KEMENTERIAN PENGAJIAN TINGGI

PROGRAMMABLE LOGIC CONTROLLER

LOGICAL SENSORS AND ACTUATORS

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ELECTRICAL ENGINEERING

LOGICAL SENSORS AND ACTUATORS

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It is hoped that with the publication of this full eBook, all matters of storage, review of information and reference in the future can be done even better. Any shortcomings seen throughout the eBook creation are acceptable and we are ready to accept views to further improve our eBook in the future.

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1.0 Logical Sensors and Actuators

Sensors are used for detecting, and often measuring, the magnitude of something. They convert mechanical, magnetic, thermal, optical, and chemical variations into electric voltages and currents. Sensors are usually categorized by what they measure, and they play an important role in modern manufacturing process control.

Sensors allow process controllers such as PLC to detect the state of a process. Logical sensors can only detect a state that is either true or false.
Examples of physical phenomena that are typically detected are listed below :

i) Inductive proximity

Inductive proximity sensor can detect metal targets approaching the sensor.

ii) Capacitive proximity

Capacitive proximity sensors can detect both metallic and non-metallic targets.

iii) Photoelectric sensor

Photoelectric sensor is an object breaking a light beam or reflecting light.

iv) Mechanical contact

Mechanical contact is an object touching a switch.

1.1 Types of Logical sensor

1.1.1 Basic logical sensor types, symbols, functions and operation.

a) Contact Switches

Manually operated switches or contact switches are **controlled by hand**. Contact switches can be used as motion limit switches or as push button switches and used as user- machine interface switches, e.g. start/stop push button switches. Contact switches are available as normally open (NO) and normally closed (NC) and detect object that touch a switch. Example:

i) Push Button

Pushbutton switches are the most common form of manual control. A pushbutton operates by opening or closing contacts when pressed. Figure 1.1 shows commonly used types of pushbutton switches, which include:

- Normally open (NO) pushbutton, which makes a circuit when it is pressed and returns to its open position when the button is released.
- Normally closed (NC) pushbutton, which opens the circuit when it is pressed and returns to the closed position when the button is released.
- Break-before-make pushbutton in which the top section contacts are NC and the bottom section contacts are NO. When the button is pressed, the top contacts open before the bottom contacts are closed.

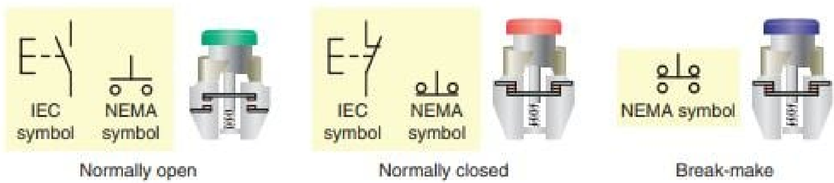


Figure 1.1: Commonly used types of pushbutton switches

ii) Limit Switches

A mechanically operated switch is controlled automatically by factors such as pressure, position, or temperature. The limit switch, shown in Figure 1.2 is a very common industrial control device. 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. These devices take the place of a human operator. They are often used in the control circuits of machine processes to govern the starting, stopping, or reversal of motors.

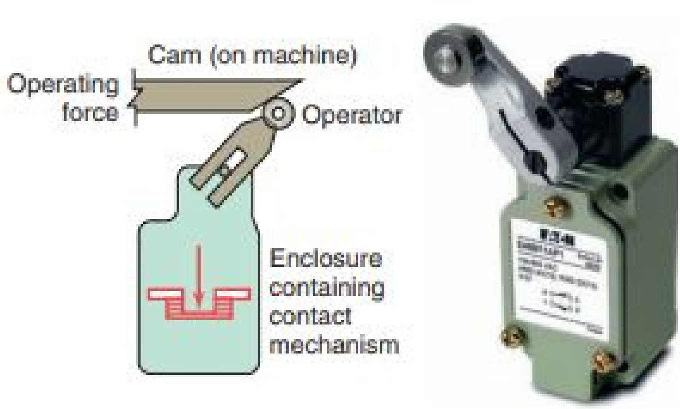


Figure 1.2: Mechanically operated limit switch

iii) Reed Switch

A magnetic reed switch is composed of two flat contact tabs that are hermetically sealed (airtight) in a glass tube filled with protective gas, as illustrated in Figure 1.3. When a magnetic force is generated parallel to the reed switch, the reeds become flux carriers in the magnetic circuit. The overlapping ends of the reeds become opposite magnetic poles, which attract each other. If the magnetic force between the poles is strong enough to overcome the restoring force of the reeds, the reeds will be drawn together to actuate the switch. Because the contacts are sealed, they are unaffected by dust, humidity, and fumes thus, their life expectancy is quite high.

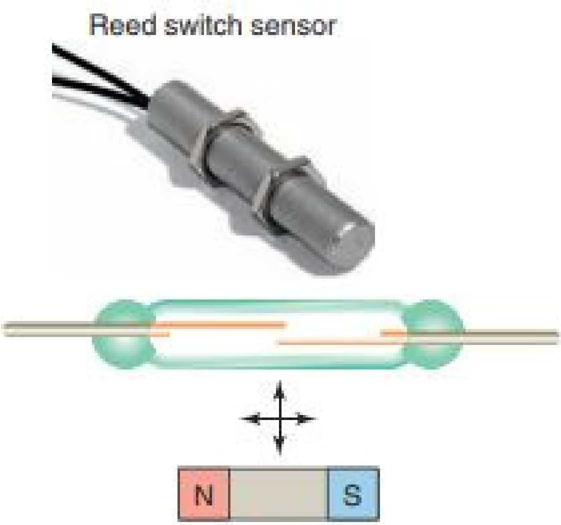


Figure 1.3: Magnetic reed switch.

b) Proximity

Proximity sensors or switches, such as that shown in Figure 1.4 , are pilot devices that detect the presence of an object (usually called the target) without physical contact. These solid-state electronic devices are completely encapsulated to protect against excessive vibration, liquids, chemicals, and corrosive agents found in the industrial environment. Proximity sensors are used when:

- The object being detected is too small, lightweight, or soft to operate a mechanical switch.
- Rapid response and high switching rates are required, as in counting or ejection control applications.
- An object has to be sensed through nonmetallic barriers such as glass, plastic, and paper cartons.
- Hostile environments demand improved sealing properties, preventing proper operation of mechanical switches.
- Long life and reliable service are required.
- A fast electronic control system requires a bounce-free input signal.

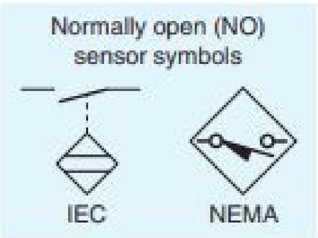


Figure 1.4: Proximity sensor

i) Inductive proximity

Proximity sensors operate on different principles, depending on the type of matter being detected. When an application calls for noncontact metallic target sensing, an inductive-type proximity sensor is used. 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 under the electrical principle of inductance, where a fluctuating current induces an electromotive force (emf) in a target object. The block diagram for an inductive proximity sensor is shown in Figure 1.5 and its operation can be summarized as follows:

- The oscillator circuit generates a high-frequency electromagnetic field that radiates from the end of the sensor.
- When a metal object enters the field, eddy currents are induced in the surface of the object.
- The eddy currents on the object absorb some of the radiated energy from the sensor, resulting in a loss of energy and change of strength of the oscillator.
- The sensor's detection circuit monitors the oscillator's strength and triggers a solid-state output at a specific level.
- Once the metal object leaves the sensing area, the oscillator returns to its initial value.

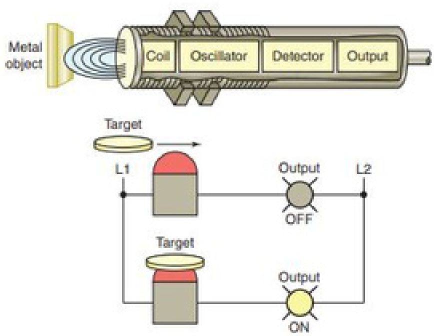


Figure 1.5: Magnetic Reed Switch

ii) Capacitive proximity

Capacitive proximity sensors are similar to inductive proximity sensors. The main differences between the two types are that capacitive proximity sensors produce an electrostatic field instead of an electromagnetic field and are actuated by both conductive and nonconductive materials.

Figure 1.6 illustrates the operation of a capacitive sensor. A capacitive sensor contains a high-frequency oscillator along with a sensing surface formed by two metal electrodes. When the target nears the sensing surface, it enters the electrostatic field of the electrodes and changes the capacitance of the oscillator. As a result, the oscillator circuit begins oscillating and changes the output state of the sensor when it reaches certain amplitude. As the target moves away from the sensor, the oscillator's amplitude decreases, switching the sensor back to its original state.

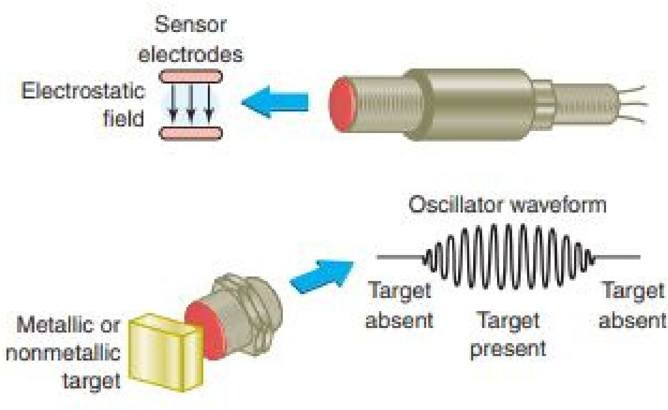


Figure 1.6: Capacitive proximity sensor.

Capacitive proximity sensors will sense metal objects as well as nonmetallic materials such as paper, glass, liquids, and cloth. They typically have a short sensing range of about 1 inch, regardless of the type of material being sensed. 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 as illustrated in Figure 1.7. In this example, the liquid has a much higher dielectric constant than the cardboard container, which gives the sensor the ability to see through the container and detect the liquid. In the process shown, detected empty containers are automatically diverted via the push rod.

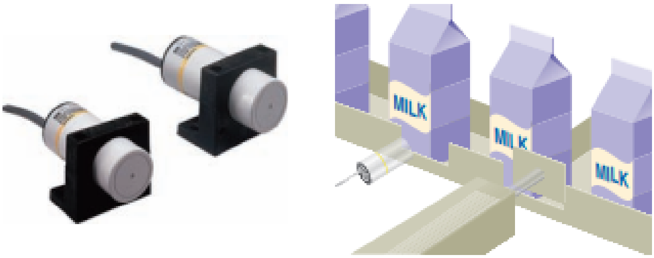


Figure 1.7 : Capacitive proximity sensor liquid detection.

Inductive proximity switches may be actuated only by a metal and are insensitive to humidity, dust, dirt, and the like. Capacitive proximity switches, however, can be actuated by any dirt in their environment. For general applications, the capacitive proximity switches are not really an alternative but a supplement to the inductive proximity switches. They are a supplement when there is no metal available for the actuation (e.g., for woodworking machines and for determining the exact level of liquids or powders).

c. Photo optics. (through beam, reflective, retro- reflective)

A photoelectric sensor is an optical control device that 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 two basic components: a transmitter (light source) and a receiver (sensor), as shown in Figure 1.8. These two components may or may not be housed in separate units. The basic operation of a photoelectric sensor can be summarized as follows:

- The transmitter contains a light source, usually an LED along with an oscillator.
- The oscillator modulates or turns the LED on and off at a high rate of speed.
- The transmitter sends this modulated light beam to the receiver.
- The receiver decodes the light beam and switches the output device, which interfaces with the load.
- The receiver is tuned to its emitter's modulation frequency and will only amplify the light signal that pulses at the specific frequency.
- Most sensors allow adjustment of how much light will cause the output of the sensor to change state.
- Response time is related to the frequency of the light pulses. Response times may become important when an application calls for the detection of very small objects, objects moving at a high rate of speed, or both.

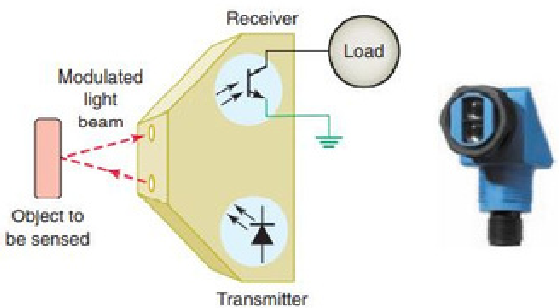


Figure 1.8 : Photoelectric sensor.

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

i) Through Beam

The through-beam scan technique (also called direct scan) places the transmitter and receiver in direct line with each other, as illustrated in Figure 1.9. Because the light beam travels in only one direction, through-beam scanning provides long-range sensing. Quite often, a garage door opener has a through-beam photoelectric sensor mounted near the floor, across the width of the door. For this application the sensor senses that nothing is in the path of the door when it is closing.

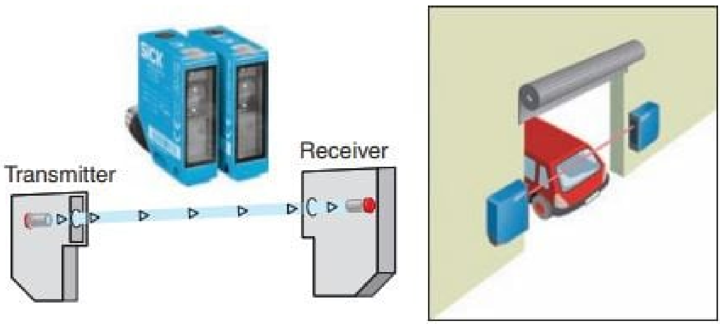


Figure 1.9 : Through-beam scan.

ii) Reflective

Diffuse (or proximity) mode is often used when it is difficult or impossible to have access to opposite sides of the object to be sensed, as shown in Figure 1.10. In this case, a light beam is directed towards the target position. When an object reaches the target position, the light beam is reflected off the object. The light is scattered by the surface at all angles and only a small portion is reflected back to the receiver. The sensor is triggered when this small reflected portion is detected in the receiver.

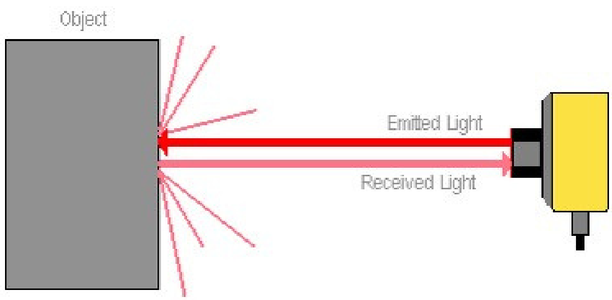


Figure 1.10 : Reflective scan.

iii) Retro- reflective

In a retroreflective scan, the transmitter and receiver are housed in the same enclosure. This arrangement requires the use of a separate reflector or reflective tape mounted across from the sensor to return light back to the receiver. The retroreflective scan is designed to respond to objects that interrupt the beam normally maintained between the transmitter and receiver, as illustrated in Figure 1.11. In contrast to a through-beam application, retroreflective sensors are used for medium-range applications.

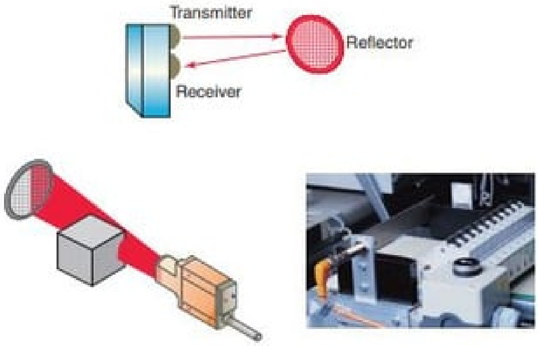


Figure 1.11 : Retroreflective scan.

1.1.2 Logical sensor and switches output wiring.

a. PNP/ sourcing technique

Current flows from the positive terminal of the DC power supply through the switch (field device) and onto the load. Switch is the source of current. Switch is called sourcing device, as shown in Figure 1.12.

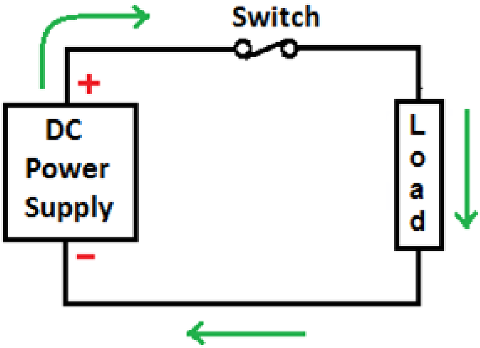


Figure 1.12 : PNP/ sourcing technique.

The sensor "Source" or "push" current from the 24VDC (+VDC) to the load. No object detected, sensor circuit turns OFF. Transistor turns OFF and current loop is open Load deactivates, as illustrated in Figure 1.13.

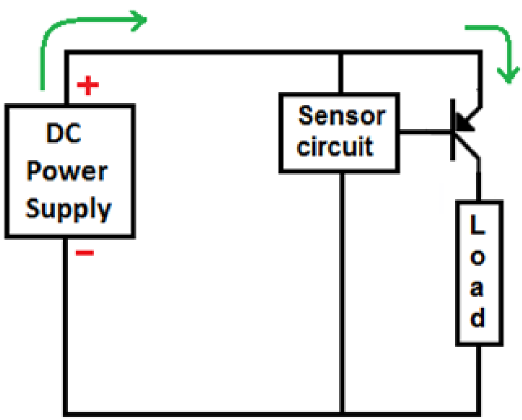


Figure 1.13 : No object detected (sourcing).

Object detected, sensor circuit turns ON. Transistor turns ON and current loop is closed. Load activates, as illustrated in Figure 1.14.

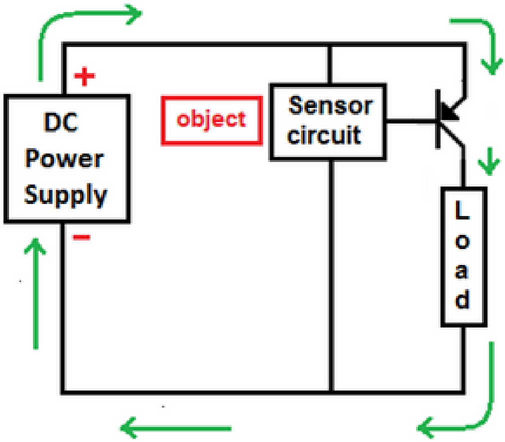


Figure 1.14 : Object detected (sourcing).

b. NPN/sinking technique

Current flows from the positive terminal of the power supply to the load. Switch sinks the current to ground. Switch is called sinking device, as shown in Figure 1.15.

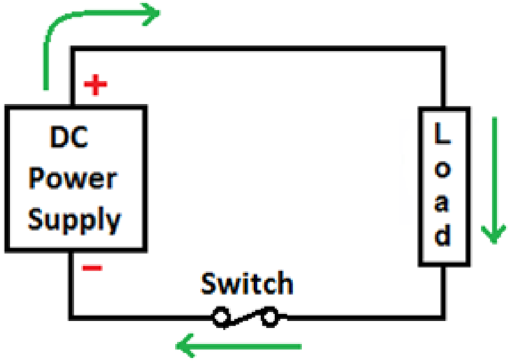


Figure 1.15 : NPN/sinking technique.

Sinking sensor – using NPN. The sensor "Sink" or "pull" current from the load to 0 VDC (-DC). No object detected, sensor circuit turns OFF. Transistor turns OFF and current loop is open. Load deactivates, as illustrated in Figure 1.16.

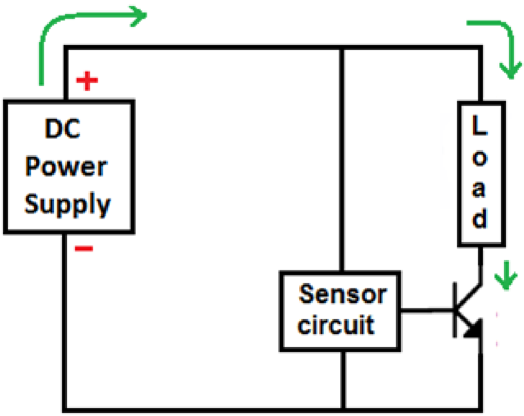


Figure 1.16 : No object detected (sinking).

Object detected, sensor circuit turns ON. Transistor turns ON and current loop is closed. Load activates, as illustrated in Figure 1.17.

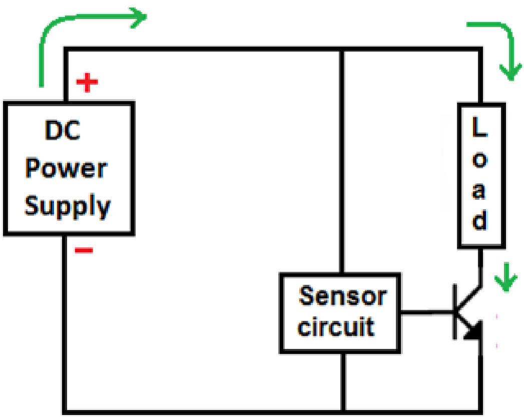


Figure 1.17 : Object detected (sinking).

The internal circuitry of some field devices requires that they be used in sinking or sourcing circuits. In general, *sinking (NPN)* and *sourcing (PNP)* are terms used to describe a current signal flow relationship between field input and output devices in a control system and their power supply. Figure 1.18 illustrates the current flow relationship between sinking and sourcing inputs to a DC input module.

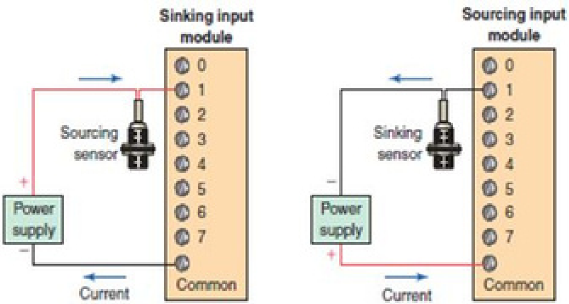
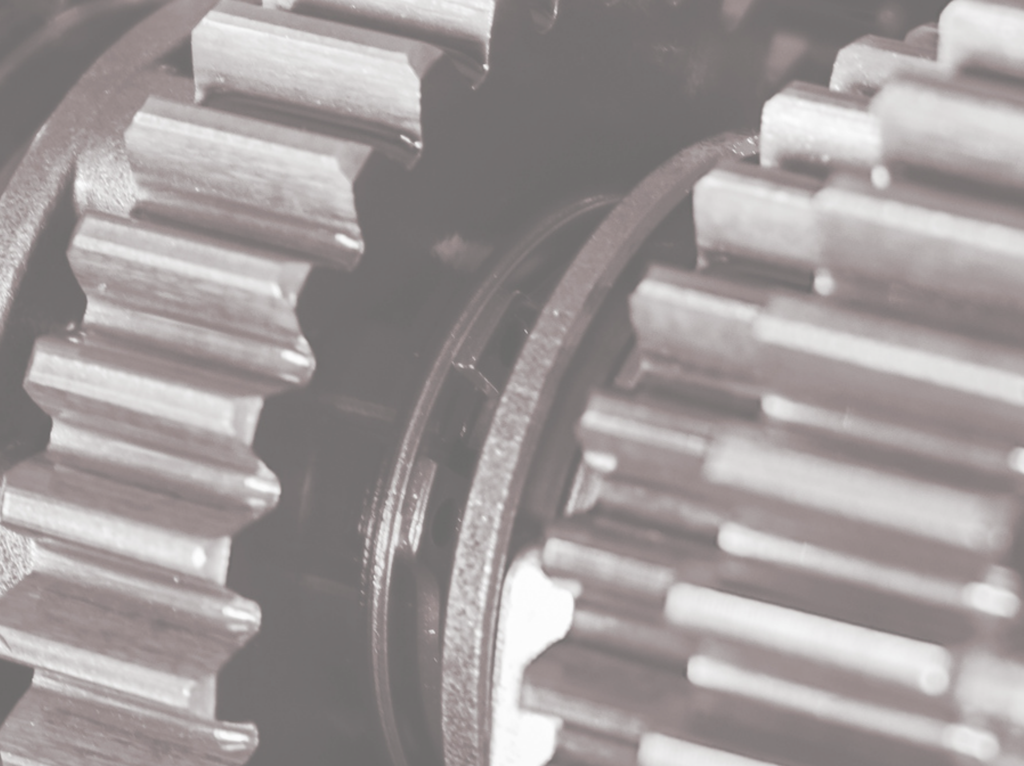


Figure 1.18 : Sinking and sourcing inputs.

1.2 Various logical actuators.

An actuator is a mechanical device for moving or controlling a mechanism or system. It is a mechanical device that converts electrical energy into motion. It is operated by a source of energy, usually in the form of an electric current, hydraulic fluid pressure or pneumatic pressure, and converts that energy into some kind of motion. Types of Actuator are Solenoid, valves, Cylinders and DC and AC motors (single phase and three phases).



1.2.1 Basic logical actuators types, symbols, functions and operation timing chart.

A variety of output control devices can be operated by the PLC output to control traditional industrial processes. These devices include pilot lights, control relays, motor starters, alarms, heaters, solenoids, solenoid valves, small motors, and horns. Similar electrical symbols are used to represent these devices both on relay schematics and PLC output connection diagrams. Figure 1.19 shows common electrical symbols used for various output devices. Although these symbols are generally acceptable, some differences among manufacturers do exist.

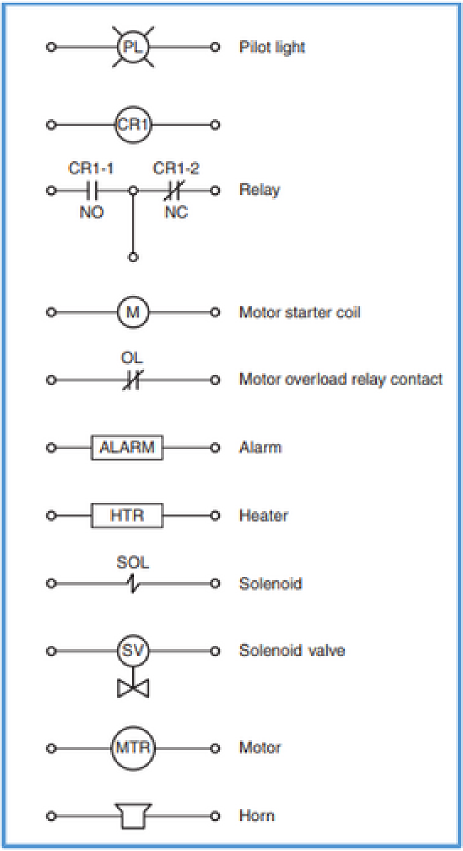


Figure 1.19 : Symbols for output control devices.

a. Solenoid valves (pilot, port and way)

An electromechanical solenoid is an actuator that uses electrical energy to magnetically cause mechanical control action. A solenoid consists of a coil, frame, and plunger (or armature). Figure 1.20 shows the basic construction and operation of a solenoid.

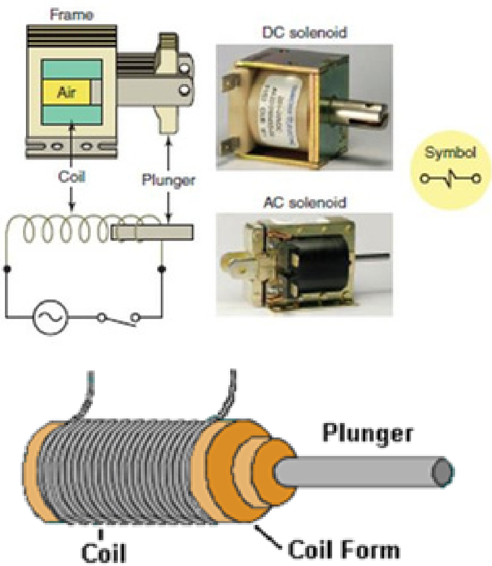


Figure 1.20 : Solenoid construction and operation.

The coil and frame form the fixed part. When the coil is energized, it produces a magnetic field that attracts the plunger, pulling it into the frame and thus creating mechanical motion. When the coil is de-energized the plunger returns to its normal position through gravity or assistance from spring assemblies within the solenoid. The frame and plunger of an AC-operated solenoid are constructed with laminated pieces instead of a solid piece of iron to limit eddy currents induced by the magnetic field.

Solenoid valves are electromechanical devices that work by passing an electrical current through a solenoid, thereby changing the state of the valve. Normally, there is a mechanical element, which is often a spring, that holds the valve in its default position. A solenoid valve is a combination of a solenoid coil operator and valve, which controls the flow of liquids, gases, steam, and other media. When electrically energized, they open, shut off, or direct the flow of media.

Figure 1.21 illustrates the construction and principle of operation of a typical fluid solenoid valve.

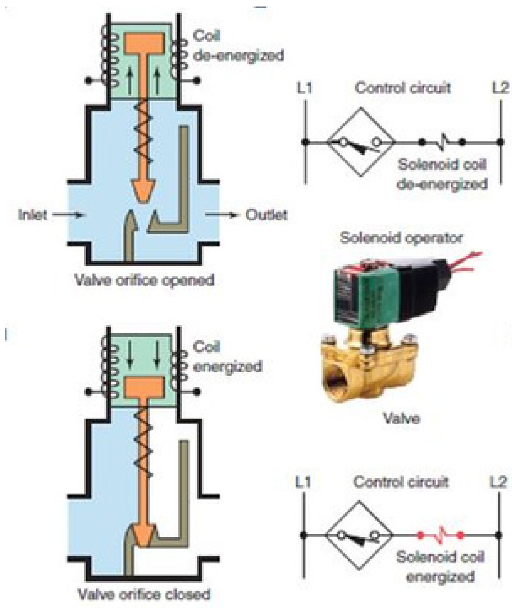


Figure 1.21 : Solenoid valve construction and operation.

Its operation can be summarized as follows. The valve body contains an orifice in which a disk or plug is positioned to restrict or allow flow. Flow through the orifice is either restricted or allowed depending on whether the solenoid coil is energized or de-energized.

When the coil is energized, the core is drawn into the solenoid coil to open the valve. The spring returns the valve to its original closed position when the current coil is de-energized. A valve must be installed with direction of flow in accordance with the arrow cast on the side of the valve body.

b. Cylinders (port and way)

A cylinder uses pressurized fluid or air to create a linear force/motion as shown in Figure 1.22. In the figure a fluid is pumped into one side of the cylinder under pressure causing that side of the cylinder to expand and advancing the piston. The fluid on the other side of the piston must be allowed to escape freely if the in compressible fluid was trapped the cylinder could not advance. The force the cylinder can exert is proportional to the cross section area of the cylinder.

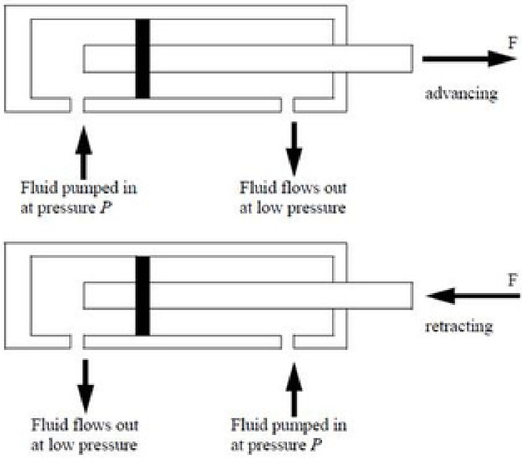


Figure 1.22 : Cylinders

Two types of cylinder; single acting cylinder and double acting cylinder.

i. Single Acting Cylinder

Driving force in one direction (extend), and a spring to return to the initial position (retract). Figure 1.23 shows single acting cylinder.

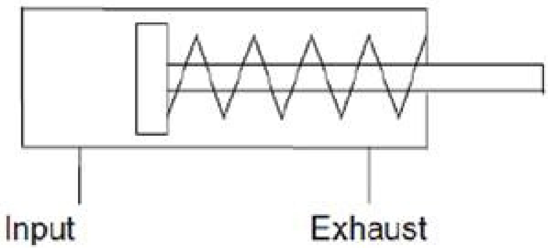


Figure 1.23 : Single acting cylinder.

ii. Double Acting Cylinder

Driving forces in both directions of extend and retract. Double acting cylinder has two ports to allow air flow in and out. Figure 1.24 shows double acting cylinder.

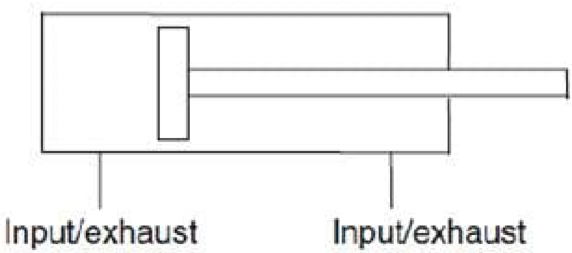


Figure 1.24 : Single acting cylinder.

c. DC and AC motors (single phase and three phases).

An electric machine is a link between an electrical system and a mechanical system. The process of converting energy from one of these forms to the other is electromechanical energy conversion. In these machines, the process is reversible. If the conversion is from **mechanical to electrical**, the machine is acting as a **generator**, and if the conversion is from **electrical to mechanical**, the machine is acting as a **motor**.

Three types of electrical machines are used extensively for electromechanical energy conversion: DC, induction, and synchronous motors. Other types of motors are permanent magnet (PM), hysteresis, and stepper motors. Electric motors are used in many different applications of automated systems, from blowers, pumps, and fans to conveyors, robotics, and actuators. They may be powered by AC supplied from a power grid within the plant or a motor drive, or DC from batteries or a converter. Motors may be classified by their construction method, their source of power, or their application and the type of motion they provide.

i) DC motor

A DC motor places the armature winding on the rotor and the field windings on the stator, which is the opposite of the AC motors. It is designed to run on DC power, though it alternates the direction of current flow in the windings through commutation. The stator has salient or projecting poles excited by one or more field windings; these produce a magnetic field that is symmetrical around the pole axis, also called the field or direct axis.

The voltage induced in the armature winding alternates by using a commutator-brush combination as a mechanical rectifier. Alternatively, brushless DC motor uses an external electronic switch synchronized to the position of the rotor. The field and armature windings can be connected in a variety of ways to provide different performance characteristics. The field windings can be connected in series, in shunt (parallel with the armature), or as a combination of both, called a compound motor. Figure 1.25 shows single acting cylinder.

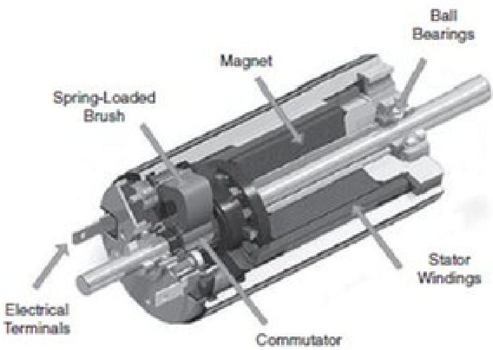


Figure 1.25 : Brushed DC motor.

ii) AC Motors

A typical AC motor consists of two parts: a stator having coils supplied with AC current to produce a rotating magnetic field and an inside rotor attached to an output shaft. The rotor is provided a torque by the rotating field that is generated by the alternating current. AC motors often include designations relating to their physical construction such as TE (totally enclosed), FC (fan cooled), and PM. Other information, such as frame size, also describes motors physically, including mounting options, sealing methods, and shaft sizes. A good motor catalog will describe these options well.

a) Single-Phase AC Synchronous Motors

A *reluctance motor* has a single-phase distributed stator winding and a cage-type rotor, often called a “squirrel cage.” A single-phase squirrel cage motor is shown in Figure 1.26.

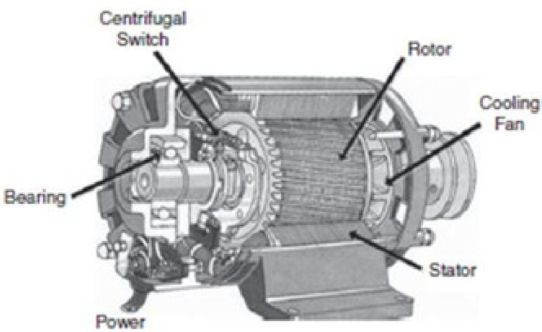


Figure 1.26 : Single-phase squirrel cage motor.

b) Three-Phase AC Induction Motors

Windings of both the stator and the rotor of a three-phase motor are distributed over several slots in the laminated sheets. Terminals of the rotor windings are connected to three slip rings using stationary brushes, the rotor can then be connected to an external circuit. Diagram of a three-phase induction motor is shown in Figure 1.27.

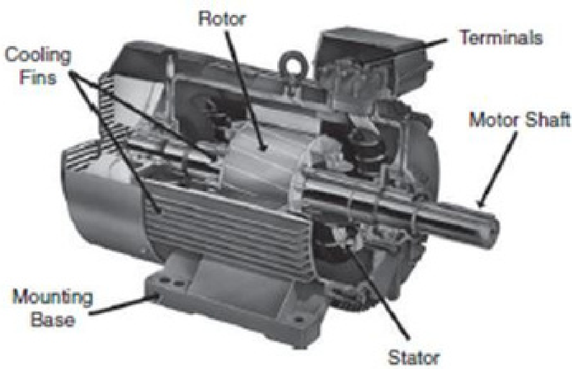


Figure 1.27 : Three-phase induction motor.

1.3 Automation system using logical sensors and logical actuators.

1.3.1 Simple/combination logical sensor and actuator applications

The converting of a simple sequential process can be examined with reference to the process flow diagram illustrated in Figure 1.28. The sequential task is as follows:

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

Other auxiliary features include:

- A stop button that will stop the table, for any reason, before the package reaches the limit switch position
- A red pilot light to indicate the table is stopped
- A green pilot light to indicate the table is running

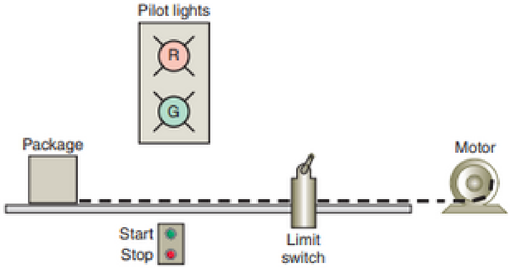


Figure 1.28 : Sequential process flow diagram.

A relay schematic for the sequential process is shown in Figure 1.29 . The operation of this hardwired circuit can be summarized as follows:

- Start button is actuated; CR is energized if stop button and limit switch are not actuated.
- Contact CR-1 closes, sealing in CR when the start button is released.
- Contact CR-2 opens, switching the red pilot light from on to off.
- Contact CR-3 closes, switching the green pilot light from off to on.
- Contact CR-4 closes to energize the motor starter coil, starting the motor and moving the package toward the limit switch.
- Limit switch is actuated, de-energizing relay coil CR.
- Contact CR-1 opens, opening the seal-in circuit.
- Contact CR-2 closes, switching the red pilot light from off to on.
- Contact CR-3 opens, switching the green pilot light from on to off.
- Contact CR-4 opens, de-energizing the motor starter coil to stop the motor and end the sequence.

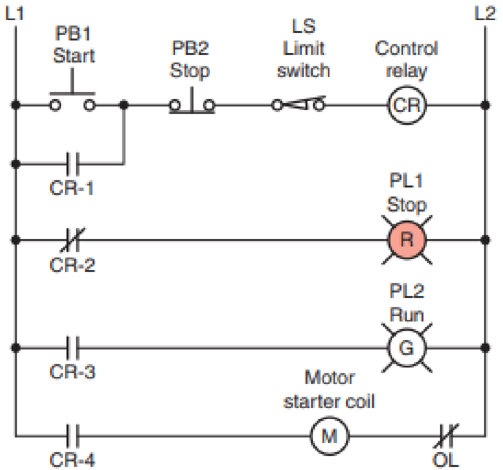


Figure 1.29 : Relay schematic for the sequential process.

1.4 Hardwire/conventional automation sequence system.

The motor stop/start circuit shown in Figure 1.30 is a typical example of a seal-in circuit. The hardwired circuit consists of a normally closed stop button in series with a normally open start button. The seal-in auxiliary contact of the starter is connected in parallel with the start button to keep the starter coil energized when the start button is released. When this circuit is programmed into a PLC, both the start and stop buttons are examined for a closed condition because both buttons must be closed to cause the motor starter to operate.

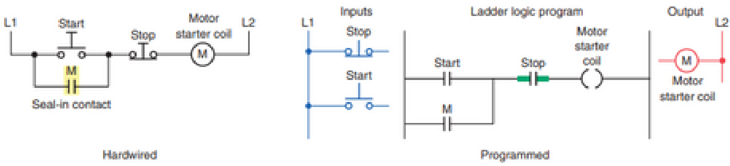


Figure 1.30 : Hardwired and programmed seal-in circuit.

QUESTION

1. Match the following listed device of A with most appropriate listed functions Of B by referring Figure 1.

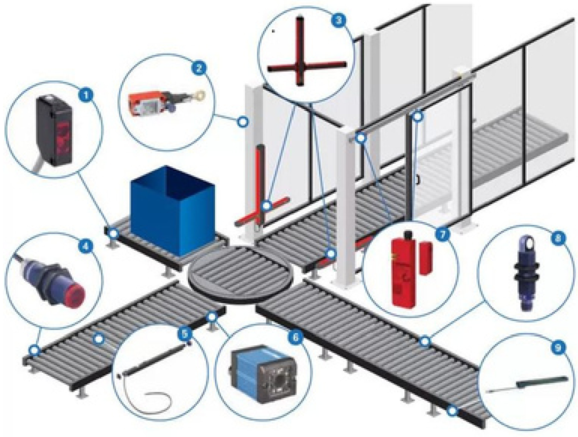


Figure 1

	Device (A)
1.	Photoelectric Sensor
2.	Wireless Limit Switch
3.	Safety Light Curtains with Muting
4.	RFID Safety Sensor
5.	Cylindrical Photoelectric Sensor
6.	Ultrasonic Sensor
7.	Radio Frequency Identification
8.	Roller Photoelectric Sensor
9.	Emergency Stop

Function (B)
Traceability of packages in the warehouse
Detecting the passage and presence of objects regardless of their colour, shape, or orientation.
Shuts down the machine if the door opens.
Transferring products from conveyor to conveyor without losing the exact direction orientation.
Emergency stop cable switch.
Detecting the passage and presence of packages with background suppression.
Integrated, between-the-rollers detection of the passage and presence of any object.
Efficient detection of machine operators with uninterrupted automation processes
Detecting the passage and presence of packages using a reflector.

QUESTION

2. A box needs to go through the conveyor before it is going to the packaging, several sequences need to be followed:

i) When START button pressed
ii) Motor will be started
iii) RUN (Green Lamp) indication lamp will be activated
iv) Motor Running, so Box will start Move
v) Proximity Sensor will detect when the box arrives at other end
vi) Motor will be stopped
vii) RUN (Green Lamp) indication lamp will be de-activated
viii) STOP (Red Lamp) indication lamp will be activated
ix) An Emergency Stop push button will be used to stop the motor at any time.

QUESTION

Proximity Sensor will detect when the box arrives at other end Motor will be stopped RUN (Green Lamp) indication lamp will be de-activated STOP (Red Lamp) indication lamp will be activated an Emergency Stop push button will be used to stop the motor at any time. Sketch this sequence by using the conventional relay schematic.

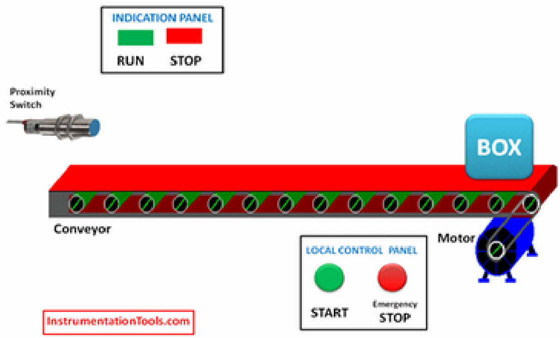


Figure 2

QUESTION

3. Based on Figure 3 below, it shows the Continuous Filling Operation requires boxes moving on a conveyor to be automatically positioned and filled. Based on operation above design the conventional sequential ladder logic of the Continuous Filling Operation.

   The operation of:

- **Solenoid** : To control the product filling from the hopper. Solenoid will be activated after the box positioned (proximity switch activation) and again de-activates after the level switch activated (level full).
- **Level Switch** : To detect the product level in the filling box.
- **Proximity Switch** : To position the box exactly below the hopper.
- **Motor** : To run the conveyor such that the box will move accordingly.
- **Local Control Panel** : It has START & STOP buttons used to control the sequence.
- **Indication Panel** : It displays the plant/batch status. Status signals are Run/Stand By/Full.

QUESTION

Based on operation above design the conventional sequential ladder logic.

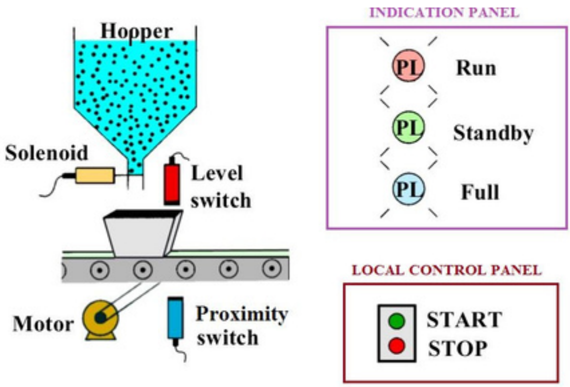
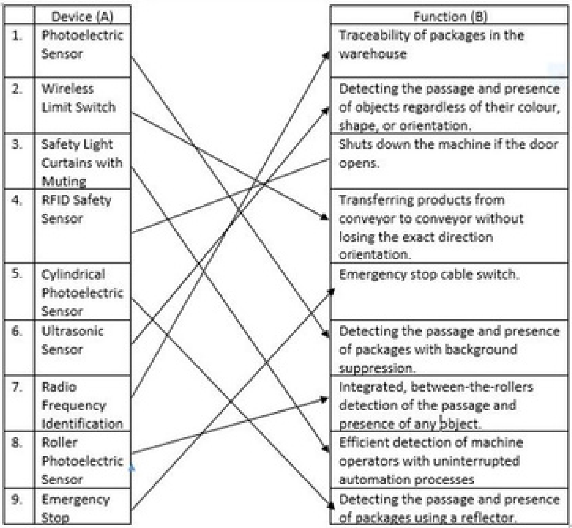


Figure 3

ANSWER

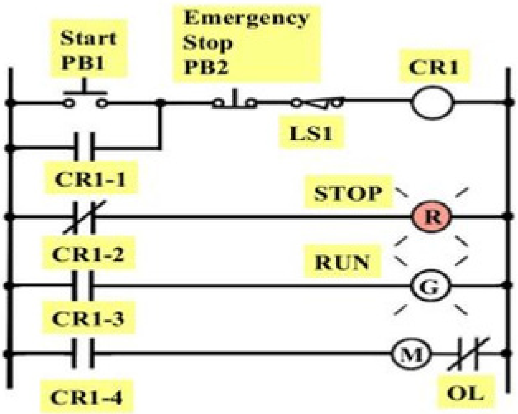
1. Match the following listed device of A with most appropriate listed functions Of B.



ANSWER

2. Sketch this sequence by using the conventional relay schematic.

Relay Schematic :

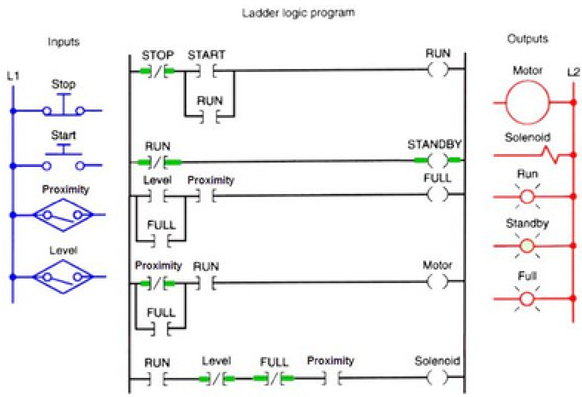


- R : STOP Indication lamp,
- G : RUN Indication lamp,
- M : Motor,
- OL : Overload Relay (Motor Protection Relay),
- LS1 : Proximity Switch,
- PB1 : Start push button,
- PB2 : Emergency Stop Pushbutton,
- CR : Contractor Relay

ANSWER

3. Design the conventional sequential ladder logic.

Ladder logic program :



- STOP Switch : Normally Close (NC)
- START Switch : Normally Open (NO)
- Proximity Switch : Normally Open (NO)
- Level Switch : Normally Open (NO)

Note : In ladder logic we can use either NO or NC contacts as default of proximity & level switch as required. if we use NO then it becomes NC after switch activated. if we use NC then it becomes NO after switch activated.

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Terbitan

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