Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-8: Proximity Sensors

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Proximity Sensor

A proximity sensor is a type of sensor that is designed to detect the presence or proximity of an object without the need for physical contact. Unlike sensors like limit switches that rely on physical contact with an object to detect it, proximity sensors work by converting information about the movement or presence of an object into an electrical signal. These sensors are widely used in various industries and applications for automation, control, and safety purposes.

Types of Proximity Sensor

There are three primary types of proximity sensors that operate on different principles to achieve non-contact detection:

1. **Inductive Proximity Sensors:** These sensors work based on electromagnetic induction. They generate eddy currents in metallic objects placed in their proximity. By detecting changes in these eddy currents, inductive proximity sensors can determine the presence or absence of metallic objects. These sensors are commonly used for detecting metal objects such as machine parts, tools, or components.

2. **Capacitive Proximity Sensors:** Capacitive sensors detect changes in electrical capacitance when an object approaches the sensor. They can be used to detect both metallic and non-metallic objects, as capacitance changes with the dielectric properties of the material. Capacitive proximity sensors are often used for applications like level sensing, presence detection of liquids or solids, and more.

3. **Magnetic Proximity Sensors:** Magnetic proximity sensors use magnets and reed switches or other magnetic field-based technologies to detect the presence of objects. These sensors are often used in applications where non-metallic objects need to be detected, or in situations where simplicity and reliability are essential.

Features of Proximity Sensors

1. **Non-Contact Detection:** Proximity sensors can detect the presence of objects without physically touching them. This non-contact detection means they do not cause abrasion or damage to the object being sensed, unlike devices like limit switches that require physical contact for detection.

2. **Long Service Life:** Proximity sensors typically have a longer service life because they do not rely on physical contacts for output. Instead, they use semiconductor outputs, which are not subject to wear and tear caused by mechanical contacts (excluding sensors that use magnets).

3. **Suitability for Harsh Environments:** Proximity sensors are suitable for use in environments where water or oil is present. They are designed to function effectively even in the presence of dirt, oil, or water on the object being detected. Some models even come with fluororesin cases for excellent chemical resistance.

4. **High-Speed Response:** Proximity sensors provide high-speed response compared to switches that require physical contact. They can quickly detect the presence or absence of objects, making them suitable for applications requiring rapid detection. Additionally, they can operate in a wide temperature range, from -40 to 200°C.

5. **Color Insensitivity:** Proximity sensors are not affected by the color of the object they are detecting. They operate by detecting physical changes in the object's properties (e.g., metal, dielectric), so the surface color of the object does not impact their performance.

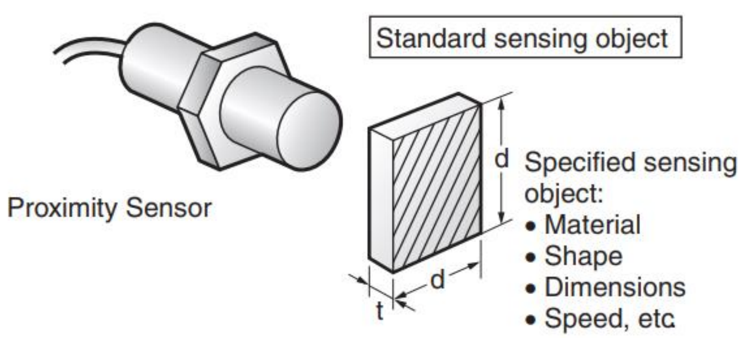
6. **Consideration for Installation:** Proximity sensors can be affected by ambient temperatures, surrounding objects, and other sensors in their vicinity. For example, both inductive and capacitive proximity sensors may experience interference when placed too close to each other or near metallic objects. Careful installation and consideration of these factors are important to prevent mutual interference.

7. **Two-Wire Sensors:** Some proximity sensors are designed as two-wire sensors, where the power line and signal line are combined. It's important to wire both the power line and the load (device being controlled) properly to ensure the sensor functions correctly and to prevent damage to its internal components.

Explanation of Terms

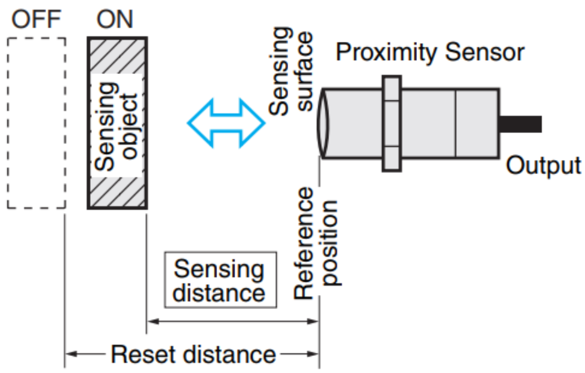
Standard Sensing Object:

Imagine you have a proximity sensor designed to detect metallic objects. In this case, the standard sensing object would be a specific metal object with known properties, such as a steel rod, that serves as a reference for measuring the sensor's basic performance. This object has specified materials, a specified shape, and known dimensions.



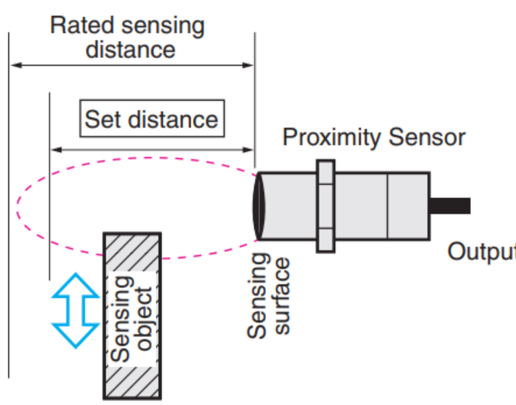
Sensing Distance:

The sensing distance refers to the distance from the reference position (the reference surface) to the point where the proximity sensor activates when the standard sensing object is moved towards it using a specified method. For example, if the sensor is rated to have a sensing distance of 10 centimeters, this means it will detect the standard sensing object when it is 10 centimeters away from the sensor.



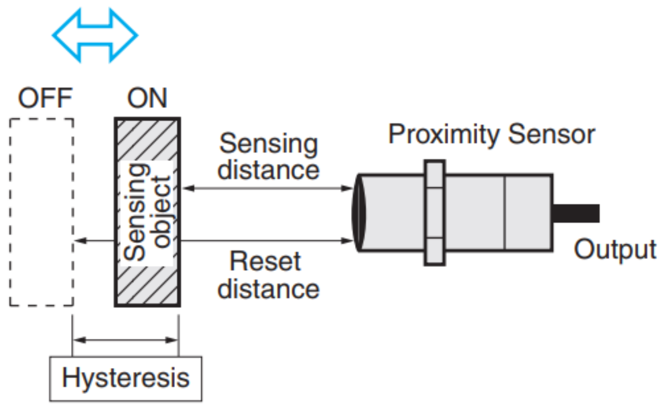
Set Distance:

The set distance is a slightly shorter distance than the rated sensing distance, typically around 70% to 80% of the rated distance. It accounts for factors like temperature and voltage variations, ensuring stable sensor performance. So, if your sensor has a rated sensing distance of 10 centimeters, the set distance might be around 7 to 8 centimeters.



Hysteresis (Differential Travel):

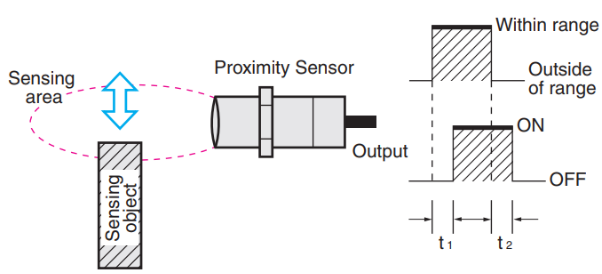
Hysteresis is the difference between the distance at which the sensor activates (turns ON) and the distance at which it deactivates (resets or turns OFF). For instance, if the sensor activates at 9 centimeters when the standard sensing object approaches and deactivates at 11 centimeters when the object moves away, the hysteresis is 2 centimeters.



Response Time:

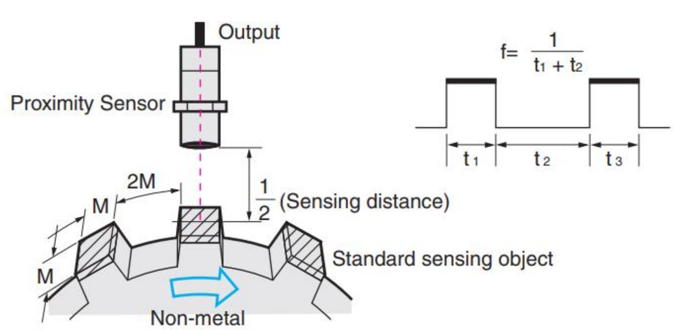
The response time of the sensor refers to how quickly it reacts to the presence or absence of the standard sensing object. There are two components:

- **t1:** The time it takes for the sensor to detect the object when it enters the sensing area and activate (output turns ON).
- **t2:** The time it takes for the sensor to detect the object leaving the sensing area and deactivate (output turns OFF).



Response Frequency:

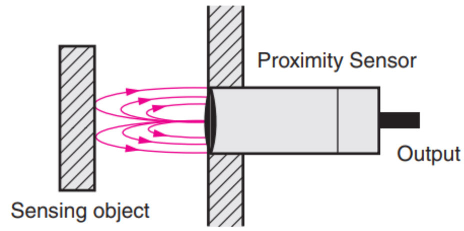
Response frequency is the number of detection repetitions the sensor can output per second when the standard sensing object is repeatedly brought into proximity. It indicates how quickly the sensor can respond to changes in the object's position.



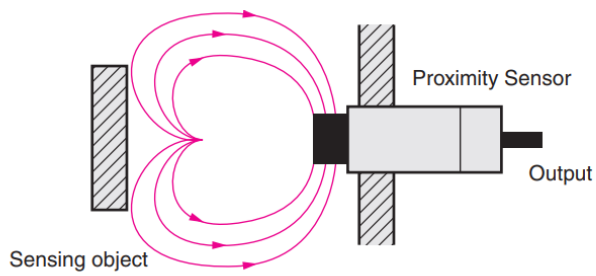
Shielded vs. Unshielded Sensors:

These terms refer to the construction of the sensor:

- **Shielded Sensor:** In this type, magnetic flux is concentrated in front of the sensor, and the sides of the sensor coil are covered with metal. These sensors can be mounted by embedding them into metal surfaces.

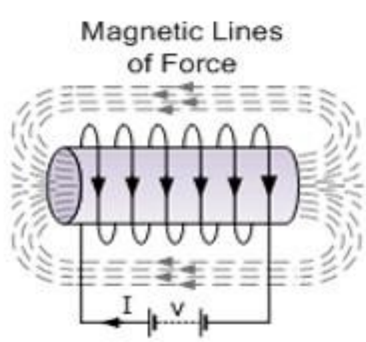


- **Unshielded Sensor:** In this type, magnetic flux is spread widely in front of the sensor, and the sides of the sensor coil are not covered with metal. Unshielded sensors are more susceptible to interference from surrounding metal objects (magnetic objects), so careful consideration is needed when selecting their mounting location.



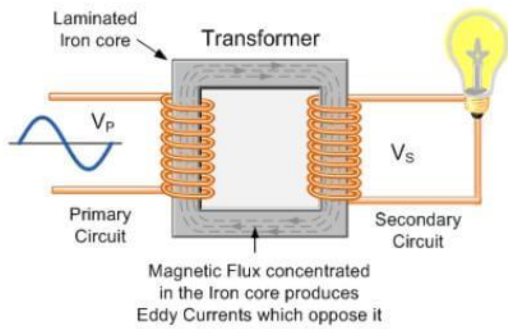
Principle of Electromagnetic Induction

When a DC current is applied to a conductor (i.e. a wire), it creates a magnetic field around the conductor. This is called a ‘static magnetic field’ because it’s generated by a DC current.



If the current source is an AC voltage, the magnetic field created starts to ‘oscillate’ back and forth.

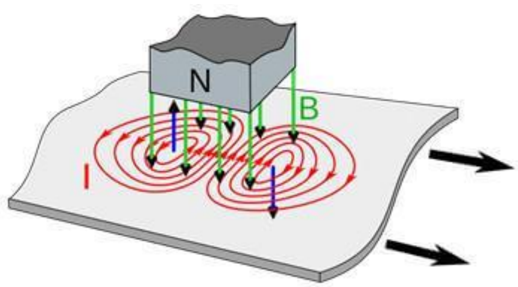
If a metallic object such as a piece of wire is placed within this magnetic field, this oscillating magnetic field causes an electric current to generate inside this second conductor. This principle is known as 'electromagnetic induction'. This is the principle that can be found in electrical transformers as well.



This same phenomenon can also be observed when the magnetic field is static and the conductor moves through the magnetic field.

Eddy Currents

When a metallic object enters into an electromagnetic field, the field creates an electrical current inside the conductor according to the principle of electromagnetic induction. Sometimes this effect becomes undesirable. Eddy currents are the type of induced currents that start to circulate/loop inside the metallic object.



Eddy currents do not exit the object as electrical current flow. Eddy currents also disrupt the existing magnetic field. This is the phenomenon that inductive proximity sensors take advantage of to detect objects.

Inductive Proximity Sensor

An inductive proximity sensor is a type of sensor that detects the presence of metallic objects within its detection range without physical contact. It achieves this through the use of electromagnetic fields.

Inductive sensors belong to the family of *proximity sensors*. They use the principle of **electromagnetic induction** to detect and measure objects. There are both digital and analog output sensors available in the market.

Inductive proximity sensors are non-contact type sensors. They can detect objects without physical contact. They find their application in detecting metallic objects in industrial automation environments. This includes objects made of iron, copper and aluminium.

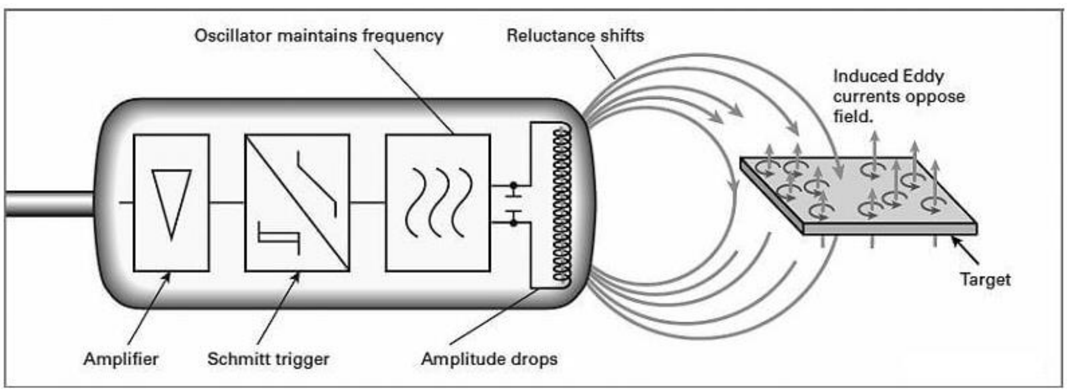
Sensing range of inductive proximity sensors depends on the material type. Inductive proximity sensors work best with ferrous metal (iron objects), but we can use them to detect other metallic objects too.

Operating Principle of Inductive Proximity Sensors:

Inductive proximity sensors use the principle of eddy currents to detect the presence of metallic objects without physical contact. Here's a more detailed explanation:

Components of the Sensor Circuit:

1. **LC Oscillator:** The sensor circuit contains an LC oscillator, consisting of a capacitor (C) and a coil (L). This oscillator generates an oscillating magnetic field when the sensor is activated.
2. **Special Circuit for Frequency Control:** A special circuit within the sensor is responsible for maintaining the oscillation frequency at a constant value. The frequency is typically around 10 to 20 Hz for AC sensors and 500 Hz to 5 kHz for DC sensors.



Detection Process:

1. **Oscillating Magnetic Field Generation:** When the inductive proximity sensor is powered or activated, the LC oscillator generates an oscillating magnetic field at the sensor's sensing face.
2. **Metallic Object Interaction:** When a metallic object enters the vicinity of the sensor and comes into contact with the generated magnetic field, several processes occur:

a. **Eddy Current Induction:** The presence of the metallic object within the magnetic field induces electrical currents inside the object. These are known as eddy currents. Eddy currents circulate within the object due to the changing magnetic field.

b. **Disruption of Magnetic Field:** Eddy currents in the metallic object disrupt the magnetic field generated by the sensor. This disruption is often referred to as "magnetic damping."

c. **Impact on Oscillator:** The disruption caused by eddy currents affects the natural oscillation of the LC oscillator circuit. It reduces the amplitude (strength) of the oscillating signal.

Output Signal Generation:

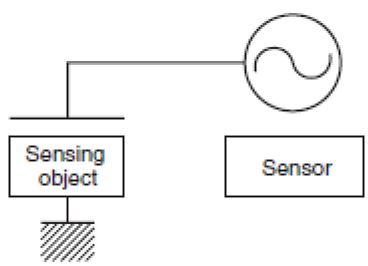
1. **Comparator Circuit:** The sensor contains a separate comparator circuit that continuously monitors the amplitude of the oscillating signal generated by the LC oscillator.
2. **Threshold Detection:** When the amplitude of the signal falls below or rises above a certain threshold, the comparator circuit is triggered.
3. **Output Signal:** The output signal generated by the comparator can take different forms:
   - For digital sensors, it can be a logic HIGH or LOW signal.
   - For analog sensors, it can be a current or voltage signal that varies with the proximity of the metallic object.

In summary, inductive proximity sensors generate an oscillating magnetic field using an LC oscillator. When a metallic object enters this field, it induces eddy currents in the object, disrupting the magnetic field and reducing the oscillation amplitude. The comparator circuit monitors this amplitude and generates an output signal when it crosses a set threshold, allowing the sensor to detect the presence of metallic objects and provide an appropriate output signal for control or monitoring purposes.

Capacitive Proximity Sensor

A capacitive proximity sensor is a sensor that can detect an object using the electrical property, **capacitance.** They are widely used to detect and measure objects/fluids that have a higher dielectric constant than air. This includes anything that is conductive or non-conductive.

Capacitive proximity sensors have many applications in industrial automation systems from detecting positions to analyzing the composition of objects in a non-invasive manner.

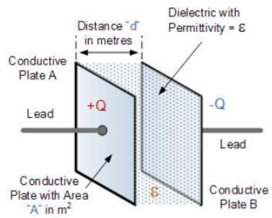


Capacitive Proximity Sensors detect changes in the capacitance between the sensing object and the Sensor. The amount of capacitance varies depending on the size and distance of the sensing object. An ordinary Capacitive Proximity Sensor is similar to a capacitor with two parallel plates, where the capacity of the two plates is detected. One of the plates is the object being measured (with an imaginary ground), and the other is the Sensor's sensing surface. The changes in the capacity generated between these two poles are detected. The objects that can be detected depend on their dielectric constant, but they include resin and water in addition to metals.

Capacitive Proximity Sensor and How It Works

Capacitive proximity sensors are a special application of capacitive sensors. We use them to detect the presence of objects in industrial environments.

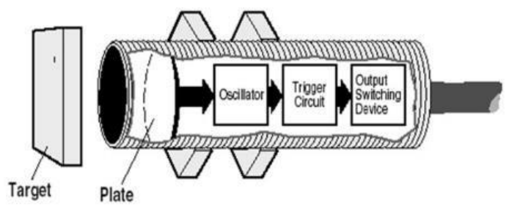
Before diving into greater detail, let's understand what a capacitor is and how it works. In simple terms, a capacitor is a device that can hold an electric charge like a battery. They are made of two conductive plates with a dielectric material filling the gap. Depending on the dielectric width, their capacitance (capacity to store electric charge) changes.



The dielectric constant depends on the material. Materials with a high dielectric constant are easy to detect. For example, water is more detectable than oil or PVC. This is because water has a dielectric constant of about 78 and for PVC it's only about 5.

A capacitive proximity sensor follows the same principle, only one of the plates is now the object we want to detect. Bringing an object close to the sensing face causes the capacitance to change. The sensor can then measure the change and determine if the object is close.

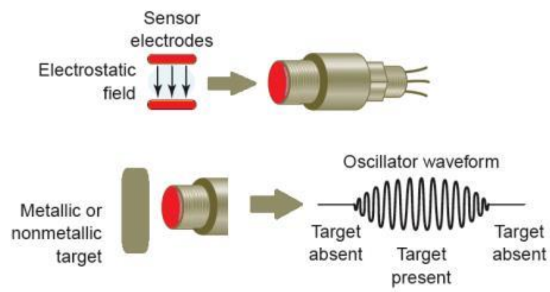
It is not possible to directly measure the change in capacitance by ordinary means. To address this, capacitive proximity sensors have specialized circuitry inside them. The circuit does all the signal processing to ultimately output a usable, digital signal.



The first stage of the sensor is the capacitor itself. When an object is near the sensing face, it forms a capacitor. The air between them becomes the dielectric material. Inside the sensor, there is an oscillator circuit. This can either be an RC or LC oscillator circuit.

The capacitance created by the external object starts an oscillation in the circuit. This smallest distance an object has to maintain with the sensor face to start the oscillation is also known as the 'operating point'. This is adjustable in most of the sensors. When an object comes closer to the sensor, this oscillation frequency increases. This causes the amplitude of the oscillation to increase.

The circuit also consists of a trigger circuit with hysteresis. The trigger circuit monitors the frequency and the amplitude of the oscillation. It controls the output if the amplitude goes beyond a pre-set value. There are sensors that can output digital or analog signals.



Proximity sensors provide means to adjust their operating point of. Some have potentiometers while others may have a dedicated ‘teach button’. This button or the potentiometer screw can be used to calibrate the sensor. Increasing the sensitivity also makes the sensor more susceptible to false detections. This means that sometimes even changes in humidity and temperature can cause the sensor to trigger.

Capacitive sensors can detect both conductive and non-conductive material. Conductive materials are the easiest to detect as they form a good capacitor with the sensor. In this case, the dielectric strength becomes negligible.

Detecting non-conductive material depends on three factors:

- Size of the sensor surface – larger surface allows longer sensing distances
- The dielectric constant of the target material – higher the constant, longer the distance
- The surface area of the target – larger surface area, longer distance

Target speed and temperature can also affect the sensing distance.

Magnetic Proximity Sensor

Magnetic proximity sensors/switches are non-contact position detection sensors. They detect objects using the magnetic property them. In other words, magnetic proximity sensors are specifically designed to work with magnets.

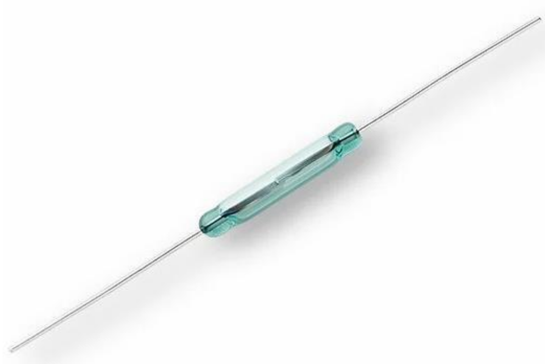
When it comes to detecting magnetic objects through non-magnetisable materials such as plastic, wood, or even aluminum, magnetic proximity sensors become extremely useful.

They are not only available in many size/package variants, but also have high mechanical stability in extreme shock/vibration conditions.

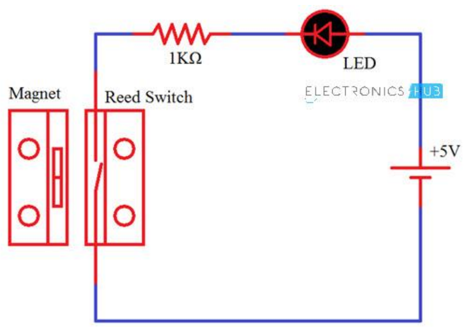
There are various technologies used in magnetic proximity sensors:

- Variable Reluctance
    - Variable reluctance sensors are built using a permanent magnet and a pick-up coil wound around a ferromagnet. These sensors do not need an external power supply. When a magnet passes by the sensor, a voltage is induced in the coil and outputs the analog signal. There are ‘active’ variants of them that are powered which can provide more accurate sensing information such as zero-speed.

- Reed switches
    - Reed switch-based magnetic sensors consist of a hermetically sealed glass bulb. The glass bulb encloses two 'reeds' that are magnetic. When a magnet is placed near the switch, the two reeds come into contact with each other, completing the circuit.



For a simple magnetic proximity switch like a reed switch, follow the circuit below to test the sensor.



If the sensor is functioning properly, placing a magnet next to the sensor will turn on the LED.

If you have a multimeter, set it to ***continuity test*** mode or ***diode mode*** and connect the two leads to the two wires of the sensor. Bring a magnet close to the sensor and observe the reading of the multimeter.

The multimeter will beep or display a very small value close to zero if the sensor is working fine.

For sensors that have a built-in indicator LED, the first step is to power up the sensor using a voltage source. The voltage depends on the sensor model and can be 5V to 24VDC.

When the sensor is powered on, place a magnet in front of the sensor. If the LED on the sensor lights up, the sensor can be determined to be fault-free.