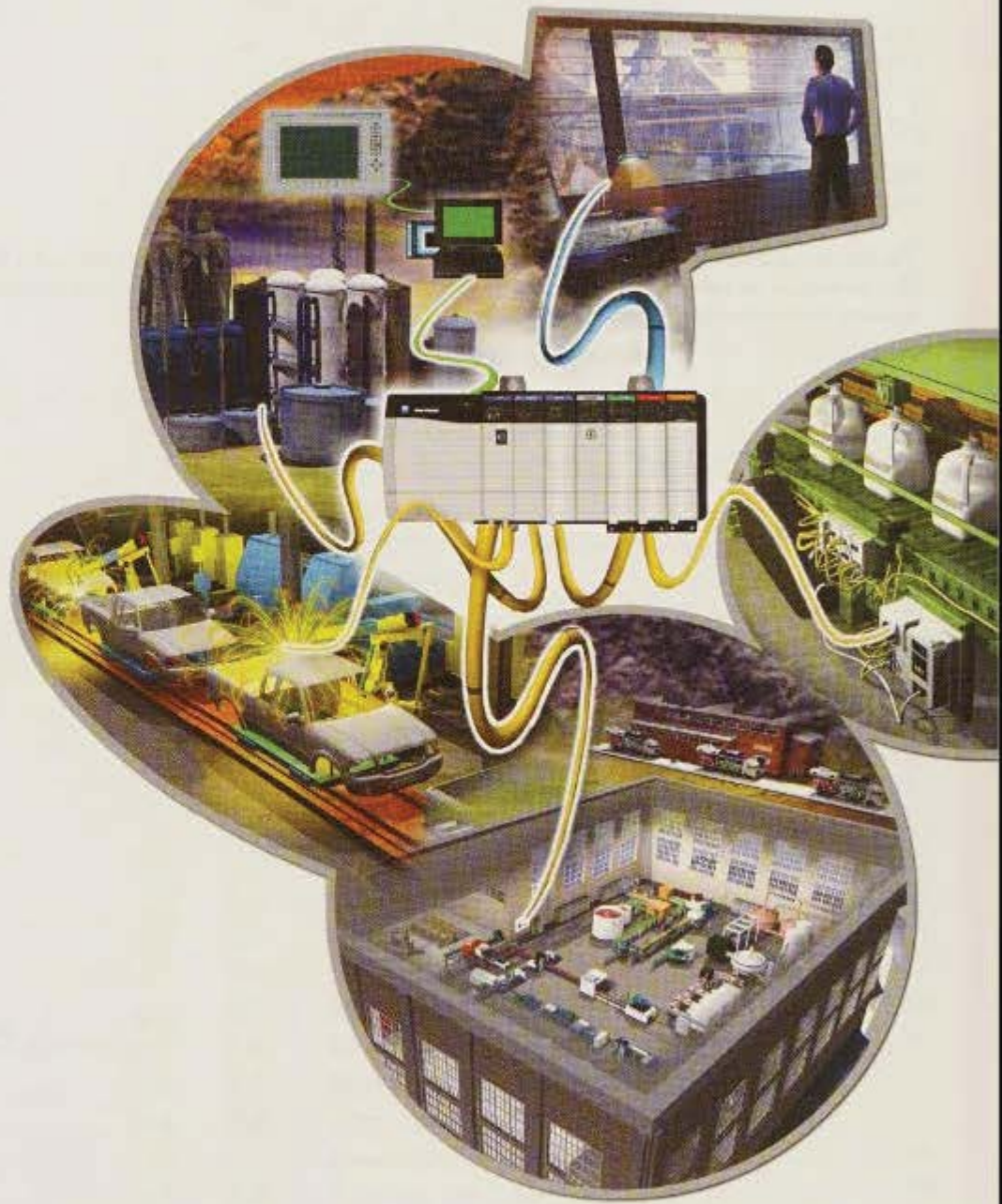


PROGRAMMABLE LOGIC CONTROLLERS

Fourth Edition



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PROGRAMMABLE LOGIC CONTROLLERS

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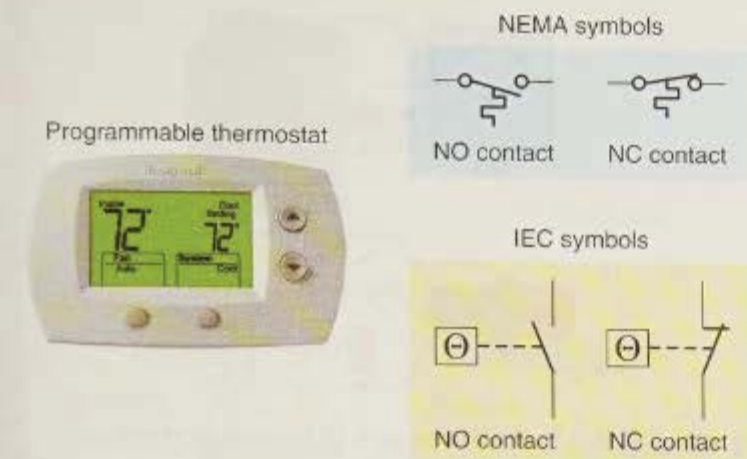


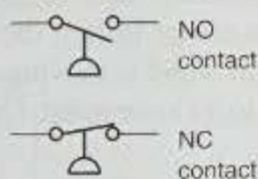
Figure 6-14 Temperature switch.
Source: Photo courtesy Honeywell, www.honeywell.com.

Temperature switches open or close when a designated temperature is reached. Industrial applications for these devices include maintaining the desired temperature range of air, gases, liquids, or solids.

Pressure switches, such as that shown in Figure 6-15, are used to control the pressure of liquids and gases. Although many different types are available, they are all basically designed to actuate (open or close) their contacts when a specified pressure is reached. Pressure switches can be pneumatically (air) or hydraulically (liquid) operated switches. Generally, bellows or a diaphragm presses up against a small microswitch and causes it to open or close.

Level switches are used to sense liquid levels in vessels and provide automatic control for motors that transfer liquids from sumps or into tanks. They are also used to open

NEMA symbols for pressure switch contacts



IEC symbols for pressure switch contacts

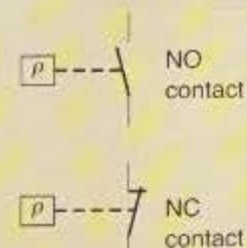


Figure 6-15 Pressure switch.
Source: Photo courtesy Honeywell, www.honeywell.com.



Figure 6-16 Float type level switch.
Source: Courtesy Dwyer Instruments.

or close piping solenoid valves to control fluids. The float switch shown in Figure 6-16 is a type of level switch. This switch is weighted so that as the liquid rises the switch float and turns upside down, actuating its internal contacts.

6.6 Sensors

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.

Proximity Sensor

Proximity sensors or switches, such as that shown in Figure 6-17, 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.



Figure 6-17 Proximity sensor.
Source: Photo courtesy Turck, Inc., www.turck.com.

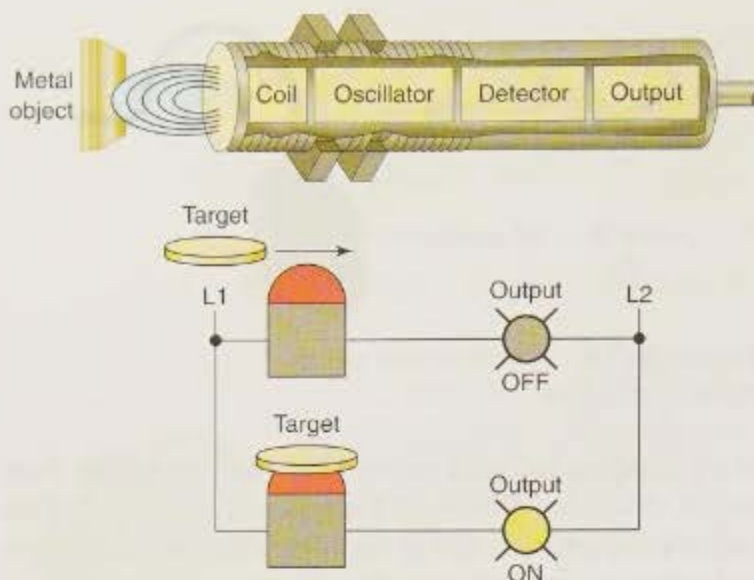


Figure 6-18 Inductive proximity sensor.

- Long life and reliable service are required.
- A fast electronic control system requires a bounce-free input signal.

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 6-18 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.

Most sensor applications operate either at 24V DC or at 120V AC. The method of connecting a proximity

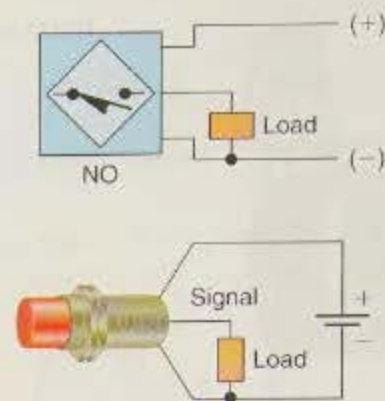


Figure 6-19 Typical three-wire DC sensor connection.

sensor varies with the type of sensor and its application. Figure 6-19 shows a typical three-wire DC sensor connection. The three-wire DC proximity sensor has the positive and negative line leads connected directly to it. When the sensor is actuated, the circuit will connect the signal wire to the positive side of the line if operating normally open. If operating normally closed, the circuit will disconnect the signal wire from the positive side of the line.

Figure 6-20 shows a typical two-wire proximity sensor connection intended to be connected in series with the load. They are manufactured for either AC or DC supply voltages. In the off state, enough current must flow through the circuit to keep the sensor active. This off state current is called leakage current and typically may range from 1 to 2 mA. When the switch is actuated, it will conduct the normal load circuit current.

Figure 6-21 shows the proximity sensor sensing range. Hysteresis is the distance between the operating point when the target approaches the proximity sensor face and the release point when the target is moving away from the sensor face. The object must be closer to turn the sensor on rather than to turn it off. If the target is moving toward the sensor, it will have to move to a closer point. Once the

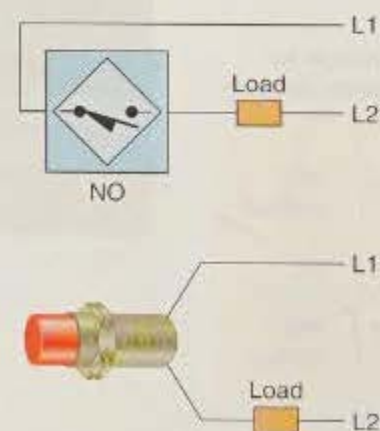


Figure 6-20 Typical two-wire proximity sensor connection.

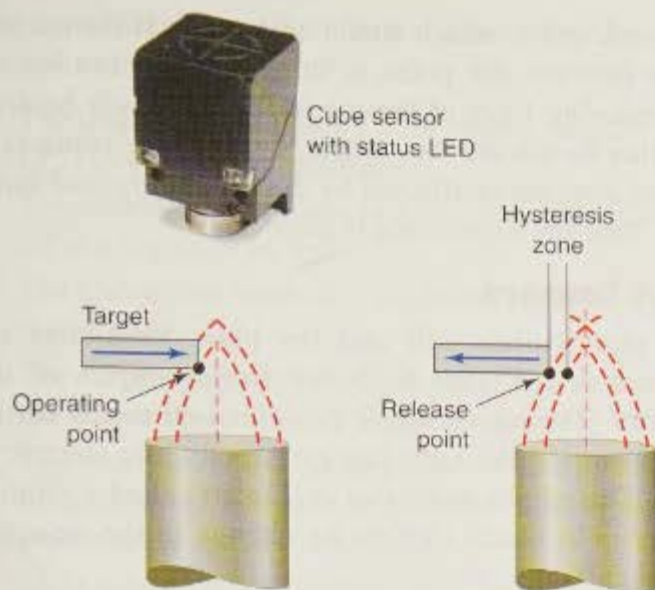


Figure 6-21 Proximity sensor sensing range.

Source: Photo courtesy Eaton Corporation, www.eaton.com.

sensor turns on, it will remain on until the target moves to the release point. Hysteresis is needed to keep proximity sensors from chattering when subjected to shock and vibration, slow-moving targets, or minor disturbances such as electrical noise and temperature drift. Most proximity sensors come equipped with an LED status indicator to verify the output switching action.

As a result of solid-state switching of the output, a small leakage current flows through the sensor even when the output is turned off. Similarly, 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. Figure 6-22 illustrates the use of a bleeder resistor connected to allow enough current for the sensor to operate but not enough to turn on the input of the PLC.

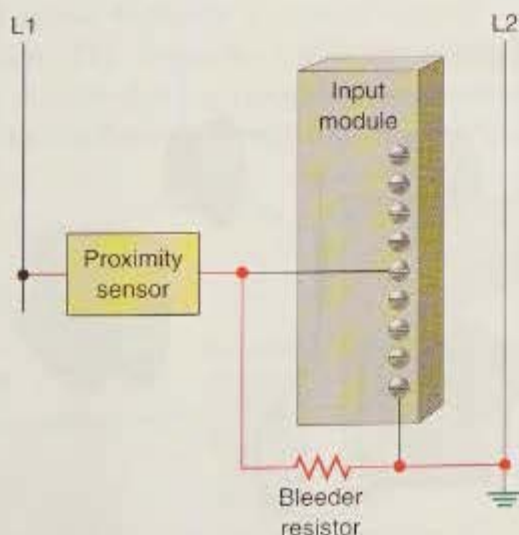


Figure 6-22 Bleeder resistor connected to continuously power a proximity sensor.

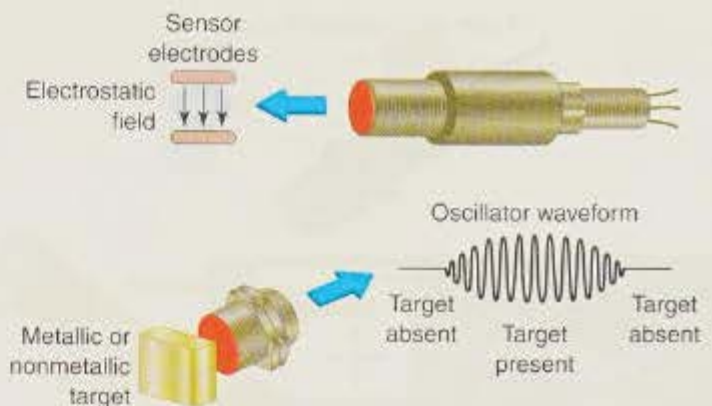


Figure 6-23 Capacitive proximity sensor.

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 6-23 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.

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 6-24. In this example, the liquid has a much higher dielectric constant than the cardboard container, which gives the sensor the ability to

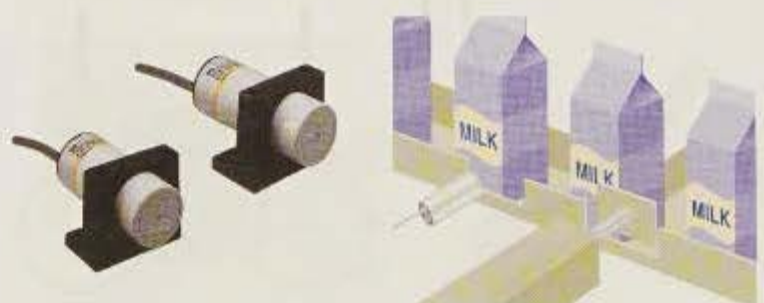


Figure 6-24 Capacitive proximity sensor liquid detection.
Source: Photo courtesy Omron Industrial Automation, www.ia.omron.com.

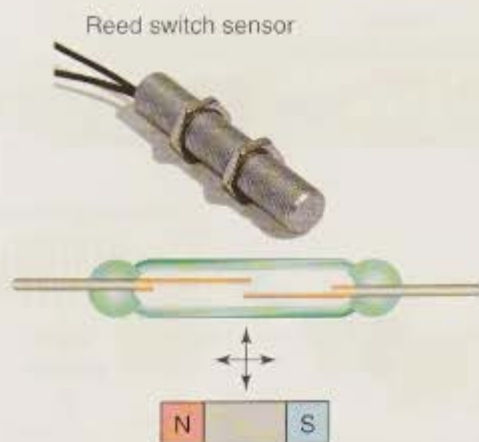


Figure 6-25 Magnetic reed switch.

Source: Courtesy of Reed Switch Developments Corp., used with permission.

see through the container and detect the liquid. In the process shown, detected empty containers are automatically diverted via the push rod.

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).

Magnetic 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 6-25. 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.

Light Sensors

The photovoltaic cell and the photoconductive cell, illustrated in Figure 6-26, are two examples of light sensors. The *photovoltaic* or *solar cell* reacts to light by converting the light energy directly into electric energy. The *photoconductive cell* (also called a *photore-sistive cell*) reacts to light by change in the resistance of the cell.

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 6-27. These two components may or may not be housed in separate units. The

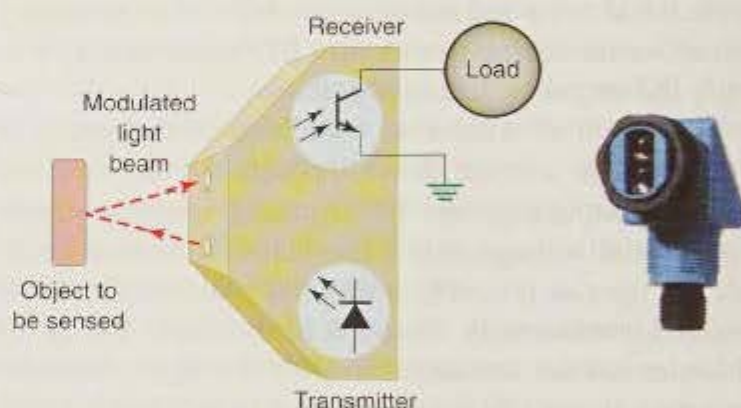


Figure 6-27 Photoelectric sensor.

Source: Photo courtesy SICK, Inc., www.sick.com

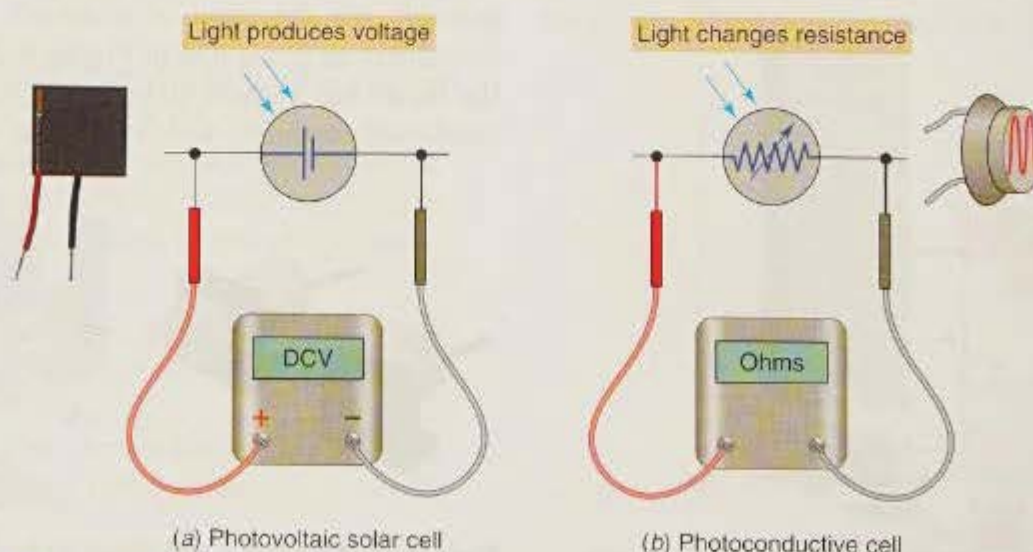


Figure 6-26 Photovoltaic and photoconductive light cells.

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.

The scan technique refers to the method used by photoelectric sensors to detect an object. The *through-beam* scan technique (also called direct scan) places the transmitter and receiver in direct line with each other, as illustrated in Figure 6-28. 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.

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

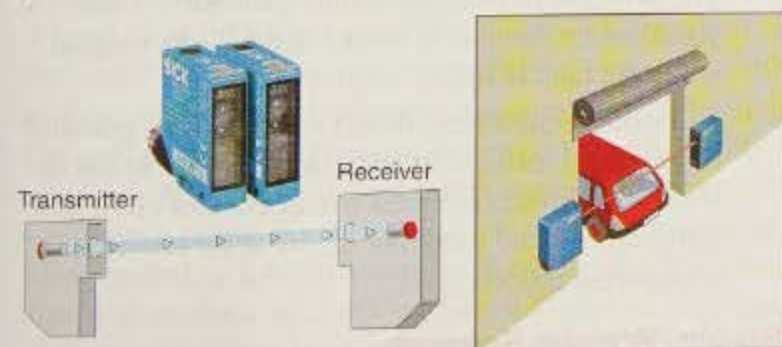


Figure 6-28 Through-beam scan.
Source: Photo courtesy SICK, Inc., www.sick.com

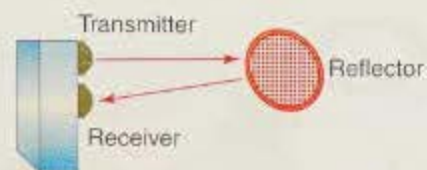


Figure 6-29 Retroreflective scan.
Source: Photo courtesy ifm efector, www.ifm.com/us

in Figure 6-29. In contrast to a through-beam application, retroreflective sensors are used for medium-range applications.

Fiber optics is not a scan technique, but another method for transmitting light. *Fiber optic sensors* use a flexible cable containing tiny fibers that channel light from emitter to receiver, as illustrated in Figure 6-30. Fiber optic sensor systems are completely immune to all forms of electrical interference. The fact that an optical fiber does not contain any moving parts and carries only light means that there is no possibility of a spark. This means that it can be safely used even in the most hazardous sensing environments such as a refinery for producing gases, grain bins, mining, pharmaceutical manufacturing, and chemical processing.

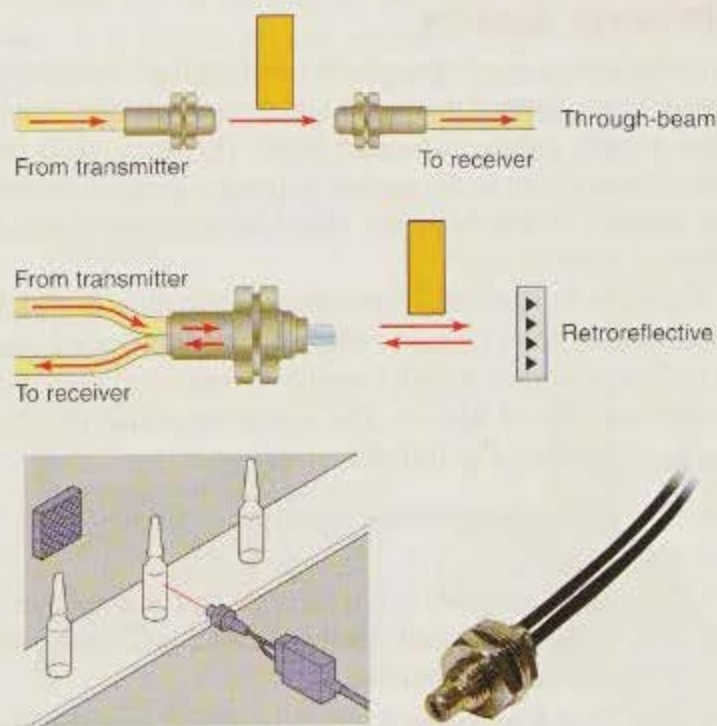


Figure 6-30 Fiber optic sensors.
Source: Photo courtesy Omron Industrial Automation, www.ia.omron.com

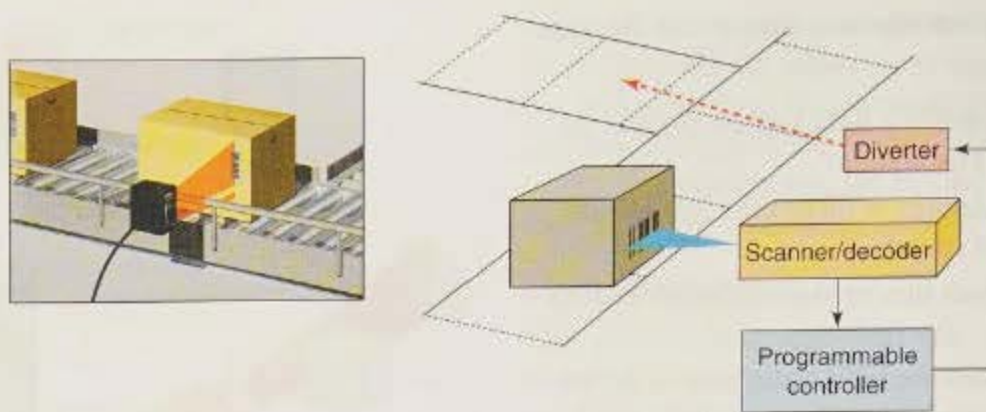


Figure 6-31 PLC bar code application.
Source: Courtesy Keyence Canada, Inc.

Bar code technology is widely implemented in industry to enter data quickly and accurately. *Bar code scanners* are the eyes of the data collection system. A light source within the scanner illuminates the bar code symbol; those bars absorb light, and spaces reflect light. A photodetector collects this light in the form of an electronic-signal pattern representing the printed symbol. The decoder receives the signal from the scanner and converts these data into the character data representation of the symbol's code. Figure 6-31 illustrates a typical PLC application which involves a bar code module reading the bar code on boxes as they move along a conveyor line. The PLC is then used to divert the boxes to the appropriate product lines according to the data read from the bar code.

Ultrasonic Sensors

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 time taken for this echo to return to the sensor is directly proportional to the distance or height of the object because sound has a constant velocity.

Figure 6-32 illustrates a practical application in which the returning echo signal is electronically converted to a 4- to 20-mA output, which supplies a monitored flow rate to external control devices. The operation of this process can be summarized as follows:

- The 4-20 mA represents the sensor's measurement span.
- The 4-mA set point is typically placed near the bottom of the empty tank, or the greatest measurement distance from the sensor.
- The 20-mA set point is typically placed near the top of the full tank, or the shortest measurement distance from the sensor.

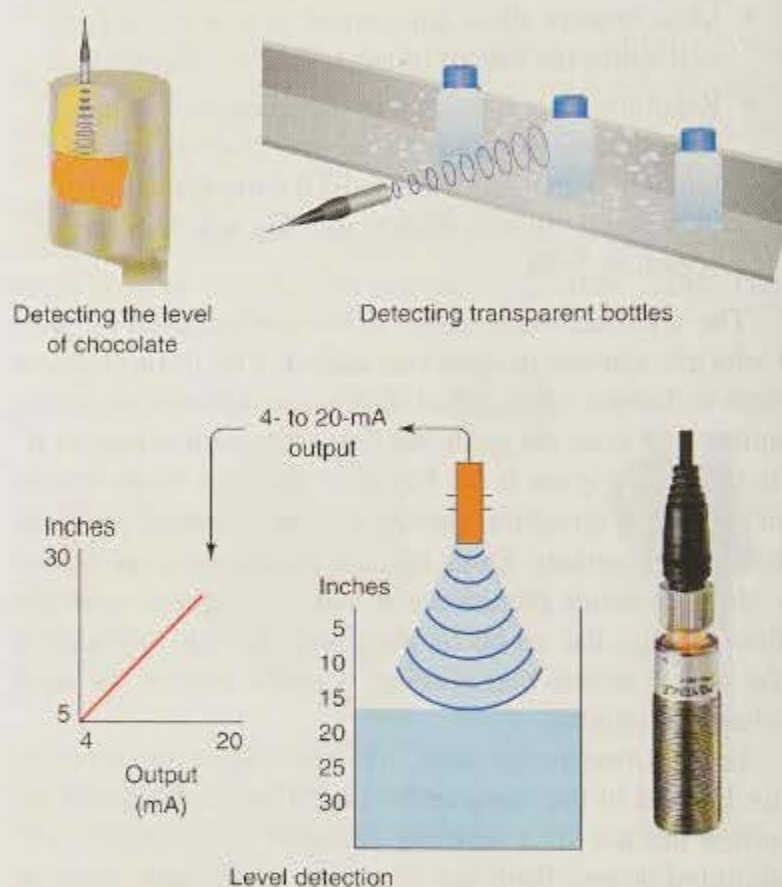


Figure 6-32 Ultrasonic sensor.
Source: Courtesy Keyence Canada, Inc.

- The sensor will proportionately generate a 4-mA signal when the tank is empty and a 20-mA signal when the tank is full.
- Ultrasonic sensors can detect solids, fluids, granular objects, and textiles. In addition, they enable the detection of different objects irrespective of color and transparency and therefore are ideal for monitoring transparent objects.

Strain/Weight Sensors

A *strain gauge* converts a mechanical strain into an electric signal. Strain gauges are based on the principle that

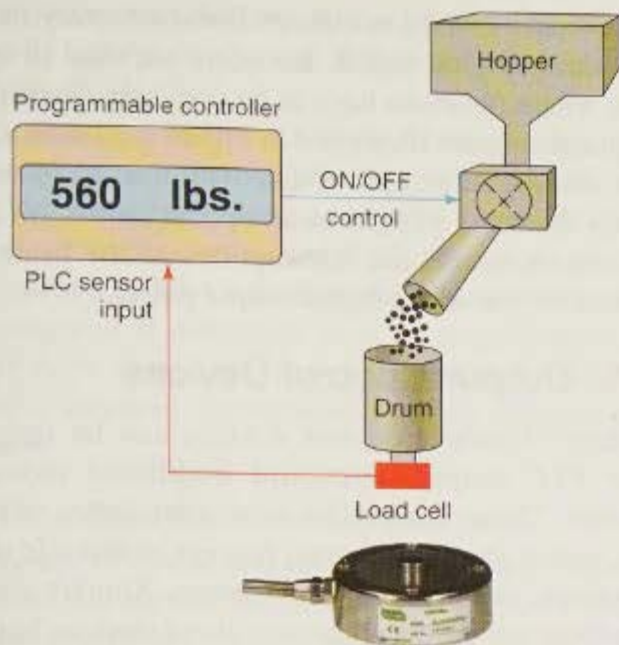


Figure 6-33 Strain gauge load cell.
Source: Courtesy RDP Group.

the resistance of a conductor varies with length and cross-sectional area. The force applied to the gauge causes the gauge to bend. This bending action also distorts the physical size of the gauge, which in turn changes its *resistance*. This resistance change is fed to a bridge circuit that detects small changes in the gauge's resistance. *Strain gauge load cells* are usually made with steel and sensitive strain gauges. As the load cell is loaded, the metal elongates or compresses very slightly. The strain gauge detects this movement and translates it to a varying voltage signal. Many sizes and shapes of load cells are available, and they range in sensitivity from grams to millions of pounds. Strain gauge-based load cells are used extensively for industrial weighing applications similar to the one illustrated in Figure 6-33.

Temperature Sensors

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 that relates to the difference in temperature between the hot junction and the cold junction (Figure 6-34). The hot junction (measuring junction) is the joined end of a thermocouple that is exposed to the process where the temperature measurement is desired. The cold junction (reference junction) is the end of a thermocouple that is kept at a constant temperature to provide a reference point. For example, a K-type thermocouple, when heated to a temperature of 300°C at the hot junction, will produce 12.2 mV at the cold junction. Because of their ruggedness and wide temperature range, thermocouples are used in industry to monitor and control oven and furnace temperatures.

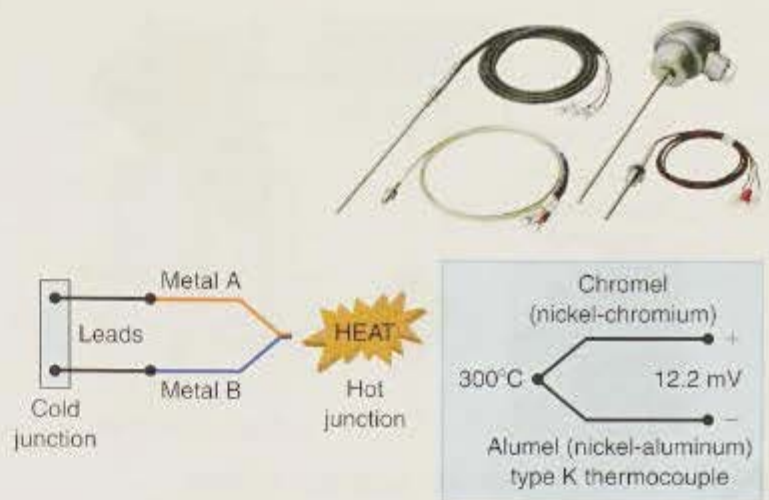


Figure 6-34 Thermocouple temperature sensor.
Source: Photo courtesy Omron Industrial Automation, www.ia.omron.com.

Flow Measurement

Many industrial processes depend on accurate measurement of fluid flow. Although there are several ways to measure fluid flow, the usual approach is to convert the kinetic energy that the fluid has into some other measurable form.

Turbine-type flowmeters are a popular means of measurement and control of liquid products in industrial, chemical, and petroleum operations. Turbine flowmeters, like windmills, utilize their angular velocity (rotation speed) to indicate the flow velocity. The operation of a turbine flowmeter is illustrated in Figure 6-35. Its basic construction consists of a bladed turbine rotor installed in a flow tube. The bladed rotor rotates on its axis in proportion to the rate of the liquid flow through the tube. A magnetic pickup sensor is positioned as close to the rotor as practical. Fluid passing through the flow tube causes the rotor to rotate, which generates pulses in the pickup coil. The frequency of the pulses is then transmitted to readout electronics and displayed as gallons per minute.

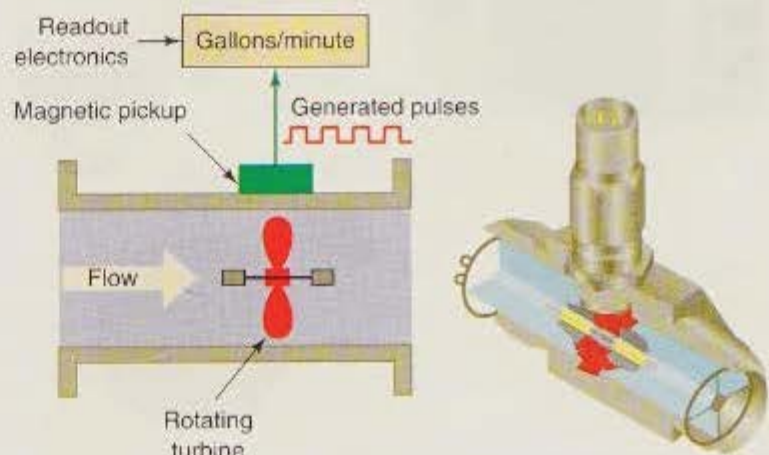


Figure 6-35 Turbine type flowmeter.

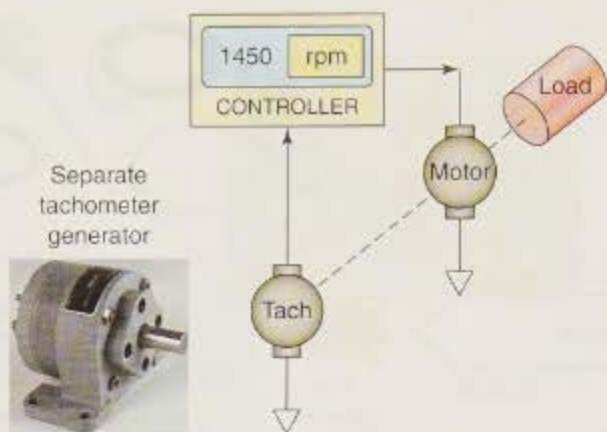


Figure 6-36 Tachometer generator feedback.
Source: Courtesy ATC Digitec.

Velocity and Position Sensors

Tachometer generators provide a convenient means of converting rotational speed into an analog voltage signal that can be used for motor speed indication and control applications. A tachometer generator is a small AC or DC generator that develops an output voltage (proportional to its rpm) whose phase or polarity depends on the rotor's direction of rotation. The DC tachometer generator usually has permanent magnetic field excitation. The AC tachometer generator field is excited by a constant AC supply. In either case, the rotor of the tachometer is mechanically connected, directly or indirectly, to the load.

Figure 6-36 illustrates motor speed control applications in which a tachometer generator is used to provide a feedback voltage to the motor controller that is proportional to motor speed. The control motor and tachometer generator may be contained in the same or separate housings.

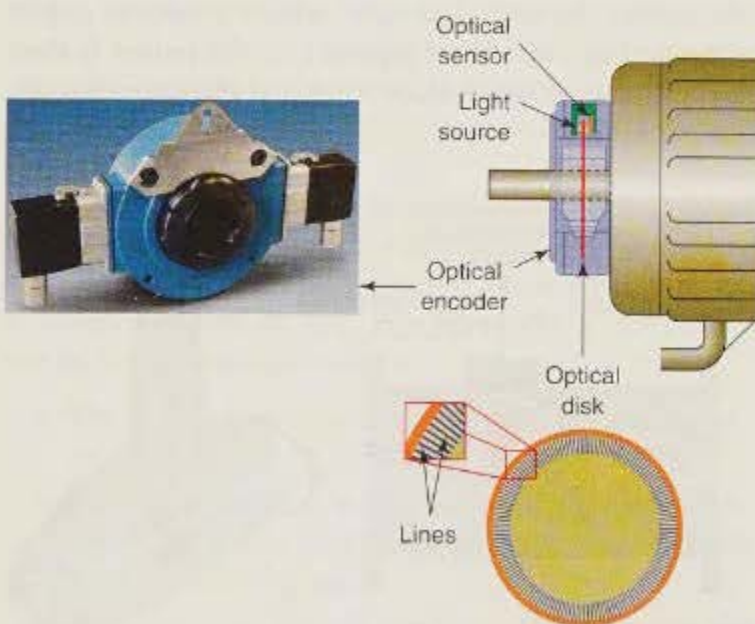


Figure 6-37 Optical encoder.
Source: Photo courtesy Avtron, www.avtron.com.

An *encoder* is used to convert linear or rotary motion into a binary digital signal. Encoders are used in applications where positions have to be precisely determined. The optical encoder illustrated in Figure 6-37 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.

6.7 Output Control Devices

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 6-38 shows common electrical symbols used

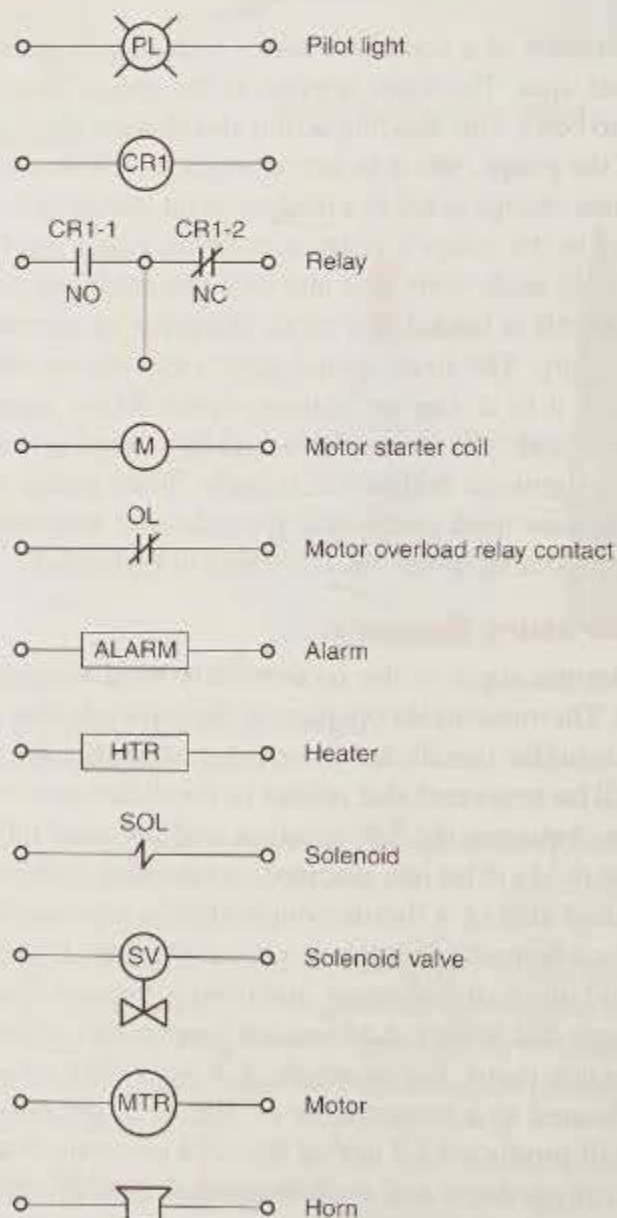


Figure 6-38 Symbols for output control devices.