

Linear Displacement - Inductive Methods

- Inductive methods use very similar principles to resistive and capacitive methods
- The inductance of a coil is given by the following equation

$$L = \frac{N^2 \mu A}{l} \quad [\text{Henrys}]$$

- Where N is the number of turns in the coil, μ is the effective permeability of the medium in and around the coil, A is the cross sectional area and l is the length of the coil in m
- As with the other examples if we change any one of these parameters we get a change in the inductance

L V D Ts

Linear Variable Differential Transformer

- **Transformer:** AC Input / AC Output
- **Differential:** Natural Null Point in Middle
- **Variable:** Movable Core, Fixed Coil
- **Linear:** Measures Linear Position

Linear Displacement - Inductive Methods

(Linear Variable Differential Transformers LVDTs)

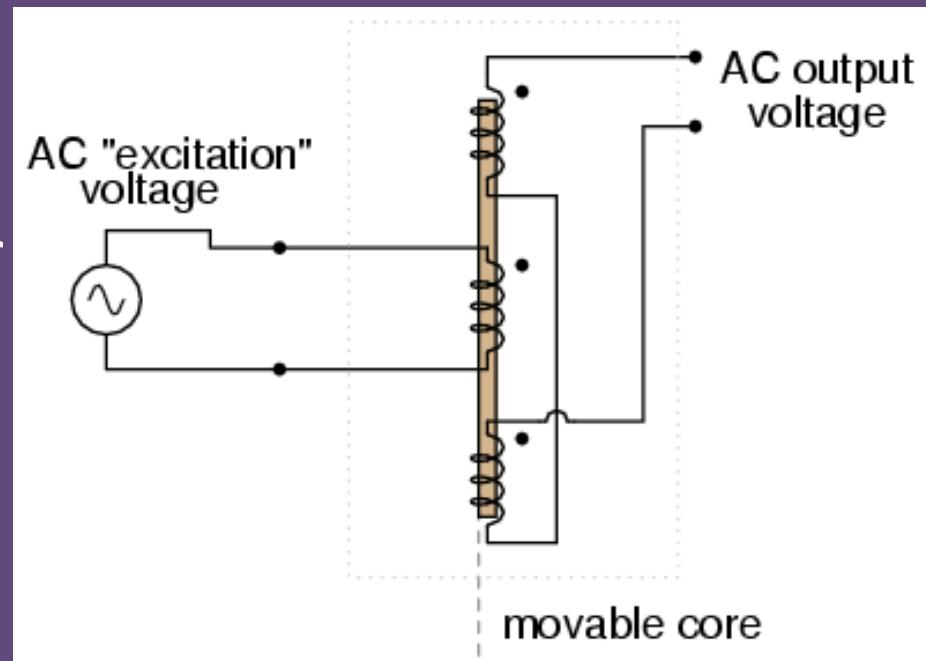
- LVDTs are accurate transducers which are often used in industrial and scientific applications to measure very small displacements



Linear Displacement - Inductive Methods

(Linear Variable Differential Transformers LVDTs)

- An LVDT consists of a central primary coil wound over the whole length of the transducer and two outer secondary coils
- A magnetic core is able to move freely through the coil

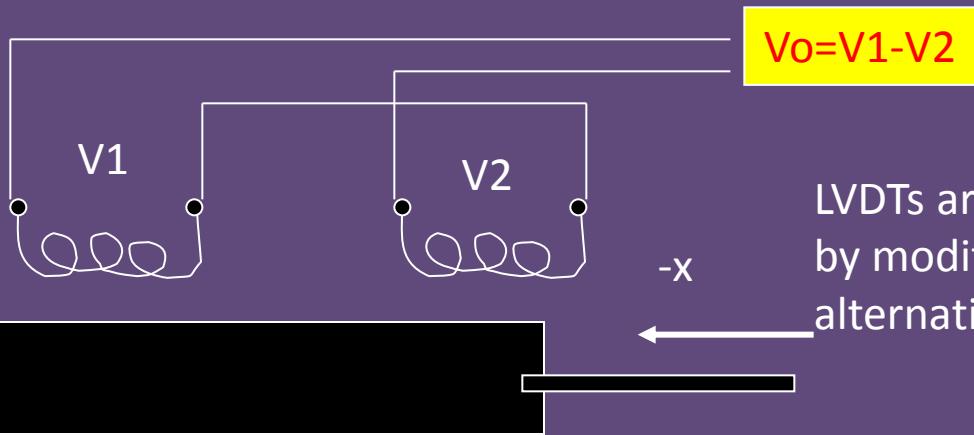


Linear Displacement - Inductive Methods

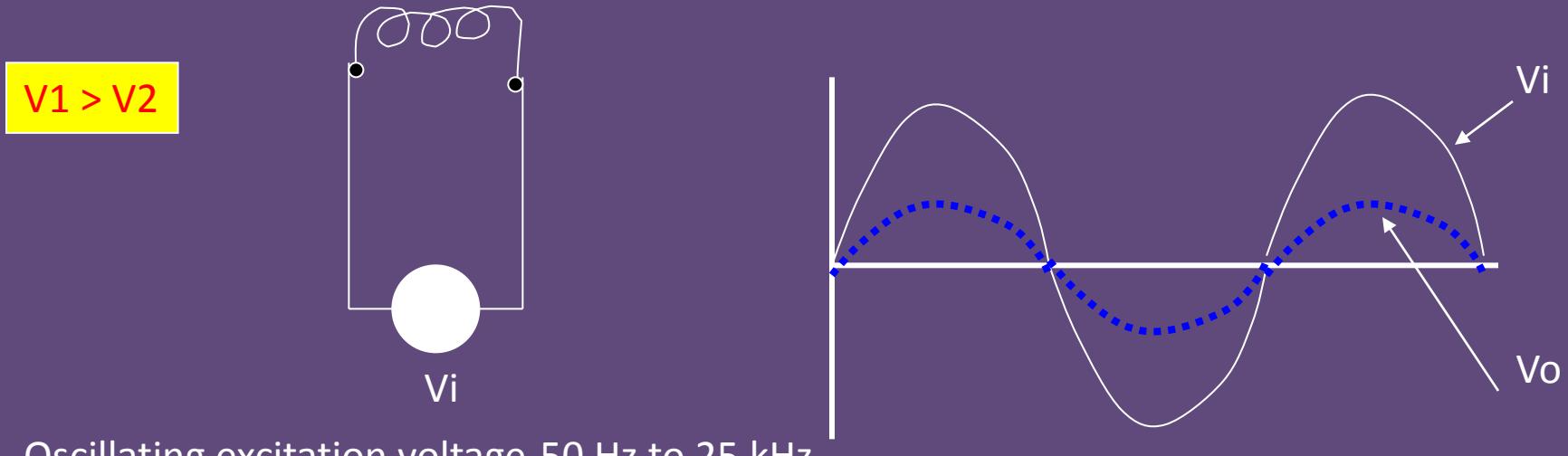
(Linear Variable Differential Transformers LVDTs)

- The primary windings are energized with a constant amplitude AC signal (1 – 10kHz)
- This produces an alternating magnetic field which induces a signal into the secondary windings
- The strength of the signal is dependant on the position of the core in the coils
- When the core is placed in the centre of the coil the output will be zero
- Moving the coil in either direction causes the signal to increase
- The output signal is proportional to the displacement

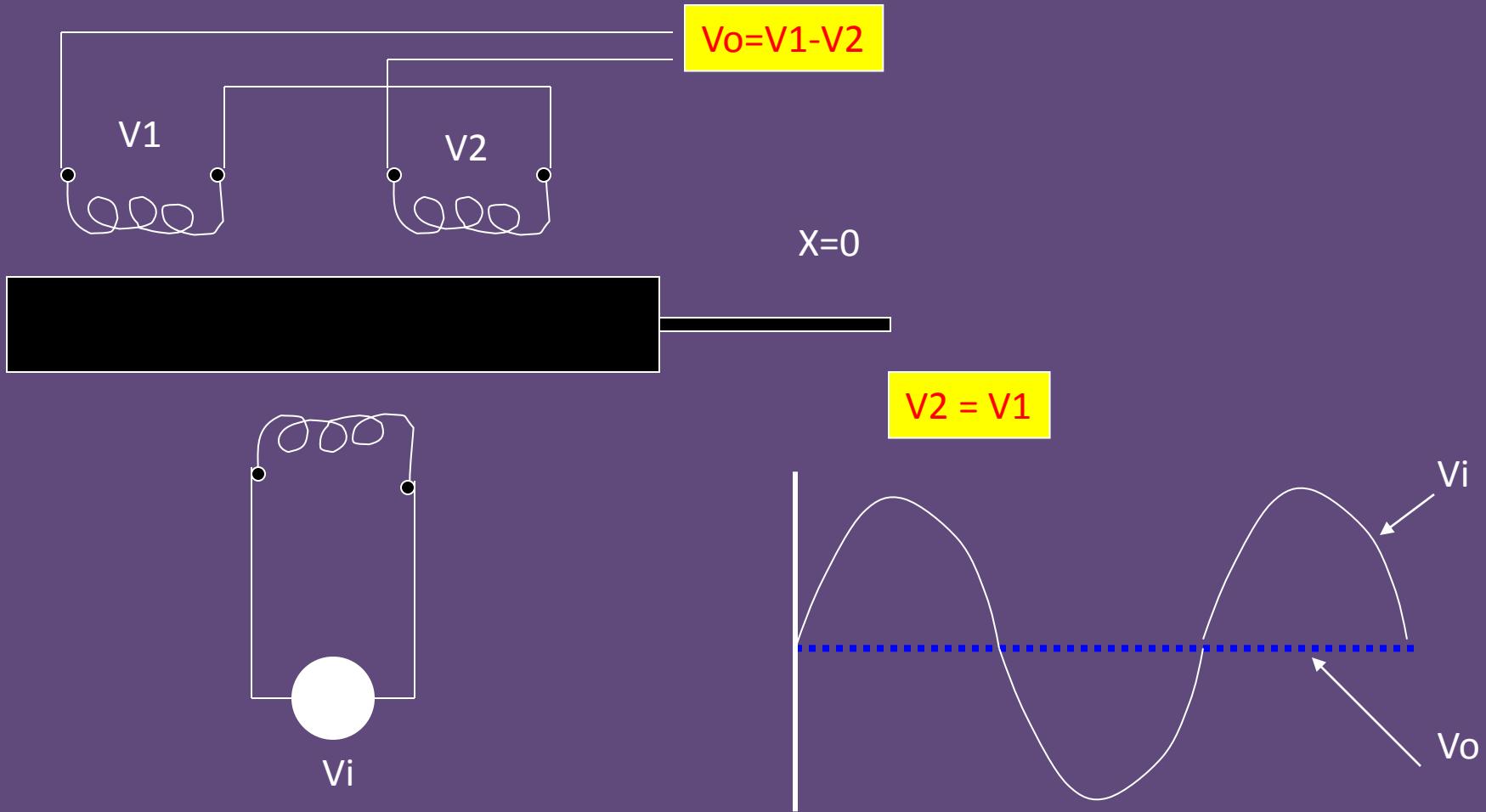
Linear Variable-Differential Transformer (LVDT)



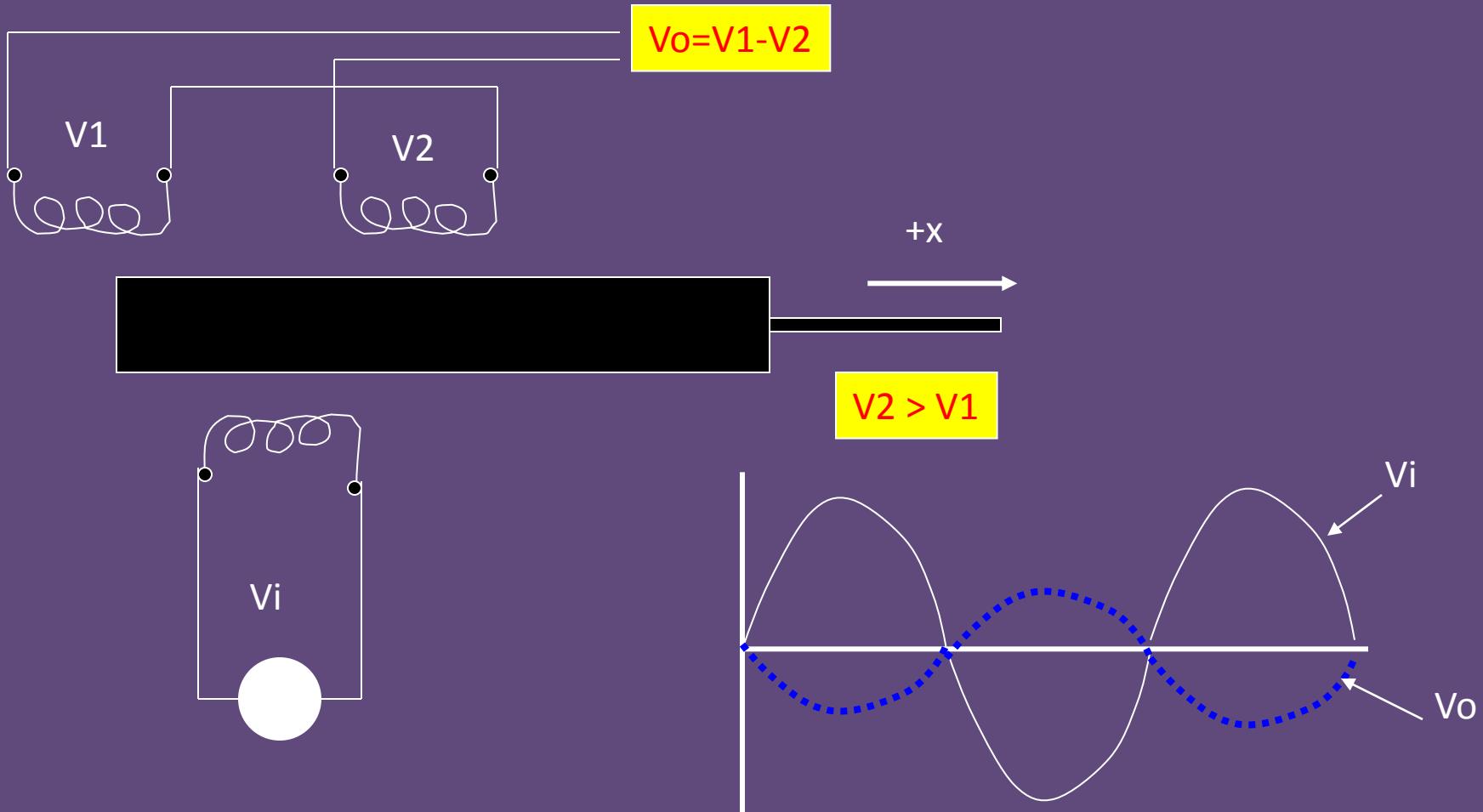
LVDTs are devices to measure displacement by modifying spatial distribution of an alternating magnetic field.



Linear Variable-Differential Transformer (LVDT)



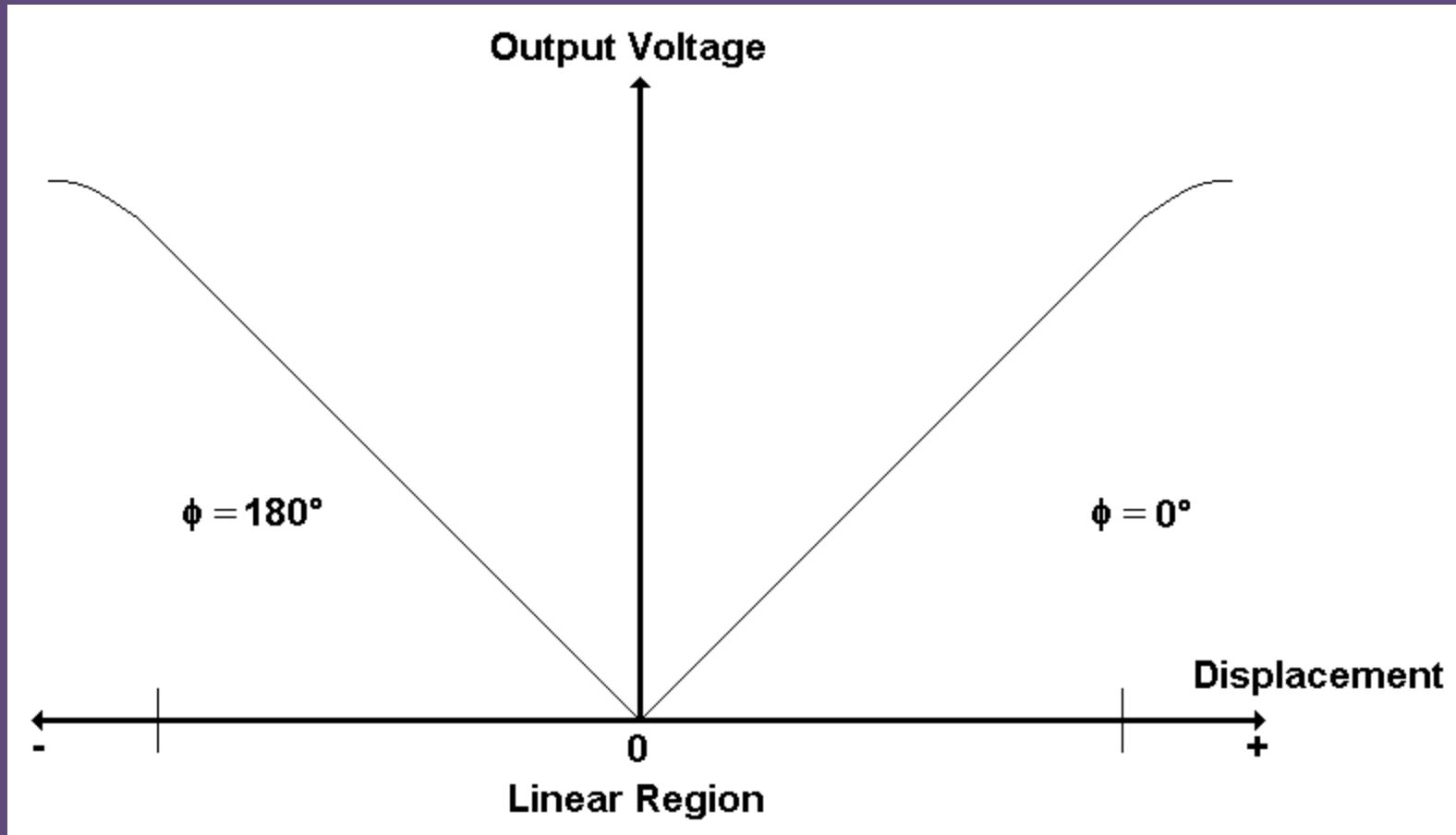
Linear Variable-Differential Transformer (LVDT)



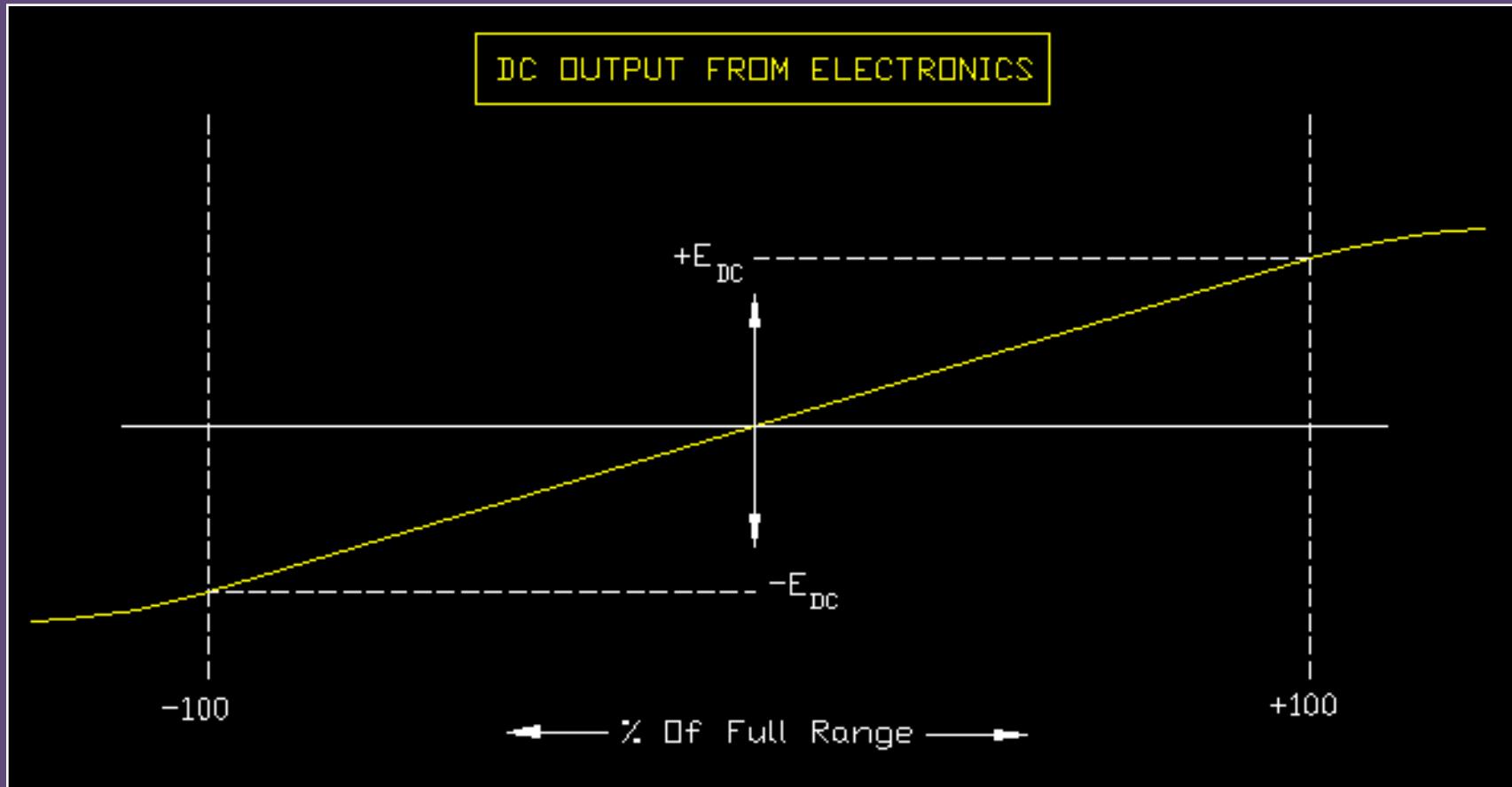
So, the direction of displacement can be determined from the relative phase of the signal.

Linear Displacement - Inductive Methods

(Linear Variable Differential Transformers LVDTs)

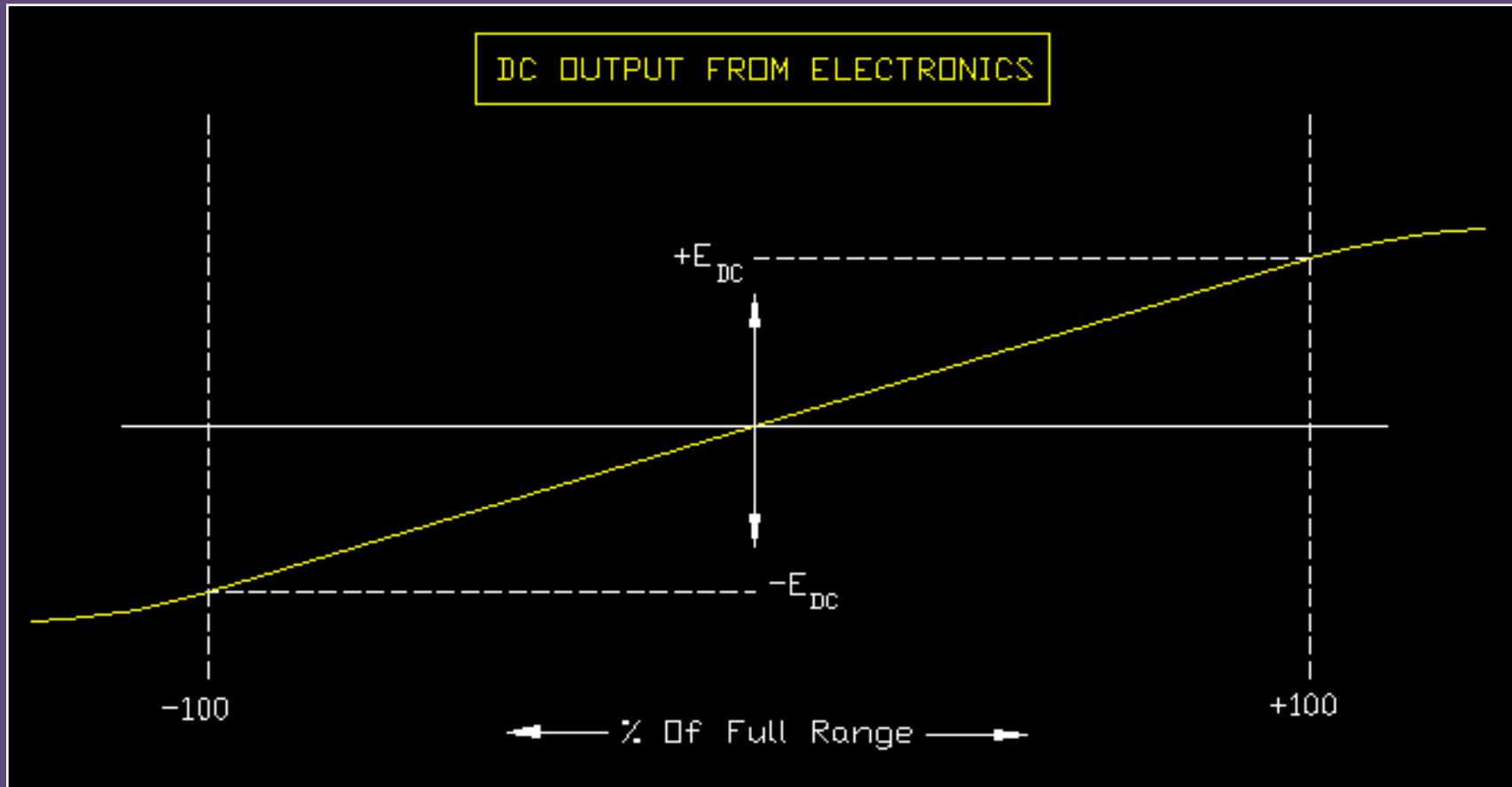


LVDT output



This 180 degree phase shift can be used to determine the direction of the core from the null point by means of appropriate circuitry. As this diagram shows, the polarity of the output signal represents the core's positional relationship to the null point.

LVDT output



The diagram shows also that the output of an LVDT is very linear over its specified range of core motion, but that the sensor can be used over an extended range with some reduction in output linearity.

Pros and Cons - LVDTs

- Range: $\pm 2.5\text{nm}$ - $\pm 10\text{cm}$
- Advantages:
 - Good resolution
- Disadvantages:
 - Needs shielding to prevent interference from magnetic sources

Why Use An LVDT?

LVDTs have certain significant features and benefits, most of which derive from fundamental physical principles of operation or from materials and techniques used in their construction.

Why Use An LVDT?

Friction-Free Operation

One of the most important features of an LVDT is its friction-free operation. In normal use, there is not any mechanical contact between the LVDT's core and its coil assembly. There is no rubbing, dragging, or other source of friction. This feature is particularly useful in materials testing, vibration displacement measurements, and high-resolution dimensional gaging systems.

Why Use An LVDT?

Infinite Resolution

Since an LVDT operates by using electromagnetic coupling principles in a friction-free structure, it can measure small changes in core position. These same factors also give an LVDT its outstanding repeatability. This resolution may be circumscribed by the LVDT signal conditioner's signal-to-noise ratio and output filtering, and by the output display's visual resolution.

Why Use An LVDT?

Unlimited Mechanical Life

Because there is normally no contact between an LVDT's core and coil structure, no parts can rub together or wear out. This means that an LVDT features unlimited mechanical life. This factor is especially important in high-reliability applications such as aircraft, satellites and space vehicles, and nuclear installations. It is also highly desirable in many industrial process control and factory automation systems.

Why Use An LVDT?

Over travel Damage Resistant

The internal bore of most LVDTs is open at both ends. In the event of unanticipated overtravel, the core is able to pass completely through the sensor's coil assembly without causing damage. This invulnerability to position input overload makes an LVDT the ideal sensor for applications like extensometers that are attached to tensile test samples in destructive materials testing.

Why Use An LVDT?

Single Axis Sensitivity

An LVDT responds to motion of the core along the coil's axis, but is generally insensitive to cross-axis motion of the core or to its radial position. Thus, an LVDT can usually function without adverse effect in applications involving misaligned or floating moving members, and in cases where the core doesn't always travel in a precisely straight line.

Why Use An LVDT?

Separable Coil And Core

Because the only interaction between an LVDT's core and coil is magnetic coupling, the coil assembly can be isolated from the core by inserting a non-magnetic tube between the core and the bore. Thus, a pressurized fluid can be contained within the tube, in which the core is free to move, while the coil assembly remains unpressurized. This feature is often employed in LVDTs used for spool position feedback in hydraulic proportional or servo valves.

Why Use An LVDT?

Environmentally Robust

The materials and construction techniques used to assemble an LVDT result in a rugged and durable sensor robust to a wide variety of environmental conditions. Bonding of the coil windings is followed by epoxy encapsulation into the case, resulting in superior moisture and humidity resistance, as well as the capability to take substantial shock loads and high vibration levels in all axes. An internal high-permeability magnetic shield minimizes effects of external AC fields on LVDT operation.

Why Use An LVDT?

Environmentally Robust

Both the case and core are made of corrosion resistant metals, with the case also acting as a supplemental magnetic shield. And for those applications where the sensor must withstand exposure to flammable or corrosive vapors and liquids, or operate in pressurized fluid, the case and coil assembly can be hermetically sealed using a variety of welding processes.

Why Use An LVDT?

Environmentally Robust

Ordinary LVDTs can operate over a very wide temperature range, but, if required, they can be produced to operate at cryogenic temperatures, or, using special materials, to operate at the elevated temperatures and radiation levels found in many locations in nuclear reactors.

Why Use An LVDT?

Null Point Repeatability

The location of an LVDT's null point is extremely stable and repeatable, even over its very wide operating temperature range. Thus, LVDTs can perform well as null position sensors in closed-loop control systems and high-performance servo balance instruments.

Why Use An LVDT?

Fast Dynamic Response

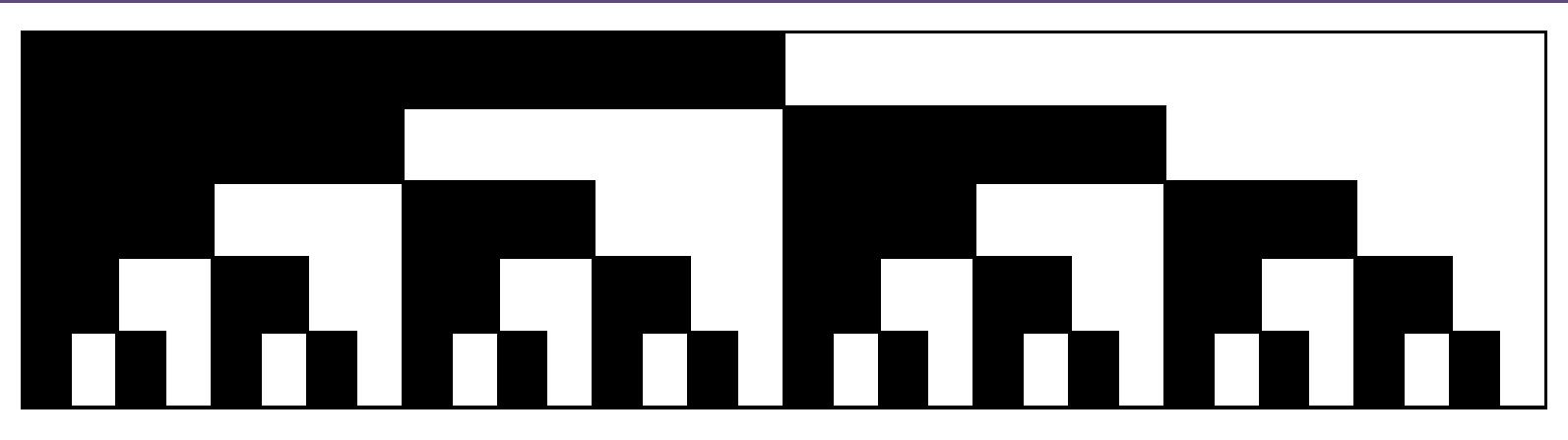
The absence of friction during operation permits an LVDT to respond very fast to changes in core position. The dynamic response of an LVDT sensor itself is limited only by the inertial effects of the core's slight mass. Often, the response of an LVDT sensing system is determined by the characteristics of the signal conditioner, usually the roll-off frequency of the low pass filter.

Why Use An LVDT?

Absolute Output

An LVDT is an absolute output device, as opposed to an incremental output device. This means that in the event of loss of power, the linear position information being sent from the LVDT will not be lost. When the measuring system is restarted, the LVDT's output value will be the same as it was before the power failure occurred.

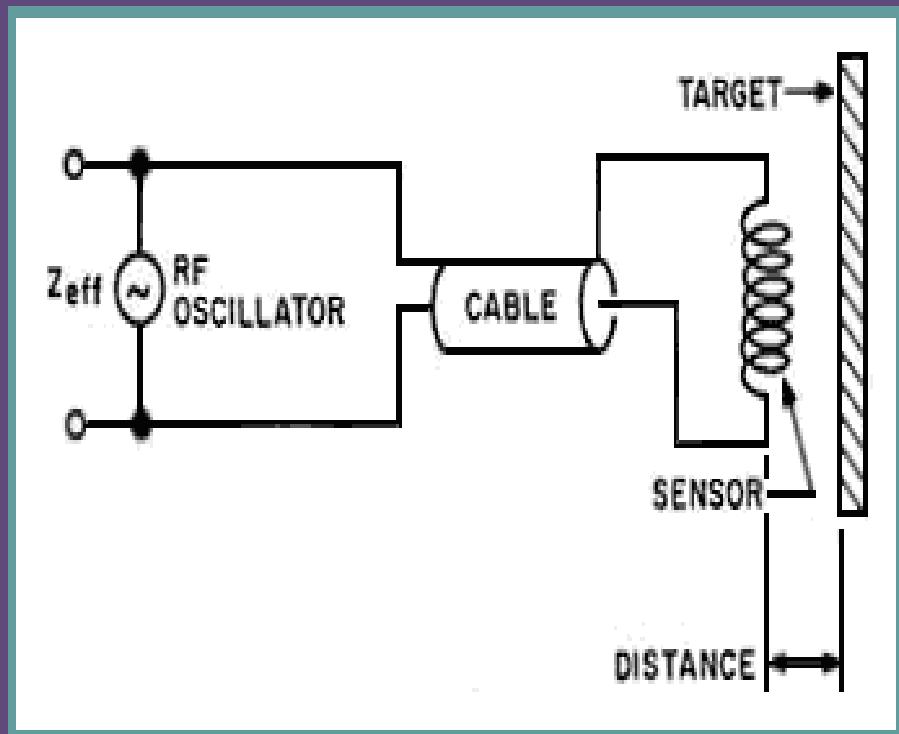
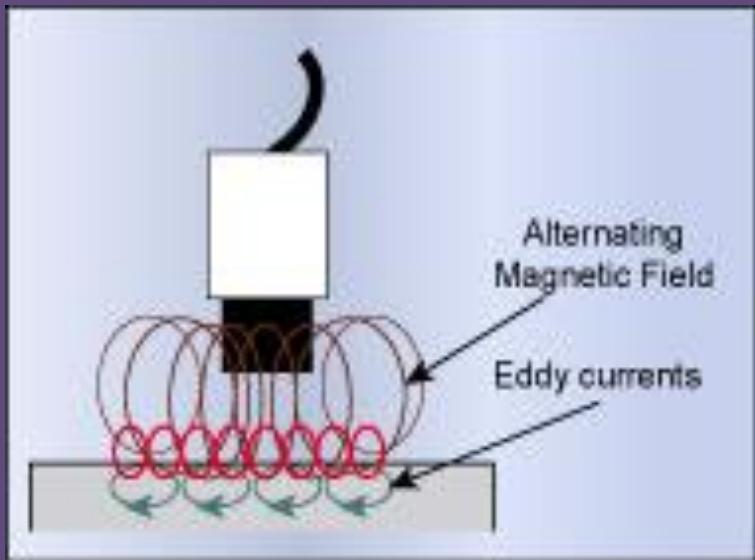
Linear Displacement – Digital Methods



- It is also possible to measure displacement using digital methods
- As a binary system only uses 0's and 1's we can represent this using transparent and opaque areas on a glass scale or conducting and non conducting areas on a metal scale
- Each position will produce a unique code which represents a specific displacement

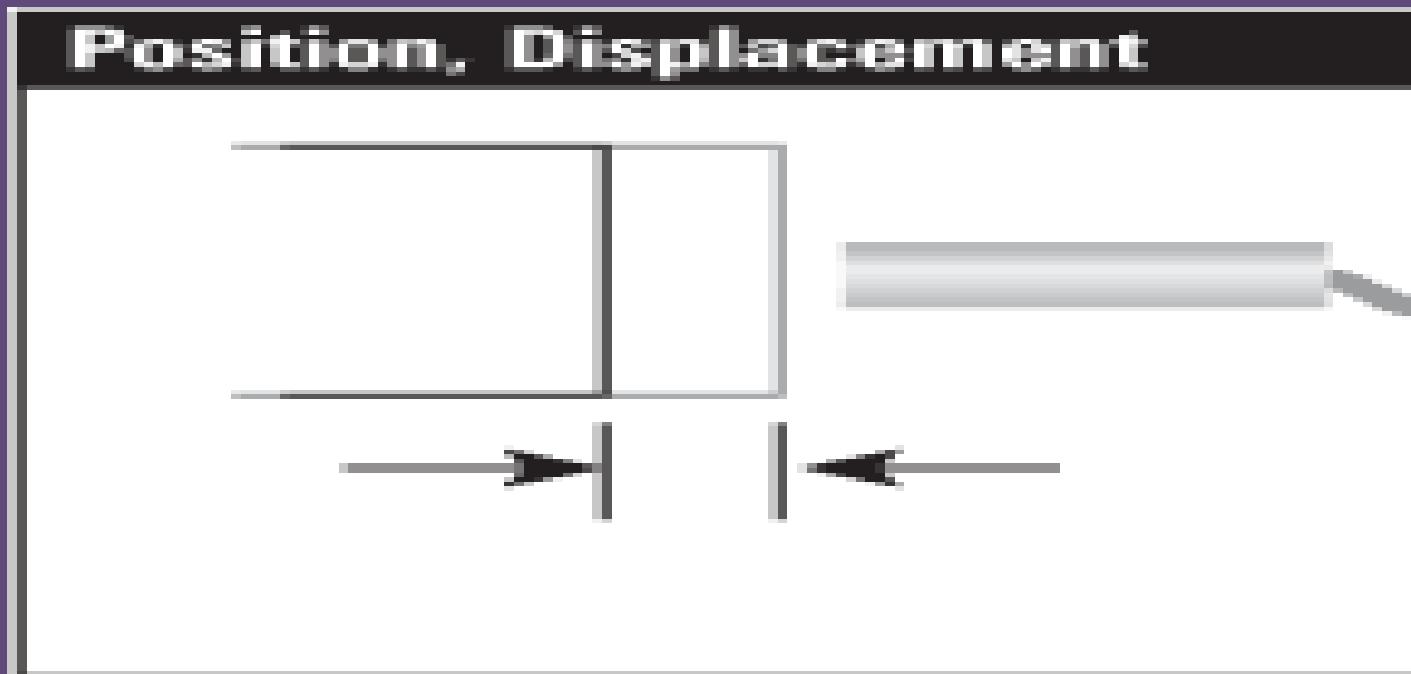
Linear Displacement – Eddy current Method

An **eddy current** is a local electric current induced in a conductive material by the magnetic field produced by the active coil. This local electric current in turn induces a magnetic field opposite in sense to the one from the active coil and reduces the inductance in the coil.



Linear Displacement – Eddy current Method

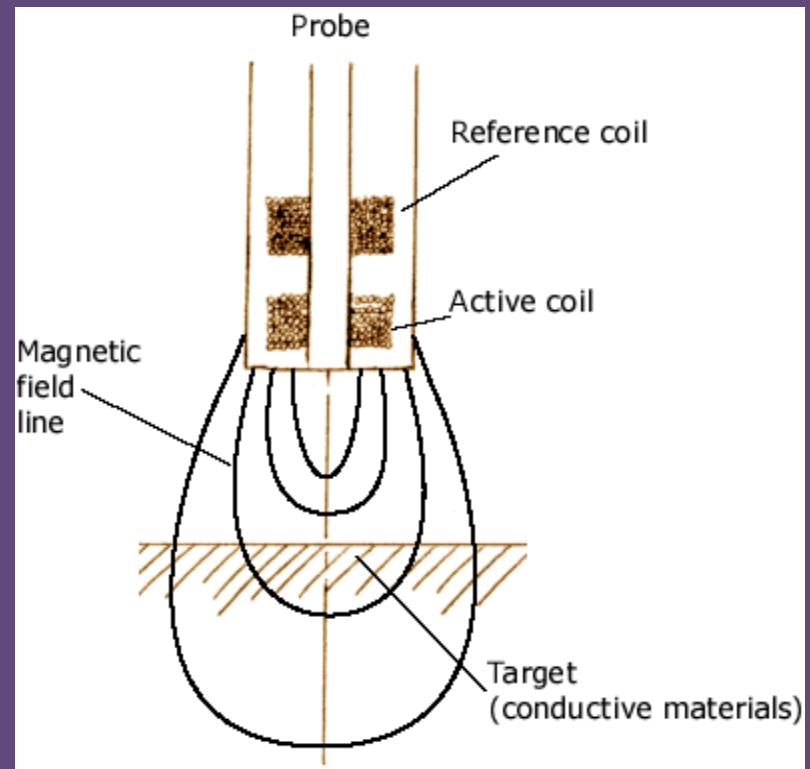
- When the distance between the target and the probe changes, the impedance of the coil changes correspondingly. This change in impedance can be detected by a carefully arranged bridge circuit.
- Eddy-Current sensors are useful in any application requiring the measurement or monitoring of the position of a conductive target, especially in a dirty environment.



Eddy Current Transducer

The **Eddy Current Transducer** uses the effect of eddy (circular) currents to sense the proximity of non-magnetic but conductive materials.

A typical eddy current transducer contains two coils: an **active coil** (main coil) and a **balance coil**. The active coil senses the presence of a nearby conductive object, and balance coil is used to balance the output bridge circuit and for temperature compensation.

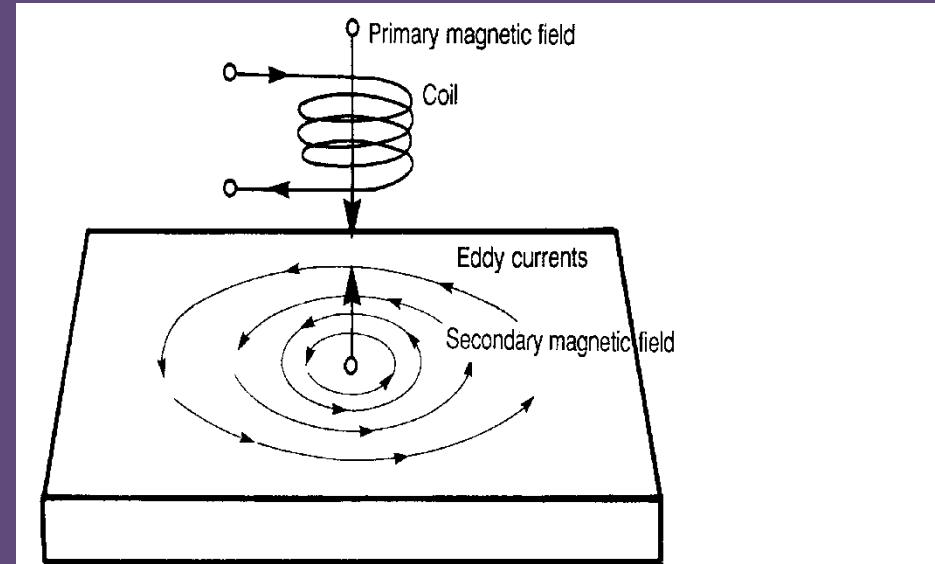
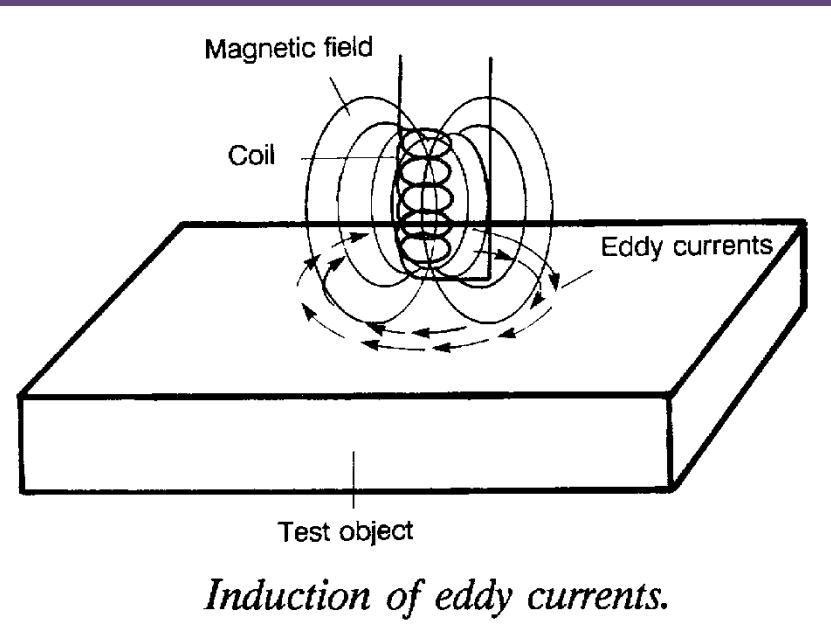


Eddy Current Testing

- Electrical currents are generated in a conductive material by an induced alternating magnetic field. The electrical currents are called **eddy currents** because the flow in circles at and just below the surface of the material.
- Interruptions in the flow of eddy currents, caused by imperfections, dimensional changes, or changes in the material's conductive and permeability properties, can be detected with the proper equipment.

Principle of Eddy Current Testing

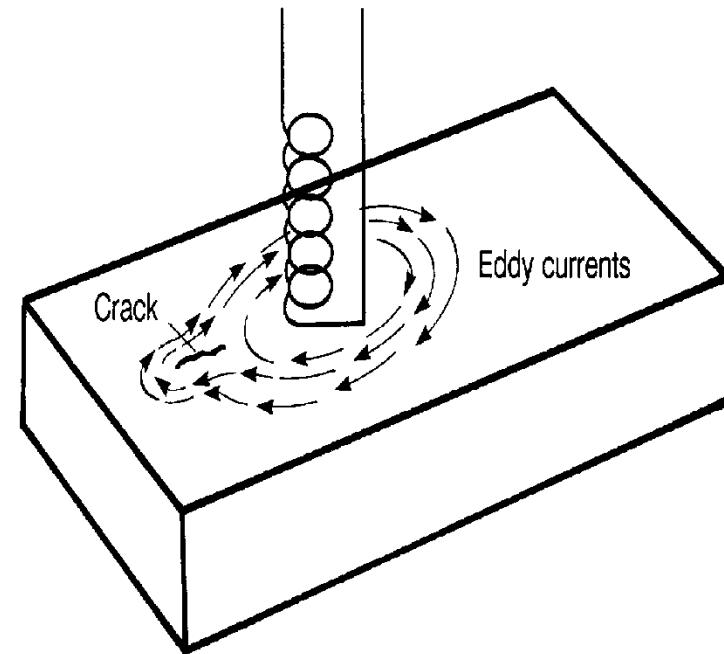
- When a AC passes through a test coil, a primary magnetic field is set up around the coil
- The AC primary field induces eddy current in the test object held below the test coil
- A secondary magnetic field arises due to the eddy current



The primary magnetic field H_p and the secondary magnetic field H_s .

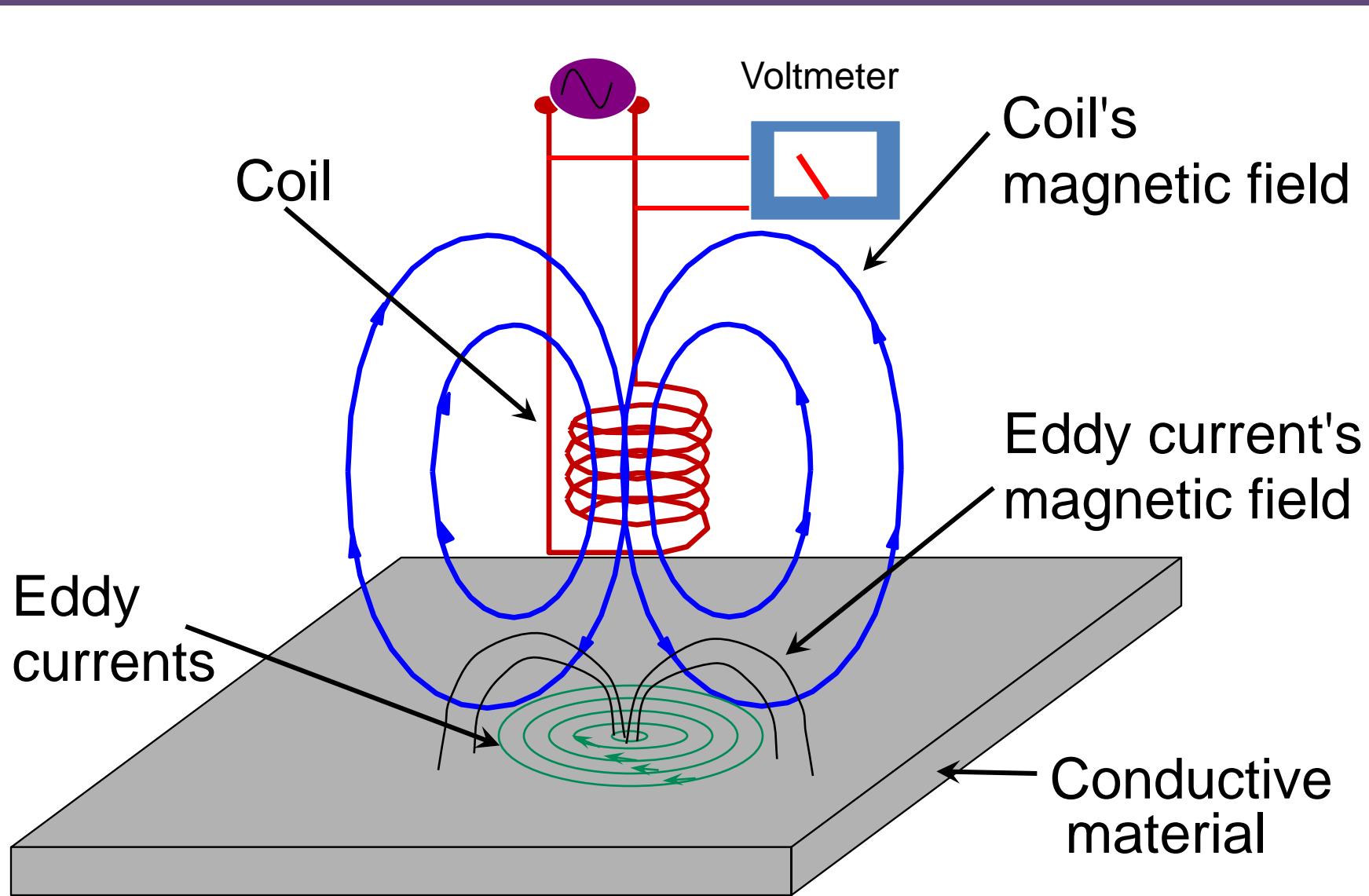
Principle of Eddy Current Testing

- The strength of the secondary field depends on electrical and magnetic properties, structural integrity, etc., of the test object
- If cracks or other inhomogeneities are present, the eddy current, and hence the secondary field is affected.



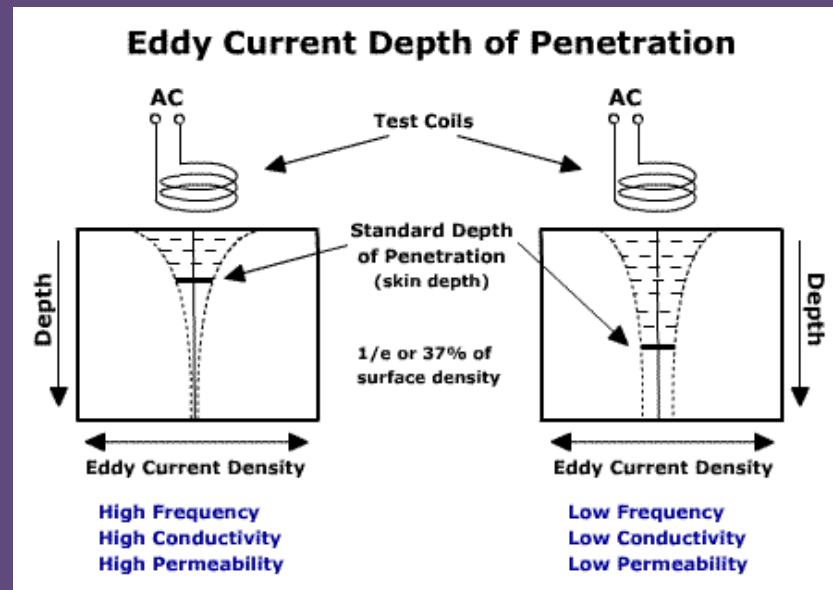
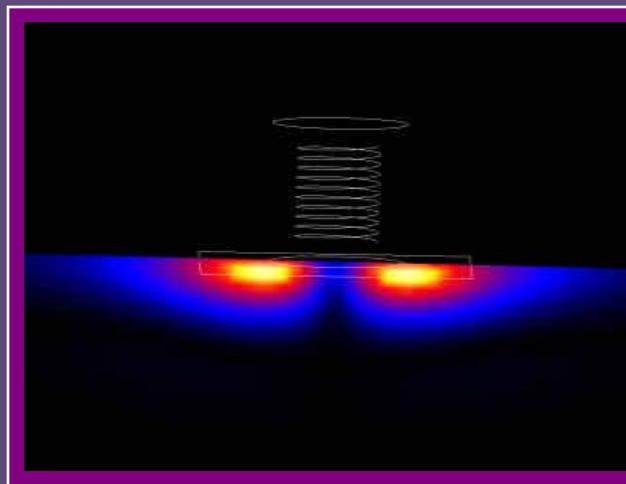
Changes in the magnetic field during passage of a crack.

Eddy Current Instruments



Depth of Penetration

Eddy currents are closed loops of induced current circulating in planes perpendicular to the magnetic flux. They normally travel parallel to the coil's winding and flow is limited to the area of the inducing magnetic field. Eddy currents concentrate near the surface adjacent to an excitation coil and their strength decreases with distance from the coil as shown in the image. Eddy current density decreases exponentially with depth. This phenomenon is known as the **skin effect**.



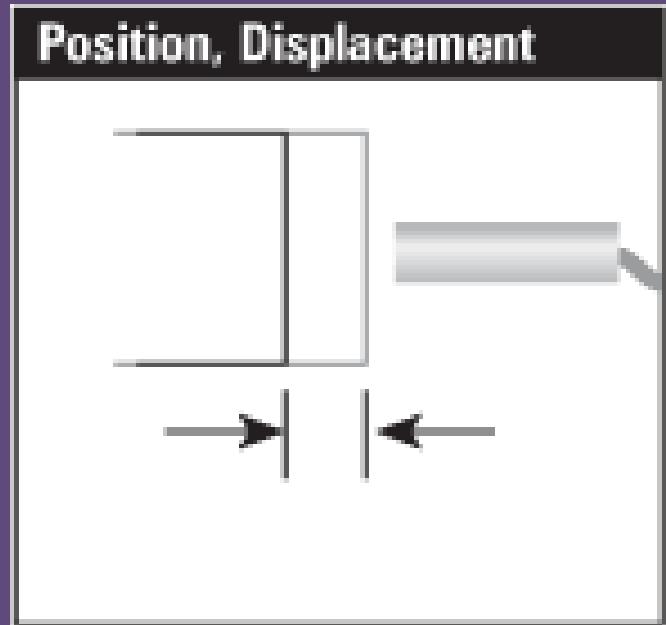
The depth at which eddy current density has decreased to $1/e$, or about 37% of the surface density, is called **the standard depth of penetration** (δ).

Applications.... position

- Eddy-Current sensors are useful in any application requiring the measurement or monitoring of the position of a conductive target, especially in a dirty environment.

Eddy-Current sensors are basically position measuring devices. Their outputs always indicate the size of the gap between the sensor's probe and the target. When the probe is stationary, any changes in the output are directly interpreted as changes in position of the target. This is useful in:

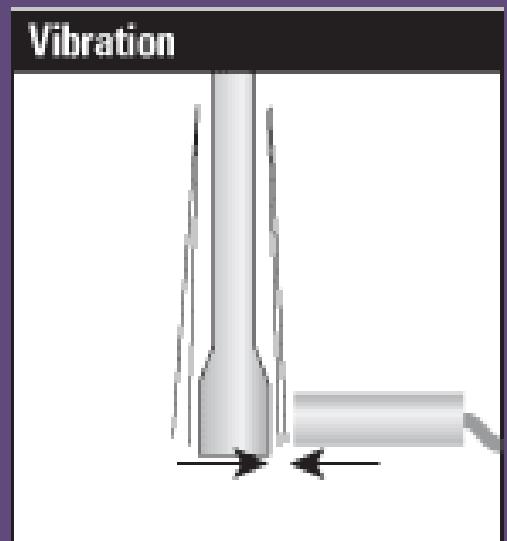
- Automation requiring precise location
- Machine tool monitoring
- Final assembly of precision equipment such as disk drives
- Precision stage positioning



ApplicationDynamic Motion

Measuring the dynamics of a continuously moving target, such as a vibrating element, requires some form of noncontact measurement. Eddy-Current sensors are useful whether the environment is clean or dirty and the motions are relatively small. Eddy-current sensors also have high frequency response (up to 80kHz) to accommodate high-speed motion.

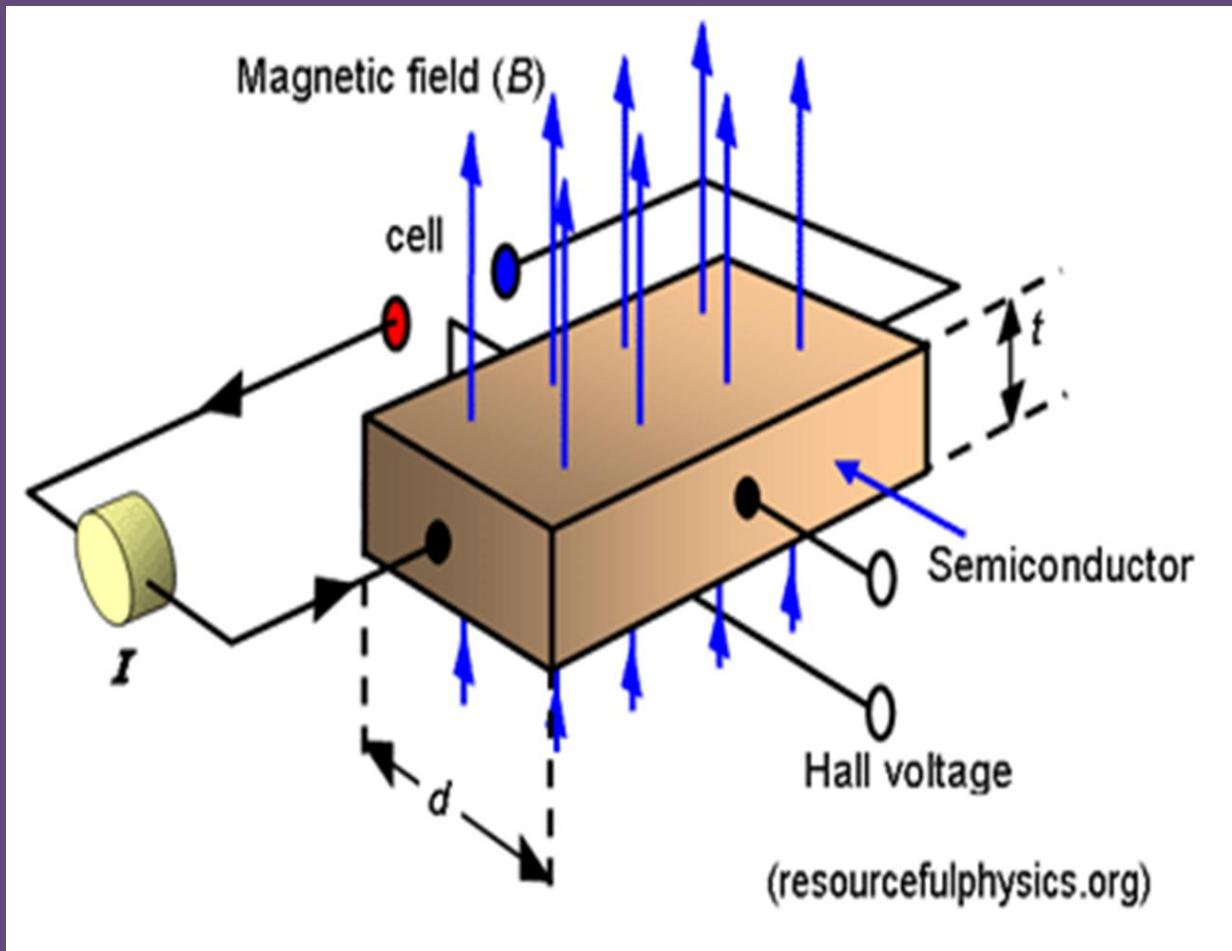
- Drive shaft monitoring
- Vibration measurements



Pros and Cons of E.C. Sensors

- **Pros:**
 - Non-contacting measurement. -
 - High resolution. -
 - High frequency response.
- **Cons:**
 - Effective distance is limited to close range.
 - The relationship between the distance and the impedance of the coil is nonlinear and temperature dependent. Fortunately, a balance coil can compensate for the temperature effect. As for the nonlinearity, careful calibrations can ease its drawback.
 - Only works on conductive materials with sufficient thickness. It can not be used for detecting the displacement of non-conductive materials or thin metalized films. However, a piece of conductive material with sufficient thickness can be mounted on non-conductive targets to overcome this drawback. A self-adhesive aluminum-foil tape is commercially available for this purpose. However, this practice is not always possible.
 - Calibration is generally required, since the shape and conductivity of the target material can affect the sensor response.

Hall Effect



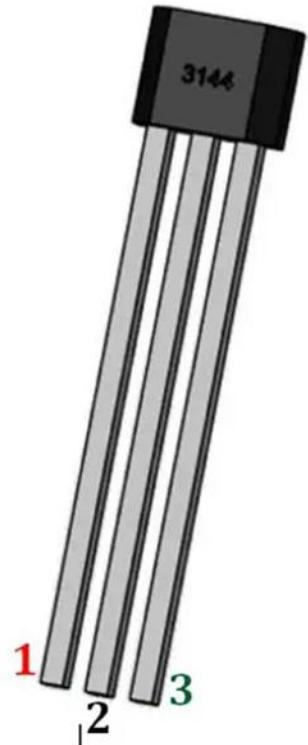
$$E_H = (-J_x / ne) B_z = (-1 / ne) J_x B_z$$

$$R_H = -1 / ne$$

$$R_H = 1 / pe$$

$$R_H = E_H / (J_x \cdot B_z)$$

linear Hall effect sensors



Pin- 1- Voltage (+5V)

Pin- 2- Ground

Pin- 3- Signal Output

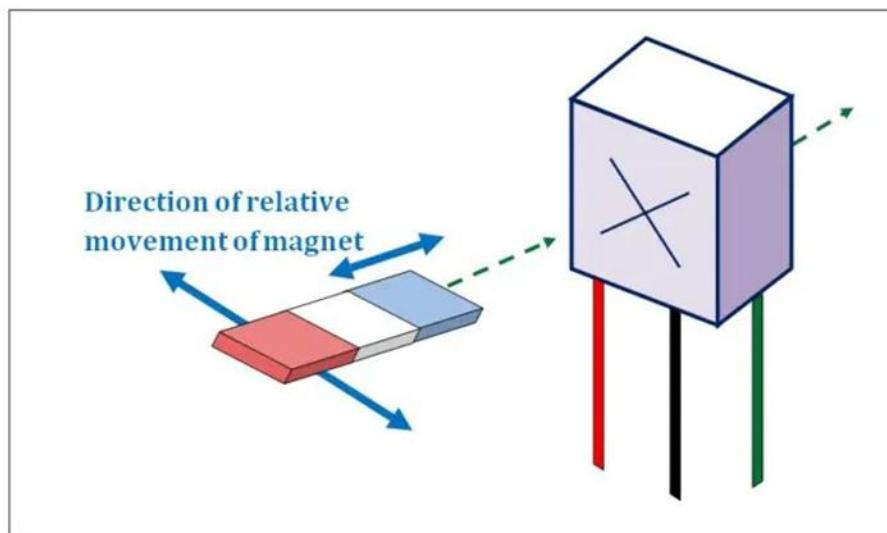
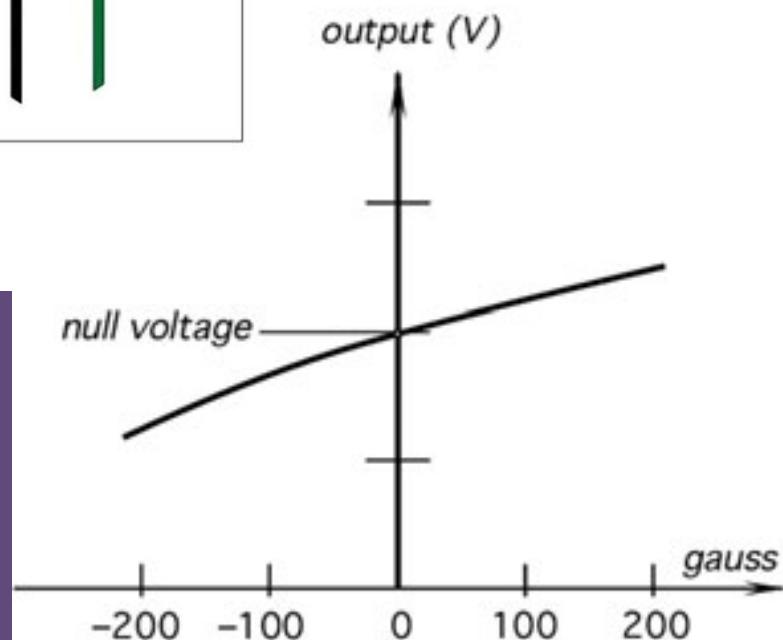
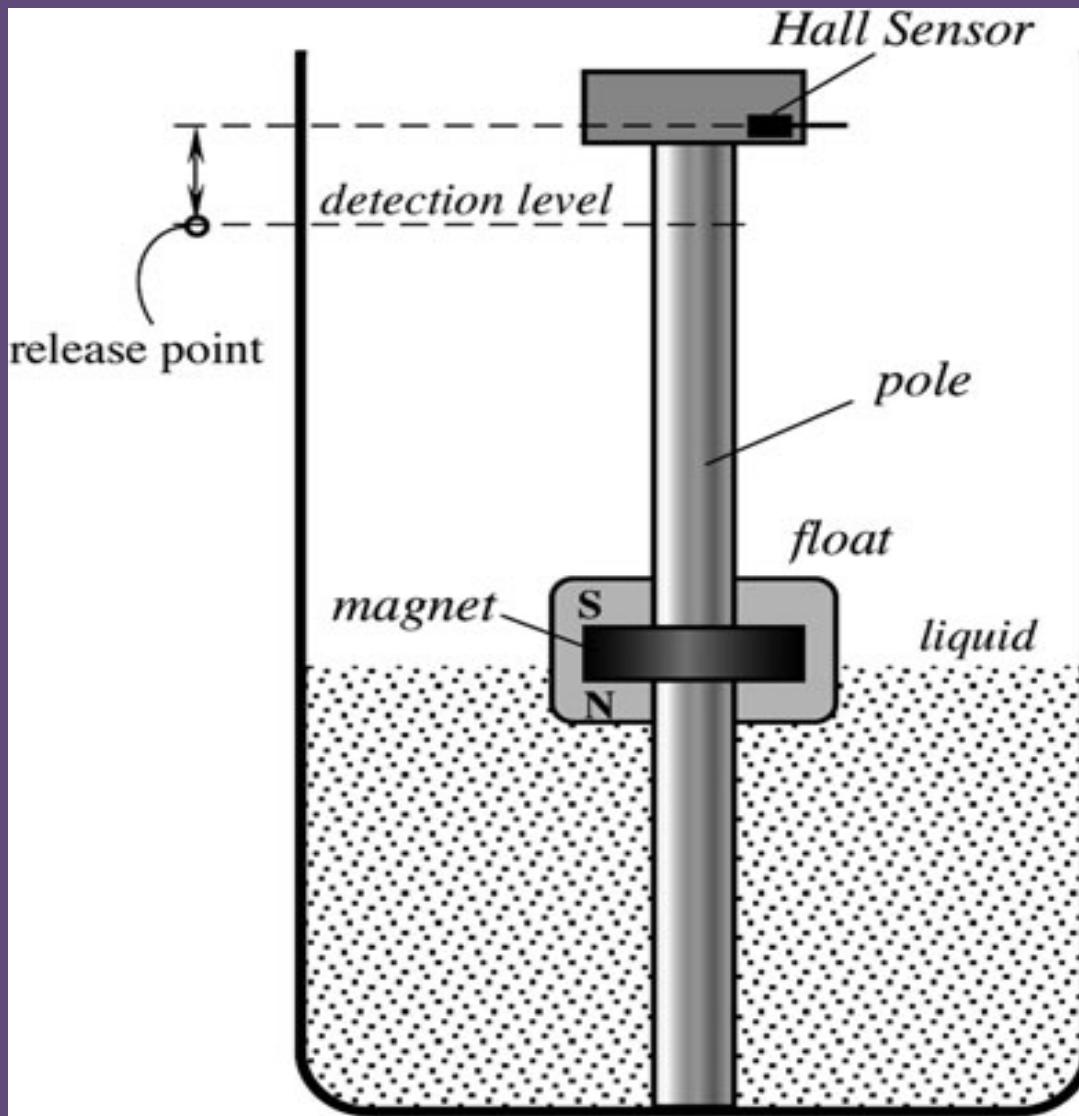


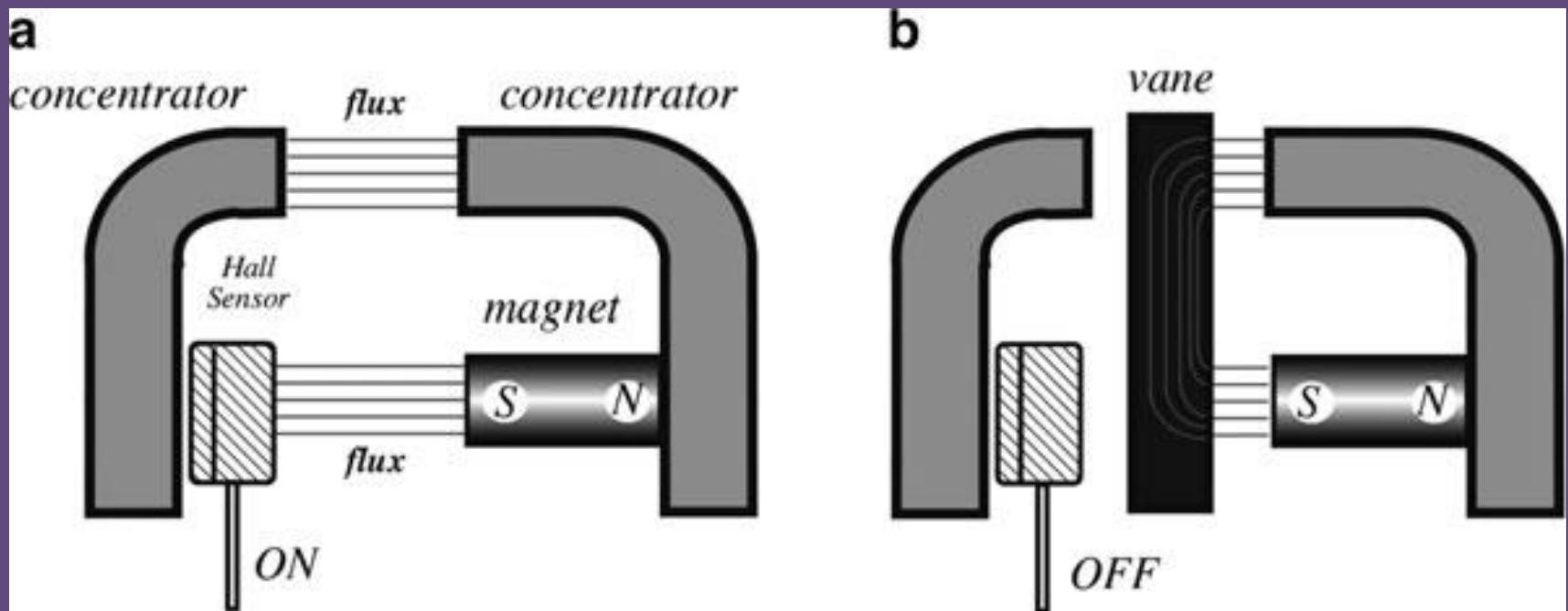
Figure- Hall Effect Sensor



Liquid level detector with a Hall sensor



The Hall effect sensor in the interrupter switching mode



The magnetic flux turns the sensor on (a); the magnetic flux is shunted by a vane (b) (after [5])

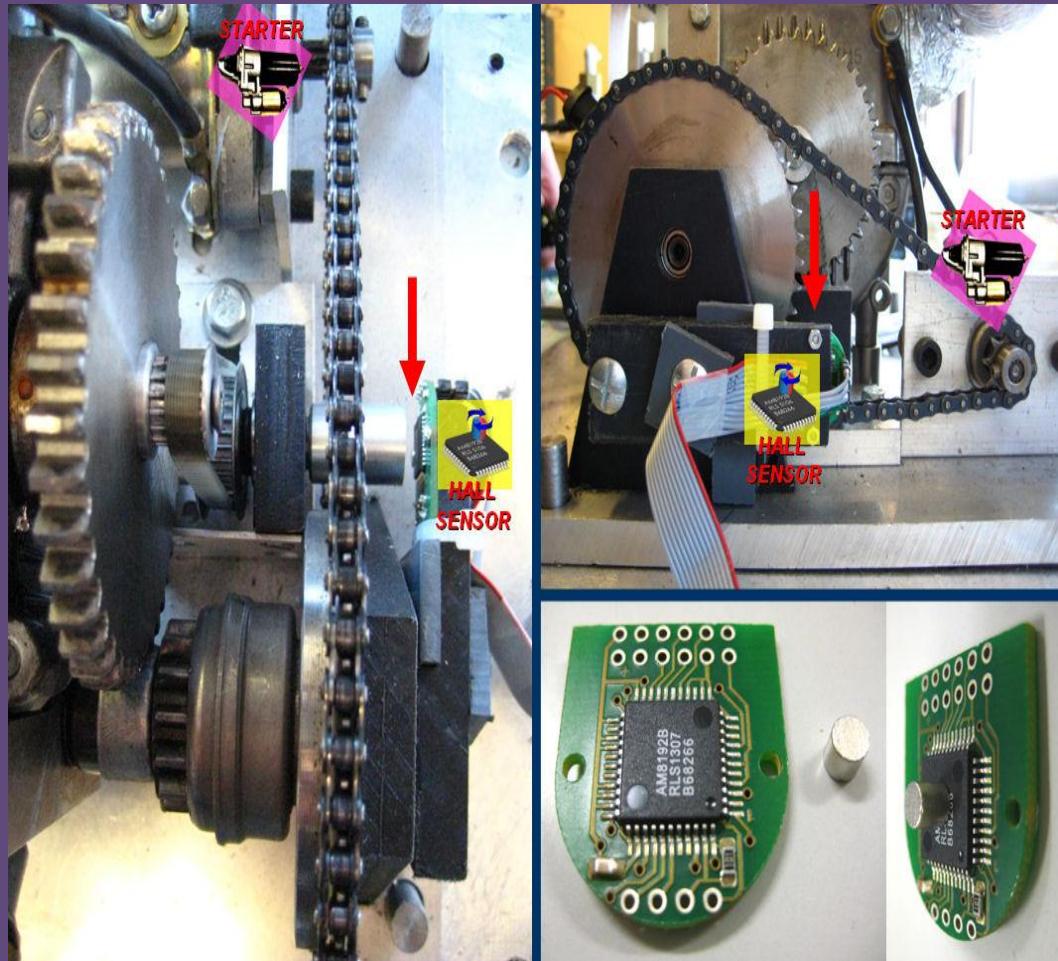
Current Sensor

- When electrons flow through a conductor, a magnetic field is produced.
- Thus, it is possible to create a non-contacting current sensor. This has several advantages:
 1. No additional resistance (a shunt) need be inserted in the primary circuit.
 2. Also, the voltage present on the line to be sensed is not transmitted to the sensor, which enhances the safety of measuring equipment.



Hall effect current sensor with internal integrated circuit amplifier.

Electric Motor Control



Some types of brushless DC electric motors use Hall effect sensors to detect the position of the rotor and feed that information to the motor controller. This allows for more precise motor control.

Magnetometer

- Smart phones like iPhone are equipped with magnetic compass.
- These compass measure Earth's magnetic field using 3-axis magnetometer.
- These magnetometer are sensors based on Hall Effect.
- These sensors produce a voltage proportional to the applied magnetic field and also sense polarity.



