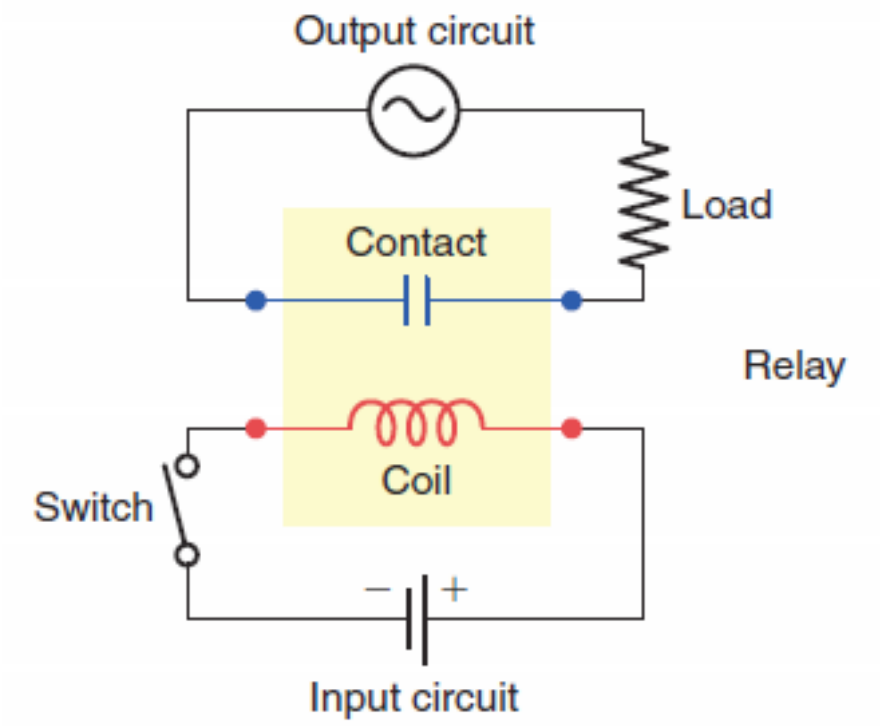
Chapter 6

Developing Fundamental PLC Wiring Diagrams and Ladder Logic Programs

6.1

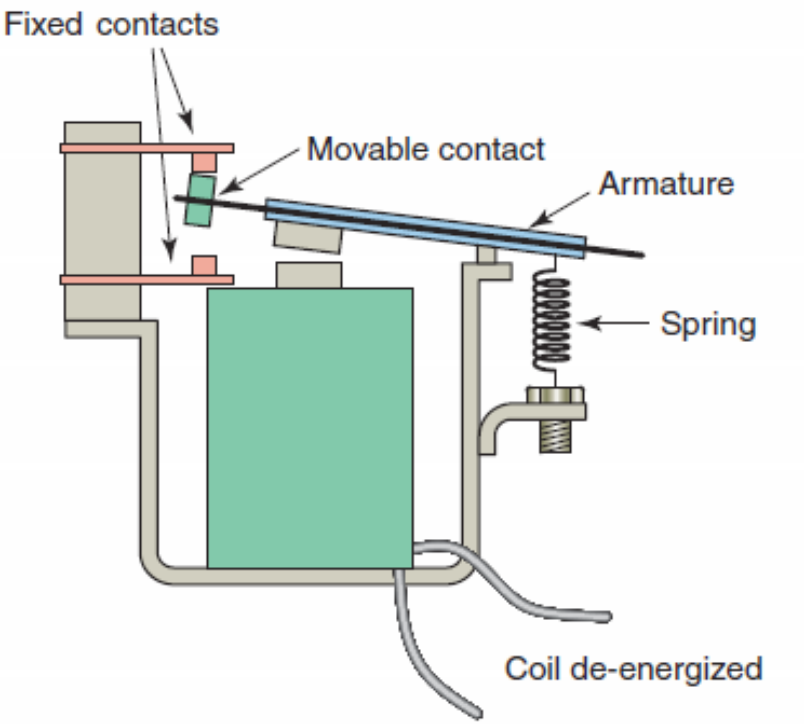
Electromagnetic Control Relays

A PLC was designed to replace control relays that made *logic decisions*.

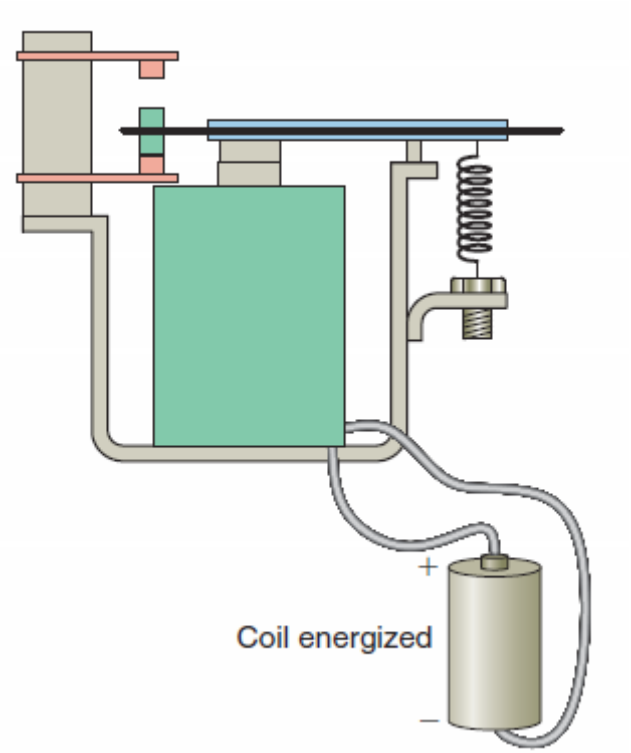


An electrical relay is a magnetic switch which uses electromagnetism to switch contacts.

Relay operation.

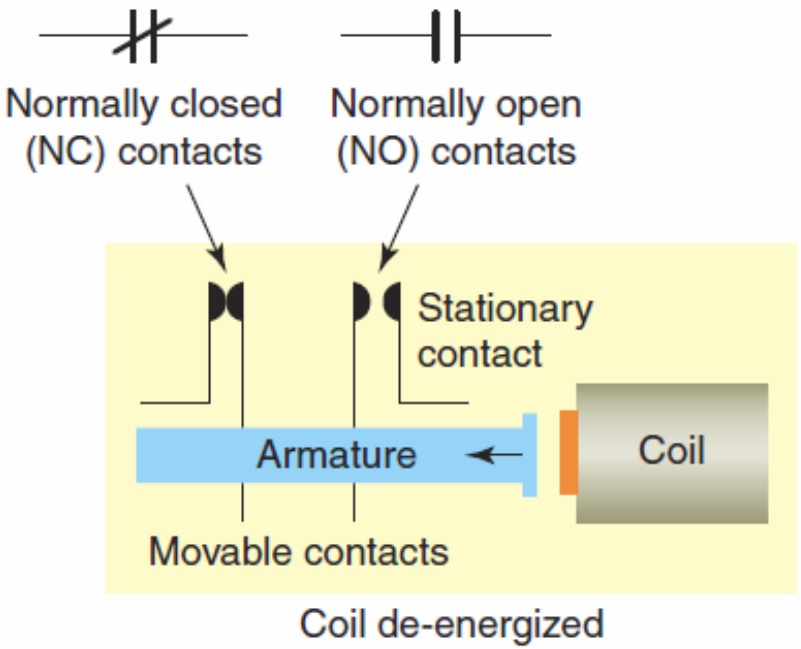


De-energized



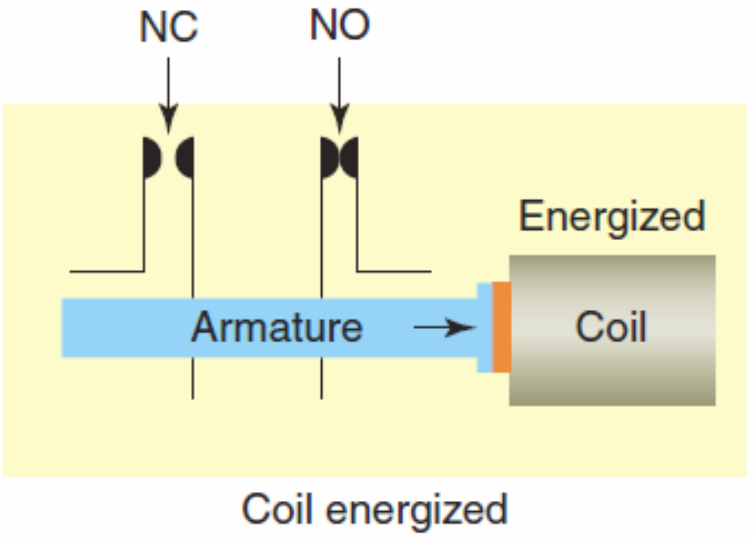
Energized

Normally open (*NO*) and normally closed (*NC*) contacts.



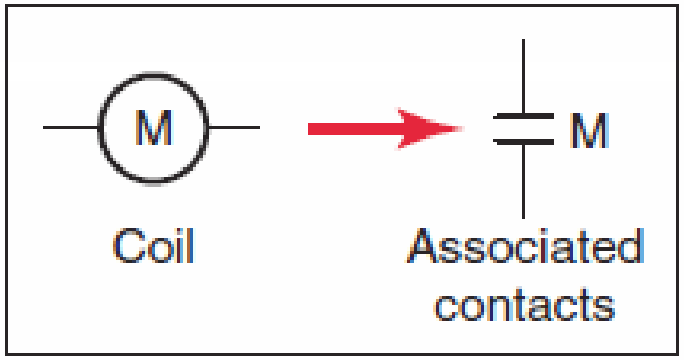
NO contacts are open when the coil is de-energized and closed when the coil is energized

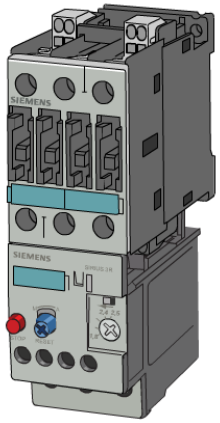
NC contacts are closed when the coil is de-energized and open when the coil is energized



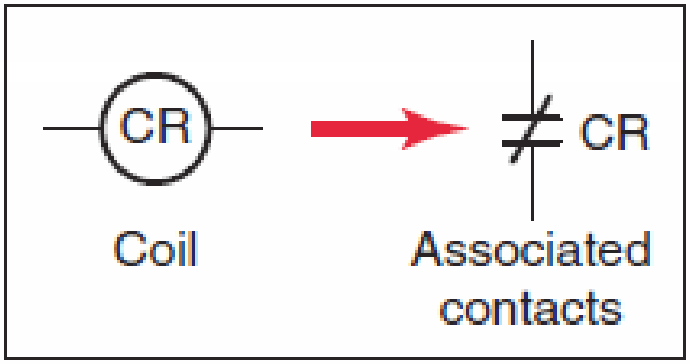
Relay symbols.

The letter M frequently indicates a motor starter coil.





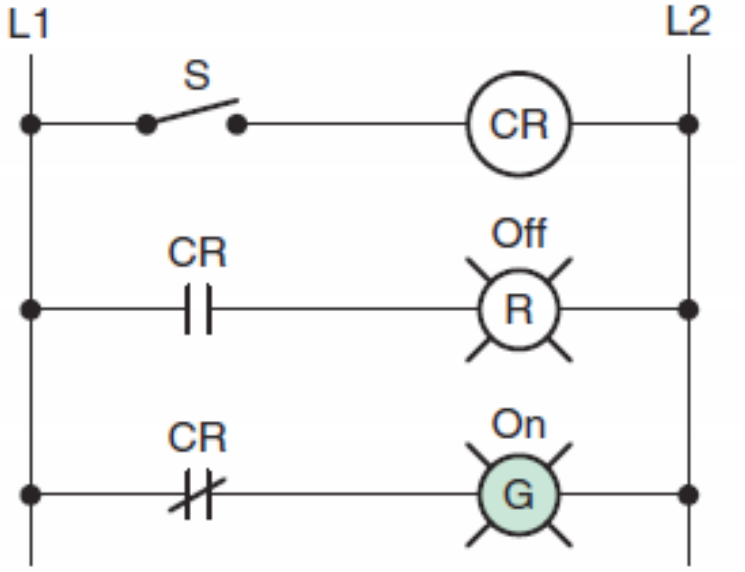
CR is used for control relays.

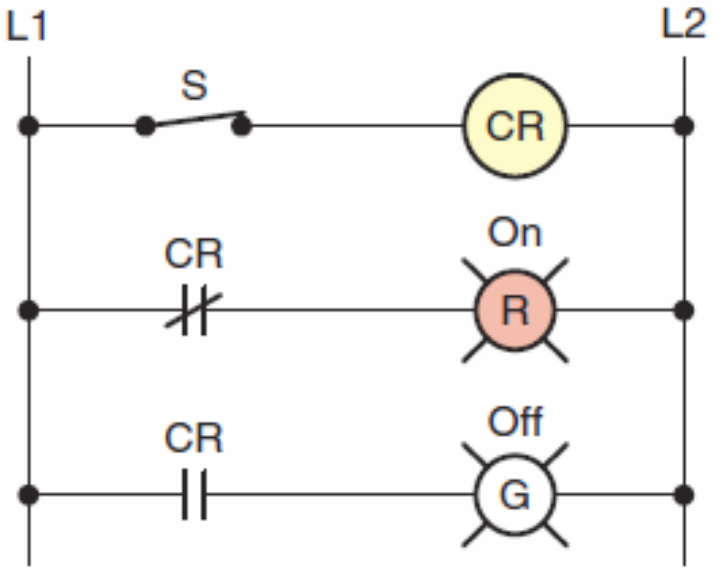


Control relay used to control two pilot lights.

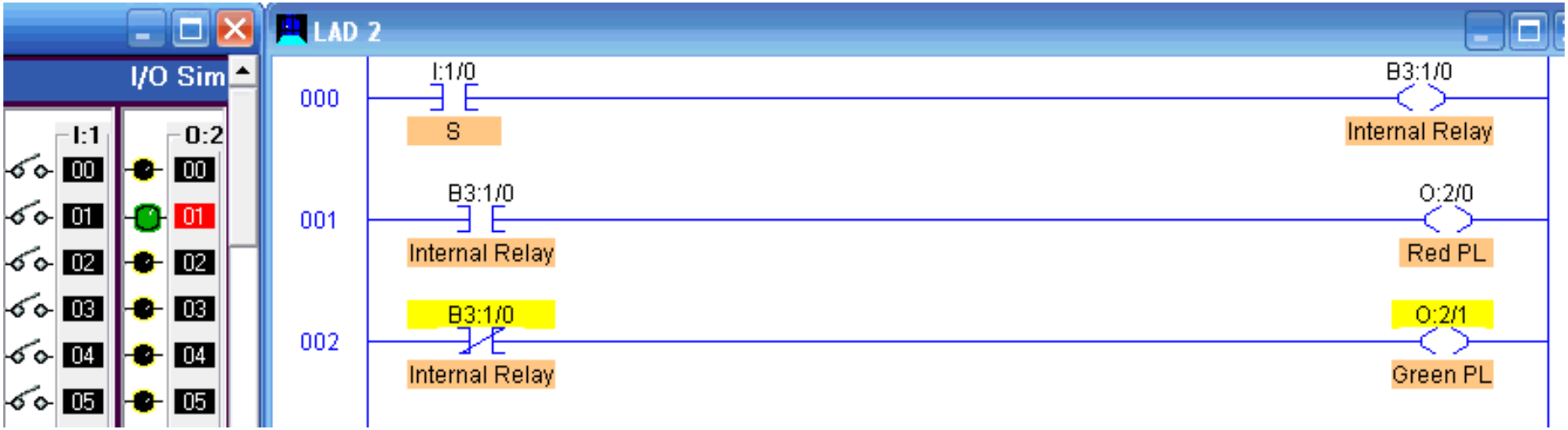
Switch open and coil de-energized

Switch closed and coil energized

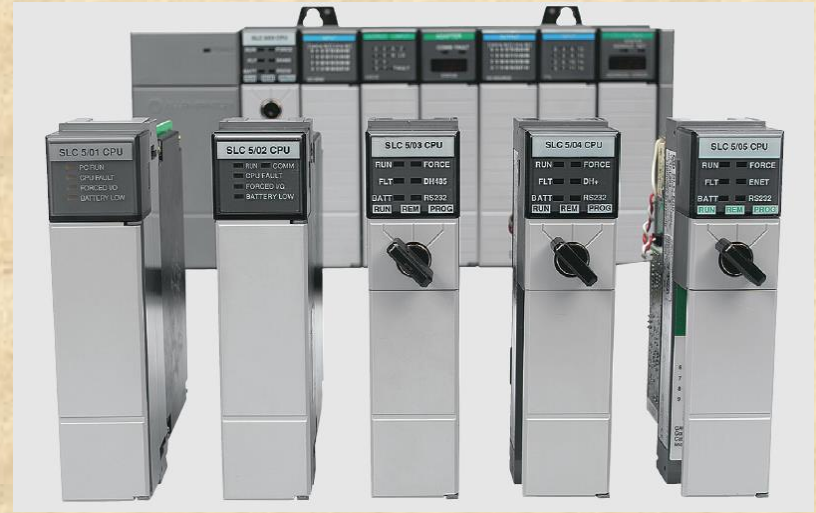




Equivalent PLC simulation of a control relay used to control two pilot lights.

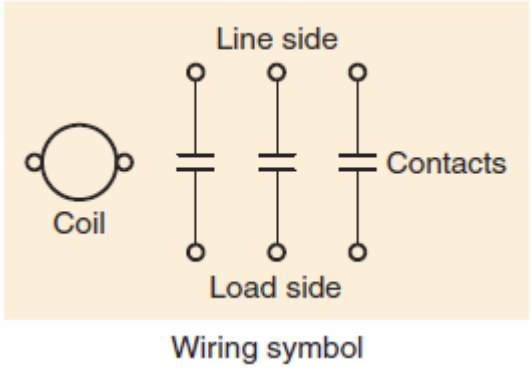


6.2

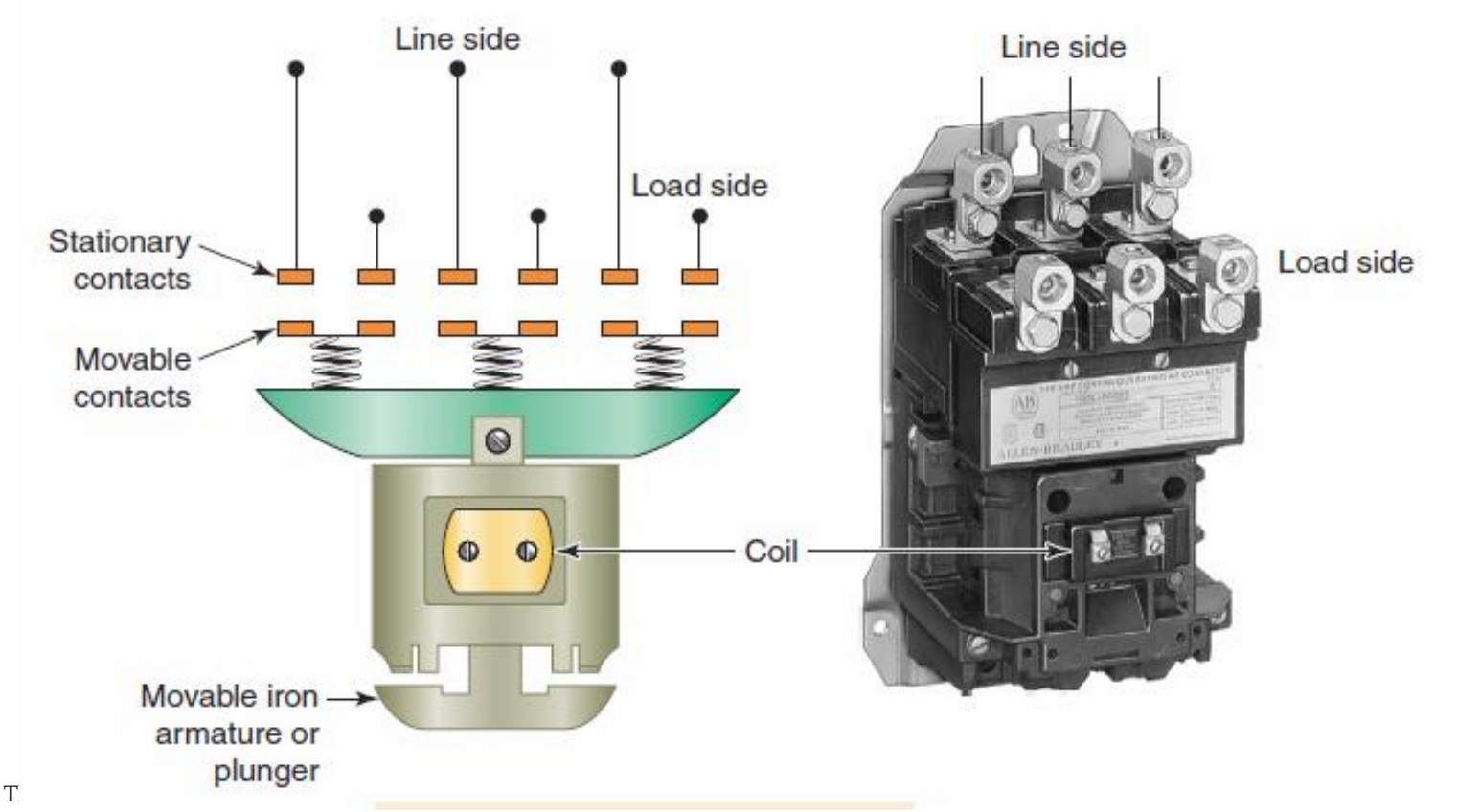


Contactors

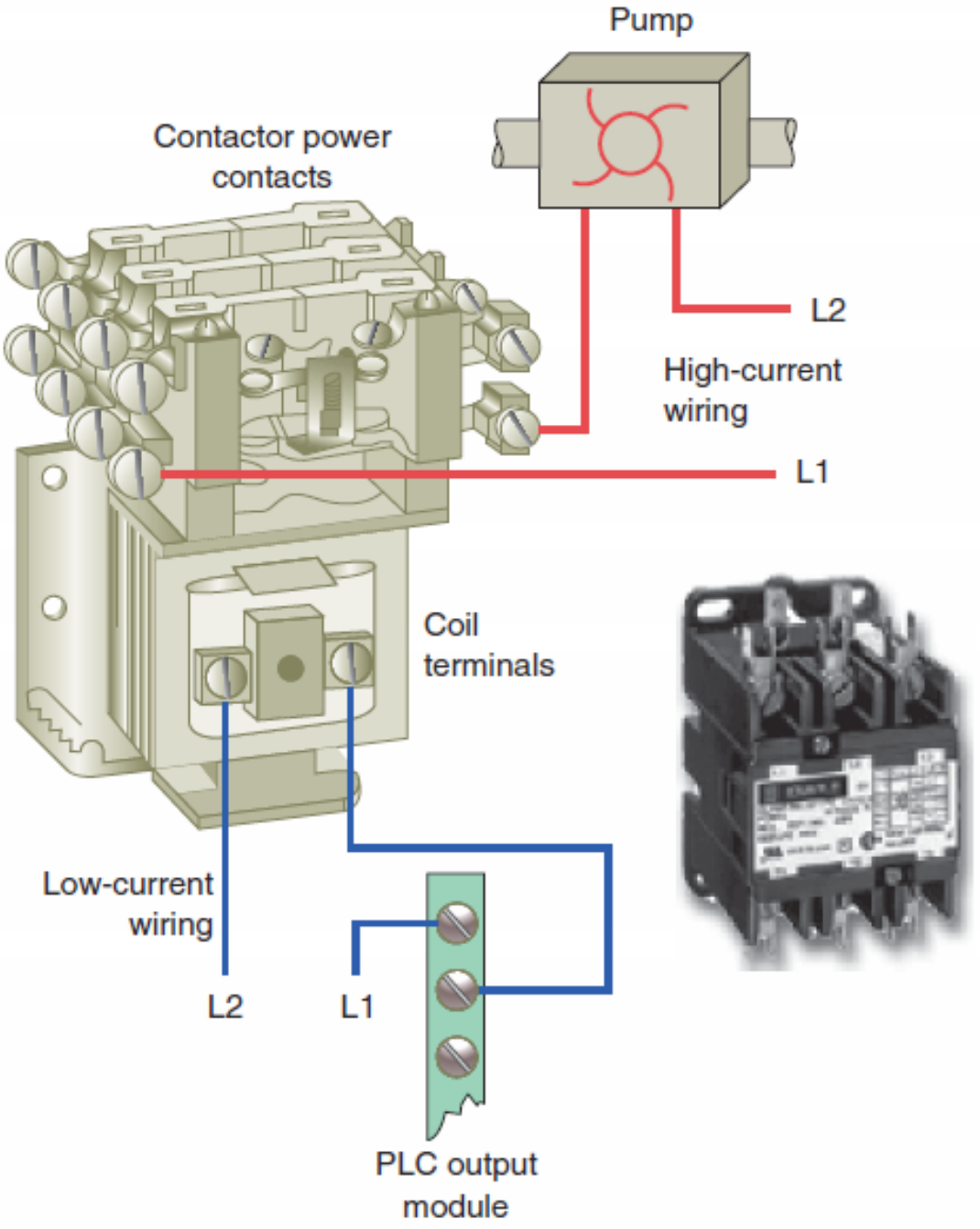
A *contactor* is a special type of relay designed to handle *heavy power loads* that are beyond the capability of control relays.



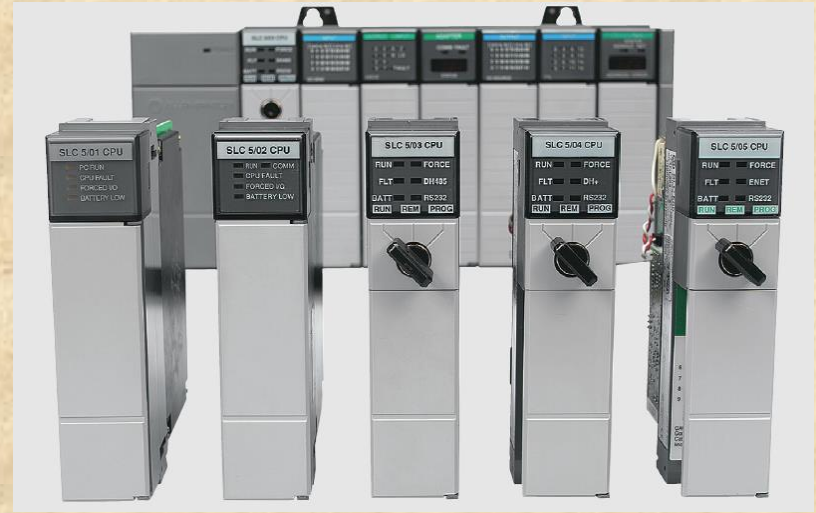
Wiring symbol



PLC used in conjunction with a contactor to *switch power* on and off to a pump.



6.3



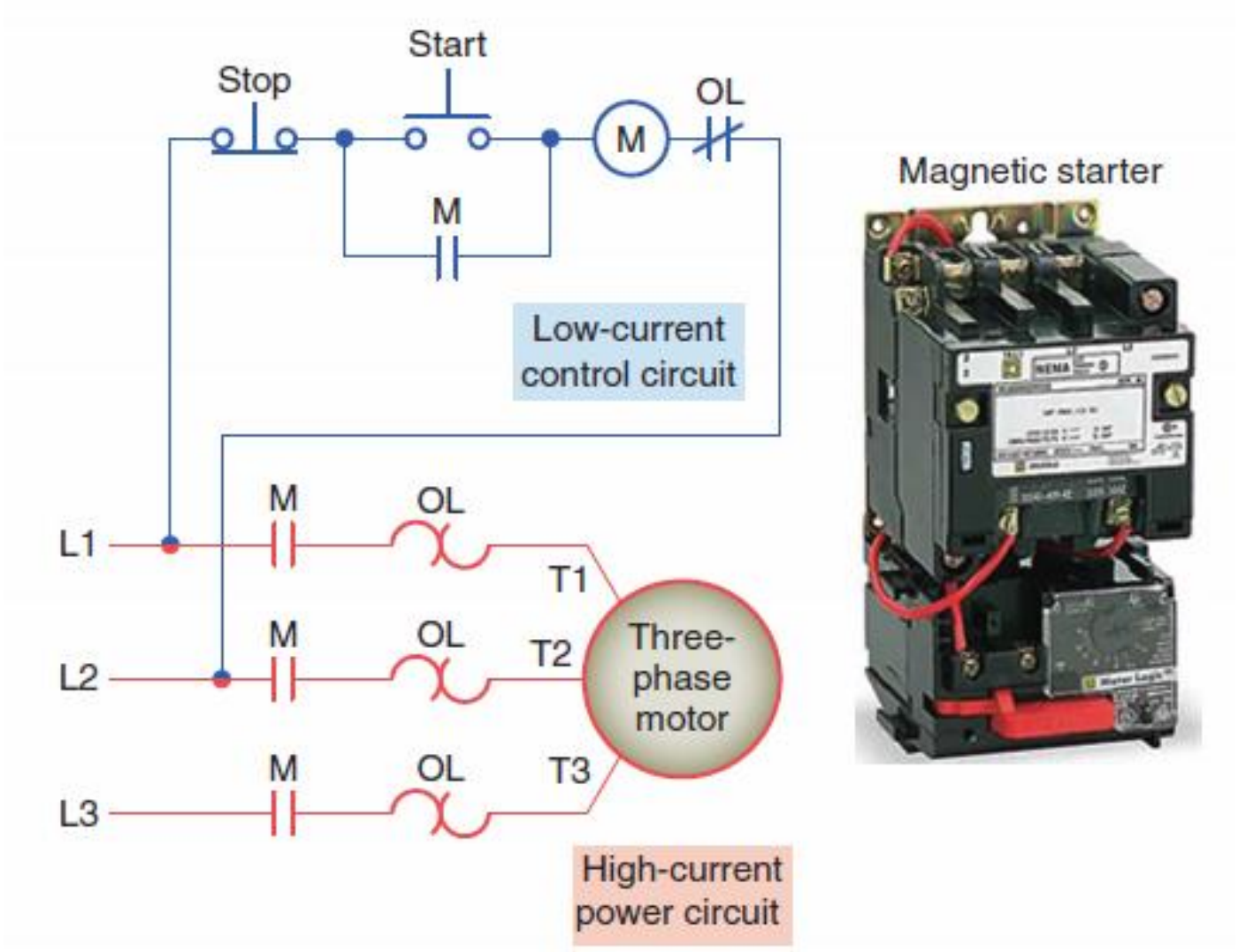
Motor Starters

The motor starter is made up of a contactor with an *overload relay* attached physically and electrically to it.

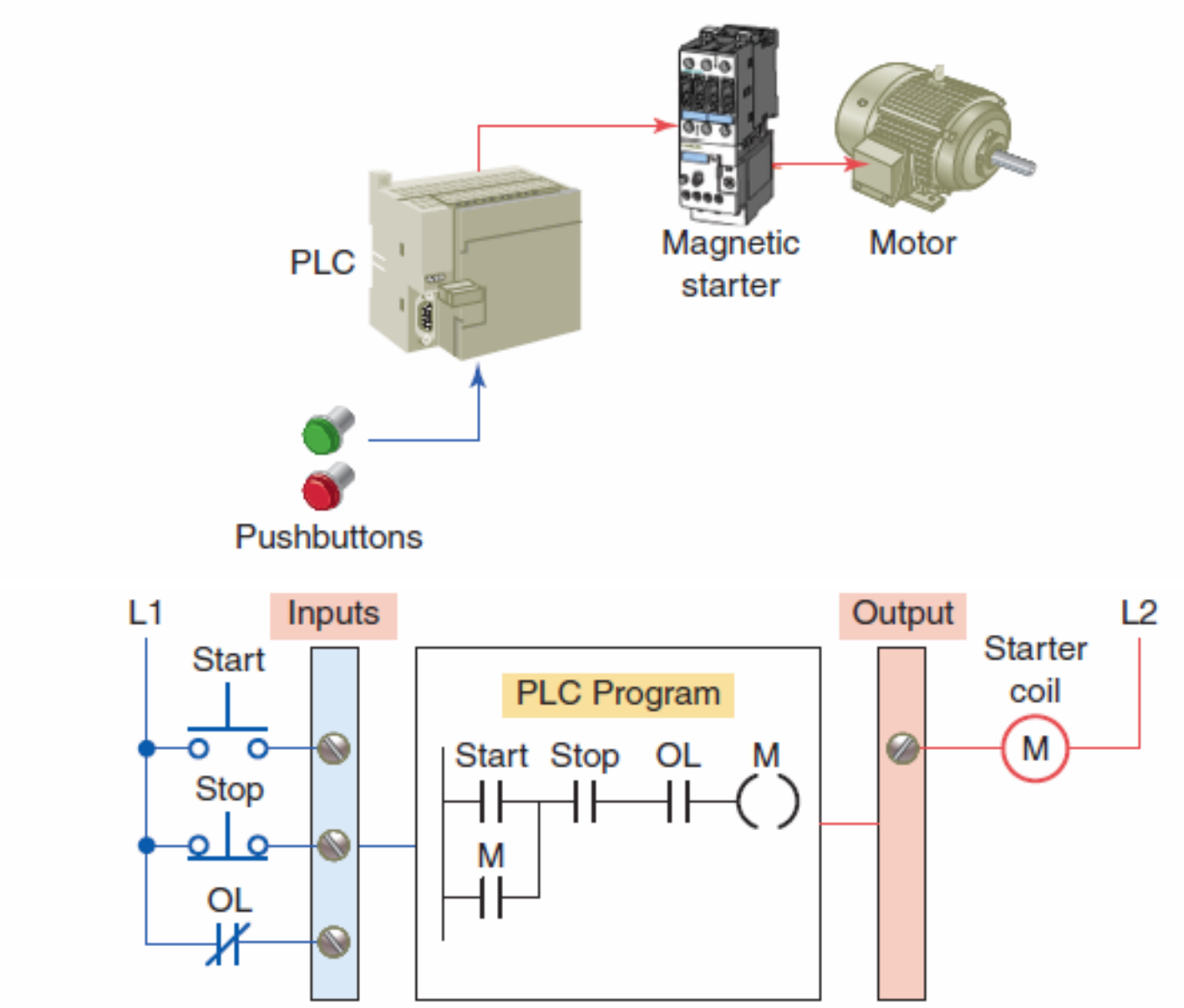
Contactor

Overload Relay

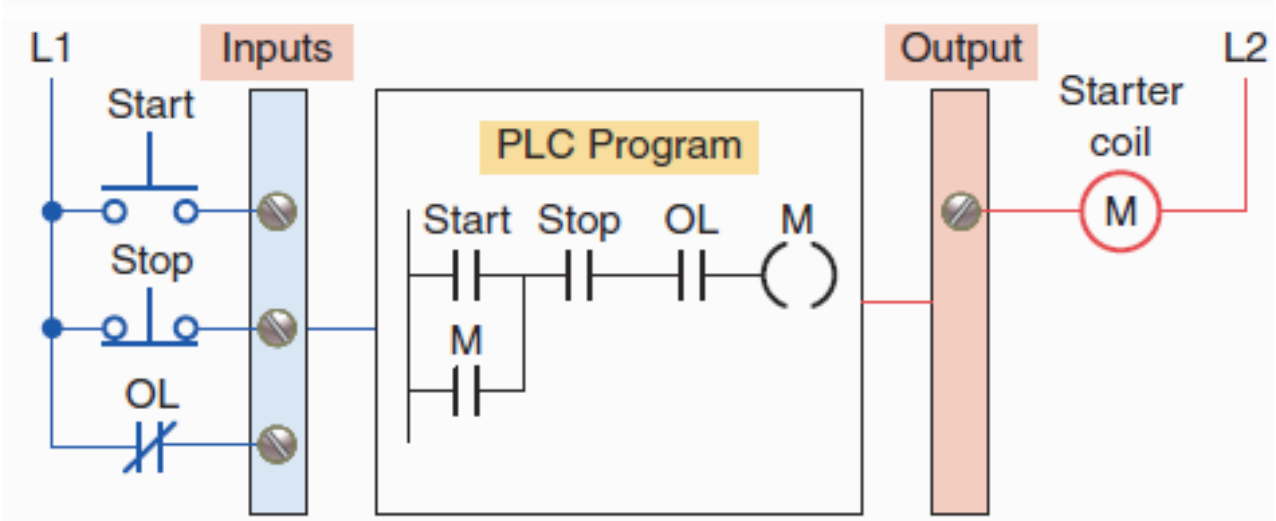
Hardwired three-phase magnetic motor starter.

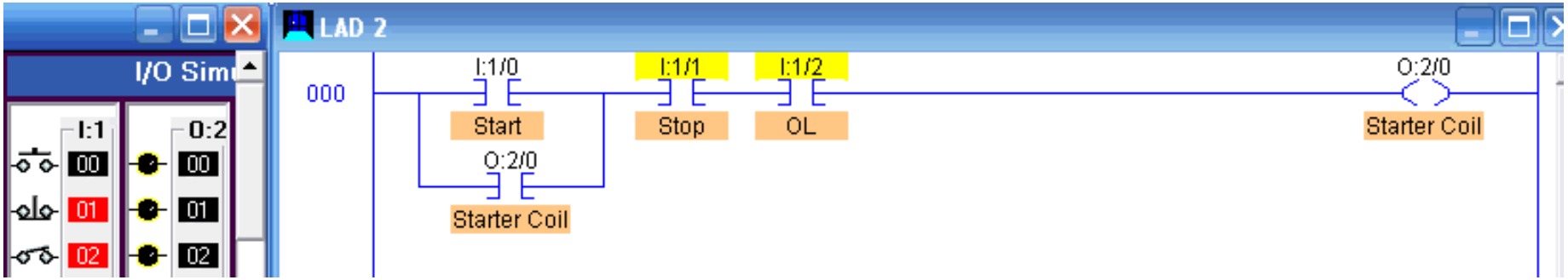


PLC programmed magnetic motor starter.

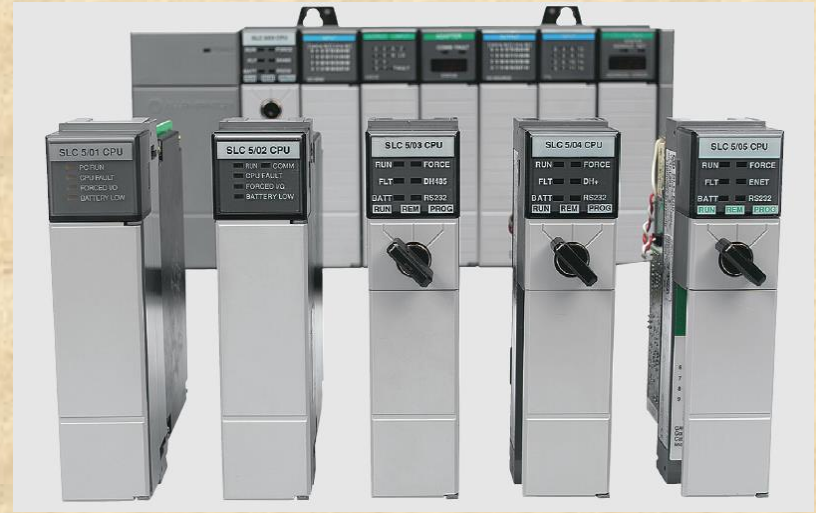


Simulated PLC magnetic motor starter.



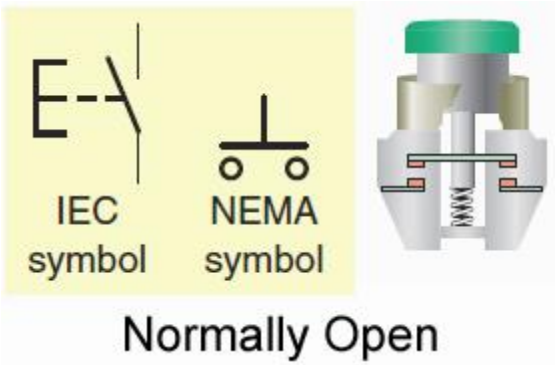


6.4



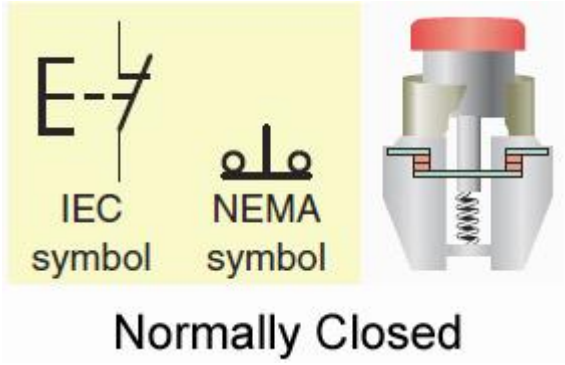
Manually Operated Switches

Manually operated switches are controlled by hand.



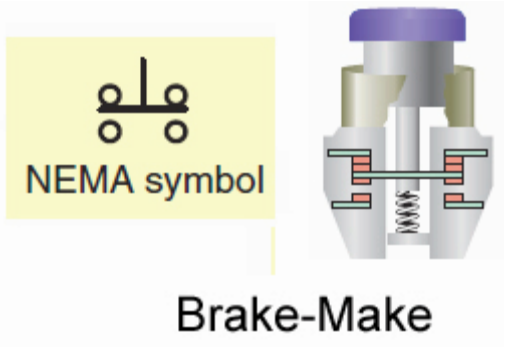
Normally Open

Makes a circuit when it is pressed and returns to its open position when the button is released.



Normally Closed

Opens the circuit when it is pressed and returns to the closed position when the button is released.



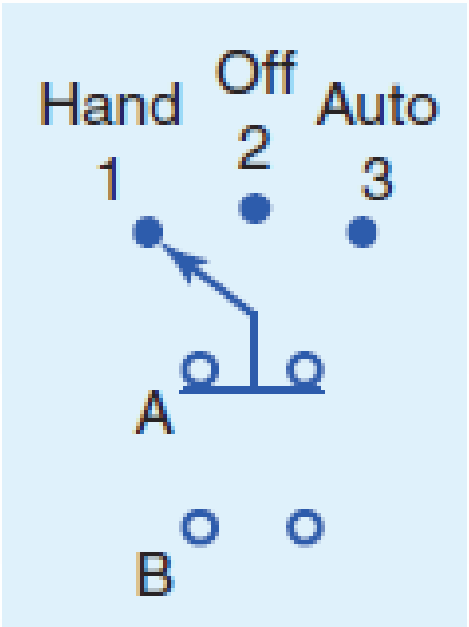
Brake-Make

When the button is pressed, the top contacts open before the bottom contacts are closed.

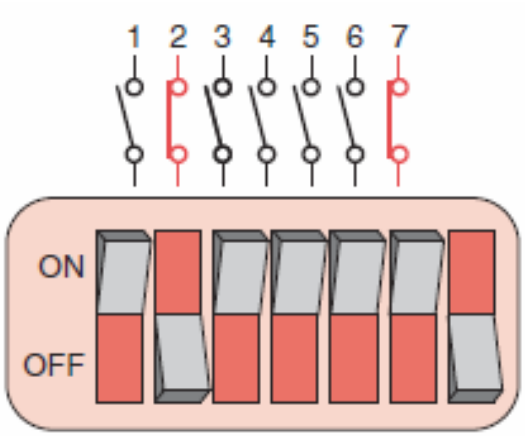
A *selector switch* operator is rotated (instead of pushed) to open and close contacts of the attached contact block.

Position	Contacts	
	A	B
1	X	
2		
3		X

Symbol

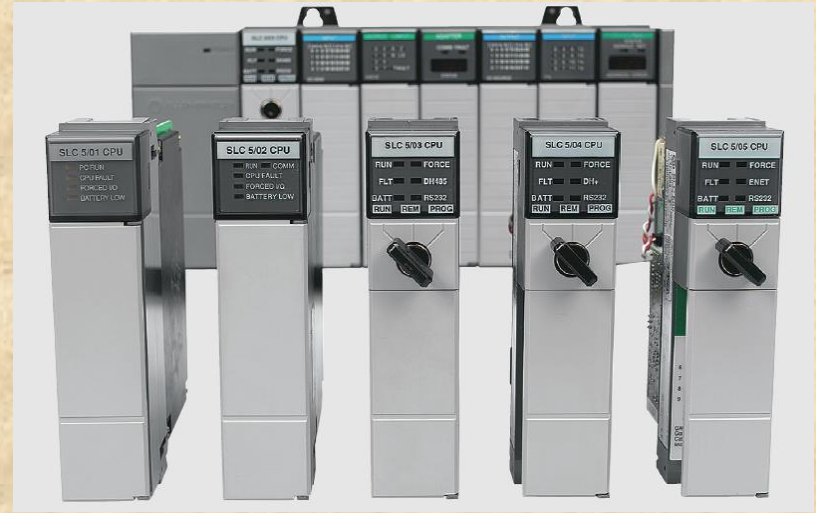


Dual in-line package (DIP) switches are small switch assemblies designed for mounting on printed circuit board modules



DIP switches use binary (on/off) settings to set the parameters for a particular module.

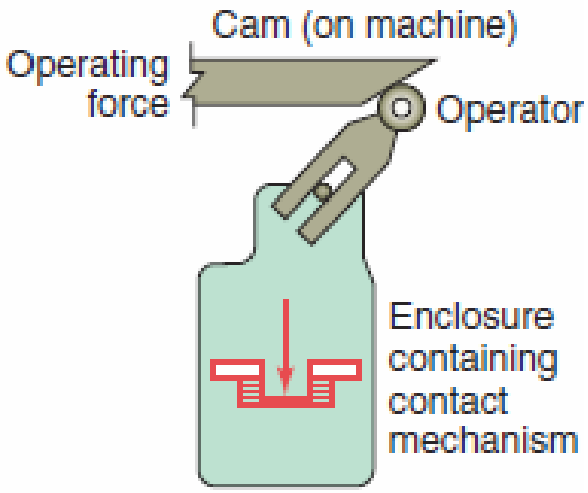
6.5

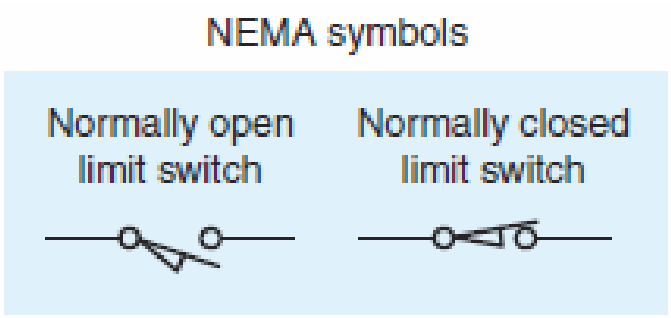


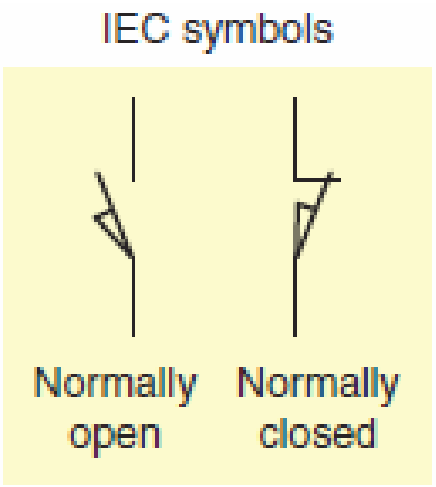
Mechanically Operated Switches

A *mechanically operated switch* is controlled automatically by factors such as pressure, position, or temperature.

Limit switches are designed to operate only when a predetermined limit is reached, and they are usually actuated by contact with an object such as a cam.

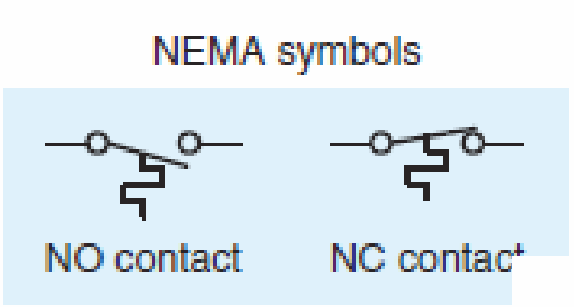


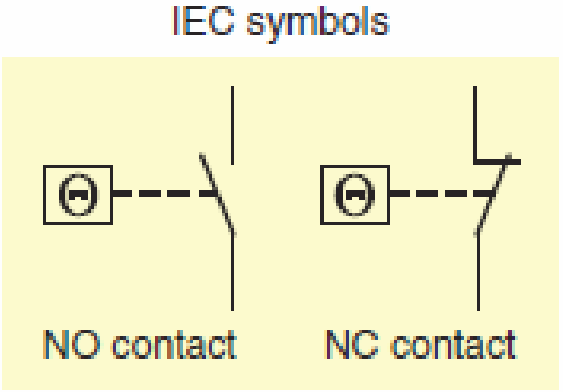




A *temperature switch*, or *thermostat*, is used to sense temperature changes.

Temperature switches open or close when a designated temperature is reached.

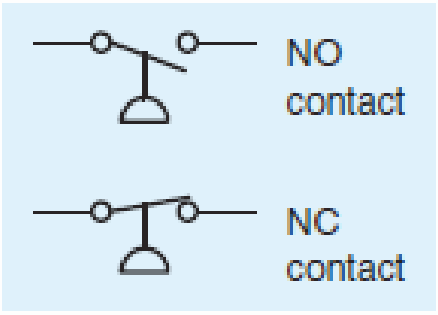




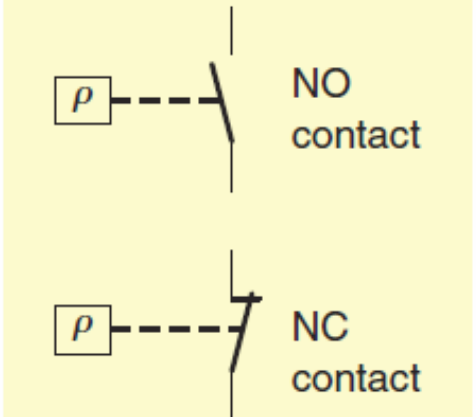
Pressure switches are used to control the pressure of liquids and gases.

They are designed to open or close their contacts when a specified pressure is reached and can be pneumatically (air) or hydraulically (liquid) actuated.

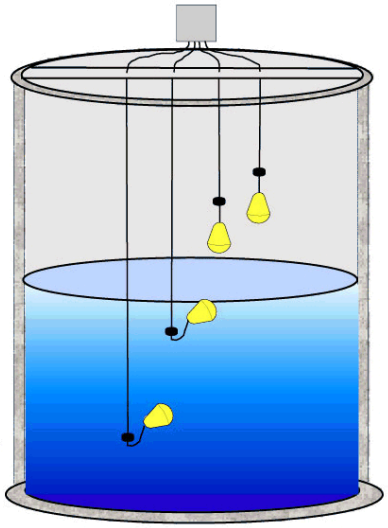
NEMA symbols for pressure switch contacts

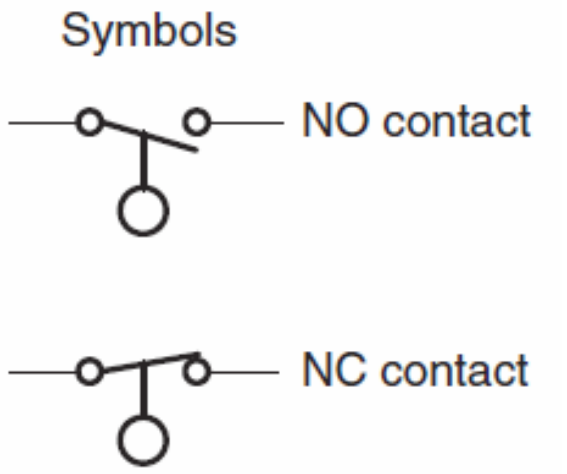


IEC symbols for pressure switch contacts



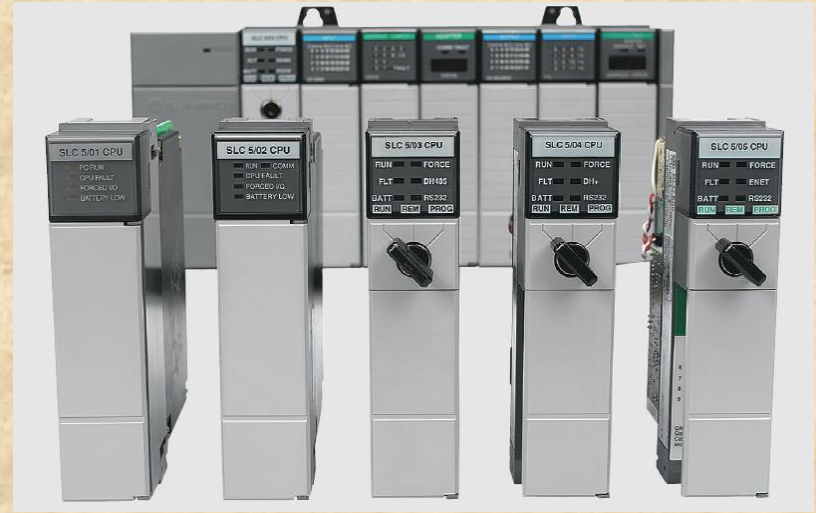
Level switches **are used to sense liquid levels.**





The float switch is a type of level switch which is weighted so that as the liquid rises the switch floats and turns upside down, actuating its internal contacts.

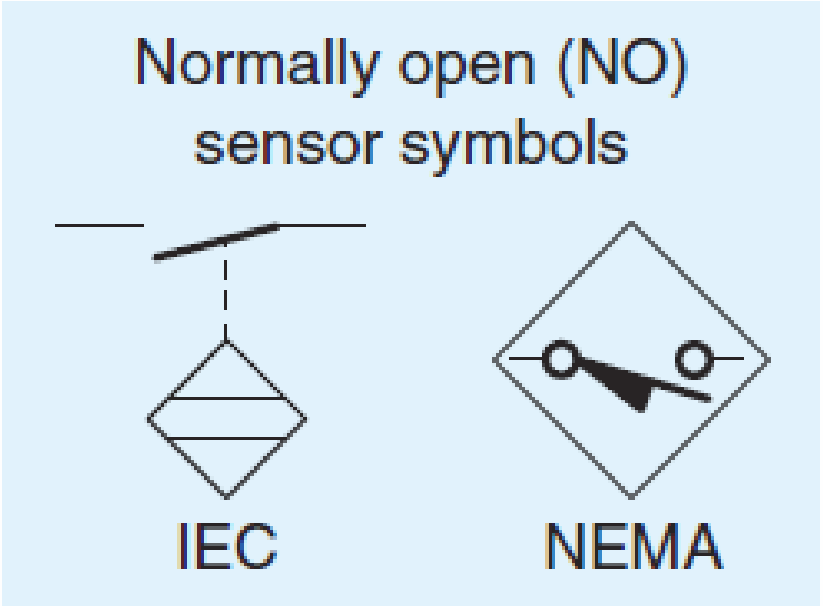
6.6



Sensors

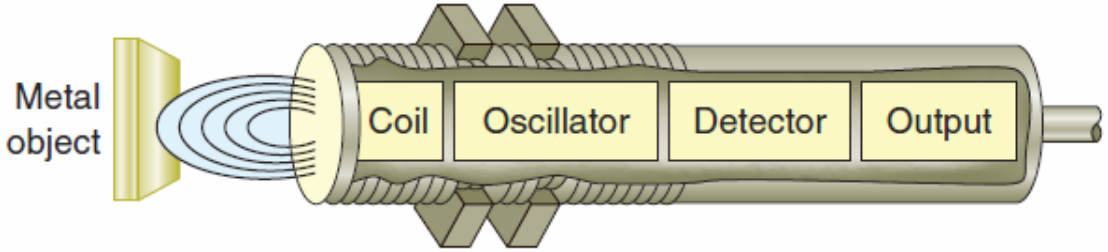
Proximity sensors* detect the presence of an object *without physical contact.

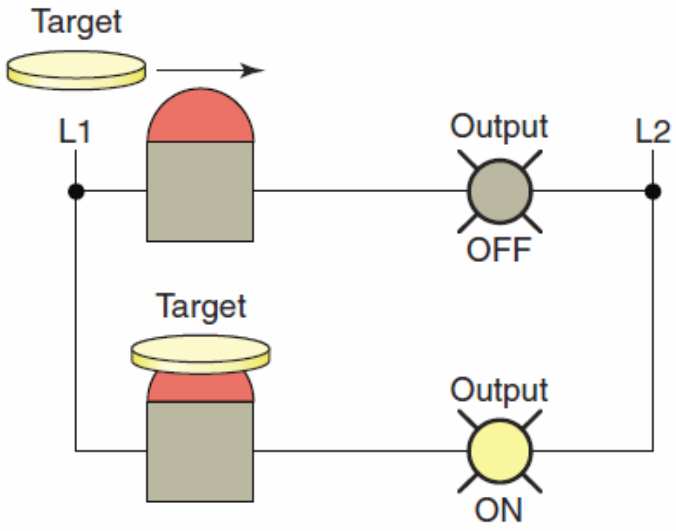
These solid-state electronic devices are completely encapsulated.



Proximity sensors operate on different principles, depending on the *type of matter being detected*.

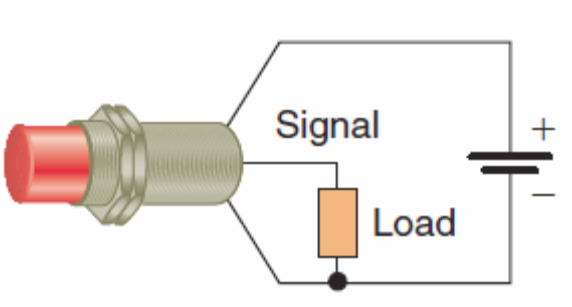
Inductive proximity sensors are used to detect both ferrous metals (containing iron) and nonferrous metals (such as copper, aluminum, and brass).

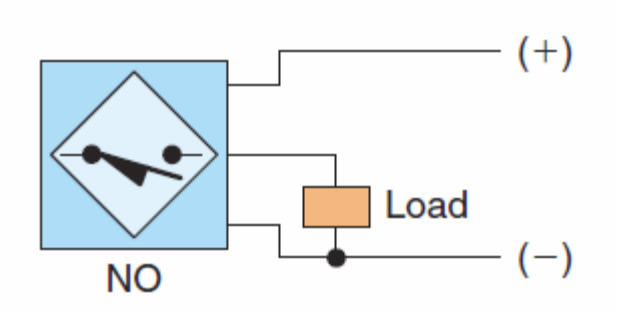




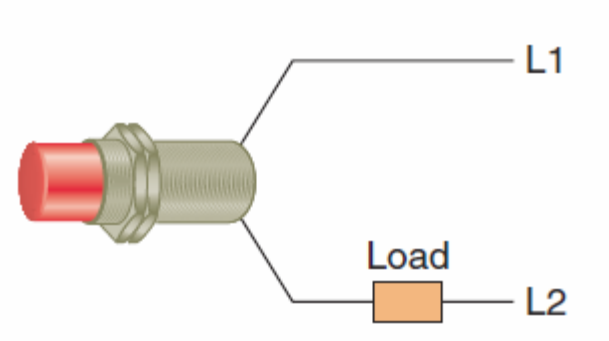
Inductive proximity sensors operate with electromagnetic field which varies in strength relative to a target.

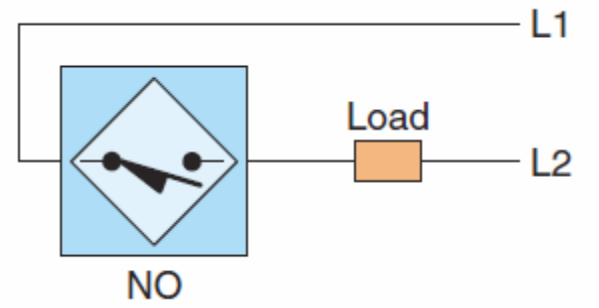
The method of *connecting* a proximity sensor *varies* with the type of sensor and its application.



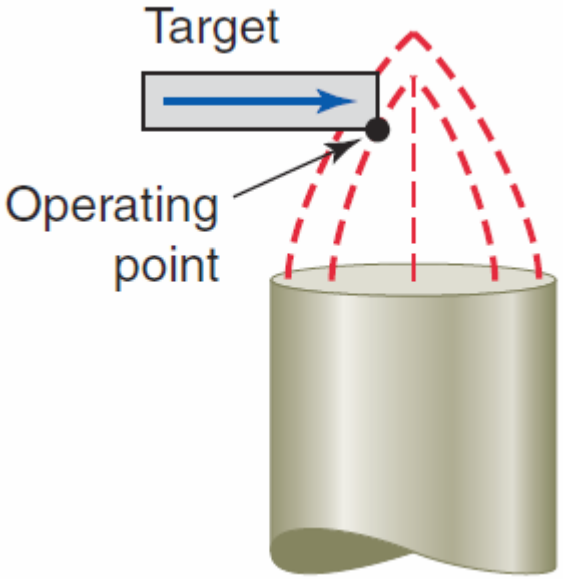


Three-wire sensor

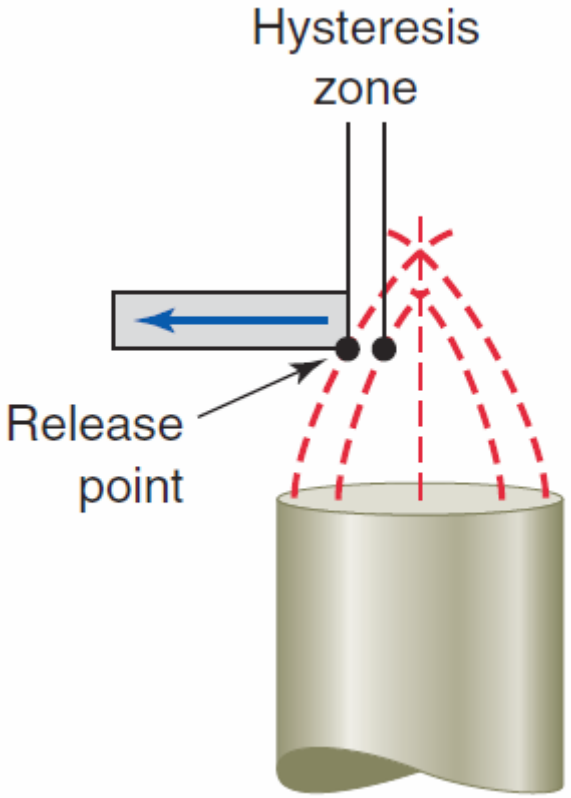




Two-wire sensor



Proximity sensor sensing range.

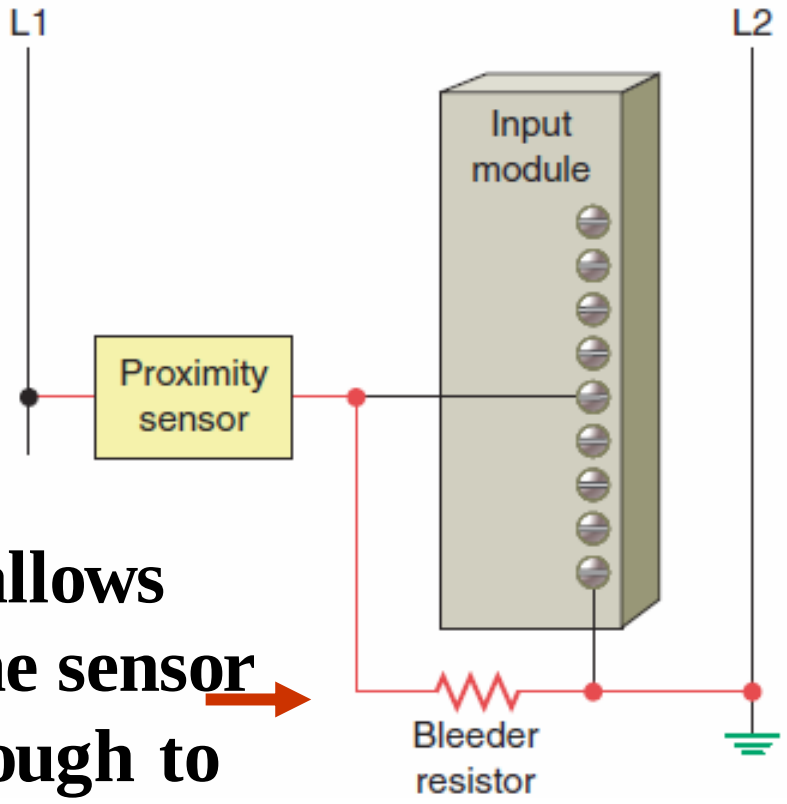


Most proximity sensors come equipped with an LED status indicator to verify the output switching action.

A small **leakage current** flows through the sensor even when the output is turned **off**.

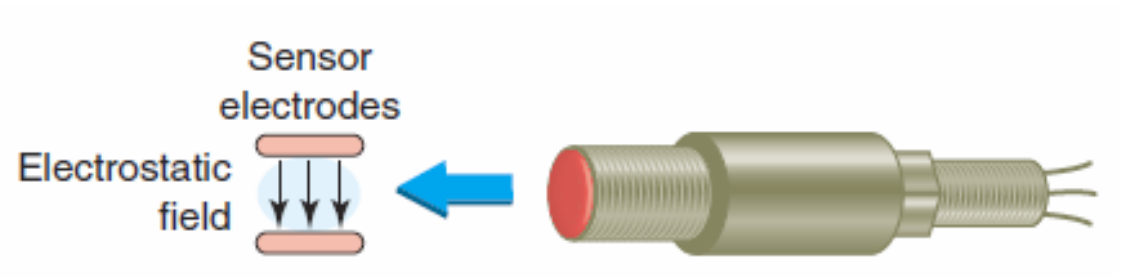
When the sensor is **on**, a small **voltage drop** is lost across its output terminals.

To operate properly, a proximity sensor should be powered **continuously**.

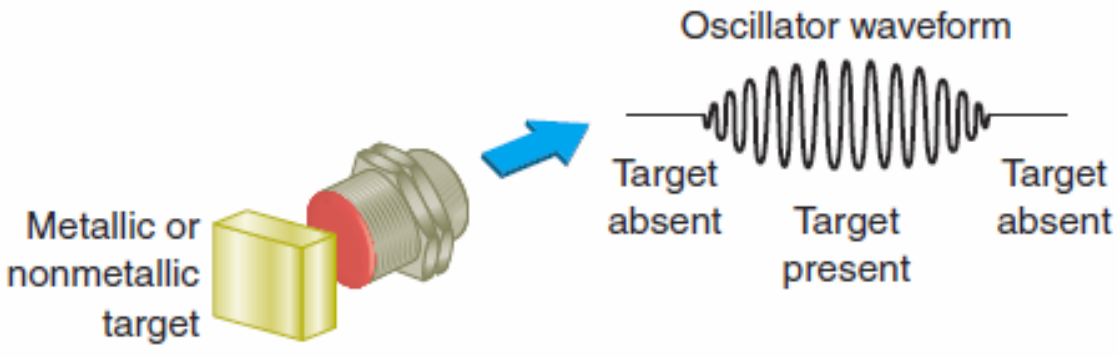


The **bleeder resistor** allows enough current for the sensor to operate but not enough to turn on the input.

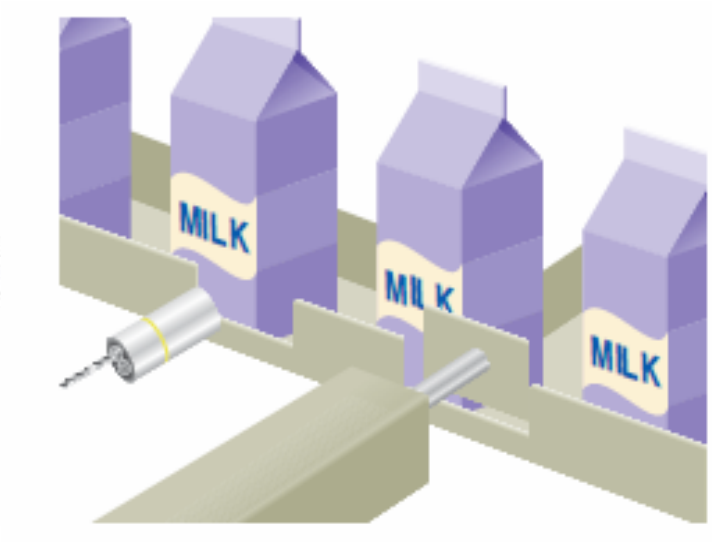
Capacitive proximity sensors operate within an *electrostatic field* and are actuated by both conductive and nonconductive materials.



When the target nears the sensing surface, it enters the electrostatic field of the electrodes and changes the capacitance of the oscillator.

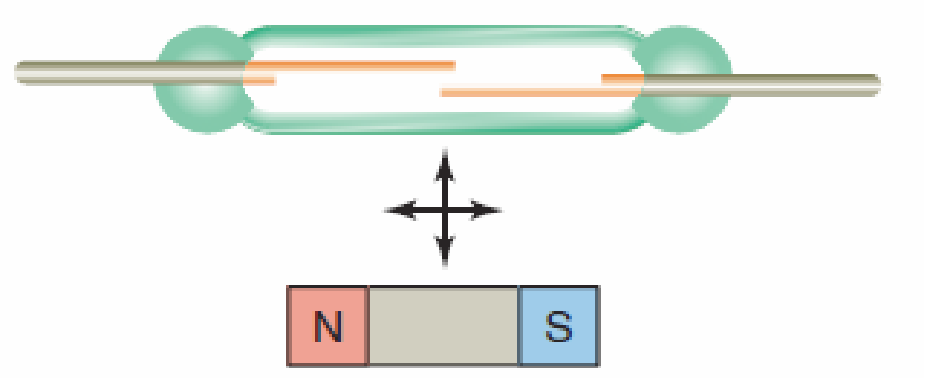


Capacitive proximity sensors will sense metal objects as well as nonmetallic materials such as paper, glass, liquids, and cloth.



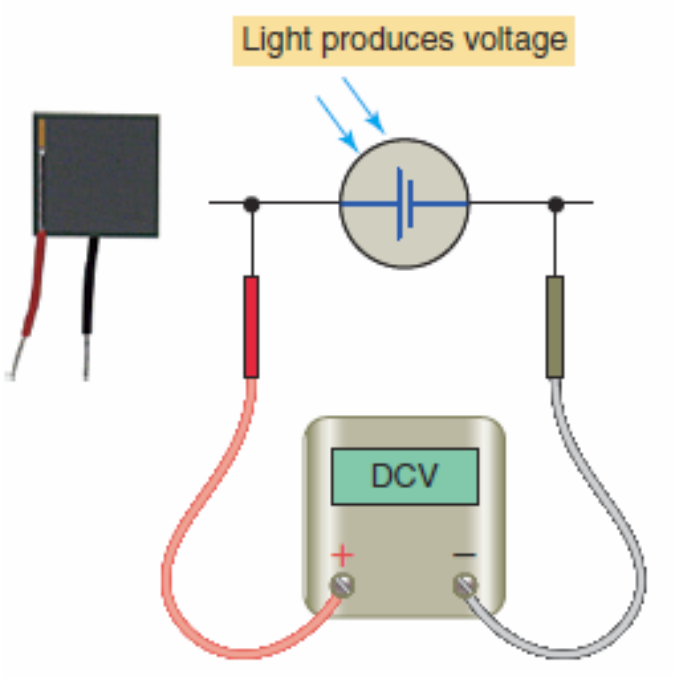
The larger the dielectric constant of a target, the easier it is for the capacitive sensor to detect. This makes possible the detection of materials inside nonmetallic containers.

A *magnetic reed switch* is composed of two flat contact tabs that are sealed in a glass tube.

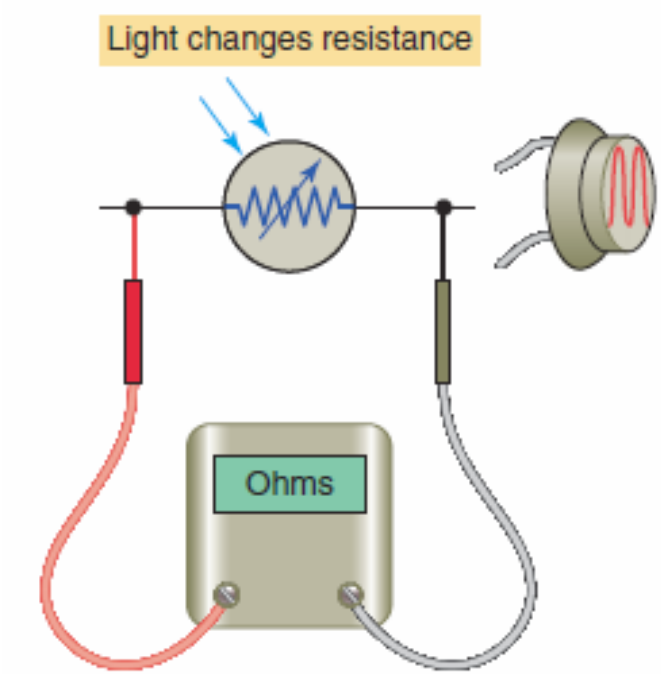


When a magnetic force is generated parallel to the reed switch, the reeds will be drawn together to actuate the switch.

The *photovoltaic* cell and the *photoconductive* cell are examples of light sensors.



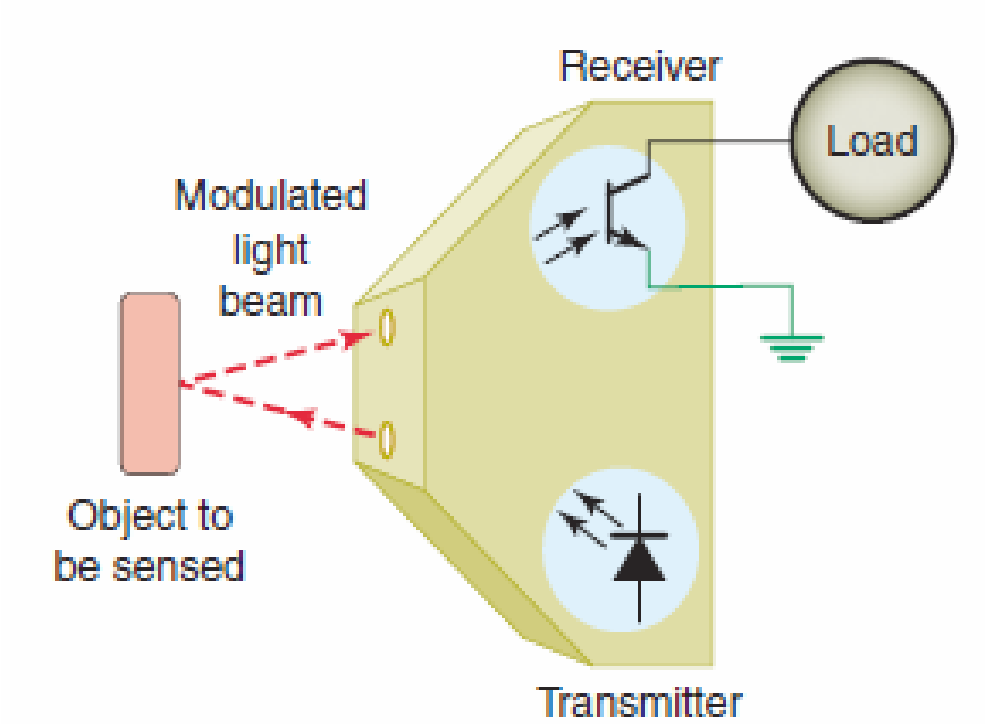
Photovoltaic solar cell



Photoconductive cell

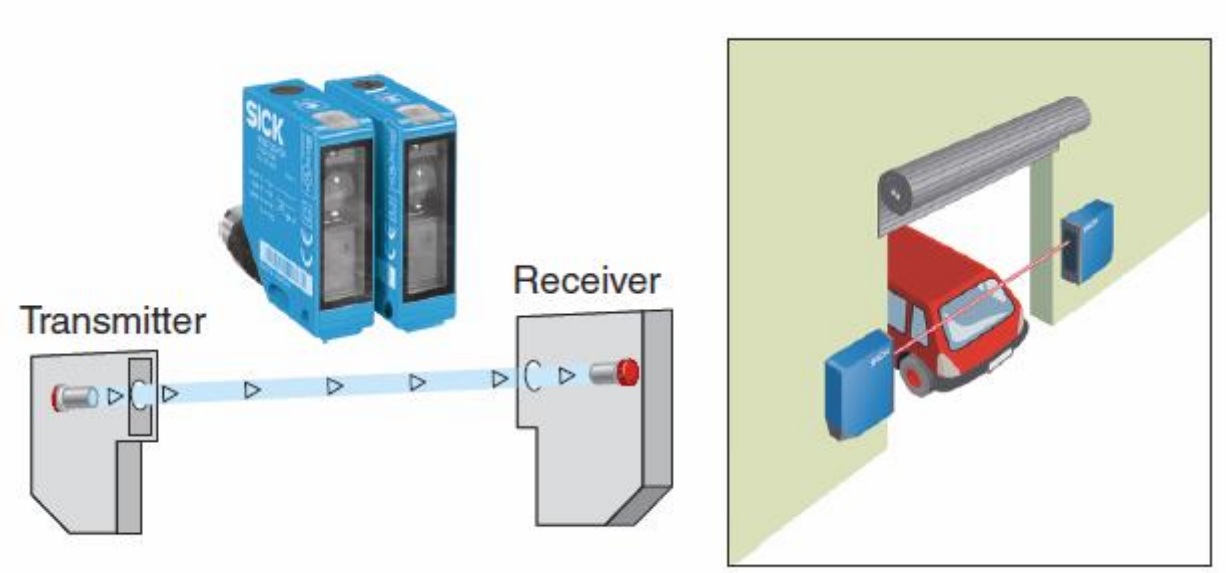
A *photoelectric sensor* operates by detecting a visible or invisible beam of light and responding to a change in the received light intensity.

Photoelectric sensors are composed of a transmitter (light source) and a receiver (sensor



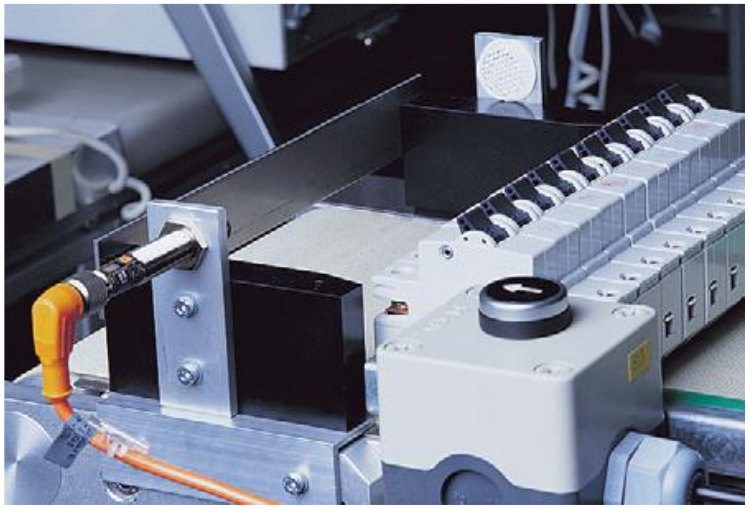
The *scan technique* refers to the method used by photoelectric sensors to detect an object.

The *through-beam* scan technique places the transmitter and receiver in direct line with each other.

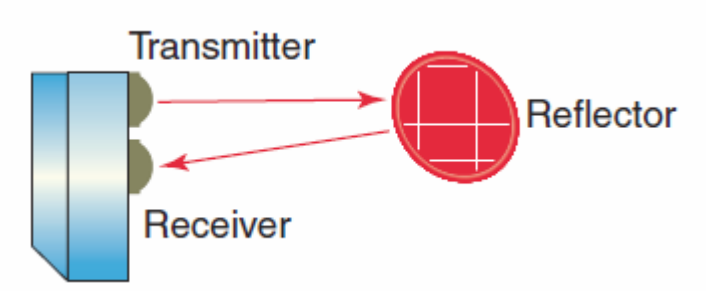


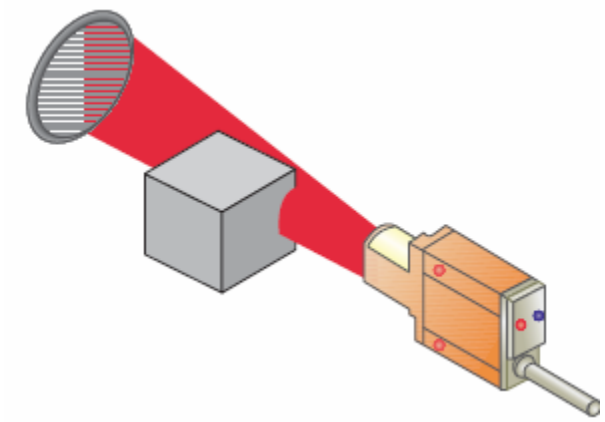
Because the light beam travels in only one direction, through-beam scanning provides long-range sensing.

In a *retroreflective* scan technique, the transmitter and receiver are housed in the same enclosure.

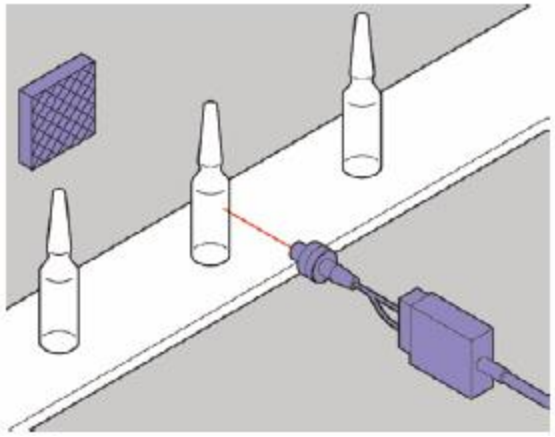


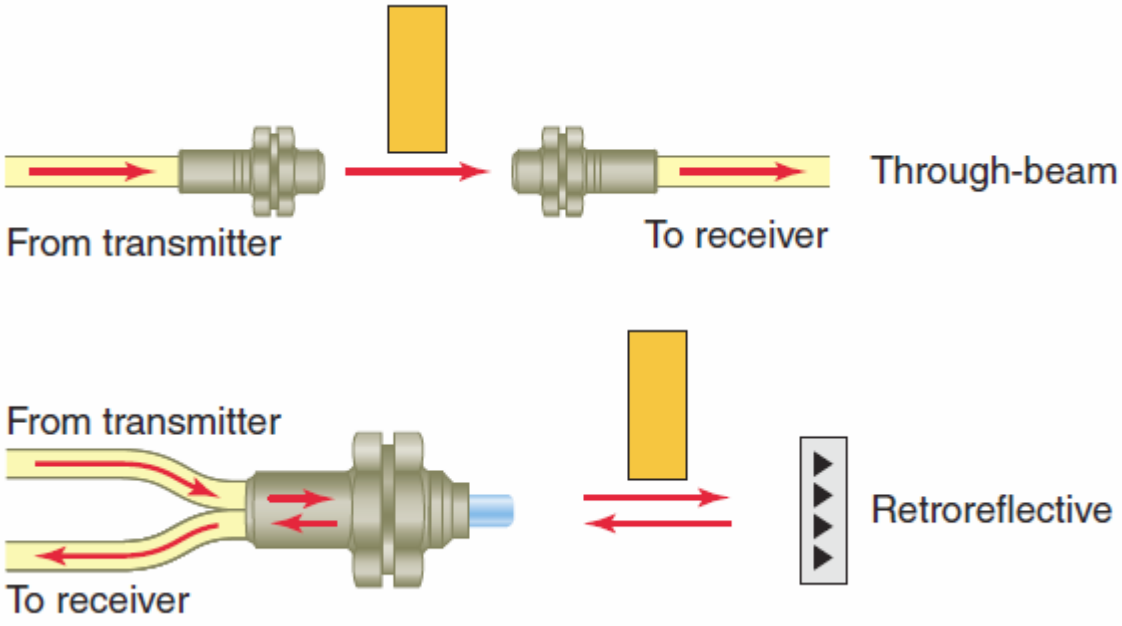
This arrangement requires the use of a separate reflector mounted across from the sensor to return light back to the receiver.





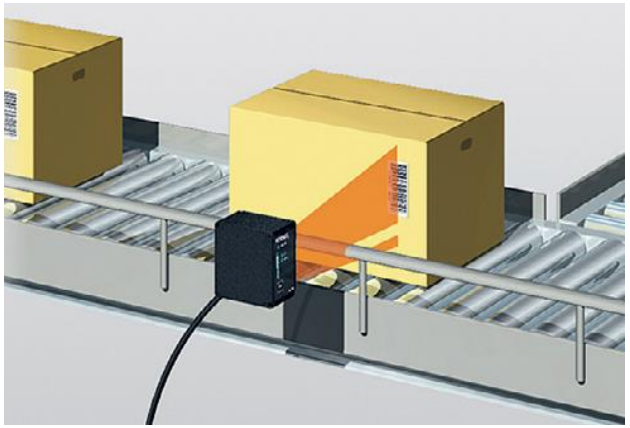
Fiber optic sensors **use a flexible cable containing tiny fibers that channel light from emitter to receiver**

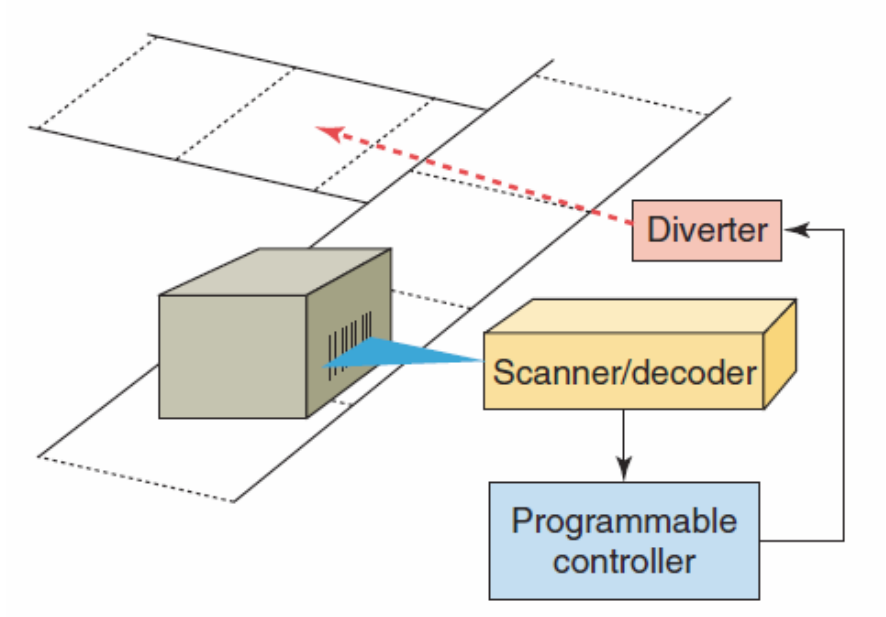




Fiber optic sensor systems are completely immune to all forms of electrical interference.

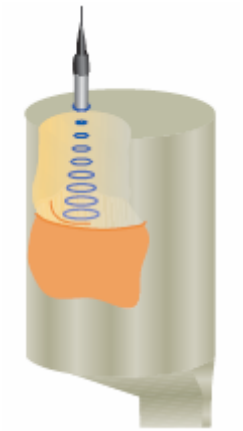
Bar code scanners are the eyes of a data collection system.



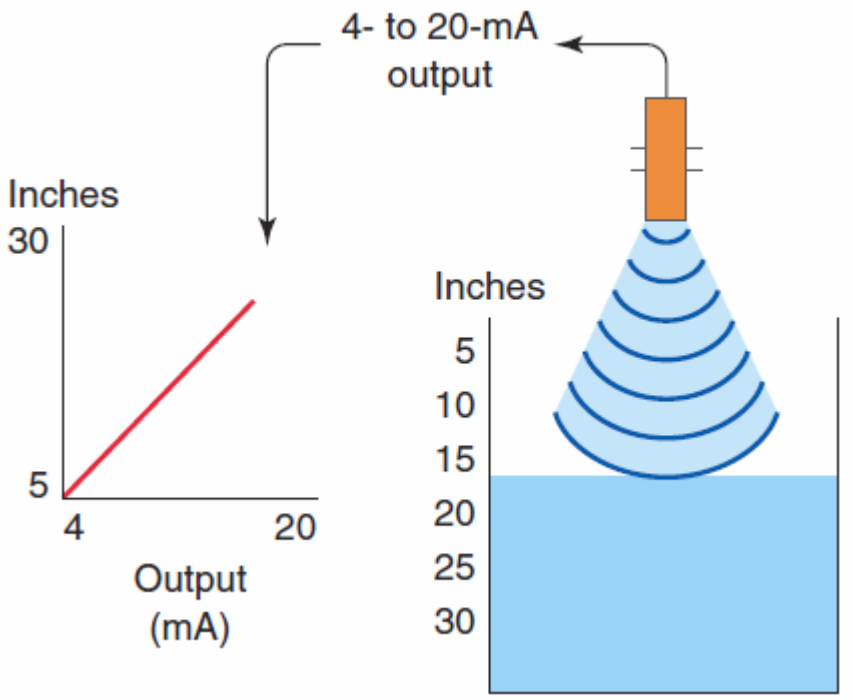


A **bar code module** reading the bar code on boxes as they move along a conveyor line.

The PLC is programmed to **divert the boxes** to the appropriate product lines according to the bar code data.

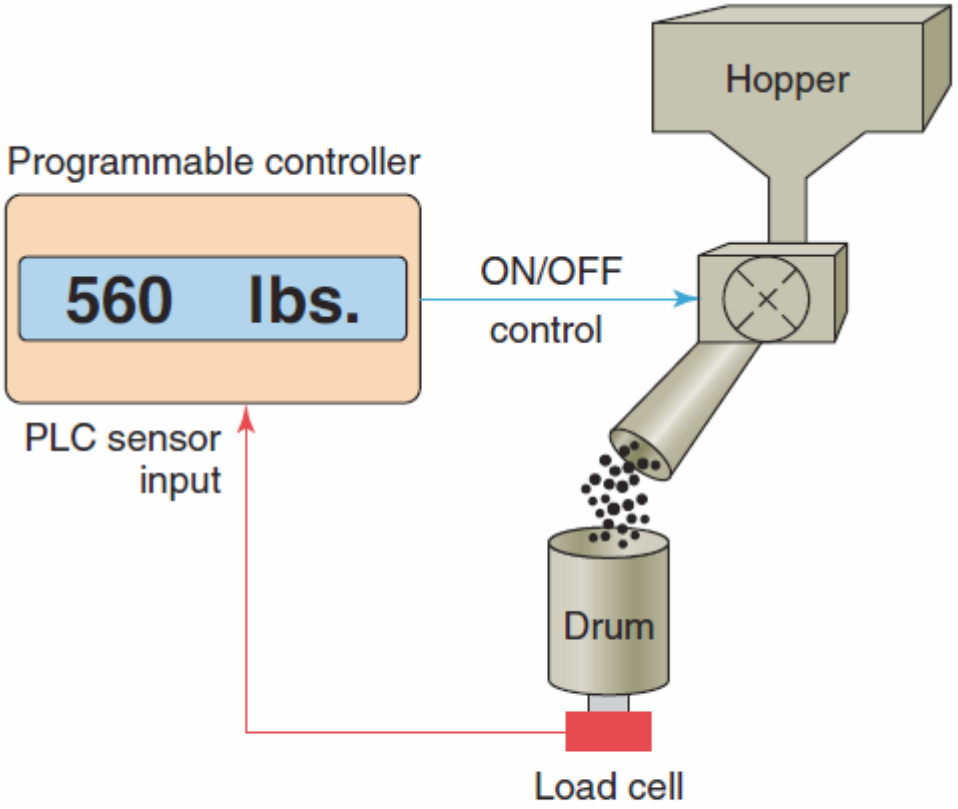


An *ultrasonic sensor* operates by sending high-frequency sound waves toward the target and measuring the time it takes for the pulses to bounce back.



The returning echo signal is electronically converted to a 4- to 20-mA output, which supplies a monitored measurement of level to external control devices.

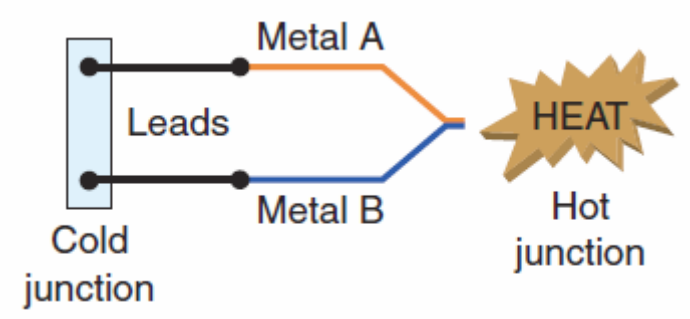
A *strain gauge* converts a mechanical strain into an electric signal.

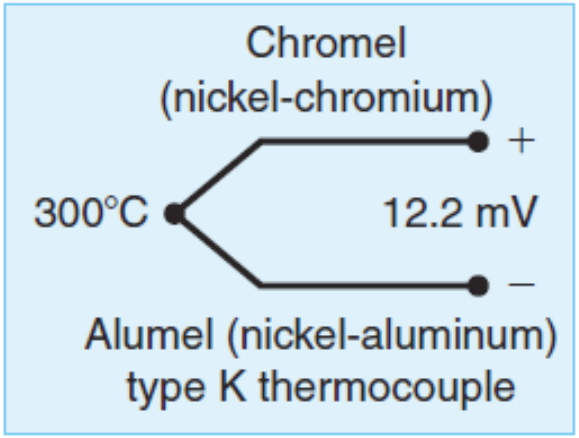


The force applied to the load cell causes it to bend. This bending action also distorts the physical size of the cell, which in turn changes its *resistance*.

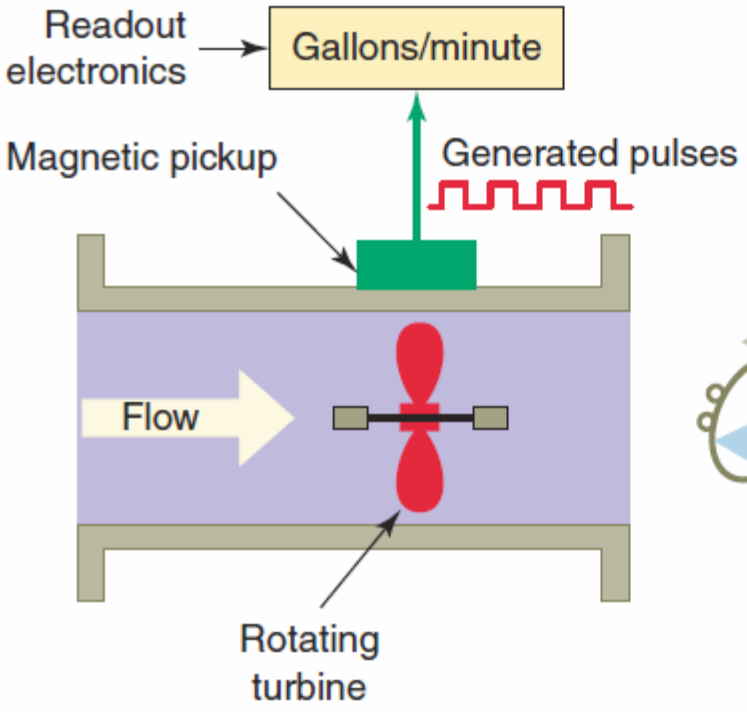
The *thermocouple* is the most widely used *temperature sensor.*

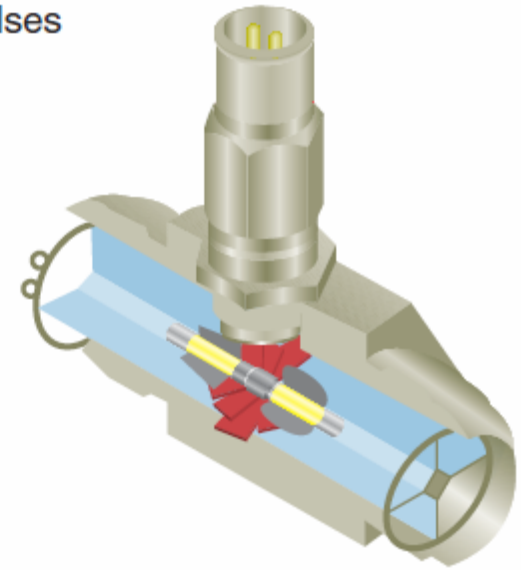
Thermocouples operate on the principle that when two dissimilar metals are joined, a predictable DC voltage will be generated





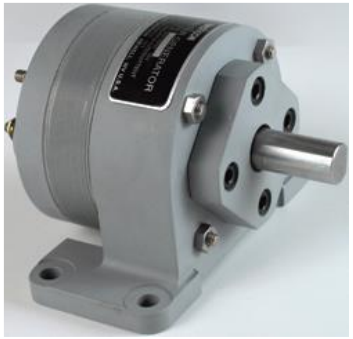
Flow measurement **involves converting the kinetic energy that the fluid has into some other measurable form.**

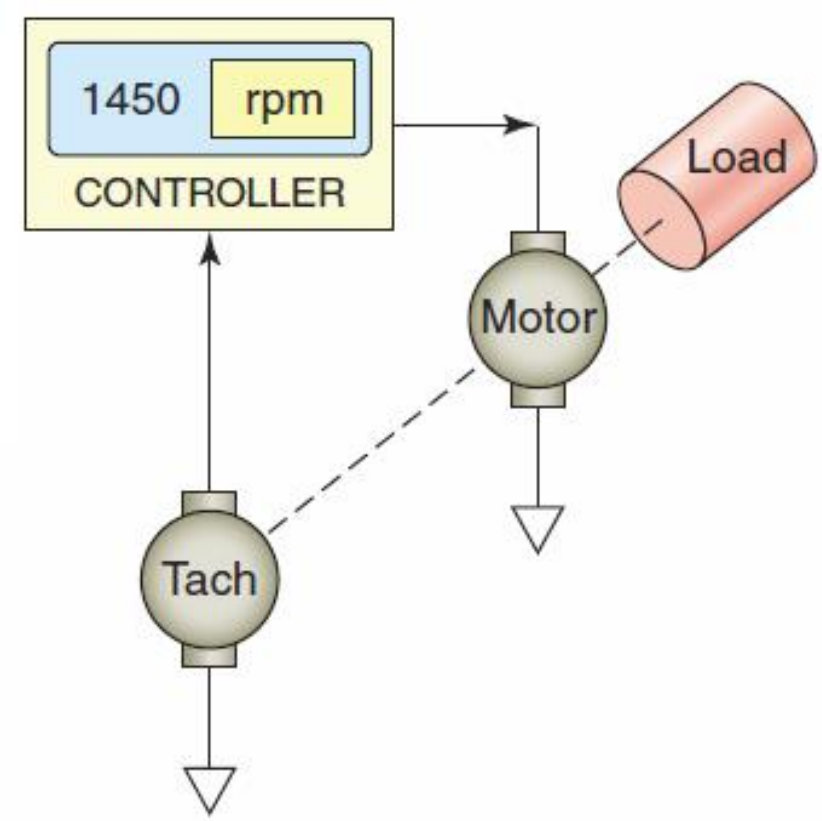




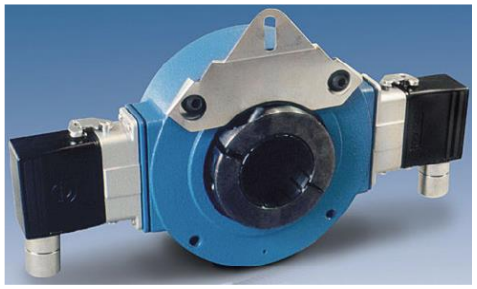
Turbine flowmeters use their rotational speed to indicate the flow velocity.

Tachometer generators **convert rotational speed into an analog voltage signal that can be used for control applications.**

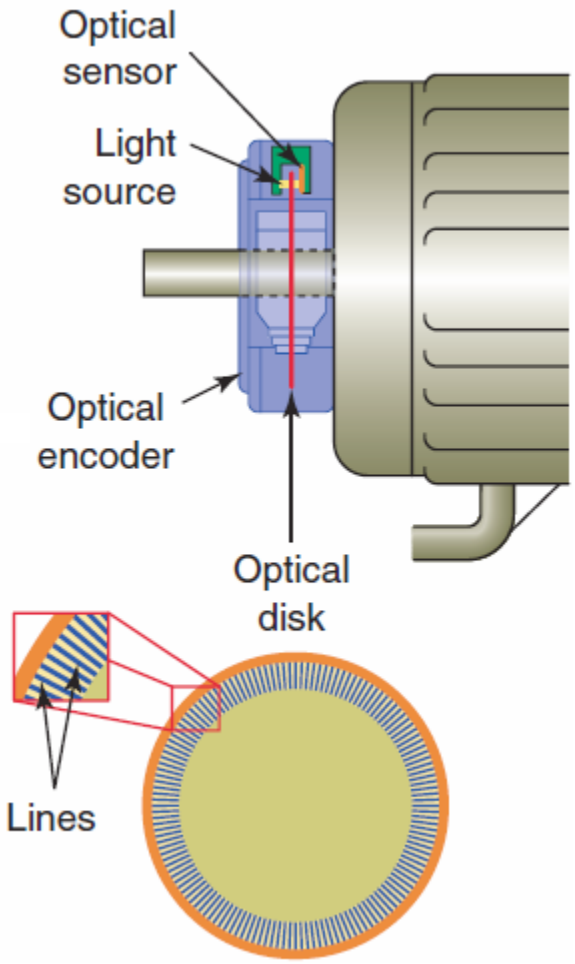


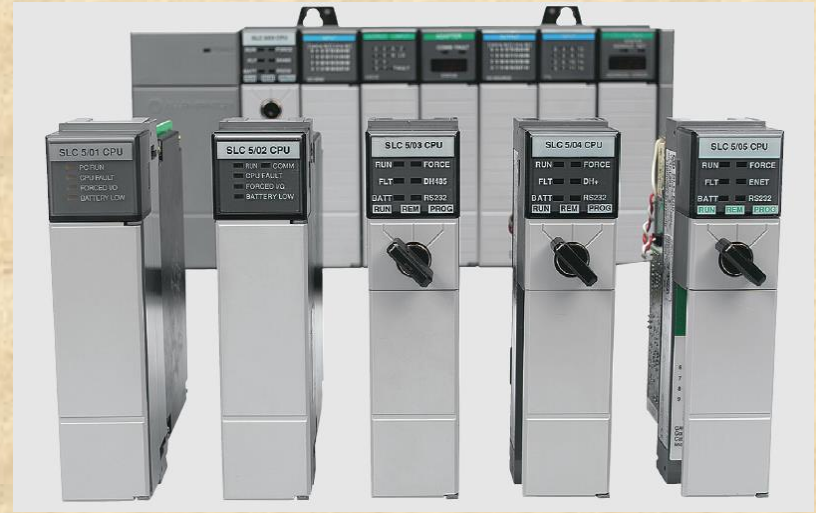


An *encoder* is used to convert linear or rotary motion into a binary digital signal.



The optical encoder uses a light source shining on an optical disk with lines or slots that interrupt the beam of light to an optical sensor. An electronic circuit counts the interruptions of the beam and generates the encoder's digital output pulses.

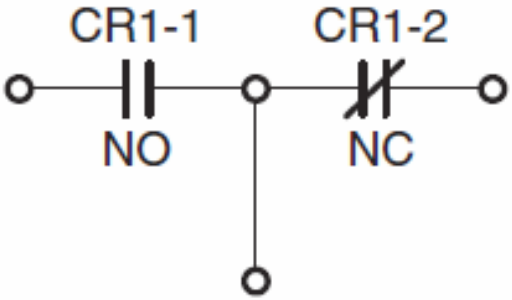




Output Control Devices

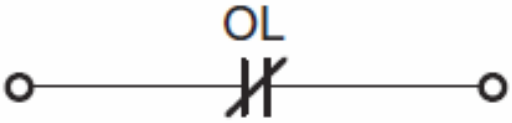
Symbols for output control devices.

Pilot light



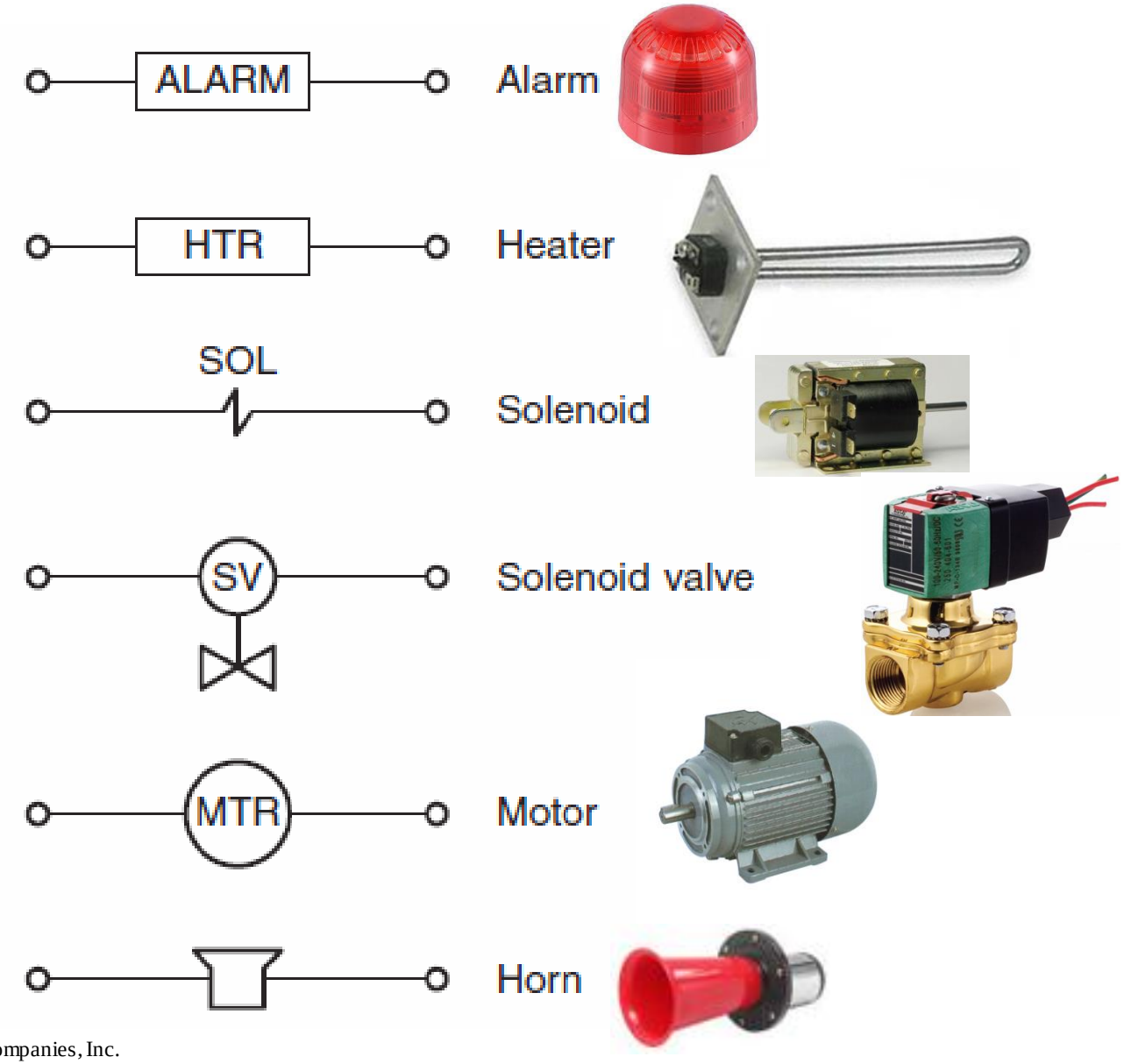
Relay

Motor starter coil



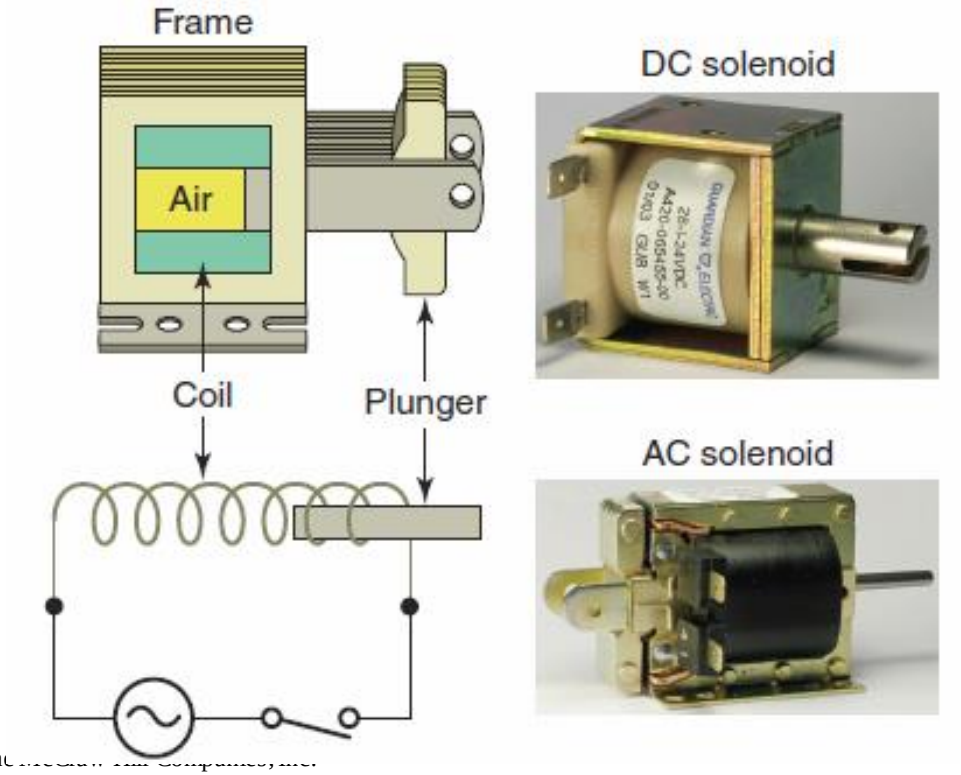
Motor overload relay contact

Symbols for output control devices.



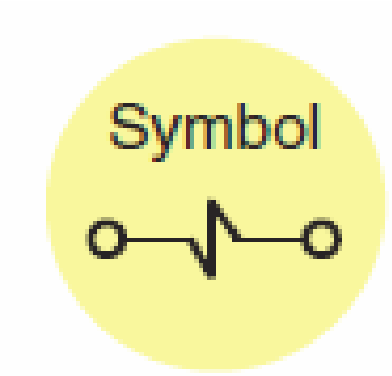
An *actuator* is a device that converts an electrical signal into mechanical movement.

An electromechanical solenoid is an actuator that uses electrical energy to magnetically cause mechanical control action.

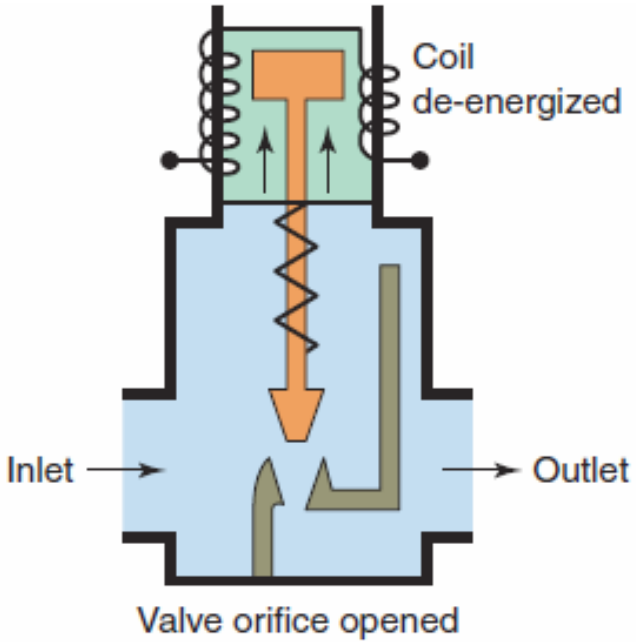


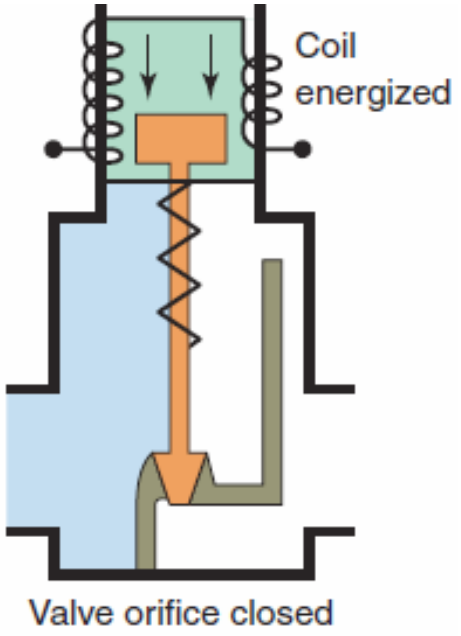
DC solenoid

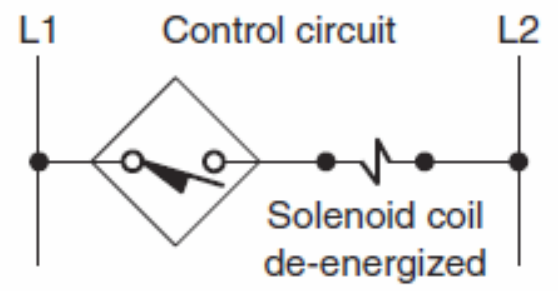
AC solenoid

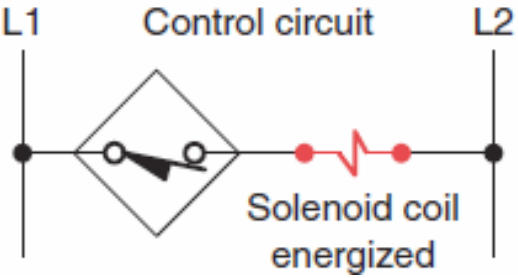


Solenoid valves are electromechanical devices that work by passing an electrical current through a coil, thereby changing the state of the valve.

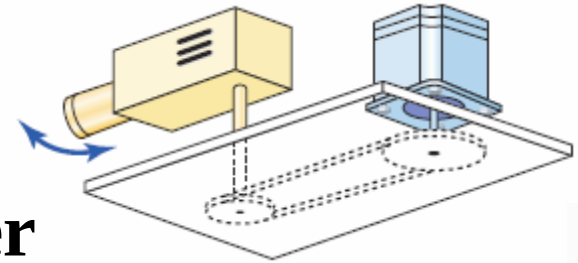




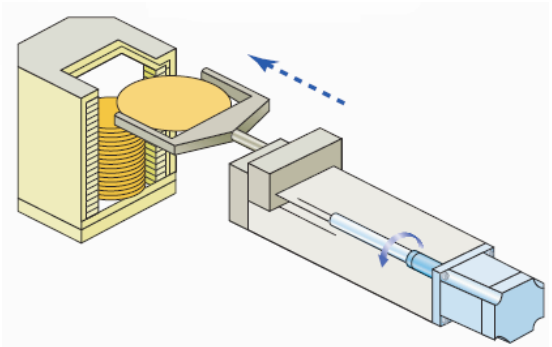




Stepper motors **rotate in discrete increments when electrical command pulses are applied to it in the proper sequence.**

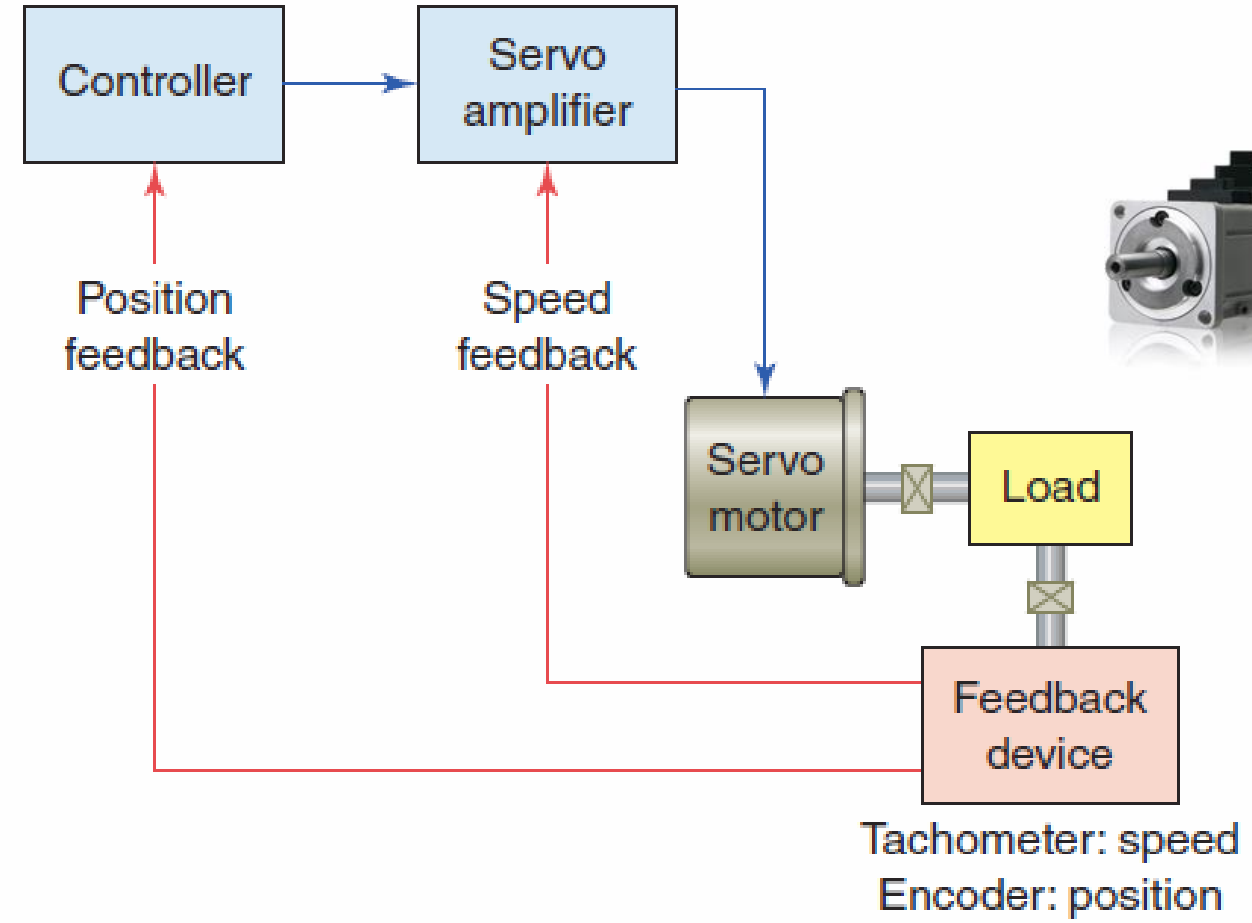


Every revolution is divided into a number of steps, and the motor must be sent a voltage pulse for each step.

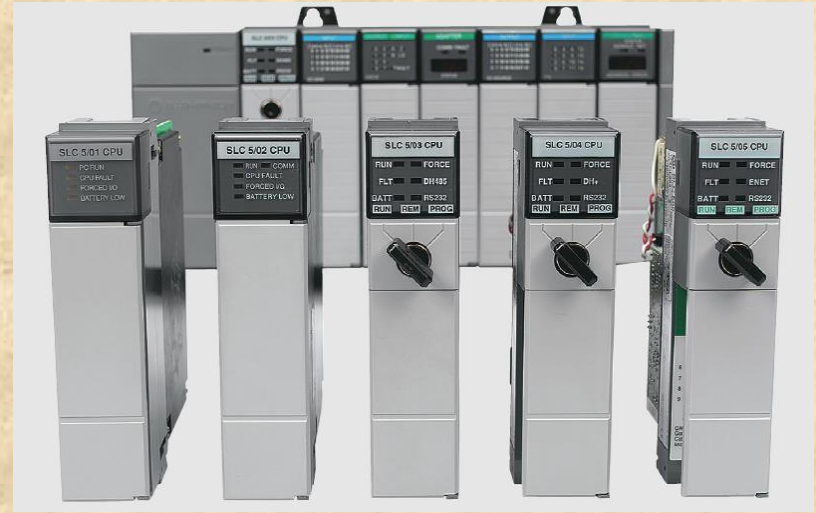


The amount of rotation is directly proportional to the number of pulses, and the speed of rotation is relative to the frequency of those pulses.

Servo motors operate in *closed-loop* mode, while stepper motors operate in *open-loop* mode.

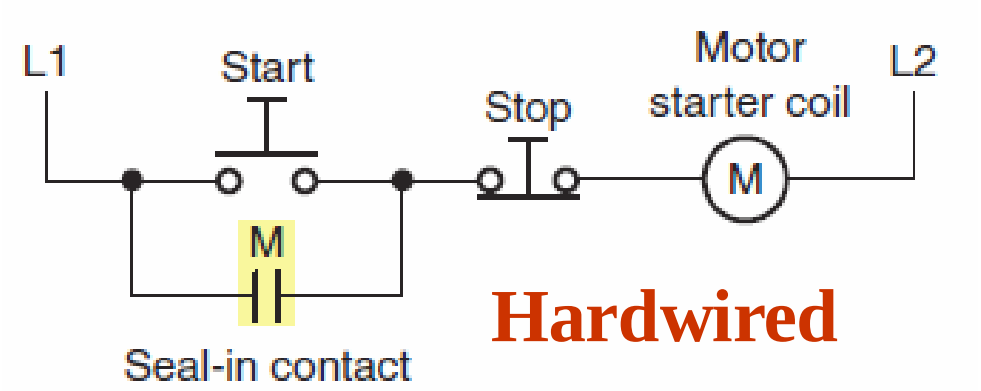


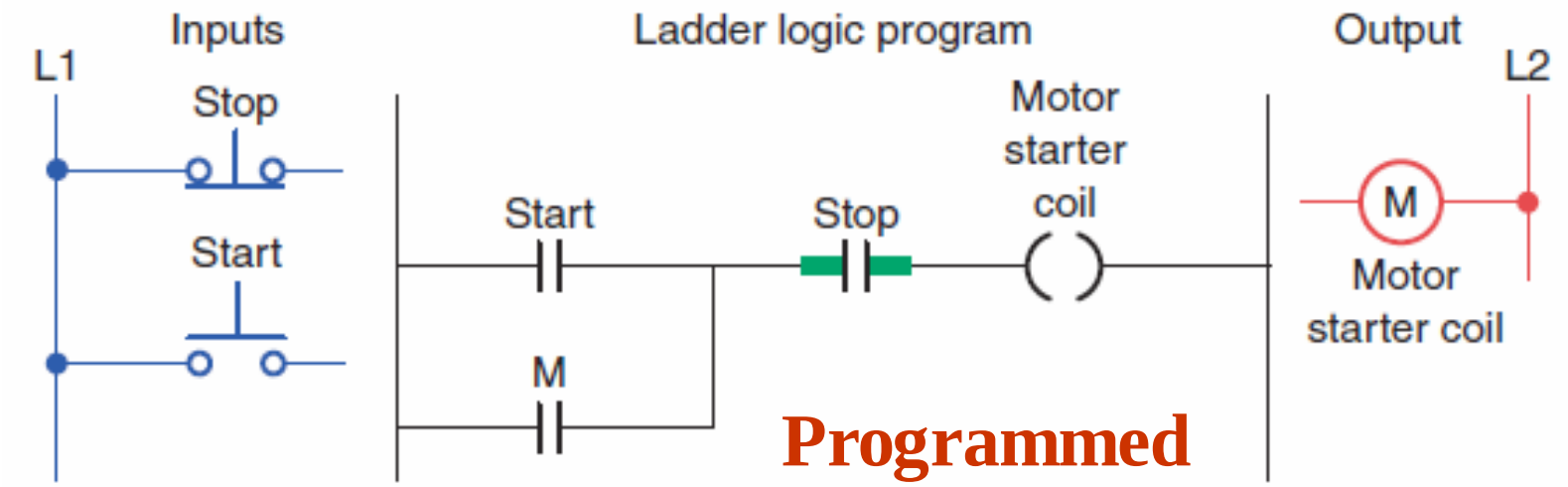
6.8



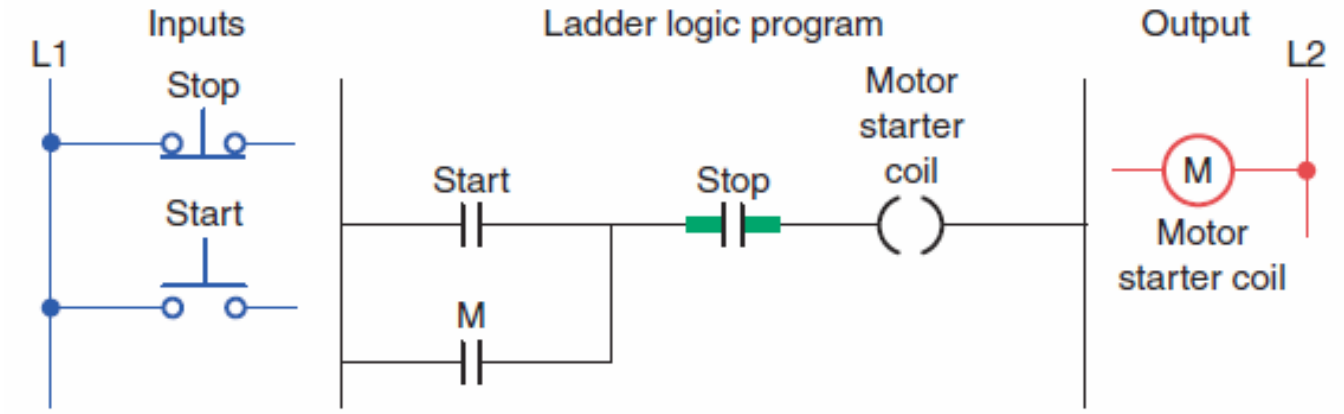
Seal-In Circuits

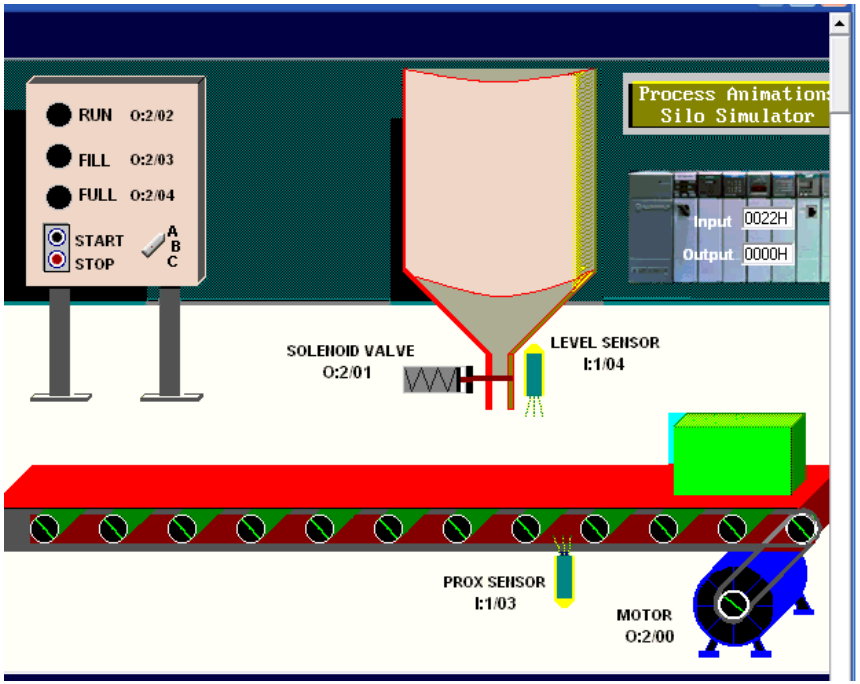
A *seal-in* circuit is a method of maintaining current flow after a momentary switch has been pressed and released.

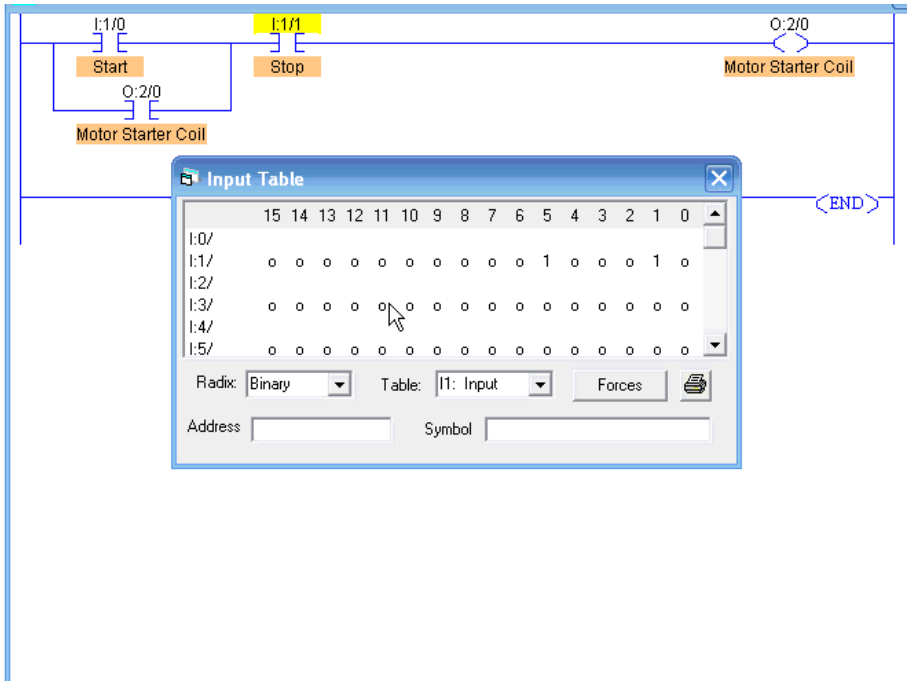




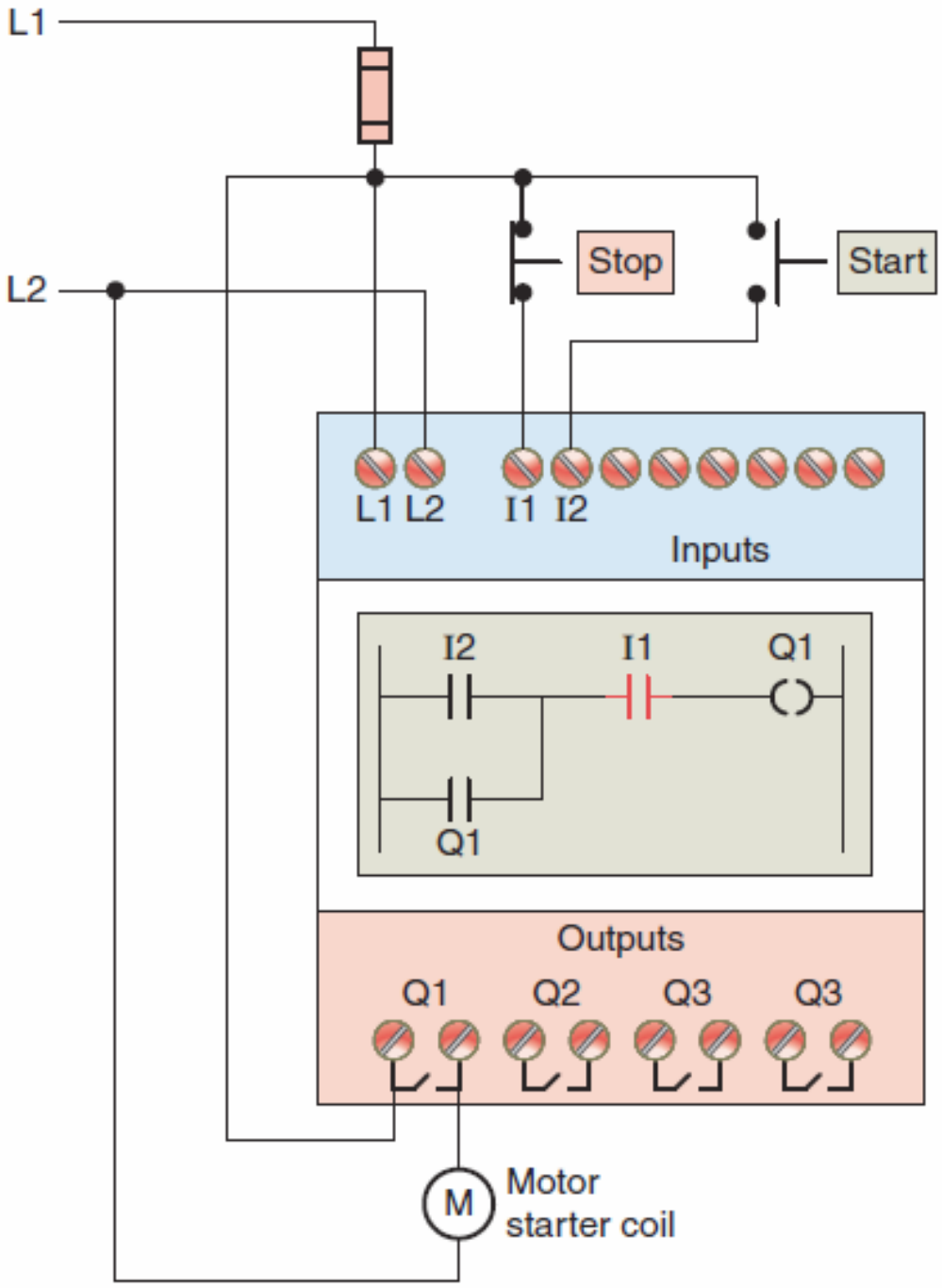
Simulated *seal-in* circuit.

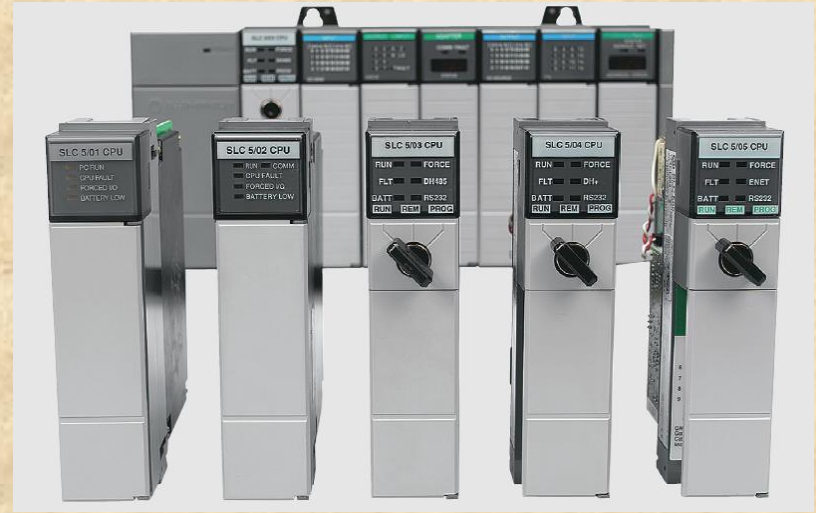






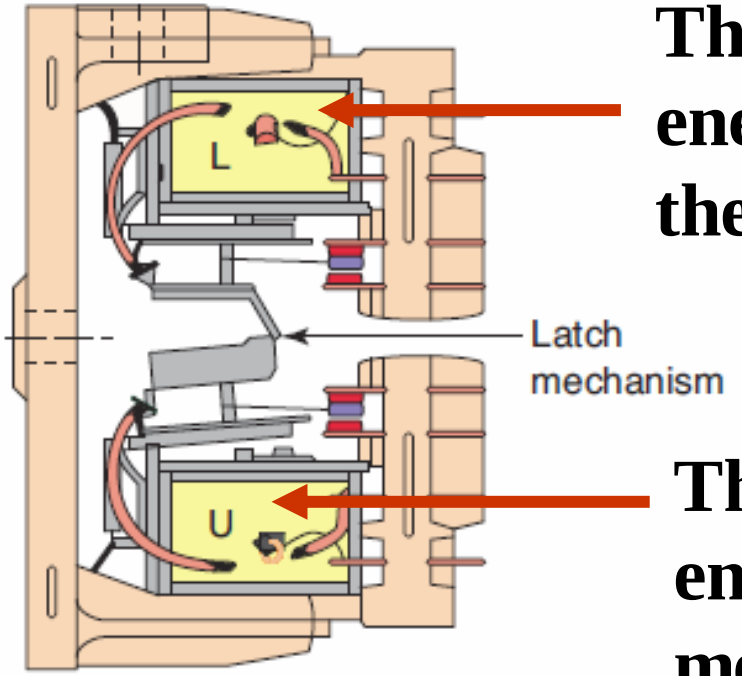
Motor seal-in circuit implemented using the Allen-Bradley Pico controller.





Latching Relays

Electromagnetic *latching relays* are designed to hold the relay closed after power has been removed from the coil.

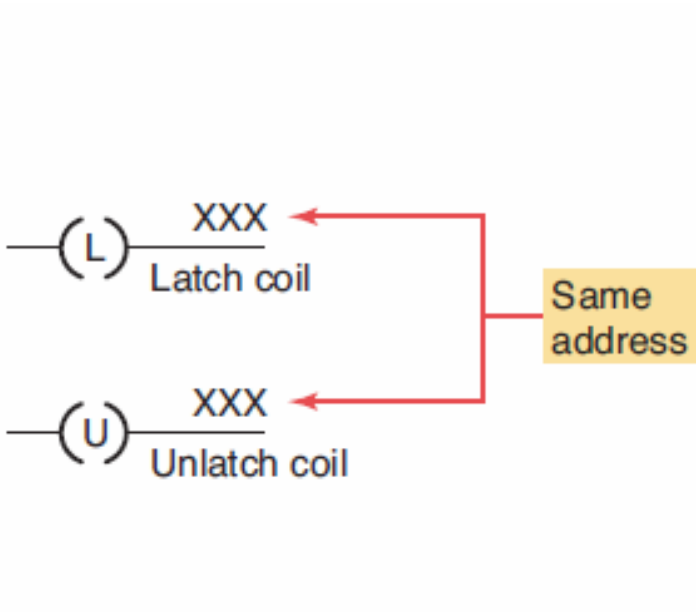


The **latch coil** is momentarily energized to set the latch and hold the relay in the latched position.

The **unlatch coil** is momentarily energized to disengage the mechanical latch and return the relay to the unlatched position.

The PLC *output latch (OTL)* and *output unlatch (OTU)* instructions duplicate the operation of the electromagnetic latching relay.

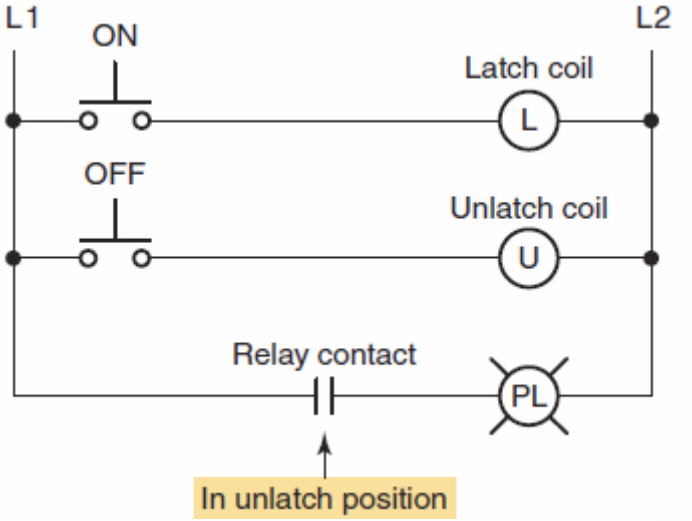
Command	Name	Symbol	Description
OTL	Output latch	(L)	OTL sets the bit to "1" when the rung becomes true and retains its state when the rung loses continuity or a power cycle occurs.
OTU	Output unlatch	(U)	OTU resets the bit to "0" when the rung becomes true and retains it.



The OTL and OTU instructions have the same address.

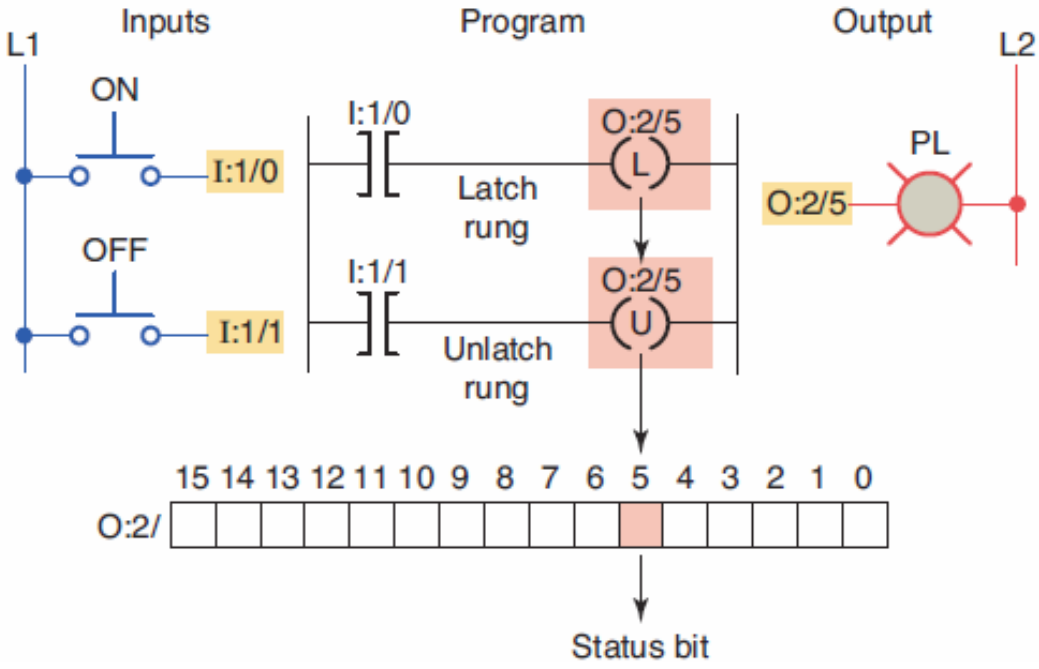
The OTL instruction can only turn a bit on and the OTU instruction can only turn a bit off.

Hardwired and *programmed* latching circuits.

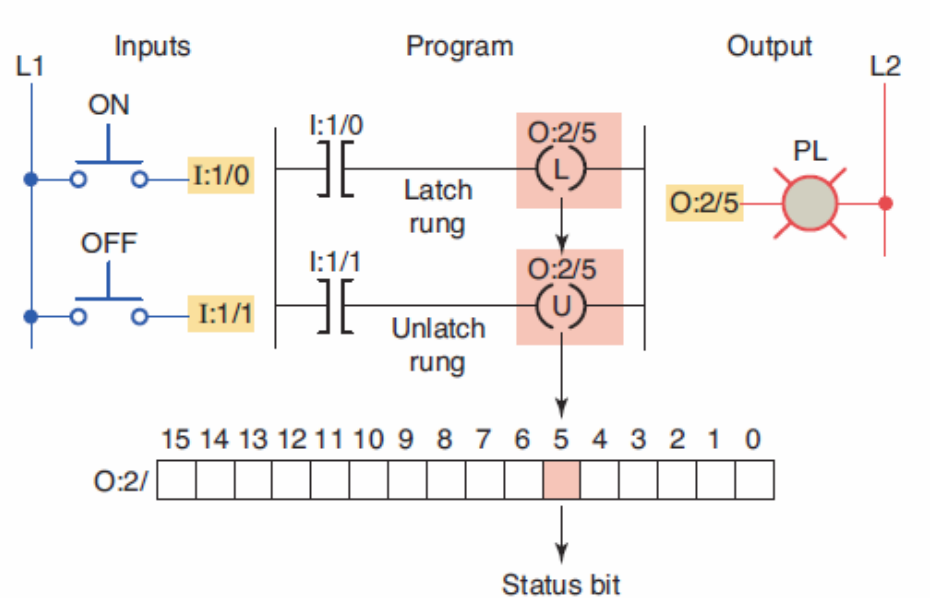


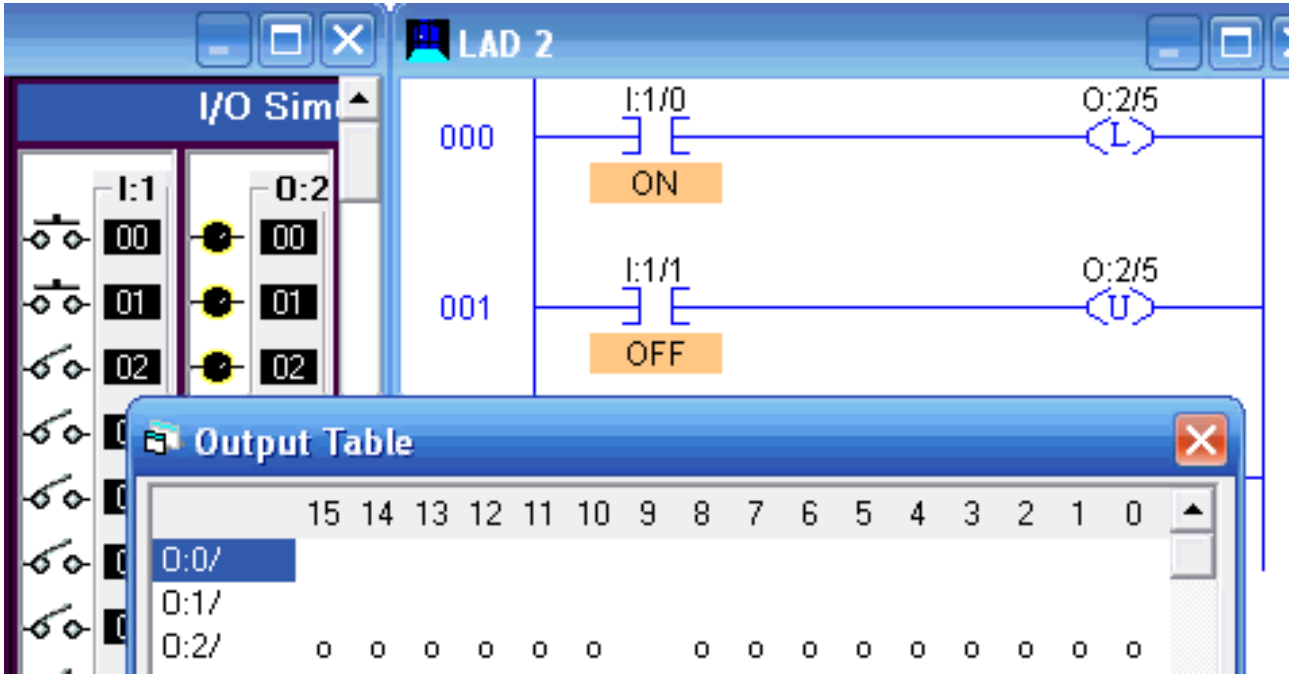
Hardwired

Programmed

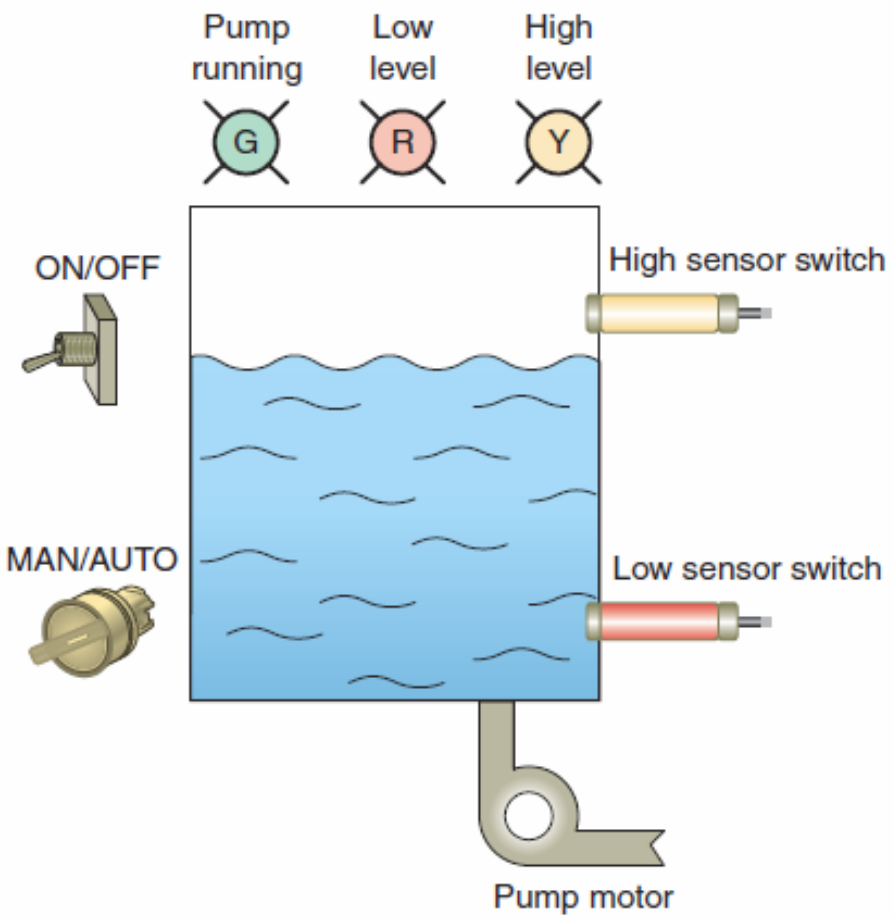


Simulated programmed latching circuit.





Process used to control the level of water in a storage tank.

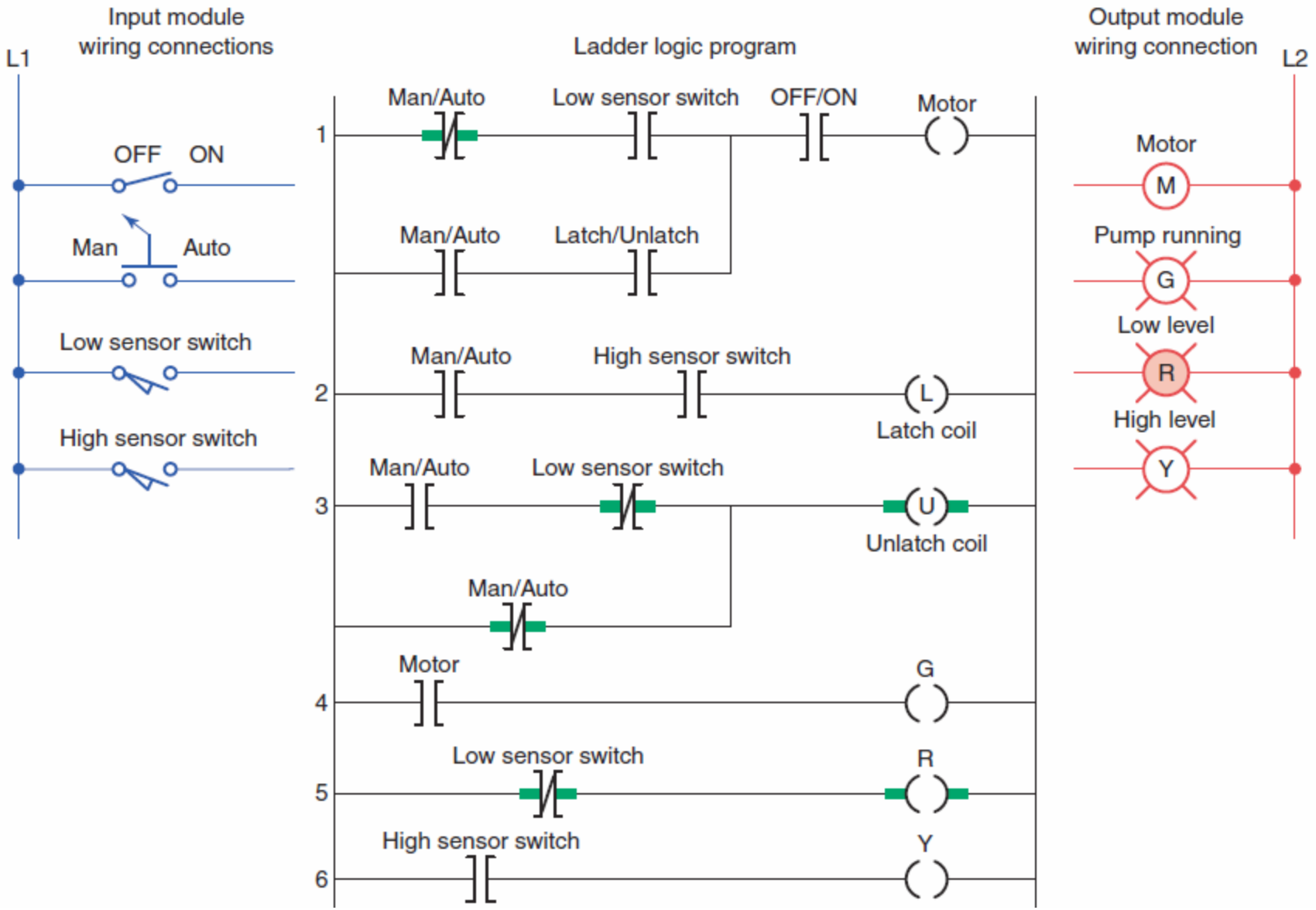


Manual Mode -The pump will start if the water in the tank is at any level except low.

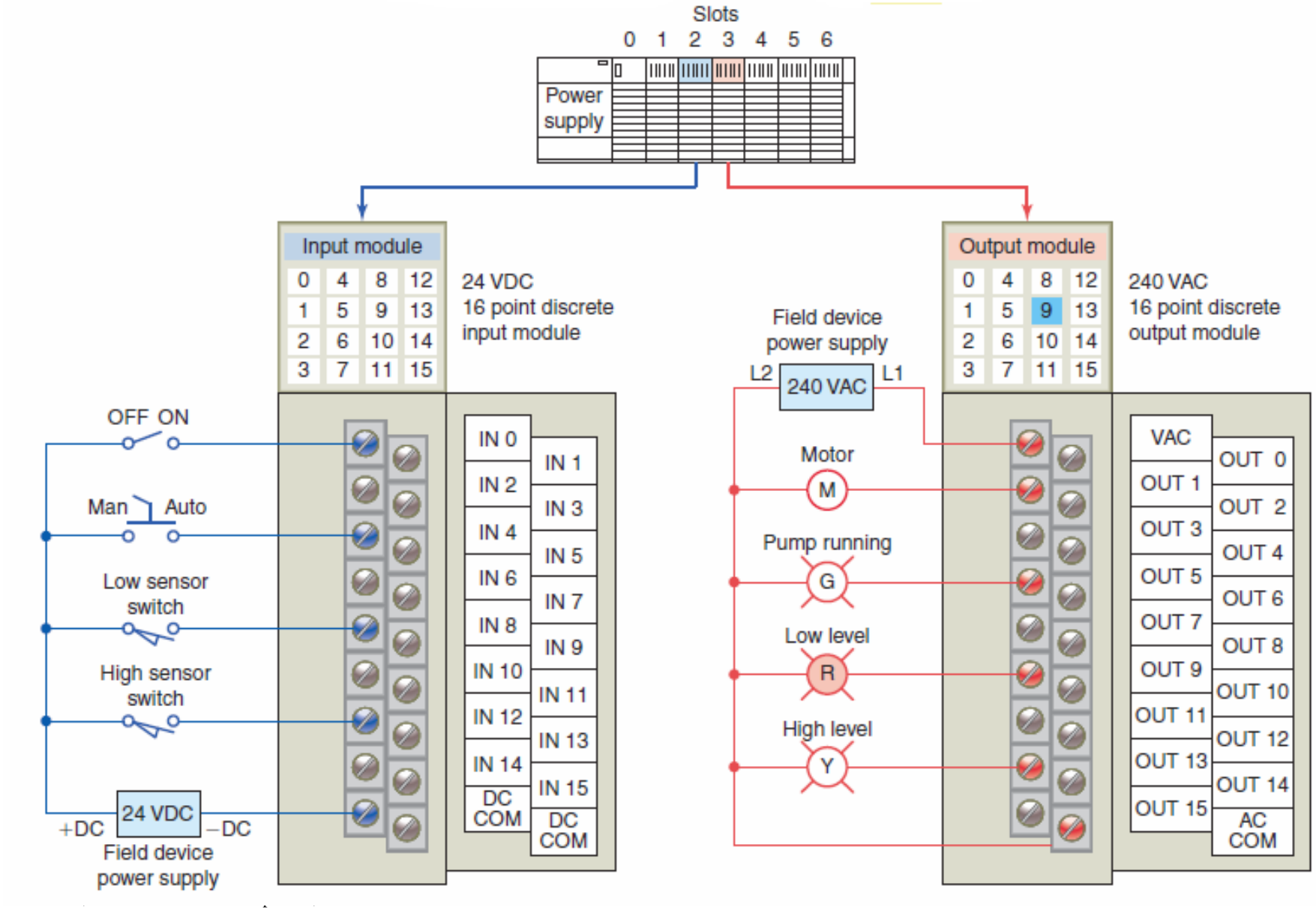
Automatic Mode - When the level of water reaches the high point, the pump will start.

-When the water level reaches the low point, the pump will stop .

Program used to control the water level.



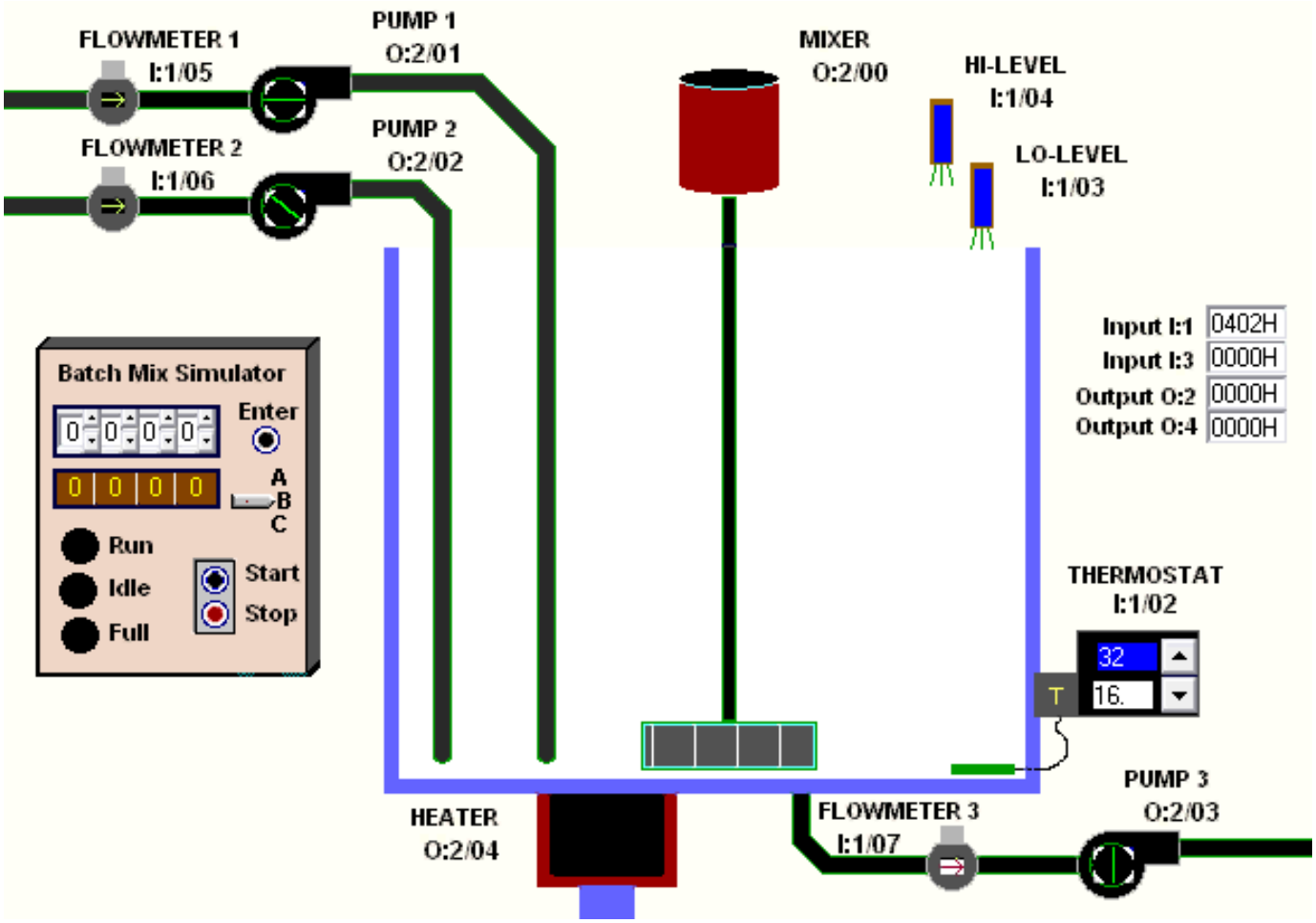
I/O connections for program.



Simulated action of program used to control the water level.

B – Manual

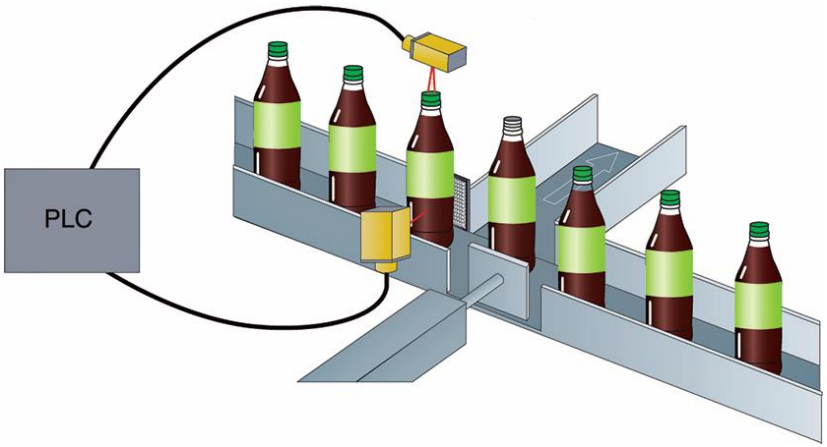
A - Auto

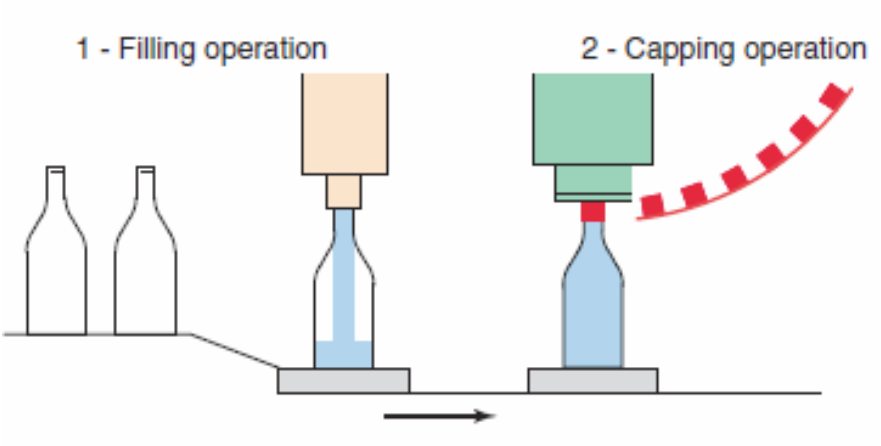


6.10

Converting Relay Schematics into PLC Ladder Programs

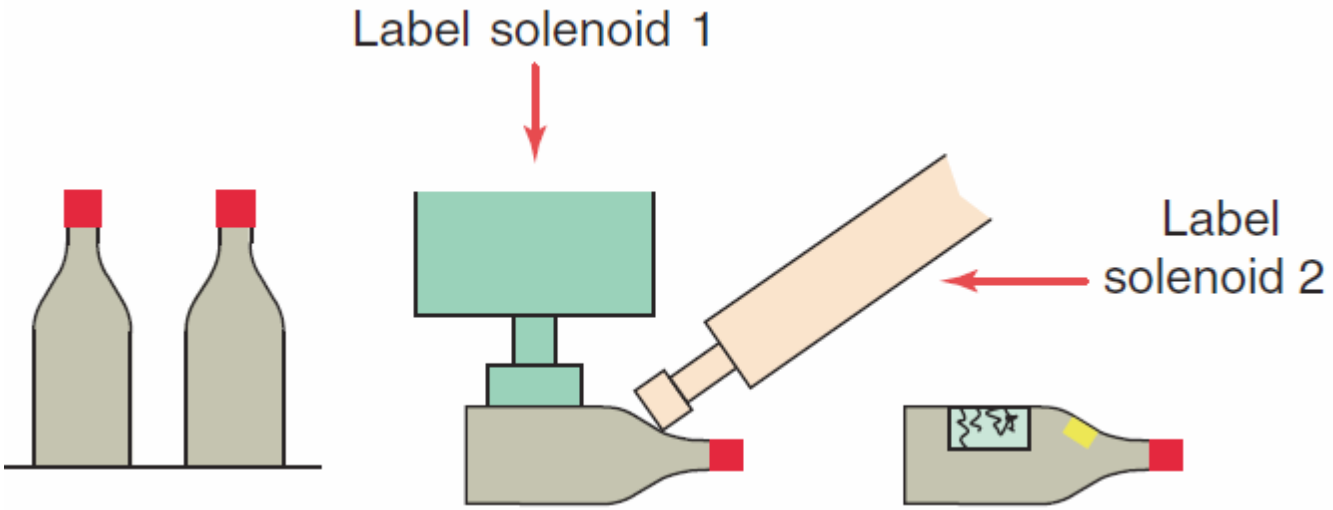
A *sequential* control process is required for processes that demand that certain operations be performed in a specific order.





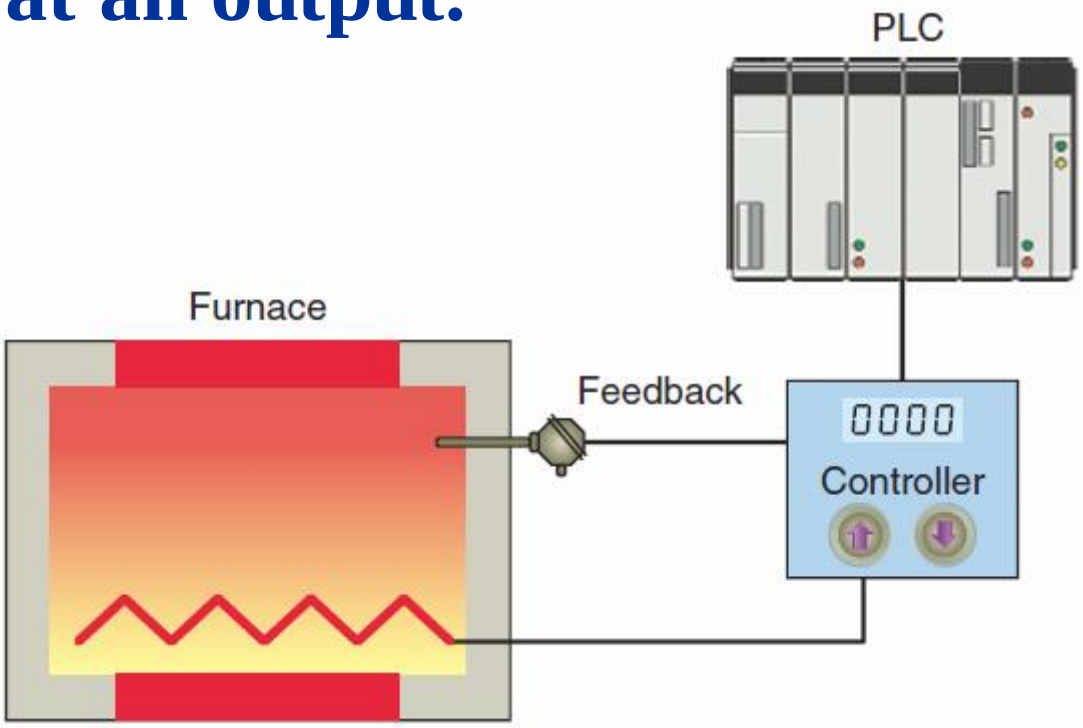
In a filling and capping operations, the tasks are (1) fill bottle and (2) press on cap. These tasks must be performed in the proper order.

Combination controls require that certain operations be performed without regard to the order in which they are performed.



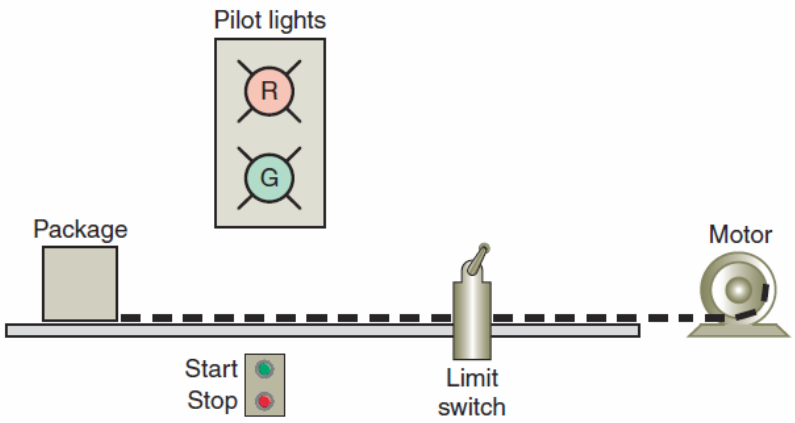
Here, the tasks are (1) place label 1 on bottle and (2) place label 2 on bottle. The order in which the tasks are performed does not really matter.

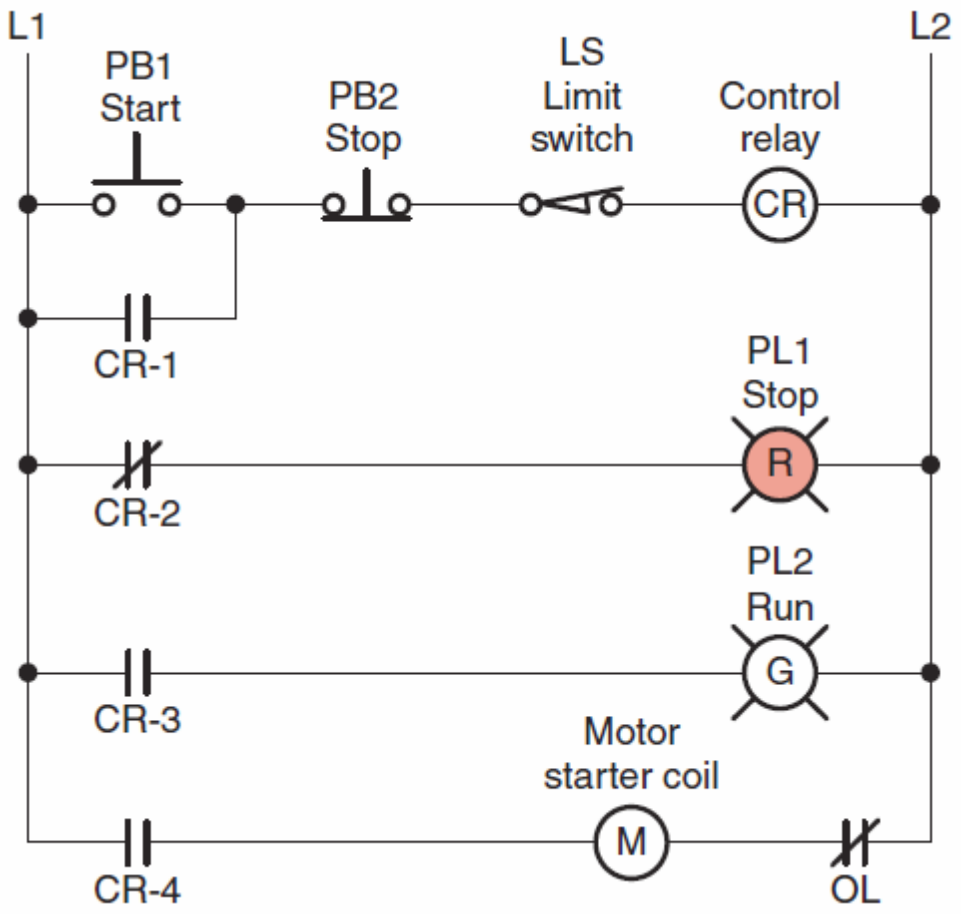
Automatic control involves maintaining a desired *set point* at an output.



When maintaining a certain set-point temperature in a furnace, if there is deviation from that set point, an error is determined by comparing the output against the set point and using this error to make a correction.

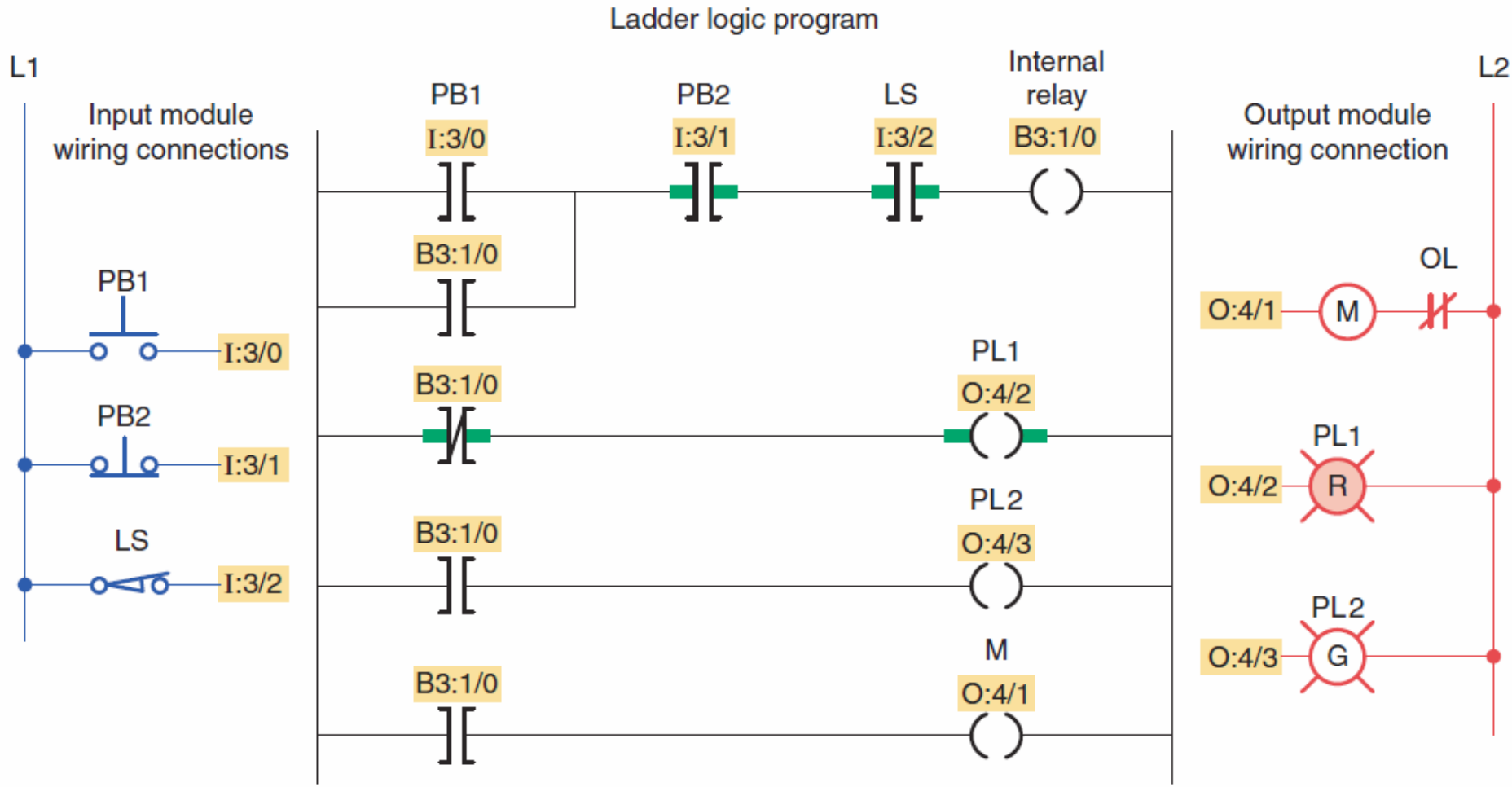
Sequential process control relay schematic.



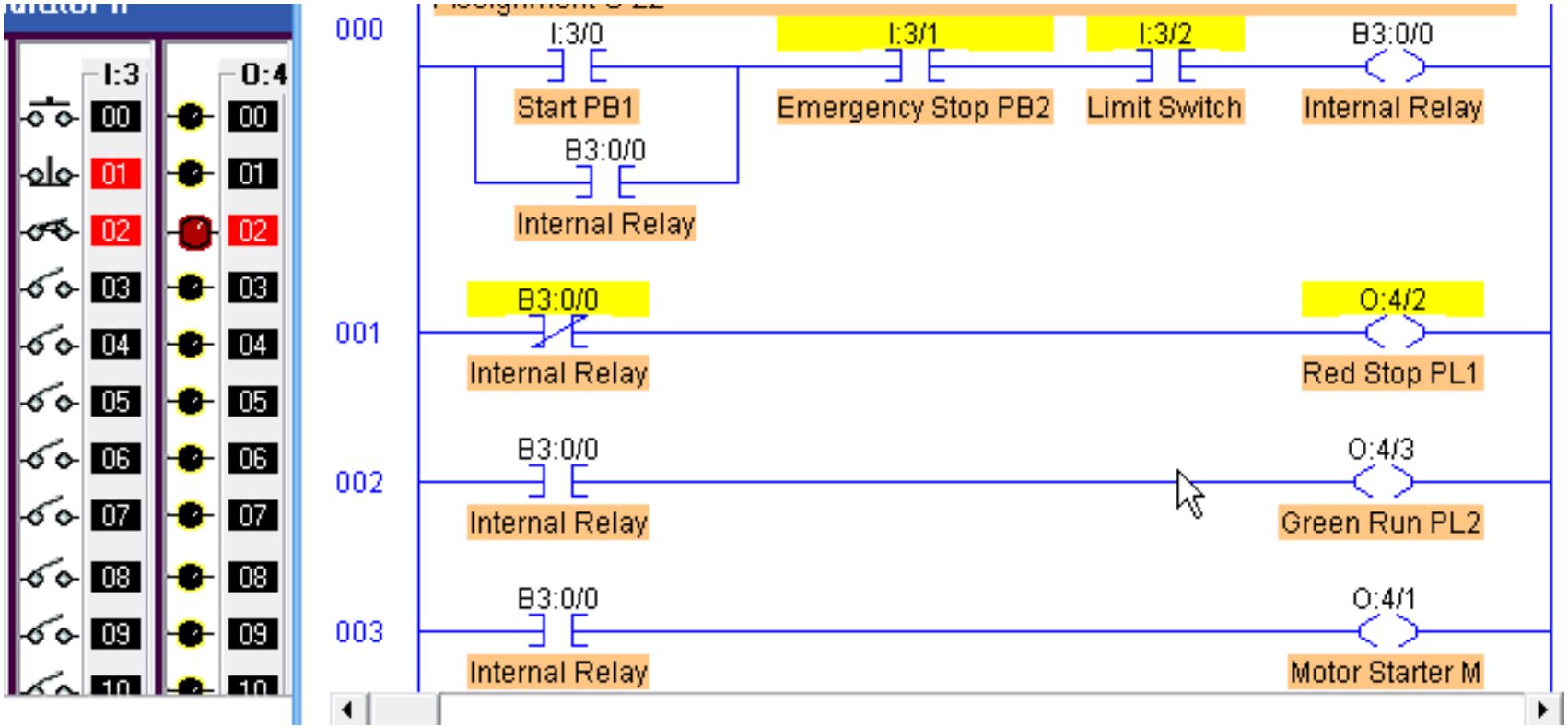


1. Start button is pressed.
2. Table motor is started.
3. Package moves to the position of the limit switch and automatically stops.

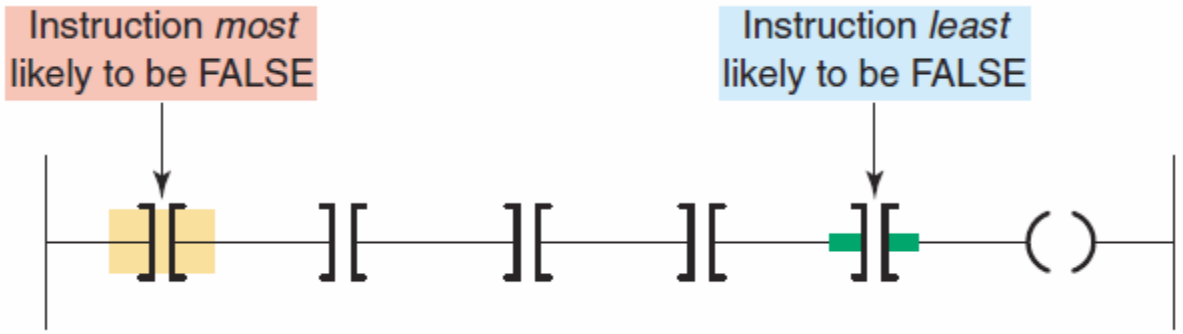
Sequential process control program.



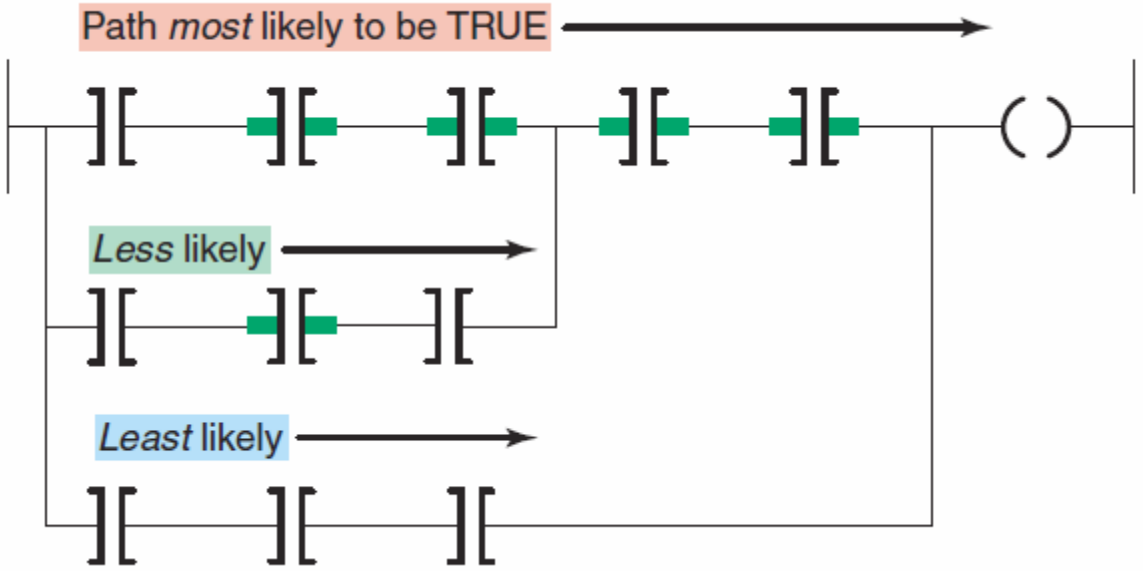
Sequential process control program simulation.



Instructions programmed for optimum scan time.

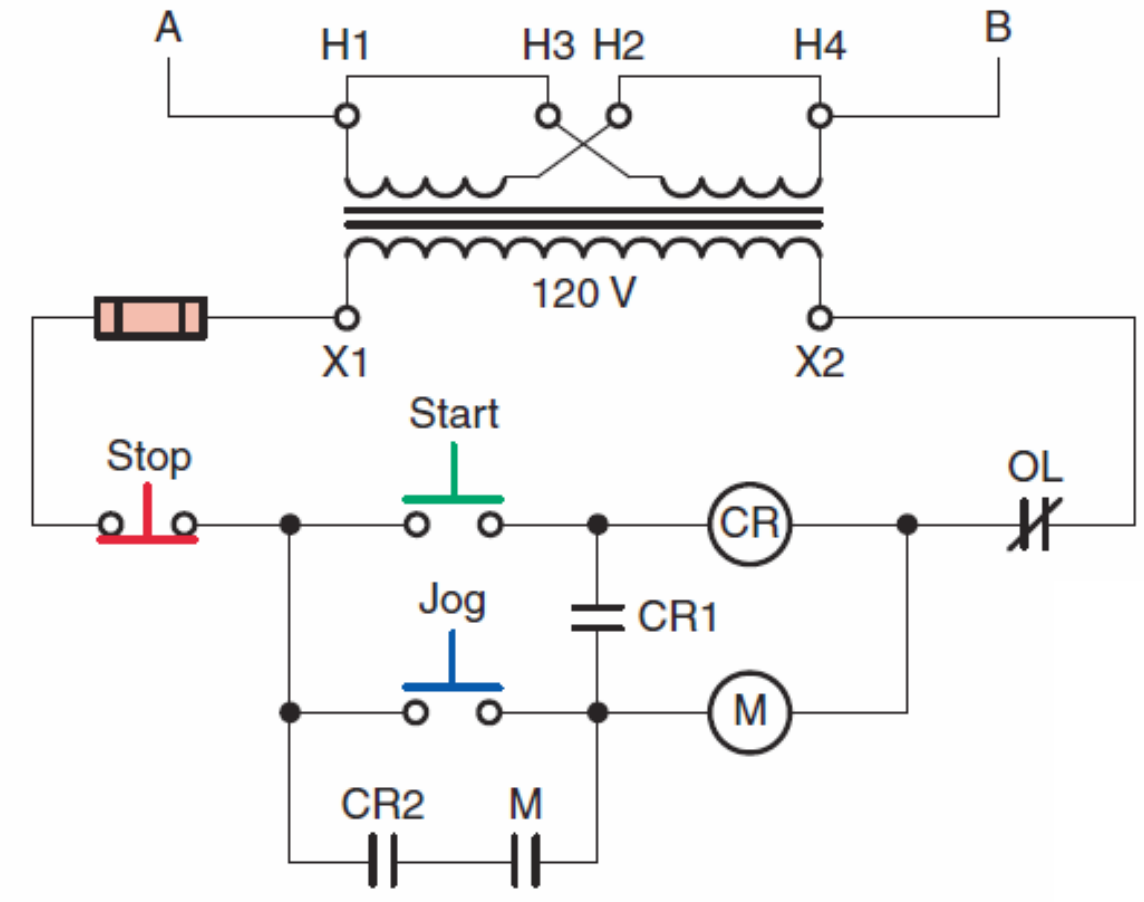


The series instructions are programmed from the most likely to be false to the least likely to be false.

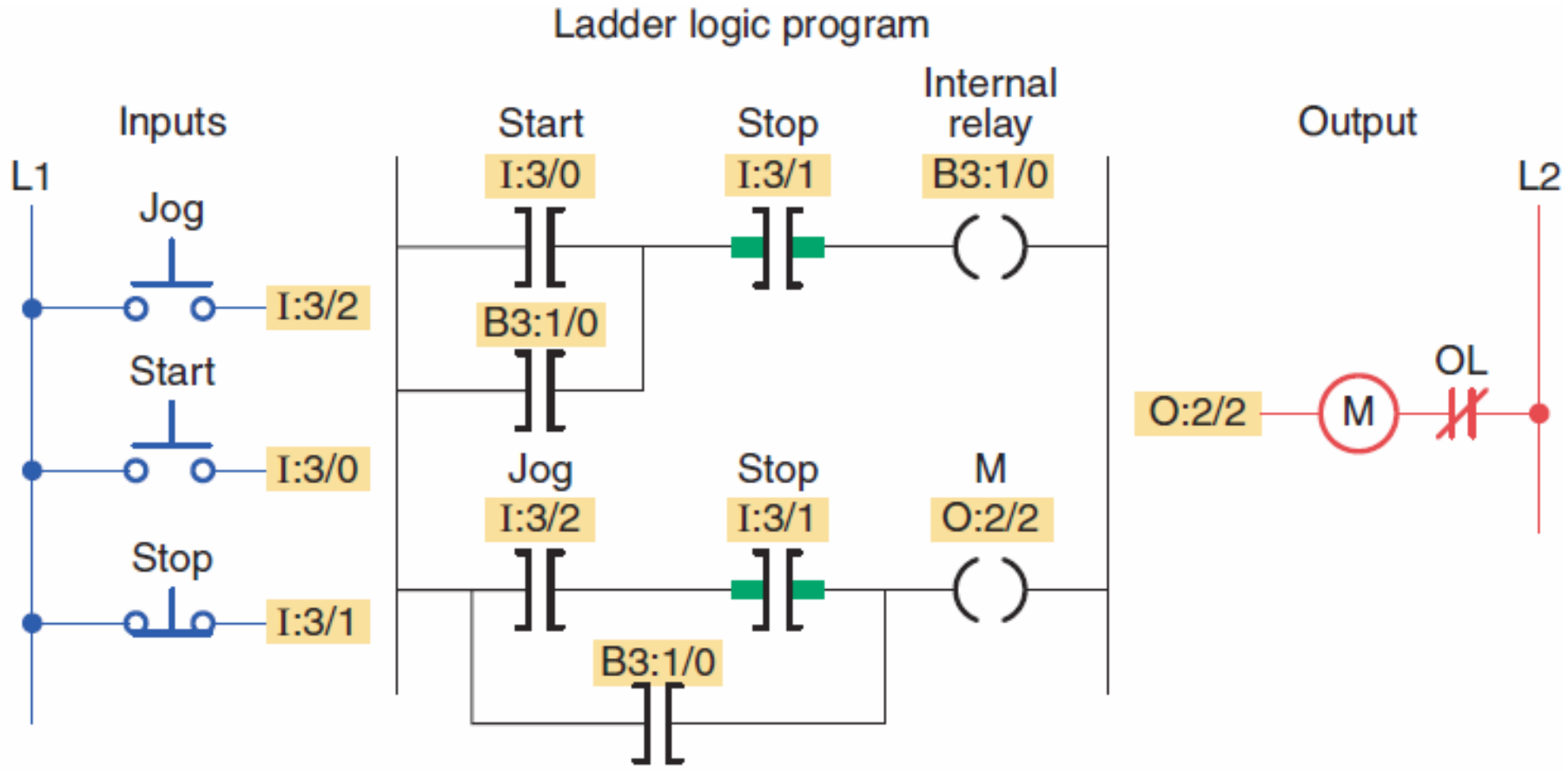


The parallel path that is most often true is placed on the top of the rung.

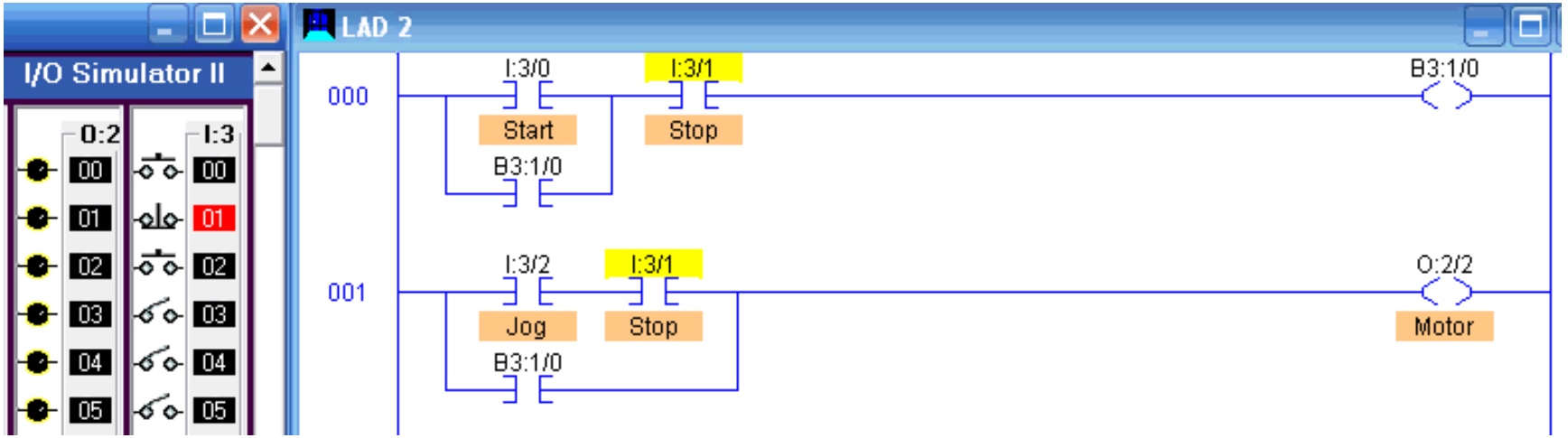
Hardwired jog circuit with control relay.



Equivalent *programmed* jog circuit.



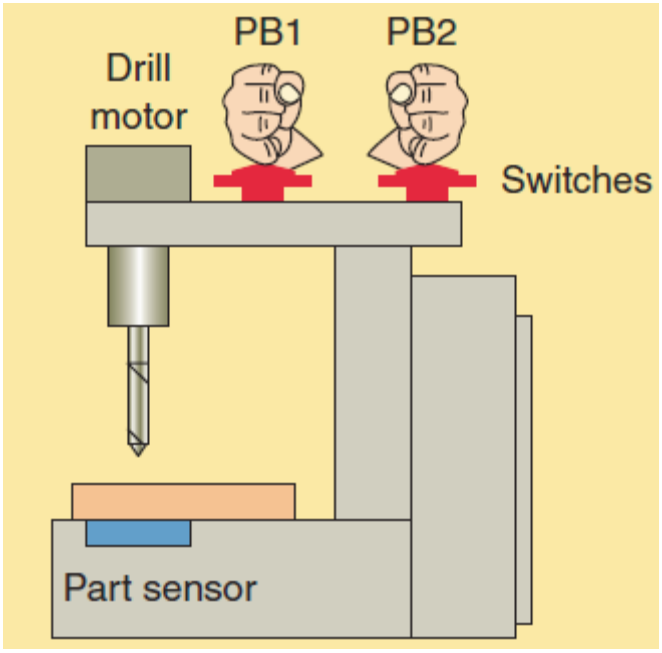
Simulated programmed jog circuit.

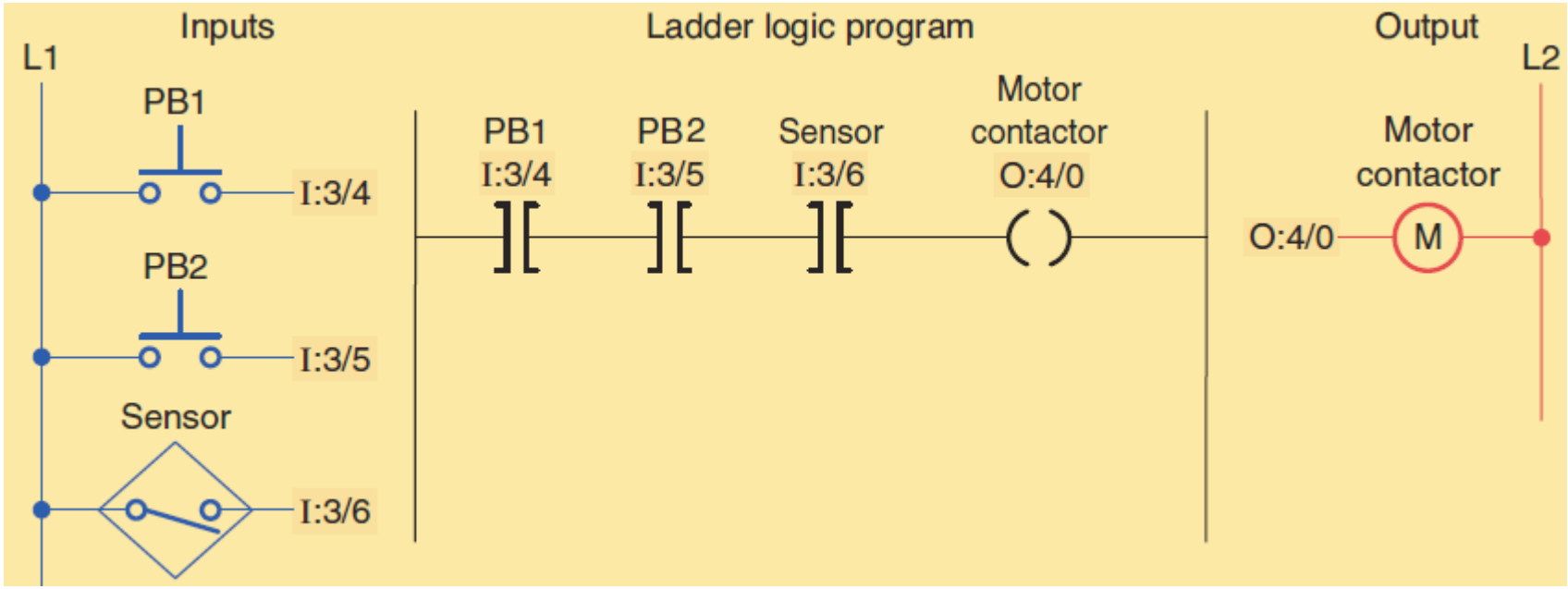


6.11

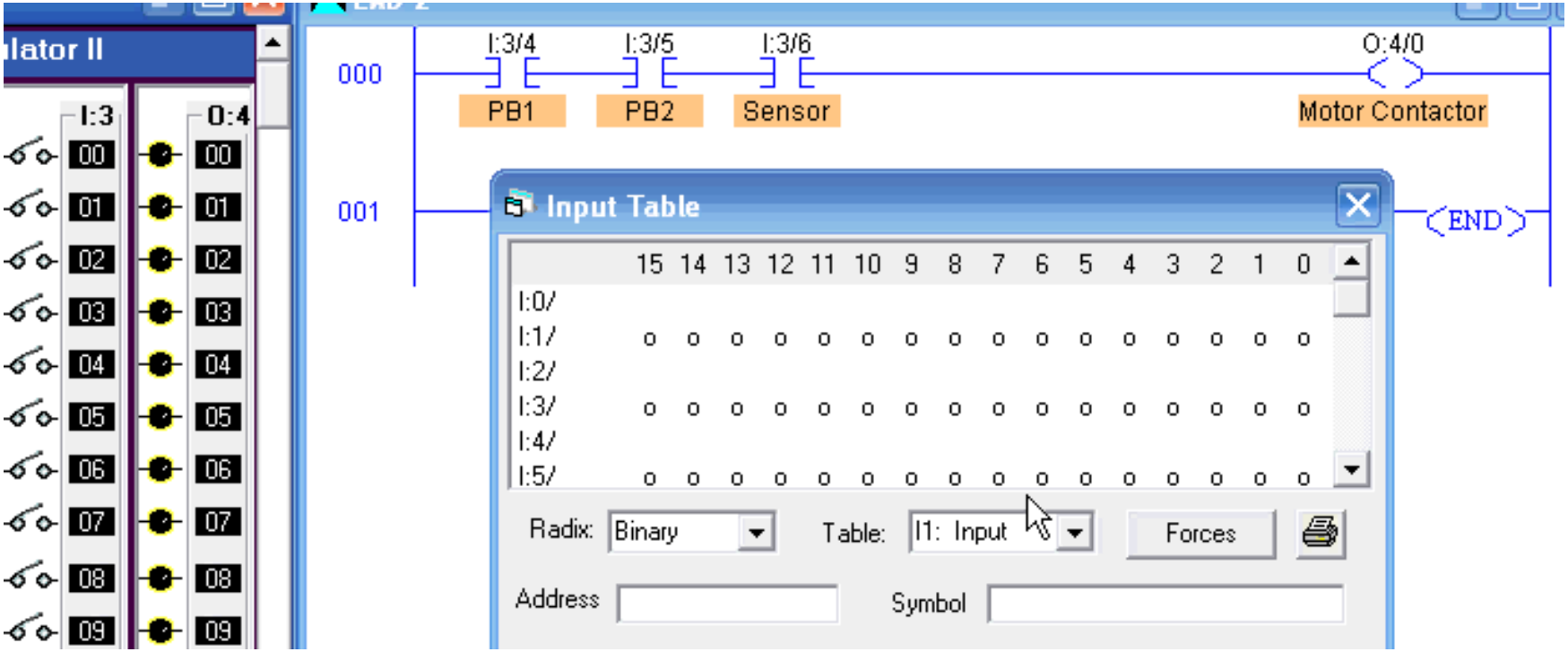
Writing a Ladder Logic Program Directly from a Narrative Description

Drilling process that requires the drill press to turn on only if there is a part present and the operator has one hand on each of the start switches.

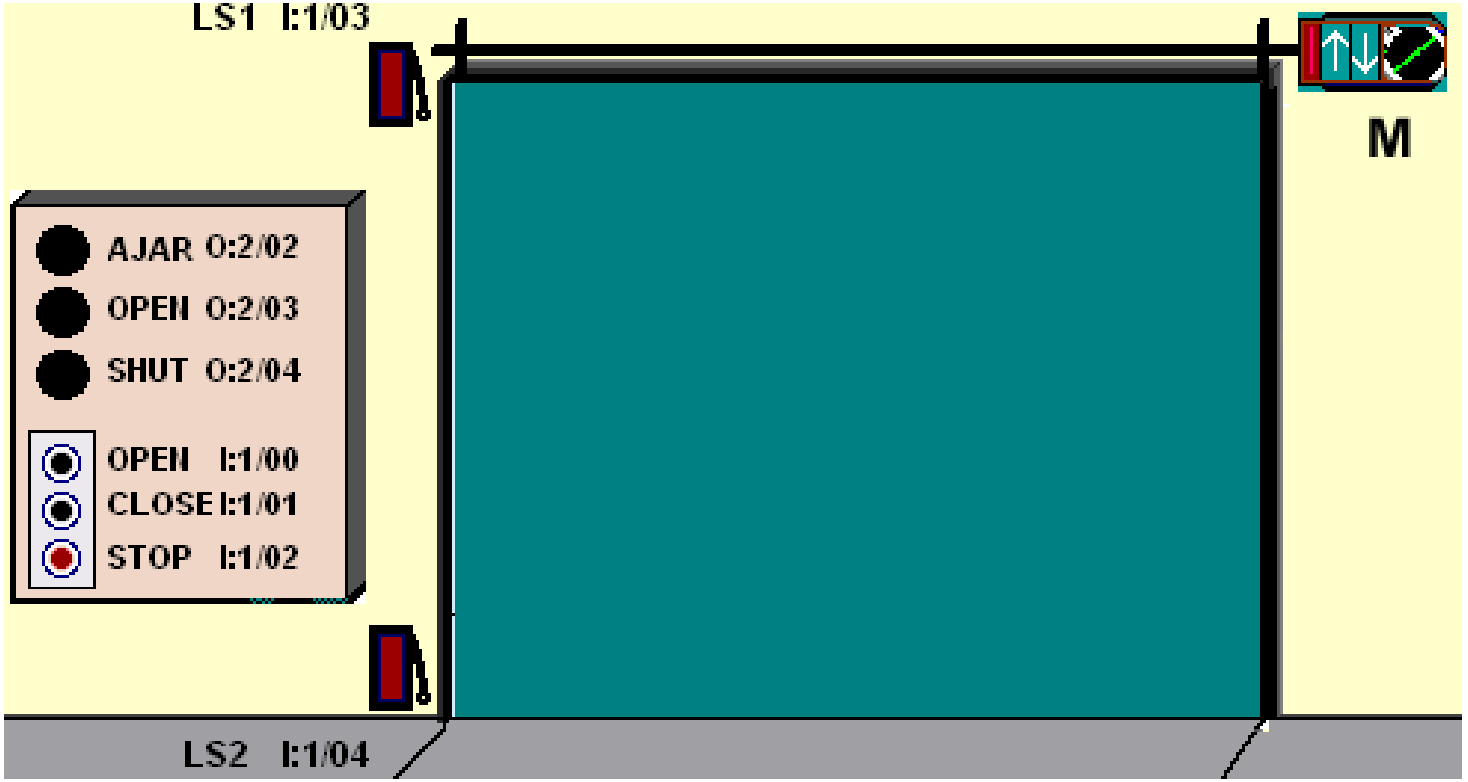




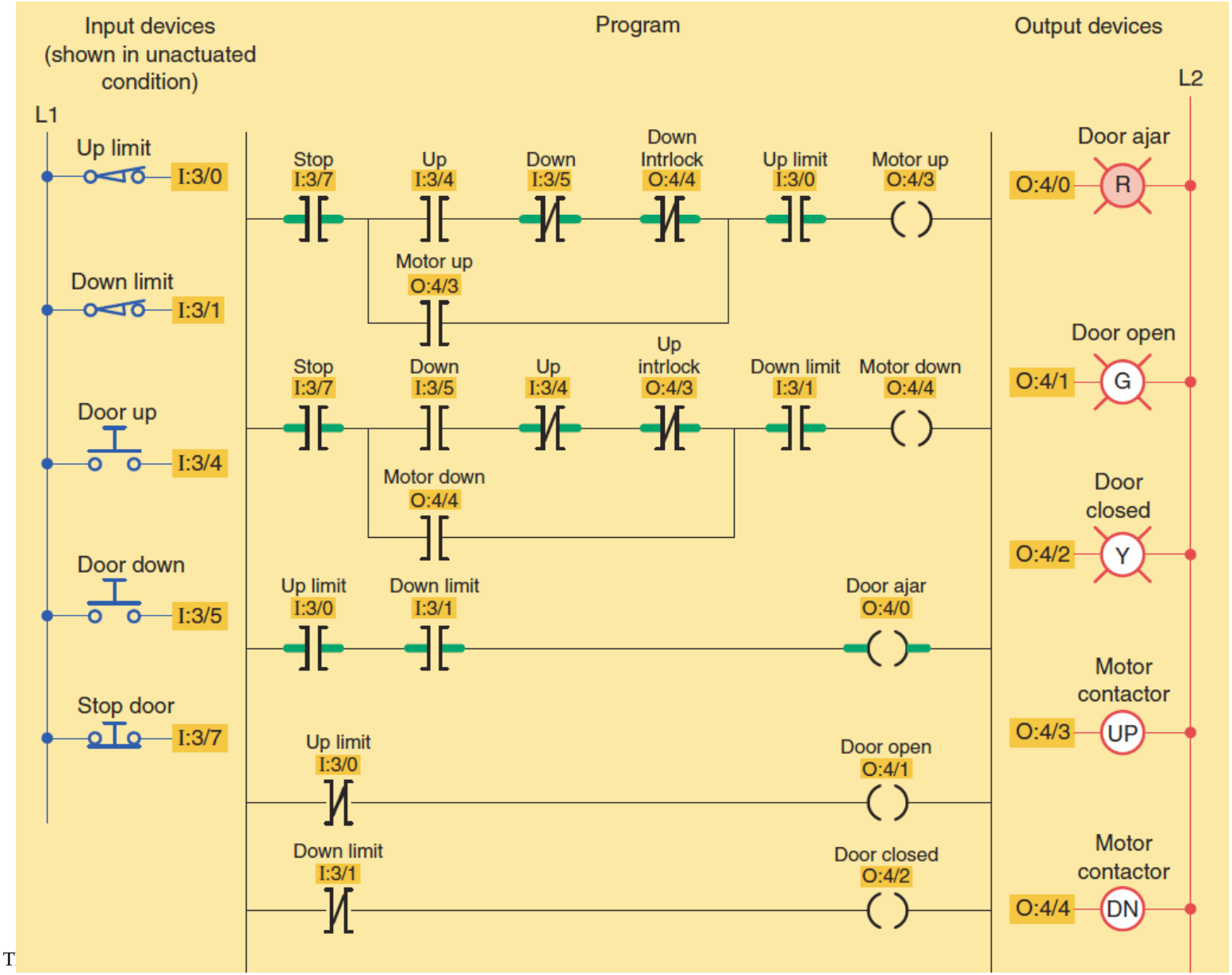
Simulated drilling process program



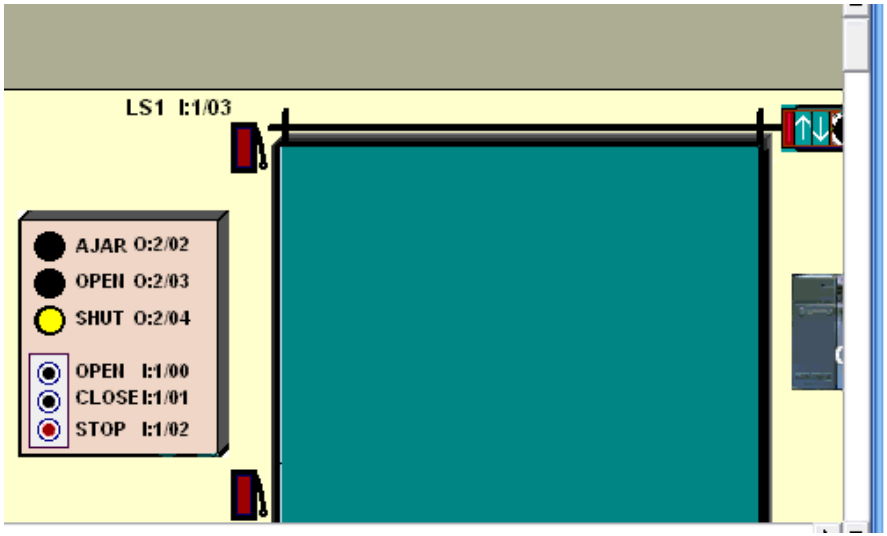
A motorized overhead garage door is to be operated automatically to preset open and closed positions.

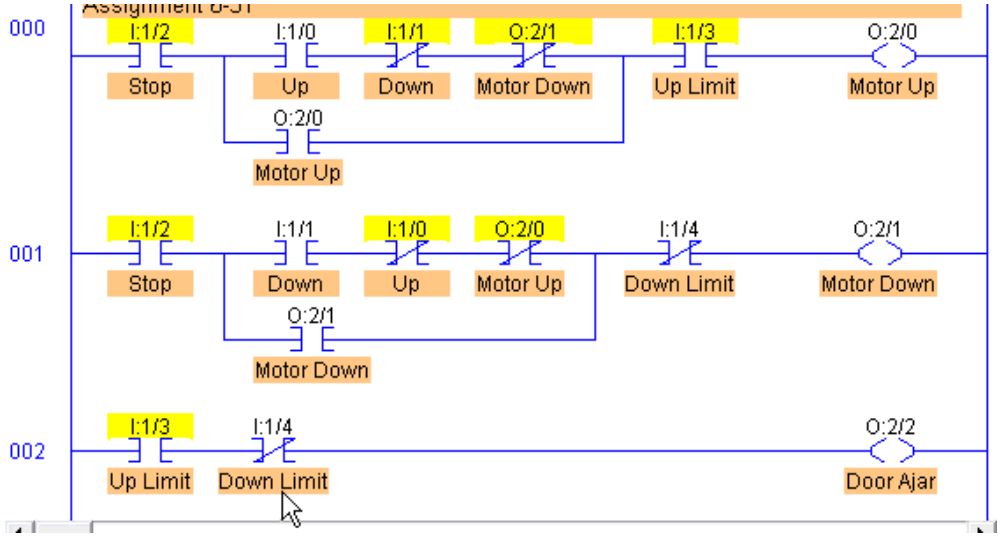


Motorized overhead garage door program.

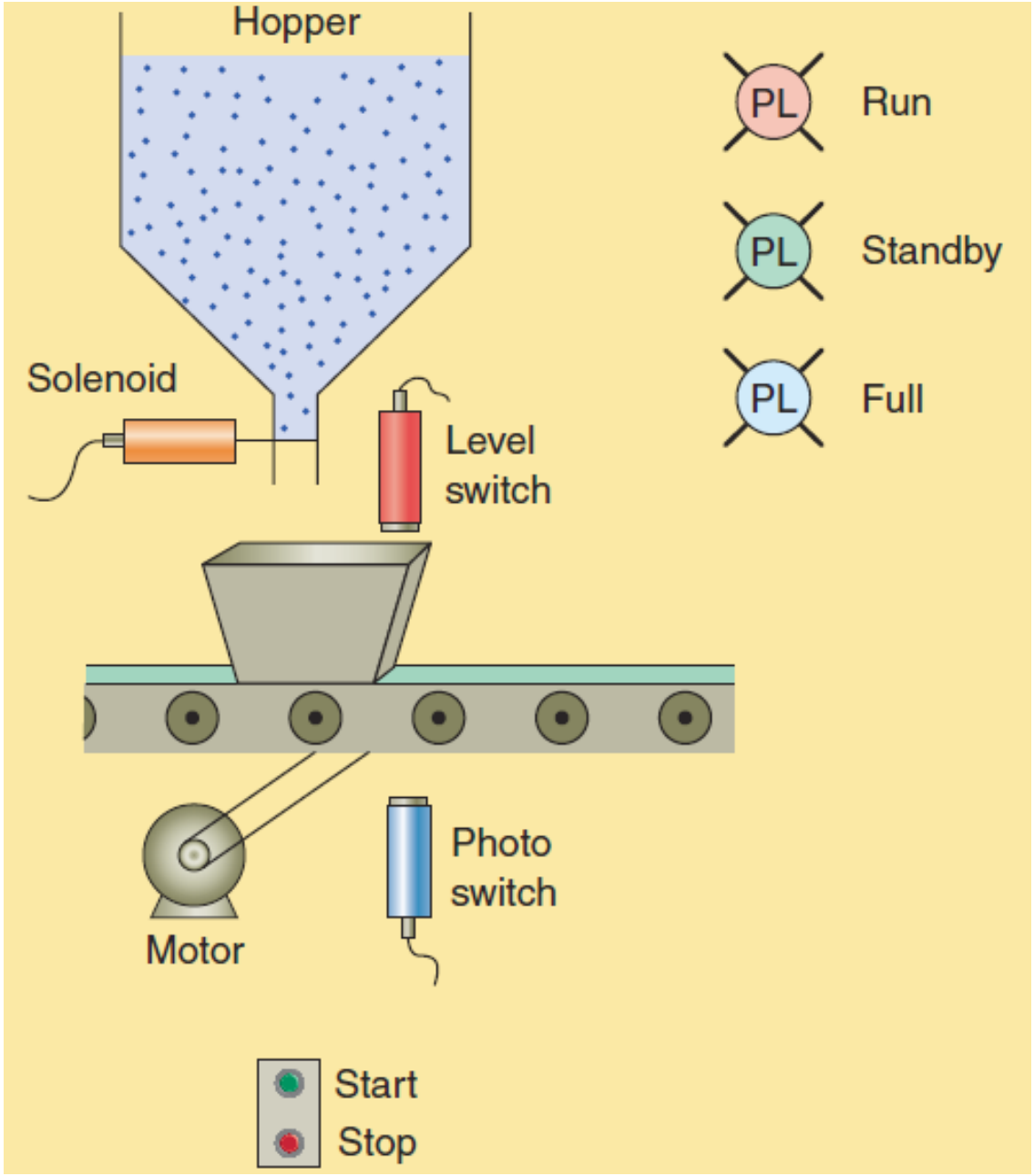


Simulated motorized overhead garage door program.

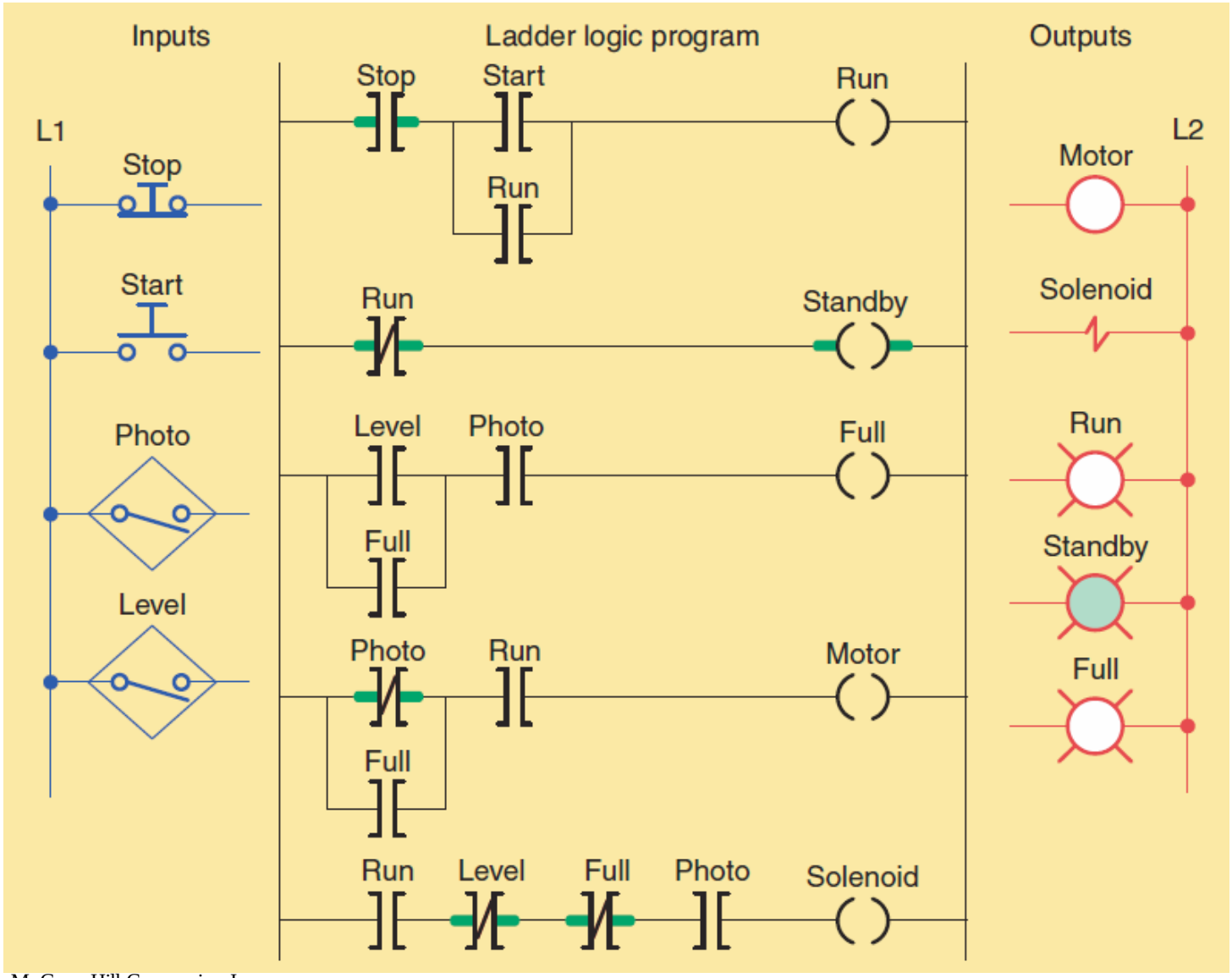




Continuous filling operation. This process requires that boxes moving on a conveyor be automatically positioned and filled.



Continuous filling operation program.



Simulated continuous filling operation program.