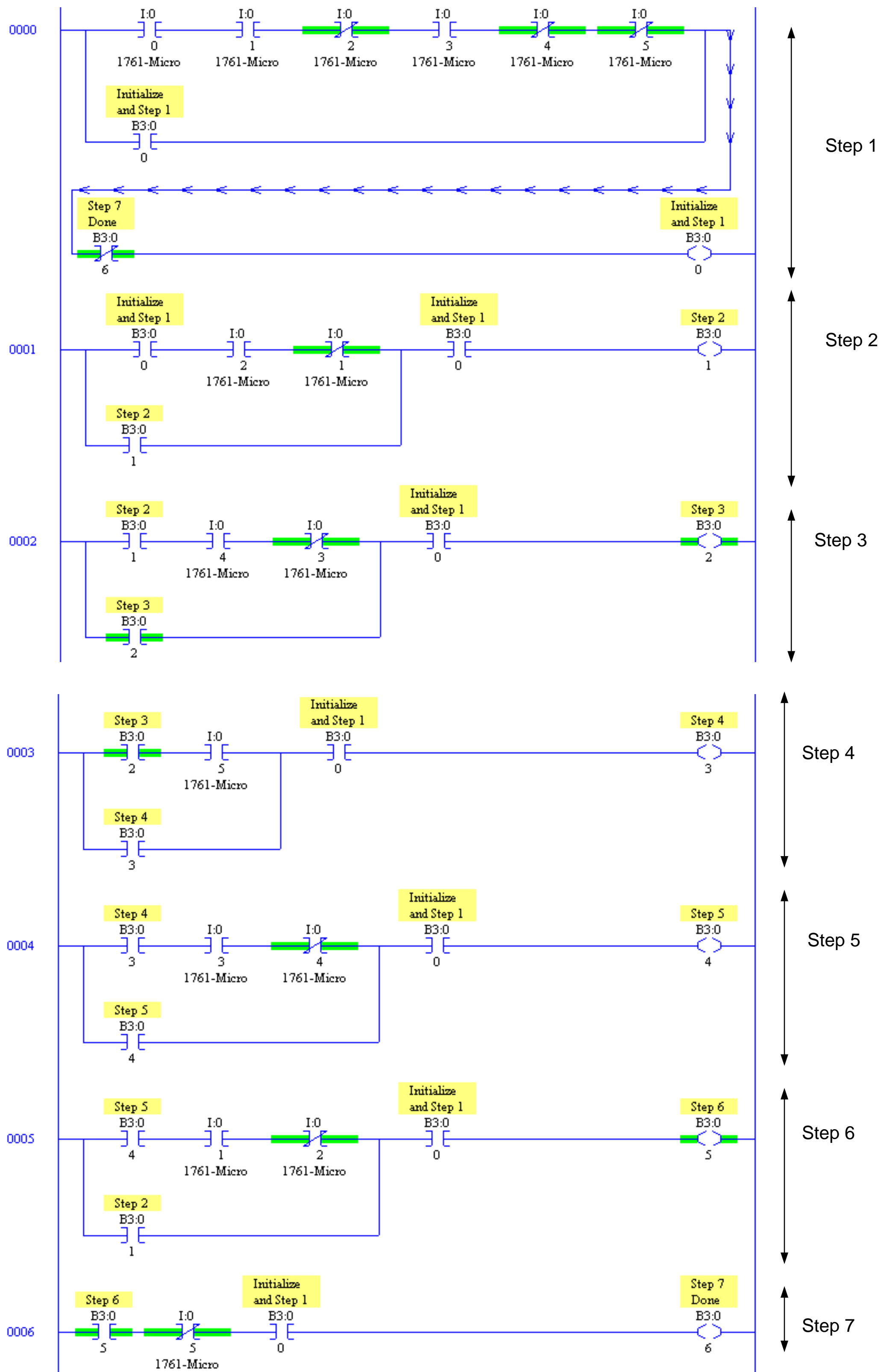


Fig. 11-38 Simple Robotic Sequencer in Ladder with Coil Logic

In the program, the initialization rung is rung 0. This rung checks all limit switches to verify the robot is in its home position. Each appropriate limit switch is checked. For instance, both the limit switch for end of travel in one direction and the limit switch for end of travel in the opposite direction are checked for each set of limit switches. The initialization button then turns on the first internal B relay coil – B3:0/0. In the PLC, it is easy and requires no additional wiring to include both end-of-travel limits. With cost no problem, the addition of both sets of contacts provide additional safety if a contact were to fail.

Rung 0 turns on starting the shift register. Then the shift register waits to proceed. Succeeding steps are entered below:

Move from step 1 to step 2:	I:0/2 on, I:0/1 off	Go to step 2	(rung 1)
Move from step 2 to step 3:	I:0/4 on, I:0/3 off	Go to step 3	(rung 2)
Move from step 3 to step 4:	I:0/5 on	Go to step 4	(rung 3)
Move from step 4 to step 5:	I:0/3 on, I:0/4 off	Go to step 5	(rung 4)
Move from step 5 to step 6:	I:0/1 on, I:0/2 off	Go to step 6	(rung 5)
Stop	I:0/5 off	Done, End	

Output List:

Step 1- Outputs change to go from step 1 to step 2
O:0/0 on Raise robot

Step 2- Outputs change to go from step 2 to step 3
O:0/1 on Arm moves CCW

Step 3- Outputs change to go from step 3 to step 4
O:0/4 on Grab part

Step 4- Outputs change to go from step 4 to step 5
O:0/2 on Arm moves CW

Step 5- Outputs change to go from step 5 to step 6
O:0/0 off Robot lowers

Step 6- Outputs change to go from step 6 to step 7
O:0/3 on Release part

The output list is not developed in the same section of rungs as the logic of the sequencer since outputs may be on or off across multiple steps. Output logic is developed after the sequencer is in place and combines the states of the sequencer for which the output is on or off.

As the sequencer moves from step to step, the sequencer using coils successively turns on the next coil set in the sequence. When the last step is being executed, all the coils in the string are

observed on. When the last step completes, the coils are turned off. This characteristic of the sequencer allows the maintenance person to quickly observe the last coil on in the string and surmise that the sequence is hung at the next step. This gives the maintenance person a handy method of troubleshooting the sequencer using relays. Care must be taken to not allow the next sequence to start while the sequencer is finishing the present sequence. Logic should account for not allowing a new starting pulse while the last sequence is still being executed.

While this type of sequencer seems to be cumbersome, it is used a great deal as long as the sequencer length is not long and the steps are well defined. If the steps are not well defined, a second method using a counter should be employed. Using a counter allows additional steps to be inserted more easily than with relays. Both methods of using coils or a counter provide a memory of where the sequence has been and where it next is expected to move. In general, coils and counters are equal. Counters can be a bit more flexible, however, when adding a number of steps quickly.

Using Counters to Control Sequencers

As sequencers become more complicated, the need for a more robust sequencer programming technique becomes necessary. As a second approach, it is suggested that a number in an N7 location be used to identify the present state of the sequencer. Usually a step number is employed. If the number is 0, the sequencer is not active. If it is positive, then the sequencer is active and the sequencer is in the state of the number. As the number is incremented, the sequencer moves to the next step.

Very large sequencers may be built in this way. If the sequencer is in a particular state, the EQU block allows logic to be performed exclusively in that state. The rung below shows an initialization step using a number for the step counter.

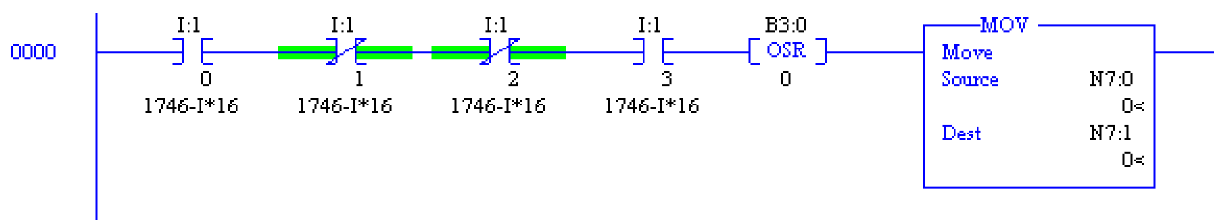


Fig. 11-39a Simple Robotic Sequencer in Ladder using Numbers for Steps

Using the logic from the original sequencer, initialization moves a 1 into the sequence counter located in N7:1. While it is not required that one-shot logic be used, it is usually recommended.

Example using Counters to Increment Sequencer:

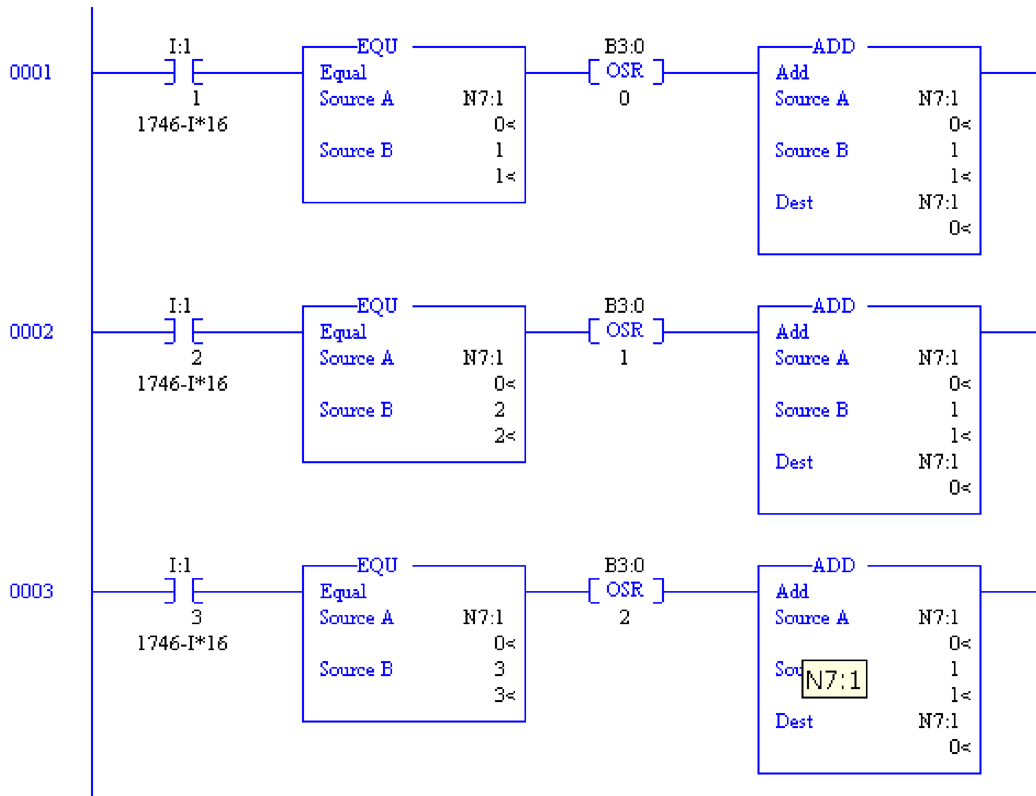


Fig. 11-39b Simple Robotic Sequencer in Ladder using Numbers for Steps

As each state is satisfied, the sequencer moves to the next state based on logic similar to the relay-based sequencer. An advantage of using a number to drive the sequencer is that several steps may be jumped over and then filled in at a later date. For instance, if it is known that a sequencer is going to be complicated and that several steps are not fully known, plan the program to skip some steps and then go back and fill them in as necessary. Skipping steps or changing steps is much easier with a number than with the sequencer using only coils and seal circuits.

Any of a number of other methods using bits or numbers can be used for sequencer control. For instance, a sequencer may be programmed using a word with a bit initially placed in the least significant bit and rotated one bit to the left for each step. This approach is as valid as either of the approaches listed above.

Adding Time between Steps

Each of the sequencer types potentially needs a time delay between the end of the prior step and the beginning of the next step. With the original relay circuit sequencer, the fix is easy. It requires only that a timer be placed between each step. This may be accomplished by programming the following:

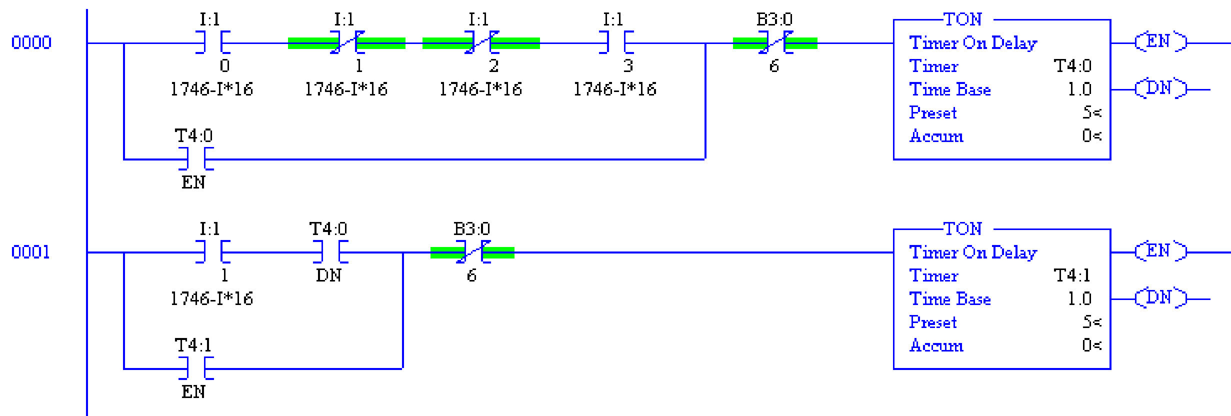


Fig. 11-40a Adding Timer Delay Between Steps using Coils

To program a time delay between steps of a sequencer using counters, sense the change of step, delay a time period and step to the next step using a one-shot. See below for an example of the time delayed counter sequencer.

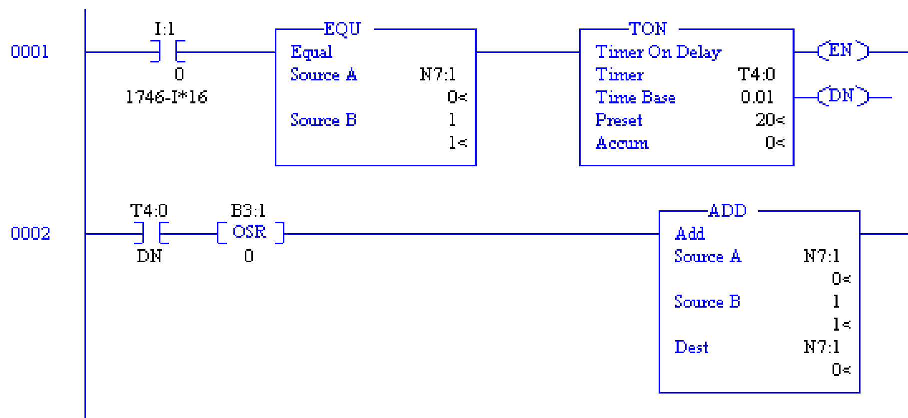


Fig. 11-40b Adding Timer Delay Between Steps using Numbers

Using the SQx Instructions

A third approach uses the sequencer instruction to direct step number and output state. The instructions SQO, SQL, and SQC of RSLogix 500 or SQI, SQO and SQL of RSLogix 5000 are three instructions used to define and operate a sequencer. Several Sequencers may be combined to coordinate large sequencer blocks.

Why is it not advisable to use these instructions as compared to the methods used above? The sequencer instruction set is quite complicated but once set up tends to work very well. The reason that sequencers are built without incorporating the SQx instruction set is that sequencers programmed with the SQx instructions tend to be very difficult to troubleshoot by others. This may lead to difficulty in keeping a process running.   The original programmer may understand the concept from layout to implementation but as documentation is lost or not available and an electrician or other technical person is brought in to troubleshoot the sequencer, the difficulty of finding broken equipment interacting with the sequencer is great. The SQC instruction moves a

step each time it receives a off-to-on transition. It moves sequentially through the programmed sequencer file. It compares data through a mask to a source word or file to check for equality.

The Mask is a hexadecimal code or the address of a mask word or file. If the mask is designated as a file, its length is equal to the sequencer file's length.

The Source is the address of the input word or file for which a SQC instruction obtains data for comparison to the sequencer's file.

Sequencers are built by setting up tables in files which then are executed with the SQx instructions. A table is built for each portion of the SQO and SQC instruction. The Output Table for a 10-step sequence controlling up to 16 outputs is shown below.

Output Table:

Step 1																
Step 2																
Step 3																
Step 4																
Step 5																
Step 6																
Step 7																
Step 8																
Step 9																
Step 10																

Mask allows bit in output word to be set either 1 or 0 when mask bit set.

Mask																

yields:

Output																

Using Sequential Logic in State Diagrams with Runoff

Combinations of sequential logic may be combined using Runoff State Diagrams. An example from industry will be used. The exact application will be somewhat obscured to protect the company's proprietary information. The application moves steel billets through a reheat process. The billets are staged on a conveyor and then positioned to transfer to a second table prior to entry to a re-heat furnace.

First, a billet is laid on a table with rolling collars capable of moving the billet in the direction noted. The billets proceed to the transfer table (second table) as shown. When two billets are on the transfer table, then they are ready to transfer as more billets are laid on the first table.

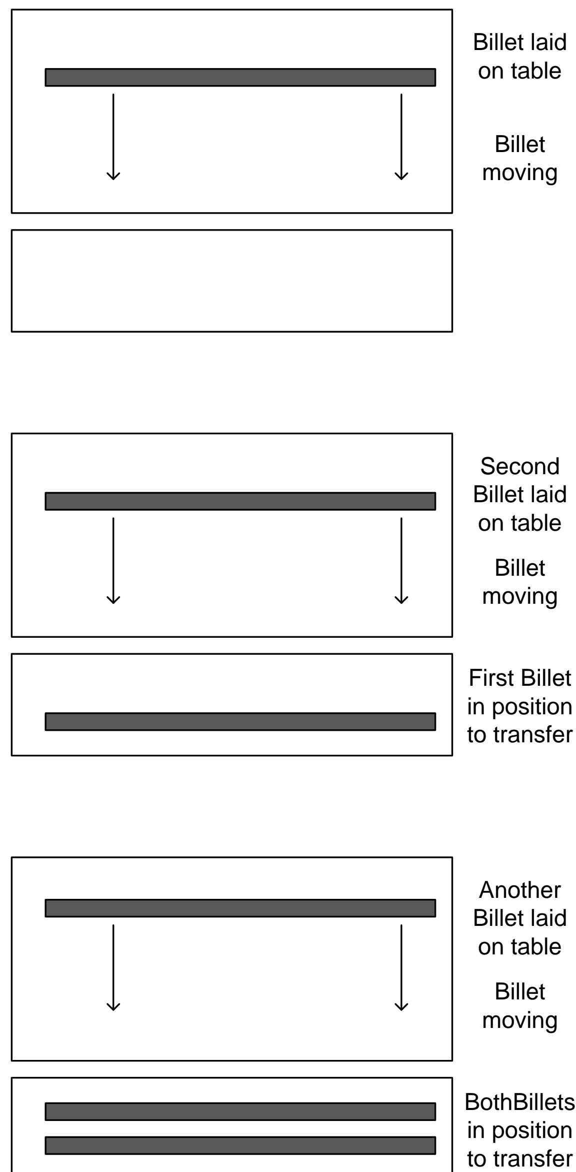


Fig. 11-41a Physical Layout of Billets Moving on Table in Steel Plant

Once the billets are in position to transfer, the second table sends a “ready” signal to the Charge Table and waits for a “clear” signal to begin transfer of billets onto the Charge Table.

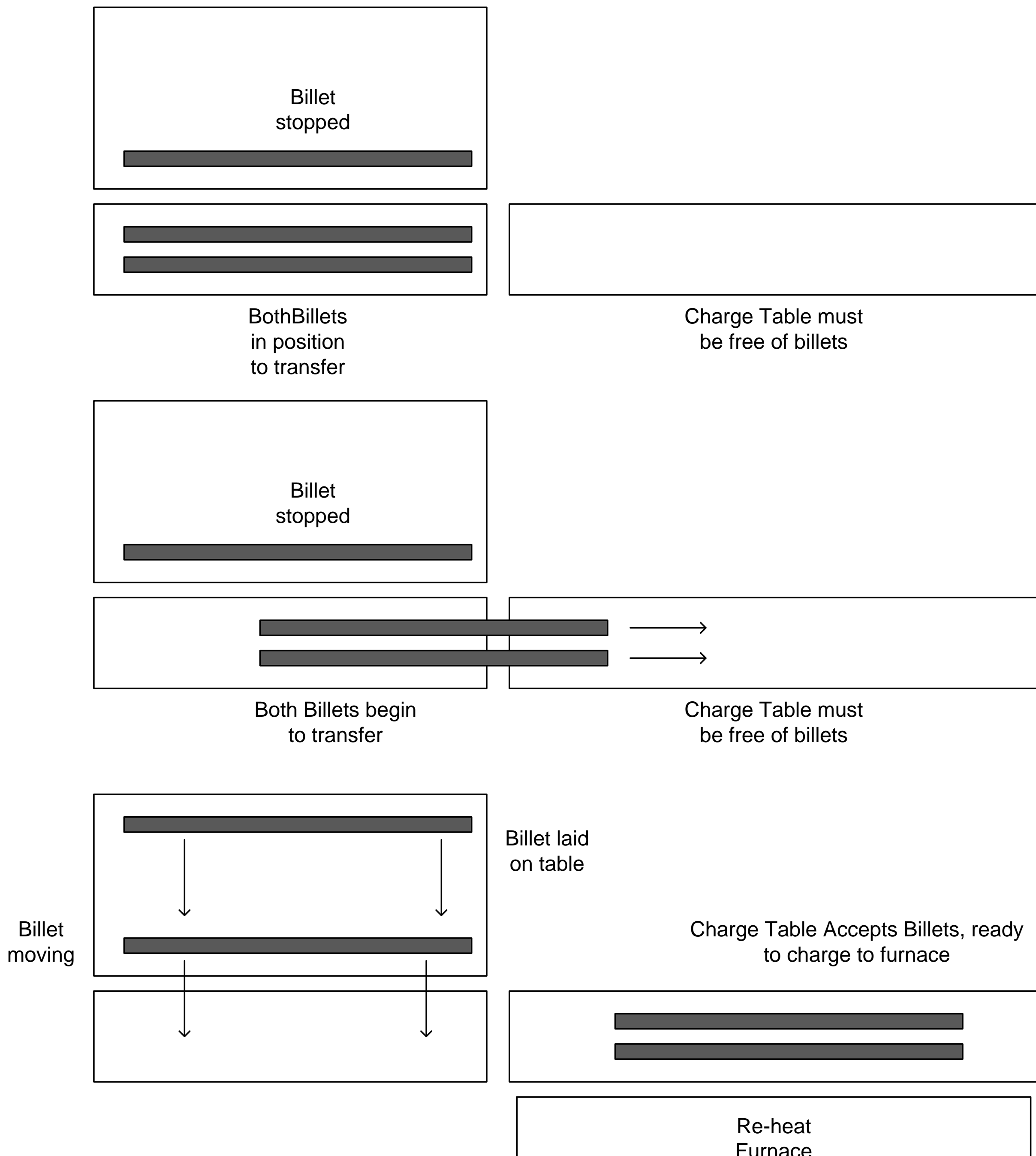


Fig. 11-41b Physical Layout of Billets Moving between Tables in Steel Plant

Now, billets are in place on the Charge Table ready to charge into the furnace while other billets are being positioned and ready to come onto the Charge Table when it is clear again.

A state diagram of the operation is shown below. Notice that the tables are linked in the state diagram. Notice that the third sequencer is used to take billets out of the back end of the furnace. This action must be coordinated with the charging of the furnace in order to keep the charge and removing of the billets in sync.

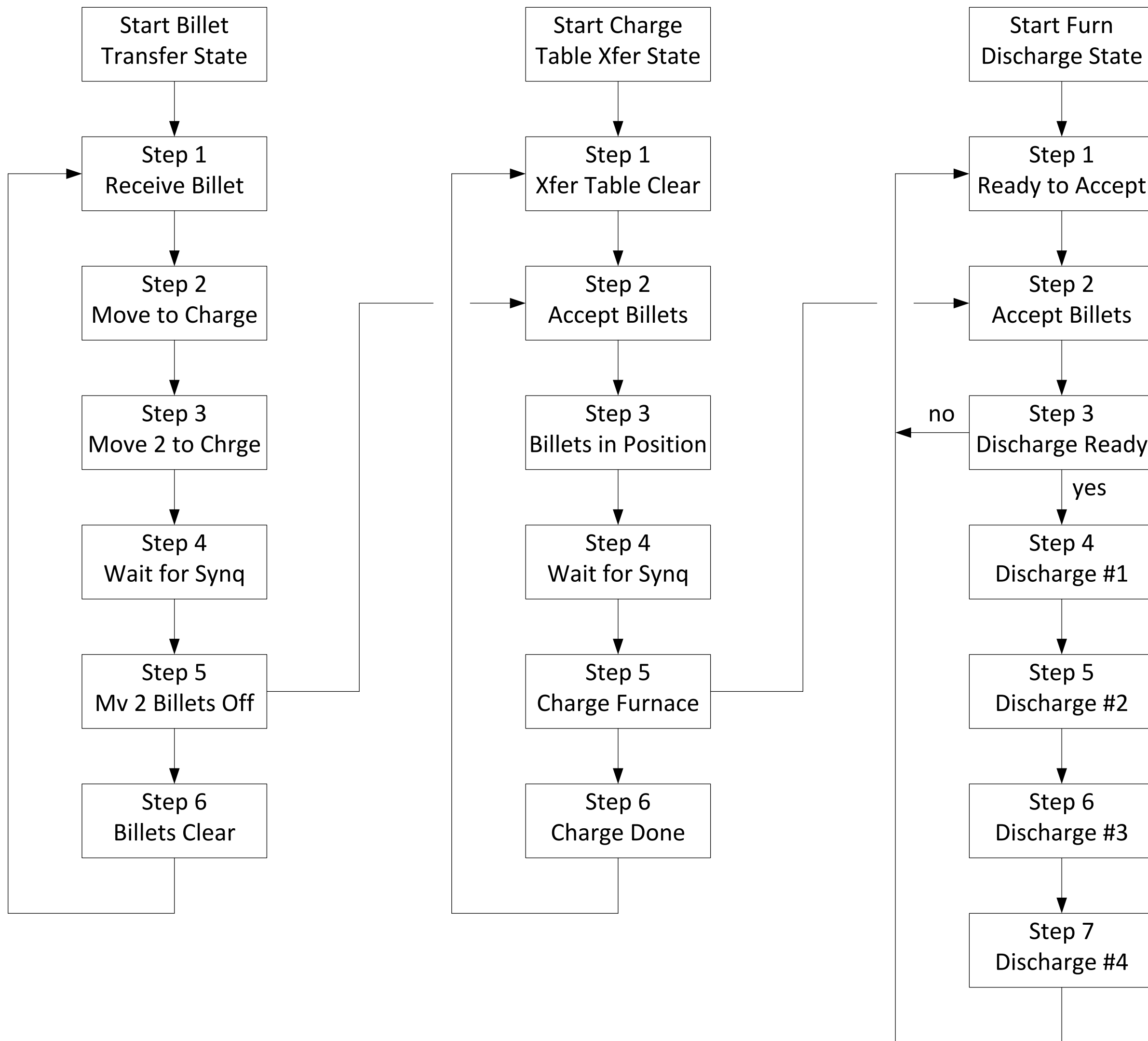


Fig. 11-41c Billet State Diagram

Here the furnace is shown with billets filling the furnace from charge end to discharge end. The billets must be able to move into the furnace but only when there is room after a discharge takes place. The charge end state table must not act until room is available after discharge happens. This corresponds to step 3 of the second state table attached to state 3 of the third state table. The charge occurs at this time. Discharge occurs at another step in the process.

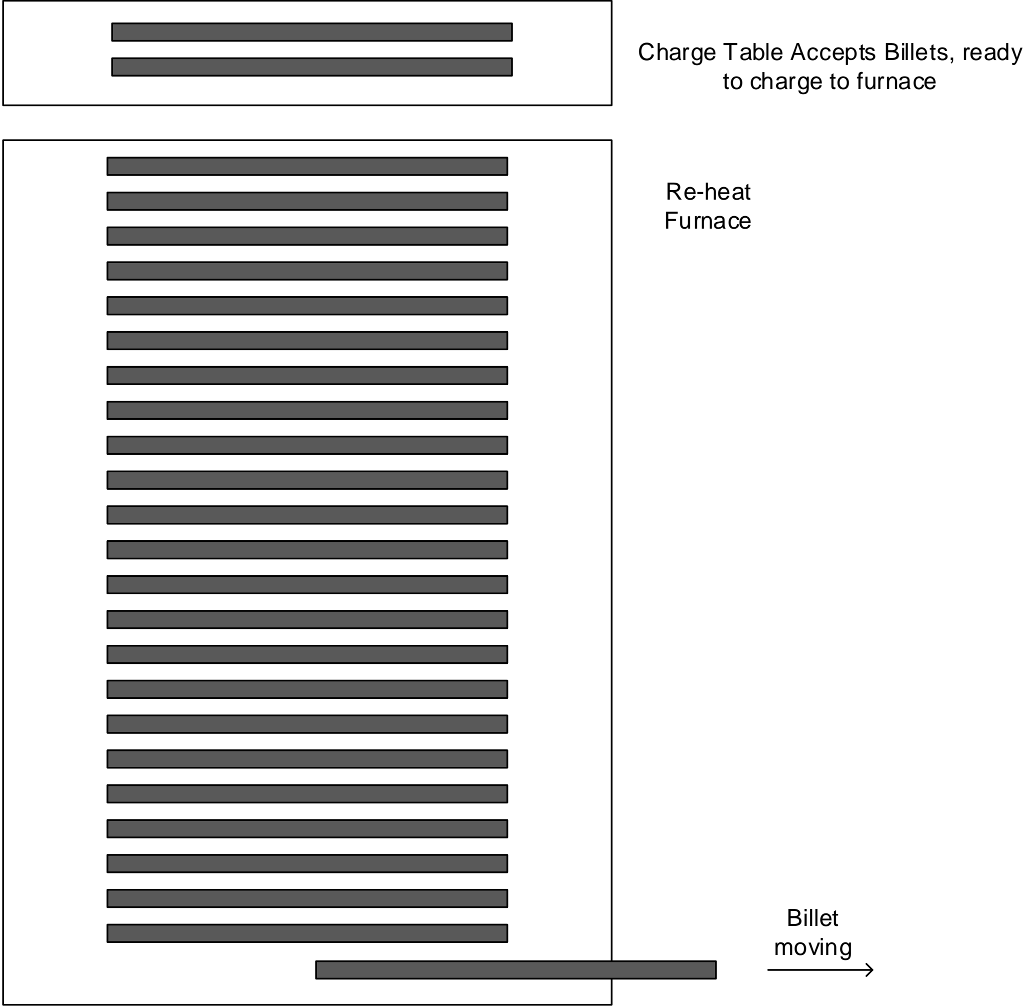
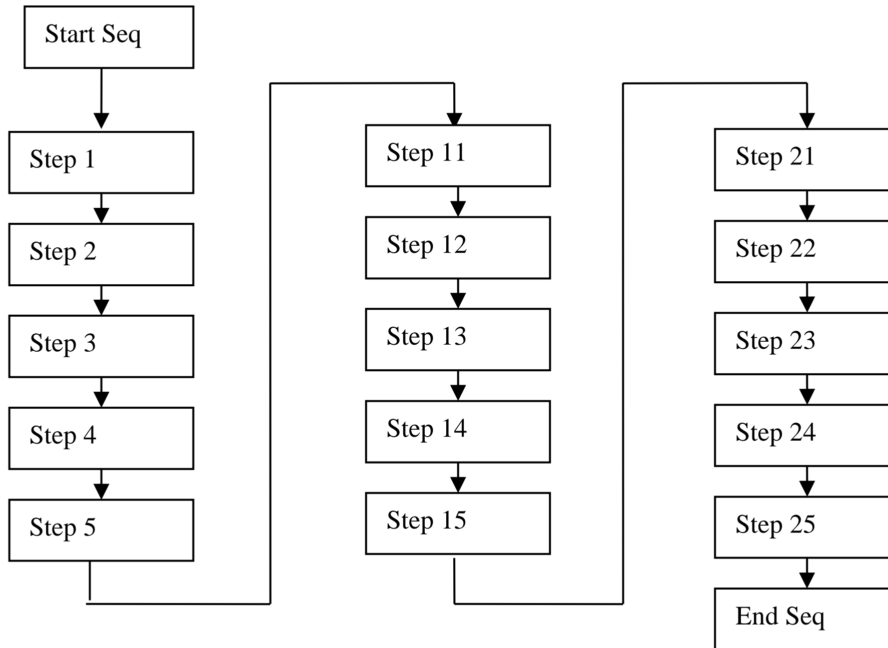


Fig. 11-41d Billet State Diagram

Multiple Sequencers Using Same Program

If an operation is similar to another operation except for the movement of a part or some other common occurrence, a state diagram may be used with the same program and multiple steps input to common logic. For example, the following state diagram may use a common program for step 1, step 11 and step 21 if the same action is done in each. A program such as this would be equivalent to a looping program in which the same operations are done in common for a number of different steps.



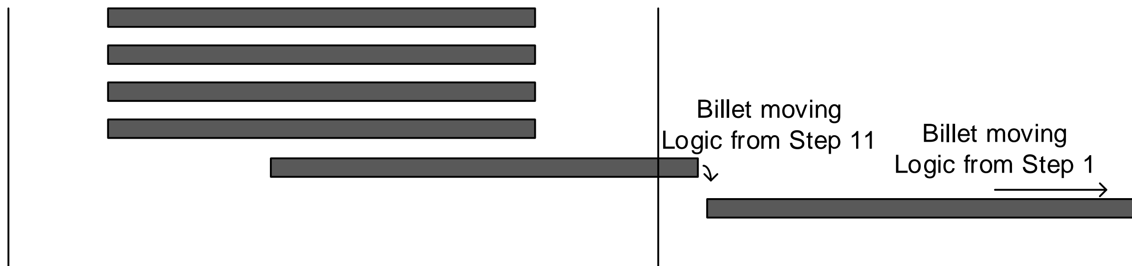
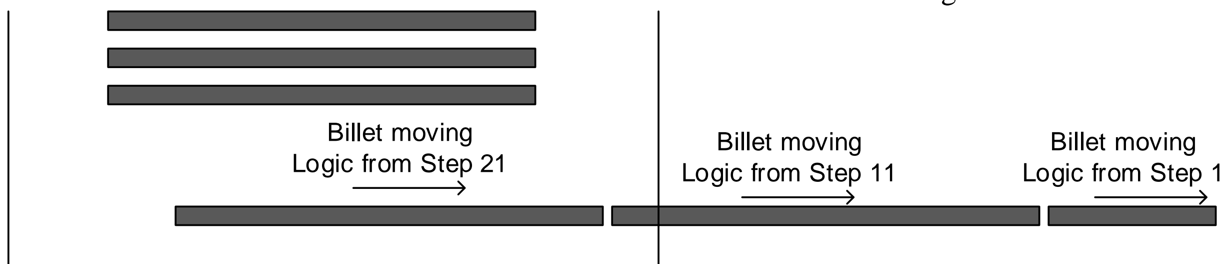


Fig. 11-41e Billets Moving From Furnace



The following logic could be used to control multiple steps using common logic:

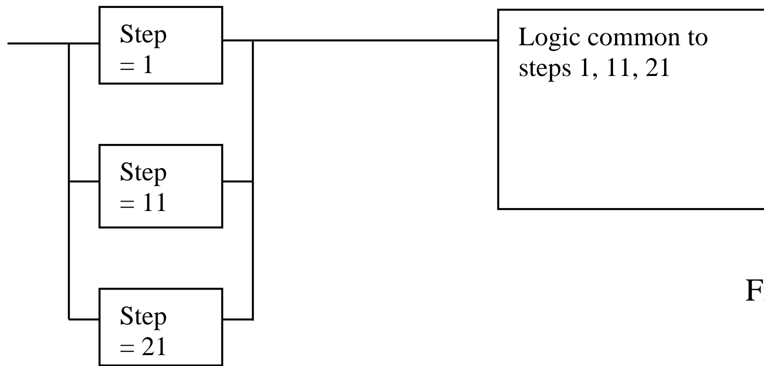


Fig. 11-41f

State diagrams using numbers can use the logic above to combine the logic of multiple steps simply by using the program structure above.

Systems of State Tables

State tables can be ganged together similar to the furnace state table described above in large systems. For example, the emptying of a parking lot of cars may resemble the following sequence:

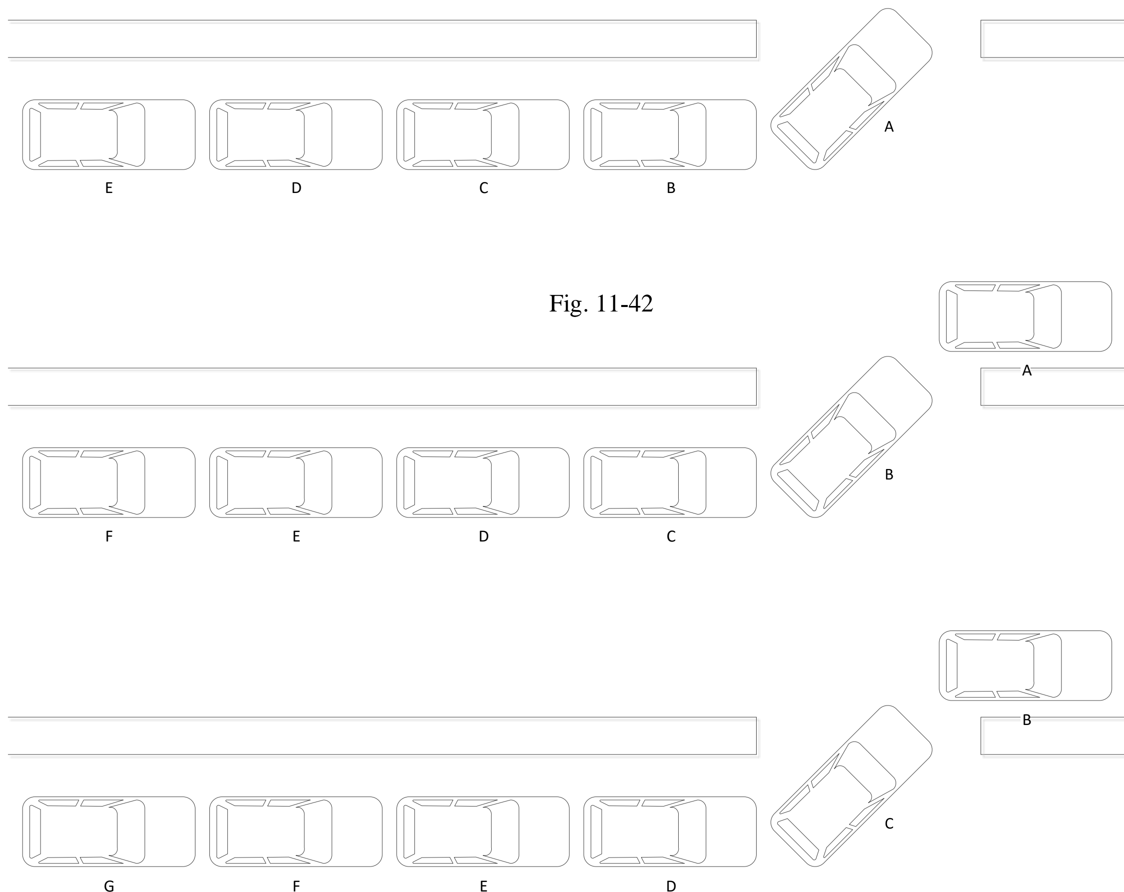
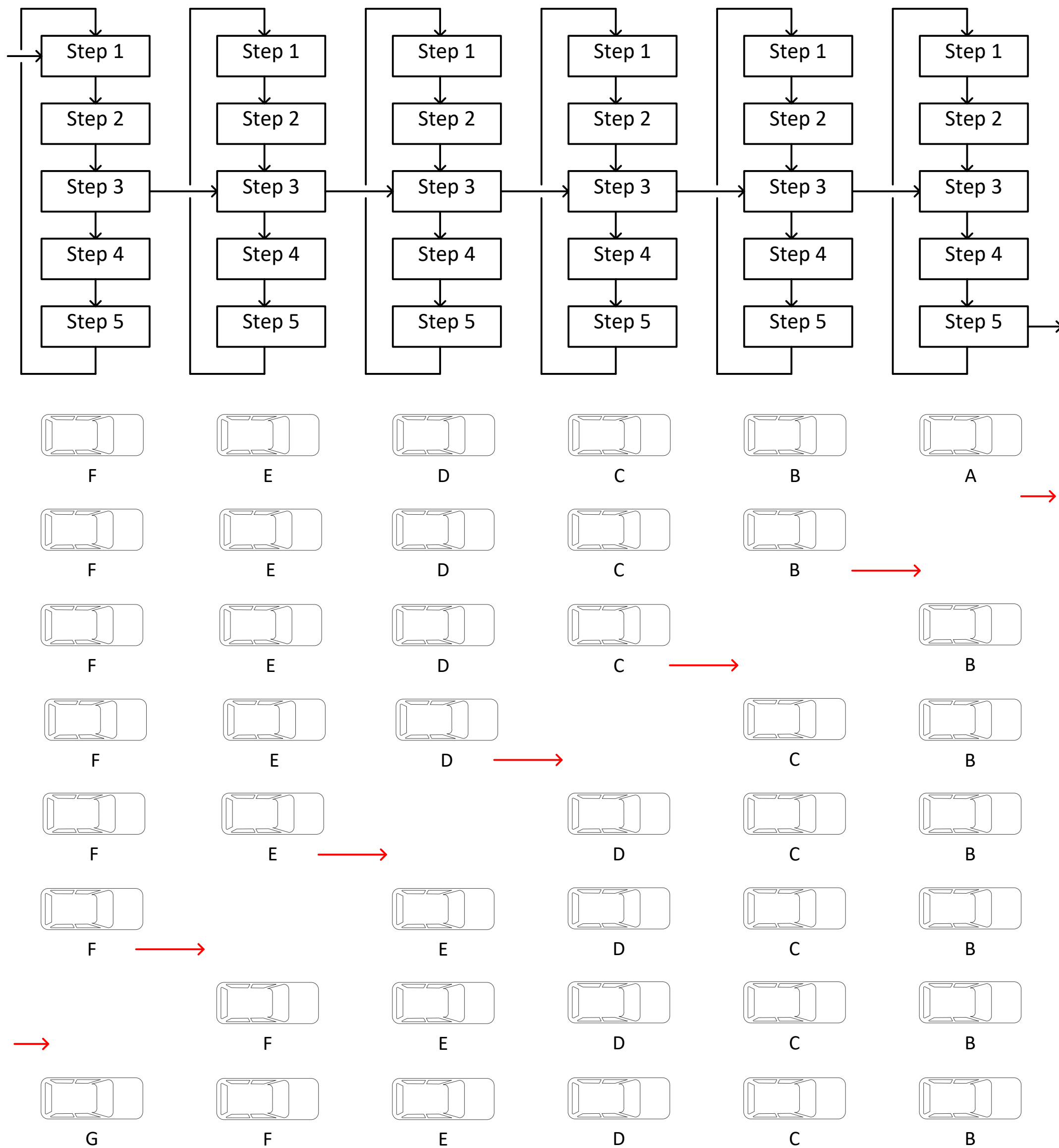


Fig. 11-42

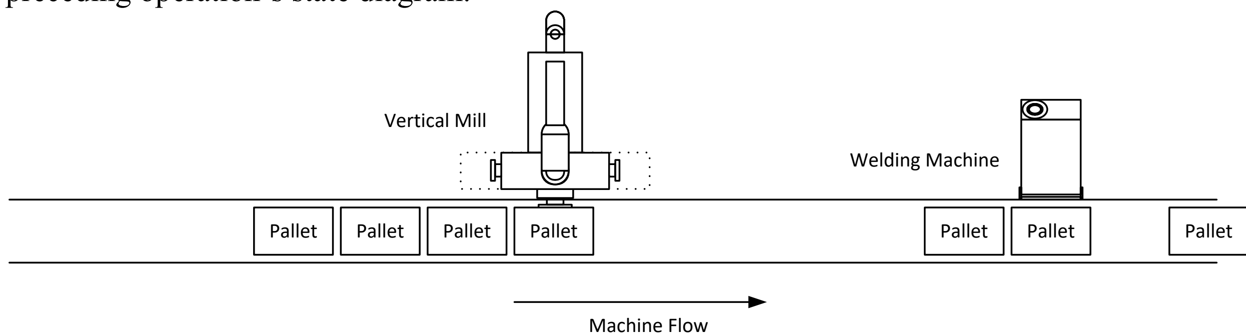
Each car moves from station to station and then waits for the next station to empty before moving forward. Each station may be a state diagram in a manufacturing setting. At each station, an action is done to the part. One station for instance can add a component and the next station can weld the component to the main body of the part. Each action depends on the prior action successfully completing and then proceeding. Without the first car moving forward, the succeeding cars are stuck but with its movement, then the next car moves forward followed by the next, etc. Each operation at each station is important to the overall fabrication of the part and each station's activity is a state diagram (possibly a sequential state diagram). The outcome is a complicated process that can be broken down into several small operations with the interlinking of states one to another.

Each process in the figure below starts with a step 1 followed by 2, 3, 4, 5, etc. At each juncture, there is a hand-off to a subsequent process. The hand-off occurs at a prescribed step in the sequence of steps. Each hand-off must be coordinated between two separate state tables.



When a sequence such as this is being planned, the last part (at the furthest downstream station) is moved off the table and then the next part is moved into the last station and each part upstream can move downstream one station. Their motion is similar to the cars moving up a station in the figure of the previous page.

While we use cars to show the sequence, the item may be a single piece of glass or anything requiring a position where only one can fit in the next station. If there is no limit to the number of parts that can fit in a waiting line for the next station, there does not need to be the linking between sequencers as shown above. An example of this would be pallets in a machining operation in which a pallet is free to move to the next station no matter what the state of the downstream operation is. In this circumstance, there would be no need to tie state diagrams together. Each operation would have a state diagram independent (for the most part) from the preceding operation's state diagram.



More intricate state diagrams are defined in future chapters such as Ch. 13 which is interested with batching operations. The state diagram defines entire portions of the programming process and serves as a discussion point to define the program prior to actually committing to a design. The state diagram is useful in the very simple diagrams at the beginning of the chapter or with those at the end of this chapter or in future chapters in this text. The state diagrams of the exercises at the end of this chapter in many cases are as difficult to design as the actual program that follows the state diagram and actually controls the process.

Timing of Steps

In many processes, there are bottle-necks which the PLC programmer may be requested to remove. Timing of movement between stations is an area of concern in many applications. If the pallet or part is not present at the station before the step is to be accomplished, then the time to travel may be the bottle-neck. If possible, the programmer should look for ways to avoid this. One method is to move a piece half-way between two stations which effectively cuts down travel time by half. If the program will not allow this type of control, other ways such as tracking of parts and knowing exact position may be used. In any event, while the PLC programmer may not be thought of as a time-study expert, he/she should consider the time taken to travel between stations as dead time and minimize it.

Troubleshooting Hint

A troubleshooting hint for one-shots is to program a counter or adder (pseudo-counter) to record the one-shot event. Either counter or adder works well to trap the event that usually is not seen

on the computer screen. I0.0 is seen but |P| of I0.0 is not. If a program contains several contacts such as |P| of I0.0, then use the circuit shown below to trap or show instances of the one-shot occurring in logic:

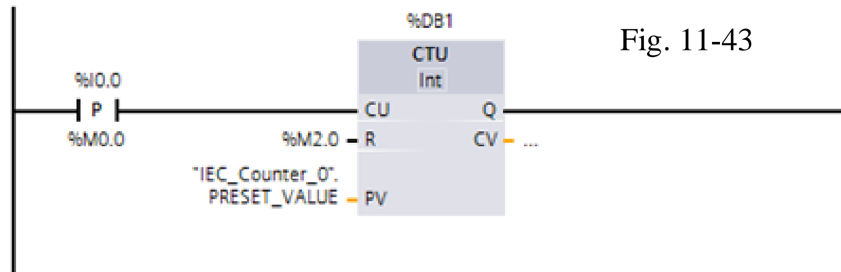
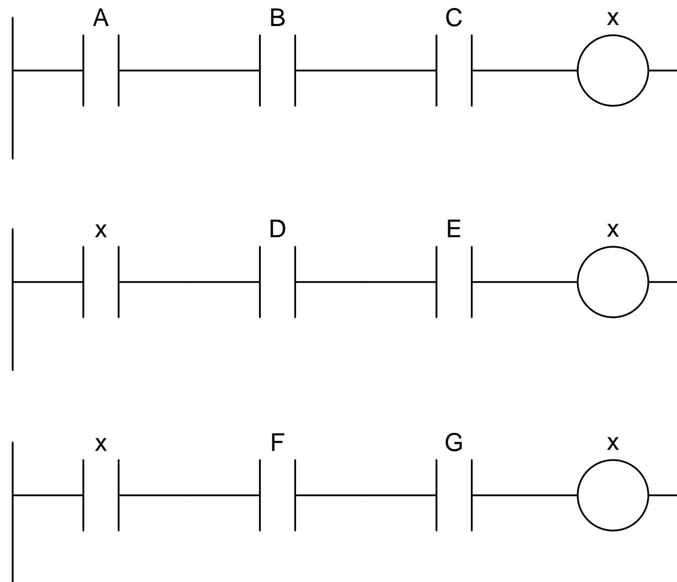


Fig. 11-43

Revisit "Last Coil Wins"

In previous chapters, it was stressed that since the last coil wins, coils should never be double programmed. However, if a coil is being used with logic from several different sources, it is possible to use a coil more than once with prior occurrences carrying forward to later occurrences. This type of programming can become a logistical nightmare and should be avoided. It does show the scan-dependent nature of programming and the ability to program ladder logic that would not work the same if re-arranged.



is equal to:

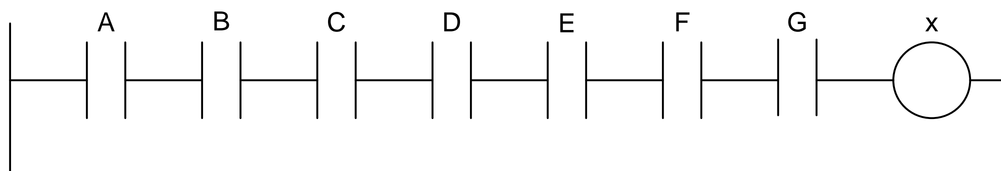


Fig. 11-44 Accepted Multiple Use of Output Coil

Care must be taken to keep rungs of logic programmed in this way close together. If the output x is programmed as the rungs above and the rungs are not close together, other rungs using x may be on when the actual state of x is off. The opposite may also be true. This is something that might be a useful tool in a program. In that case, ignore the previous warning of “last coil wins” and use the programming technique.

We may have drifted a bit from the original subject of the chapter with a discussion of state diagrams. The topics discussed are of importance in developing good programs and should be considered in the scope of the state diagram. The importance of understanding when the programmer has need of state diagrams is extremely important and should be discussed in tandem with the subject of how to program a state diagram program.

Planning For Problems at End of Chapter

The problems at the end of the chapter are good practice problems for you to try your skill at developing a state diagram. Some are quite difficult. Others will be able to be done in a few minutes. The longer, harder problems can be split into a number of smaller state diagrams that are joined together.

For instance, the problems involving stacking or moving of material each have three modes:

- Manual
- Homing
- Automatic

The elevator problem has two modes:

- Regular operating
- Irregular operating

A good first step would be to look for the modes if defined and build a state diagram for the mode. The mode might involve a number of simple state diagrams within the over-all diagram. For instance, most manual modes allow the operator to move independently an axis or part of the machine from a jog control as long as the movement does not bind or hurt another part of the machine. Some programs don’t care and allow the user to do what they want in this mode with the realization that if a crash or crunch occurs, the user will be the one to suffer. Sometimes this is best since the machine may need to be moved or jostled a little to free it from a bind or abnormal position. The programmer is usually the one to decide the safety limits and the programmer may decide to include the safety logic or not, especially in the manual mode.

Homing includes a number of moves the machine must make to restore it to a proper start position. Home is the position the machine expects to start its automatic operation from.

Automatic is the mode most used. It should include time delays between steps sufficiently long to allow for proper movement but short enough to allow the proper amount of parts to be manufactured to satisfy the operation.

If a problem does not define the mode, the programmer has the discretion to include certain attributes of the program in the mode or not. Usually the operator will help with defining the mode so that this person can most easily understand the operation of the machine and diagnose simple problems without the aid of the electrician or engineering programmer. Your best defense is to please the operator. Then please everyone else to the best of your ability. The machine tender or operator and the electrician are your best friend. Cultivate a positive atmosphere with each of them and your job will be easier by far.

The following common device has similar characteristics to the sequencers built above. The device is used to turn on and off household lights with the programming of the timer by pushing in the indented buttons around the 24-hour clock.

Fig. 11-45 Sequencer Simplified

Summary

This chapter is about state diagrams and their little cousin, the sequencer. Both of these tools are useful in programming difficult machine operations and allow the programmer to walk away after an installation with the satisfaction that the operation of the machine has been developed logically and the maintenance of the machine will be easier than if developed otherwise.

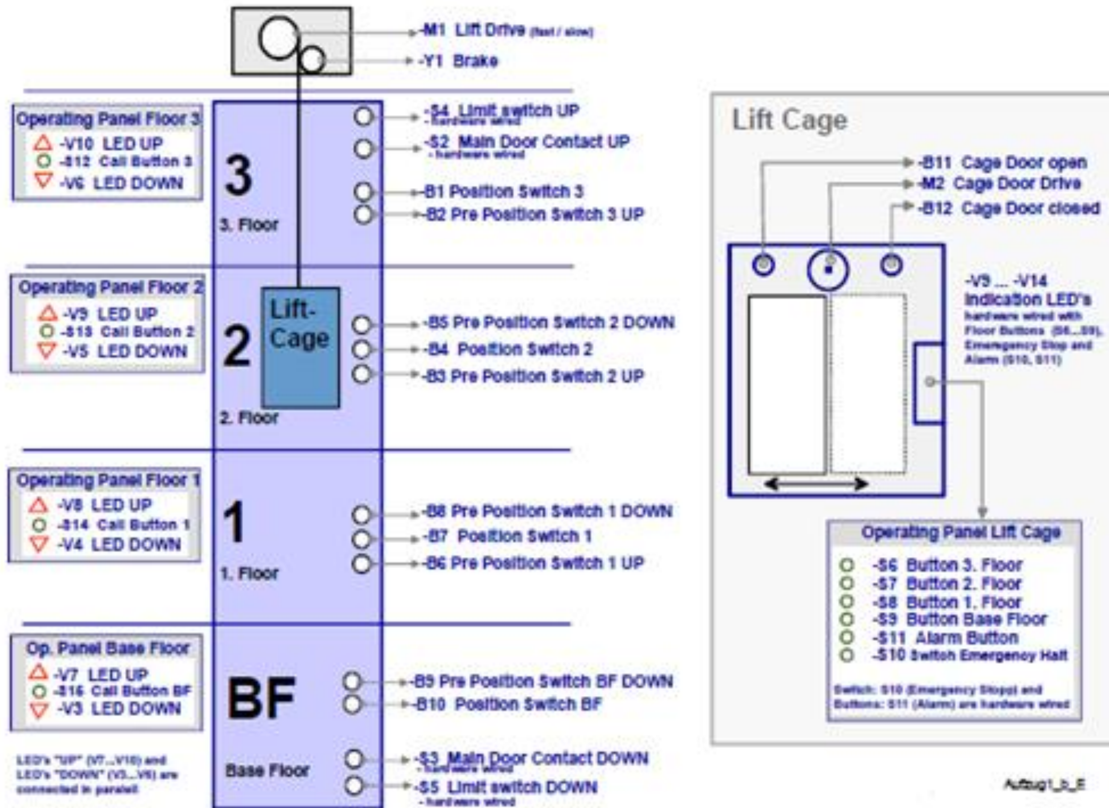
A common statement from many end users who depend on others to program their processes is that they don't want "spaghetti code". This is a metaphor for difficult-to-diagnose code. We have all seen others' code that we would term spaghetti code and wonder who would have ever created such a mess. We should remember that we need to look at the end product from the customer's point of view and give the best effort to create a program that both works and is maintainable.

A systems engineer once looked at my efforts and asked if I knew the KISS method. I did and I got it. The last letter of the KISS method is one that you or I do not ever want as part of our label.

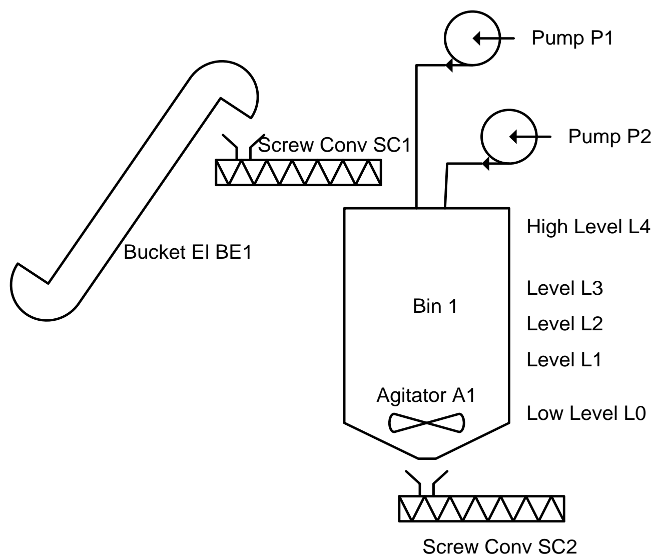
Whether you are strongly convinced that state diagrams are a good way to see how to start a program or not, consider that one of the first programs you will probably be asked to produce is one similar to the one with the small robot moving the egg seen in this chapter. The 'boss' will try you out on something considered quite simple and in most cases developed in a few hours as opposed to days or weeks or months. It is a test. So, if you are to pass this initial test, you should be able to see the problem as a simple sequence and develop the program appropriately. This is a strong motivator for you to understand the concepts, at least to a point, for how to develop a sequential program (or state diagram program). Hopefully you will be able to move quickly through this initial test and onto more meaningful programs down the road.

Exercises

1. Elevator Problem – Provide a set of State Diagrams for the Elevator

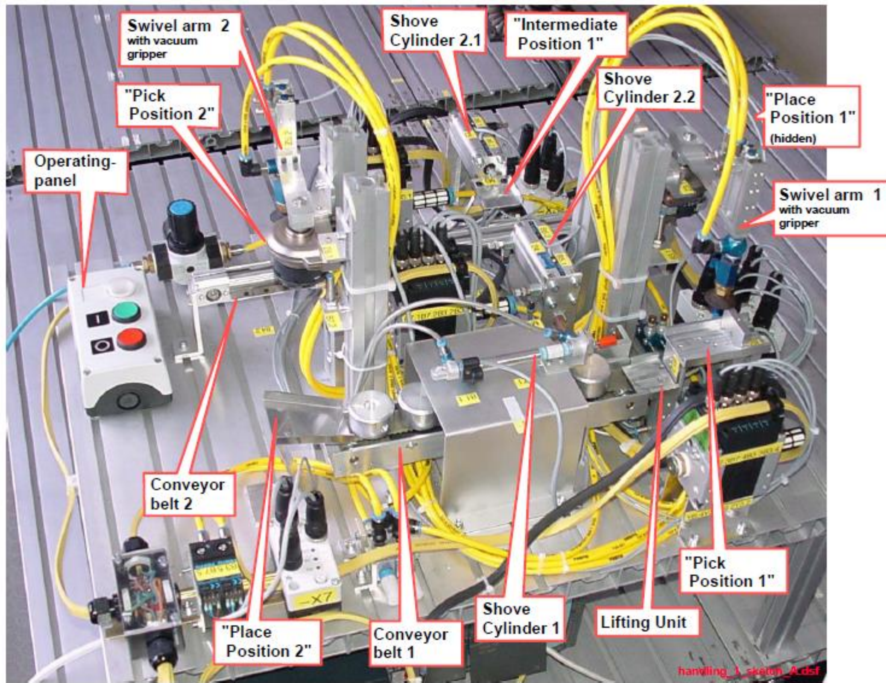


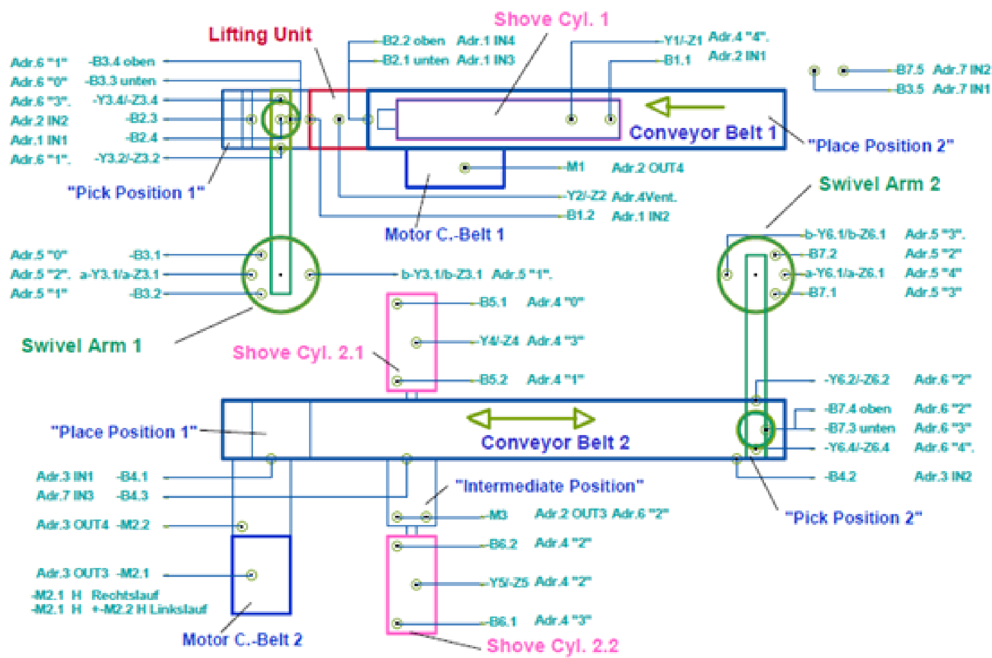
2. Provide State Diagram(s) for the following:



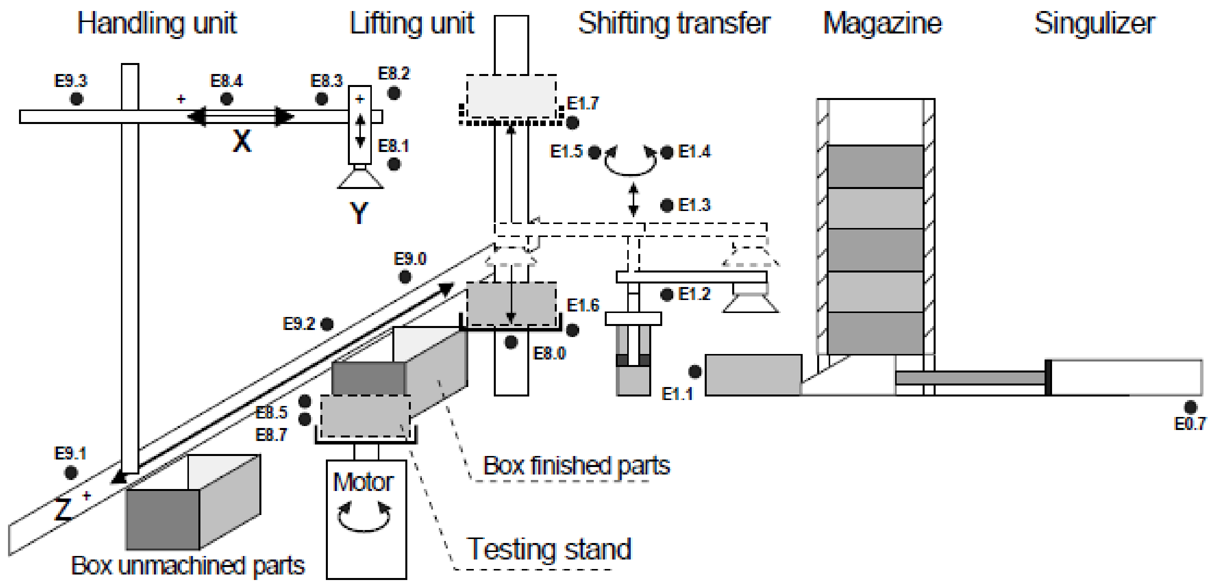
The main tank will fill with conveyor SC1 and bucket elevator BE1 as well as liquid from pumps P1 and P2. To make a batch, fill to a level L1 with the ingredient from the bucket elevator. Then fill to a second level L2 with the ingredient from Pump P1. Then turn on the agitator and fill to a final level P3 with the ingredient from Pump P2. When done, agitate for a time and dump using SC2.

3. Provide State Diagrams for the following machine:



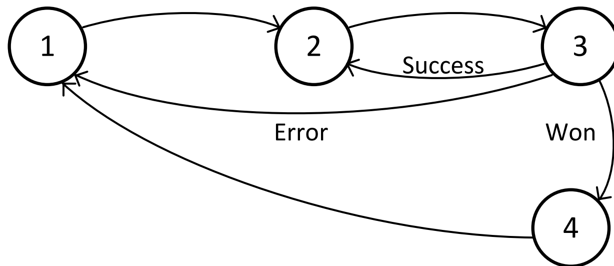


4. Provide State Diagrams for the following machine:

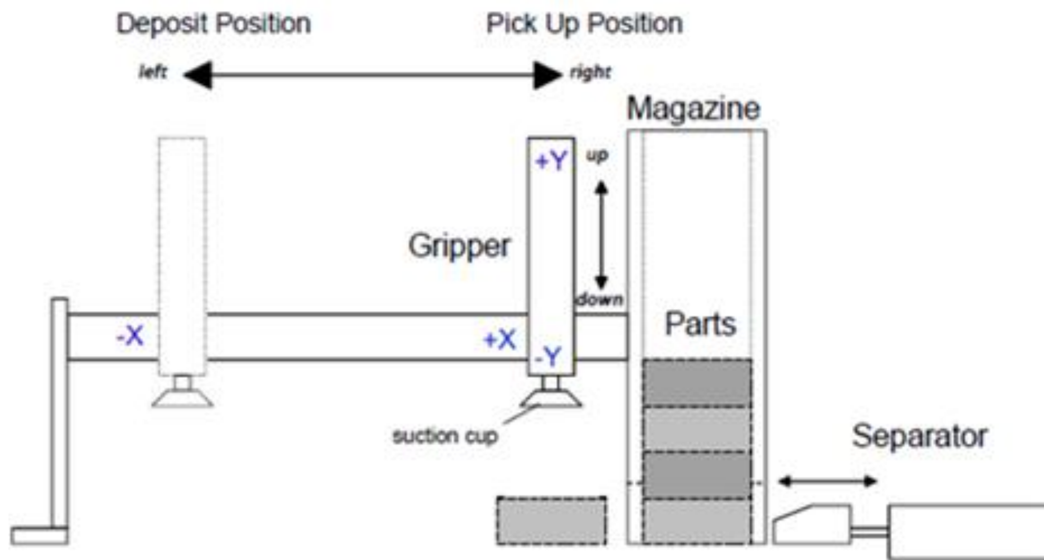


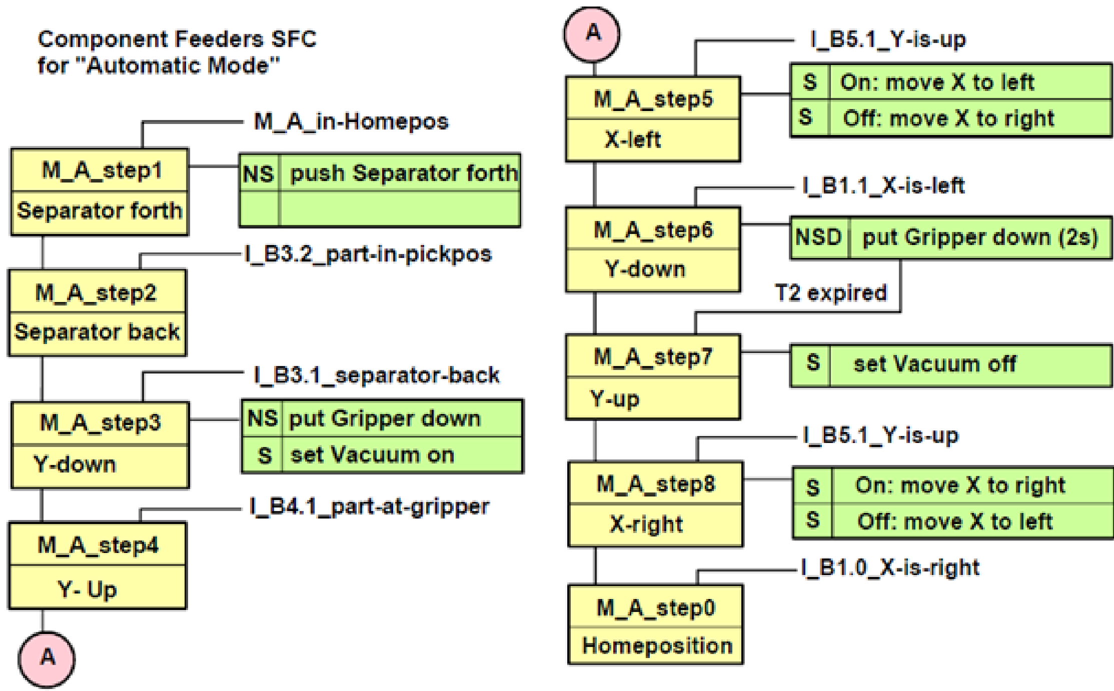
5. The following Simon Says State Diagram has various labels associated with the circles (bubbles). Label each bubble according to the attached list:

   a. Not Playing
   b. Flash Lights
   c. Playing/Pushing Buttons
   d. Playing/Showing Lights



6. From the following two figures below, first fill in the table of inputs and outputs:





SFC for Automatic Mode of Component Feeder

Fill in Definition of Inputs:

Sensor	Function/State	Signal Assignment

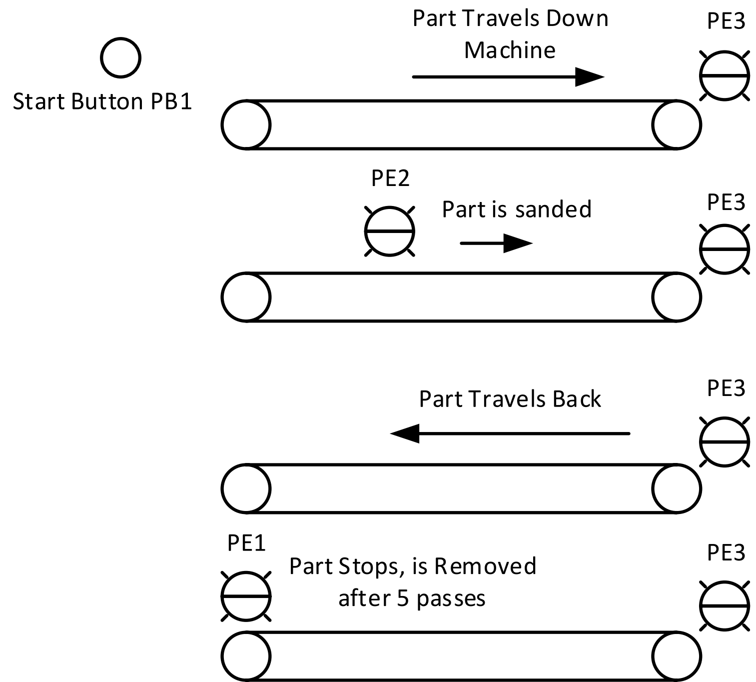
Fill in Definition of Outputs:

Actuator	Function/State	Signal Assignment

Then write logic to perform the automatic operation of the feeder.

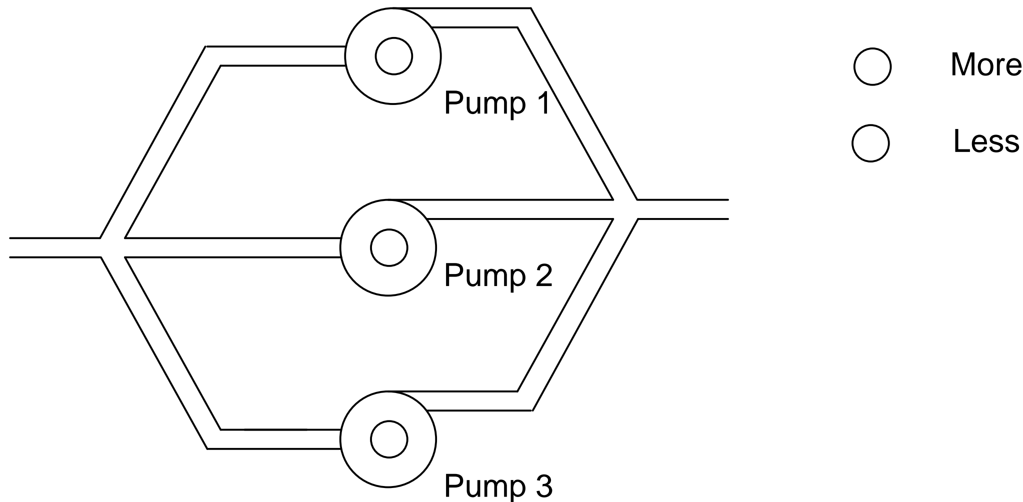
7. The problem below moves a part left to right and into a sanding station. The sander only turns on after PE 2 sees the part. When the part reaches PE 3, the sander turns off and the part returns to the left to PE 1.

   Draw a state diagram and then write a program in Ladder to control the action described when the start button is pushed and the system automatically repeats the travel right, then left **five** times. Include a short time delay at each end of travel.


Part Travels Down
Machine
PE3
Start Button PB1
PE2
Part is sanded
PE3
Part Travels Back
PE3
PE1
Part Stops, is Removed
after 5 passes
PE3

Lab 11.1   Three Pumps

Three pumps are arranged as follows to provide cooling water for a manufacturing plant. For cooling to occur, at least one of the pumps must be on at all times but if no cooling is required, all pumps are to be turned off. For more cooling, a second pump is requested to turn on, followed by a third pump if sufficient cooling is still not received. To protect each from wearing out prematurely, a plan has been devised to allow each pump to turn on and off by using logic to turn on the next pump in sequence and turn off the pump that has been on the longest. Timers should not be used to determine the pump on longest but rather logic should be used to determine which pump should have been on the longest. For example, if pump 2 and 3 are on but 1 is off, pump 2 is the one that should be turned off since it probably came on before 3 did. If a call for less cooling is received and all three pumps are on, the pump that was logically on for the longest time should be turned off. The system starts out with no pumps on and when a call for more occurs, pump 1 will turn on. Then the system is cyclical rotating through pumps 2, 3, 1, 2, etc.



Options:

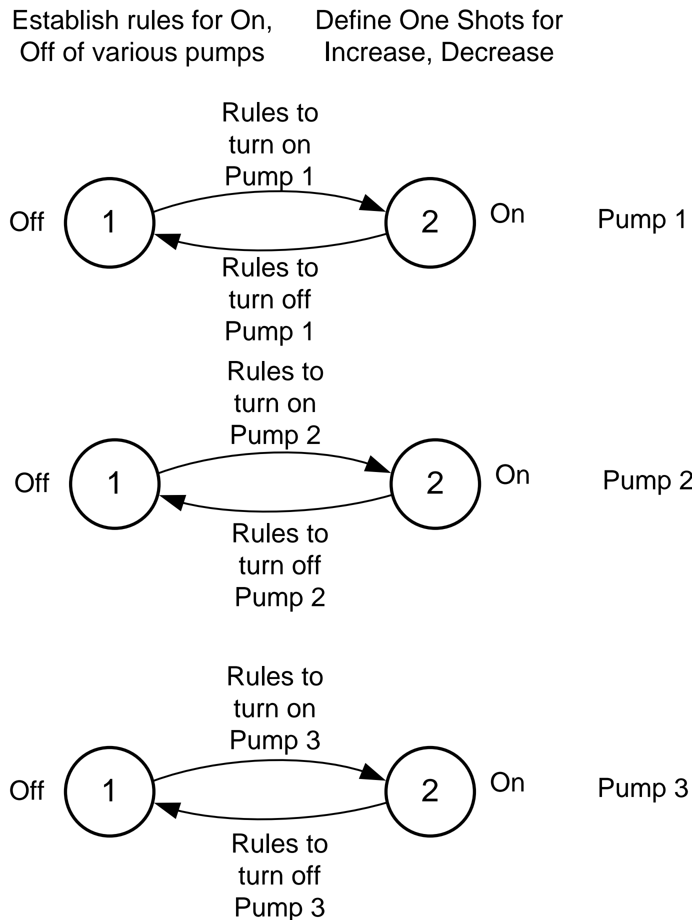
Lab 11.1 Add auto/manual switches for 1, 2, or 3 pumps. Auto will allow cycling of a pump normally while manual will allow a pump to be started and stopped with a push-button.

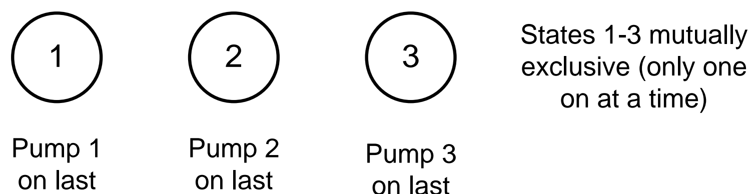
.1- P1(A/M), P2(A/M), P3(A/M)
.2- P1(A/M), P2(A/M), P3(A)
.3- P1(A/M), P2(A), P3(A/M)
.4- P1(A), P2(A/M), P3(A/M)
.5- P1(A/M), P2(A), P3(A)
.6- P1(A), P2(A/M), P3(A)
.7- P1(A), P2(A), P3(A/M)
.8 - add a fourth pump and have all P1-P4 either (A/M)

Note: The base program of **Lab 11.1** is called a floating master for the pumps. The master is initialized as pump 1 until pump 2 turns on when it becomes the master. Pumps turn of based on the principle of leaving the master pump on as long as possible. Therefore, pump 1 would turn off before pump 2 if both pump 1 and pump 2 are on.

The Pump Demand Program Hints

Notice the position of the logic is extremely important in that the scan is used to do operations in a sequential order within the scan. This programming technique can aid in solving very difficult sequential logic such as this problem with minimal difficulty. Use of the scan is a great aid in programming and sequential programming in particular.





Lab 11.2 Four Fans – Repeat of 11.1 except for four fans instead of three pumps

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