Reactance Variation and Electromagnetic Sensors

Second Stage

Biomedical Transducers and Sensors

Lecture No. 5&6

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Introduction to Reactance Variation Sensors

Unlike resistive sensors, reactance sensors operate based on variations in **capacitive reactance** or **inductive reactance** rather than resistance.

In AC circuits:

Capacitive Reactance: $X_c = 1 / (2\pi f C)$

Inductive Reactance: $X_l = 2\pi f L$

Where:

- f: Frequency
- C: Capacitance
- L: Inductance

So, any physical quantity that changes capacitance (C) or inductance (L) produces a measurable **electrical change.**

Reactance sensors are widely used in: Displacement measurement, Pressure sensing, Flow measurement, and Biomedical monitoring.

Capacitive Sensors

Definition: A capacitive sensor is a transducer in which the measure and produces a change in capacitance. The output signal is obtained by measuring variations in the electric field between conductive plates.

Capacitive sensors are widely used for measuring:

- ❑ Displacement
- ❑ Pressure
- ❑ Level
- ❑ Humidity
- ❑ Proximity

Fundamental Principle: The capacitance of a parallel-plate capacitor is defined

$$\frac{\varepsilon A}{d} = C$$

Where: $\boldsymbol{C}$**:** Capacitance $\boldsymbol{\varepsilon}$**:** Permittivity of dielectric medium $\boldsymbol{A}$**:** Effective overlapping area $\boldsymbol{d}$**:** Distance between plates

Methods of Capacitance Variation

From the capacitance equation, it is evident that capacitance can be varied through three fundamental mechanisms:

1. **Variation in Plate Separation (d):-** If the distance between the plates changes, capacitance changes inversely with distance. A decrease in separation increases capacitance, while an increase in separation decreases capacitance.

This method is commonly used in:

- ❑ Displacement sensors
- ❑ Pressure sensors (diaphragm deflection)
- ❑ Vibration measurement systems

2. Variation in Effective Area (A):- If the overlapping area between plates changes, capacitance changes proportionally. An increase in overlapping area increases capacitance.

This principle is used in:

- ❑ Linear position sensors
- ❑ Rotational position sensors
- ❑ Sliding plate measurement systems

3. Variation in Dielectric Constant (ε):- If the dielectric material between the plates changes, capacitance varies according to the permittivity of the material.

This method is applied in:

- ❑ Humidity sensors
- ❑ Liquid level measurement
- ❑ Biomedical bio-impedance sensing
- ❑ Gas detection systems

Advantages of Capacitive Sensors

Capacitive sensors offer several important advantages:

- High resolution and sensitivity
- Fast dynamic response
- Low power consumption
- No mechanical contact
- Suitable for micro-scale fabrication

Limitations of Capacitive Sensors

Despite their advantages, capacitive sensors have certain limitations:

- Sensitive to stray capacitance
- Affected by environmental conditions (humidity, dust)
- Require shielding and stable AC excitation

Inductive Sensors

Definition : An inductive sensor is a transducer in which the measurand causes a change in inductance due to modification of the magnetic field or magnetic circuit.

Inductive sensors are widely used in displacement and motion measurement.

Fundamental Principle: Inductance of a coil is given by:

$$\frac{N^2 \mu A}{l} = L$$

Where:

- ❑ N: Number of turns
- ❑ μ: Magnetic permeability
- ❑ A: Cross-sectional area
- ❑ l: Magnetic path length

Inductance varies when any of these parameters change.

Methods of Inductance Variation

Inductance can be varied through the following mechanisms:

1. Variation in Magnetic Permeability (μ):- If the magnetic core material changes or moves, permeability changes.

Used in :

- ✓ Inductive proximity sensors
- ✓ Ferromagnetic detection systems

2. Variation in Magnetic Path Length (l):- Changing the position of a movable core modifies the magnetic path.

Used in:

- ✓ Linear displacement sensors
- ✓ LVDT systems

3. Variation in Coil Geometry (N or A):- Changing number of turns or cross-sectional area affects inductance.

Used in:

- ✓ Variable inductance measurement devices

LVDT (Linear Variable Differential Transformer)

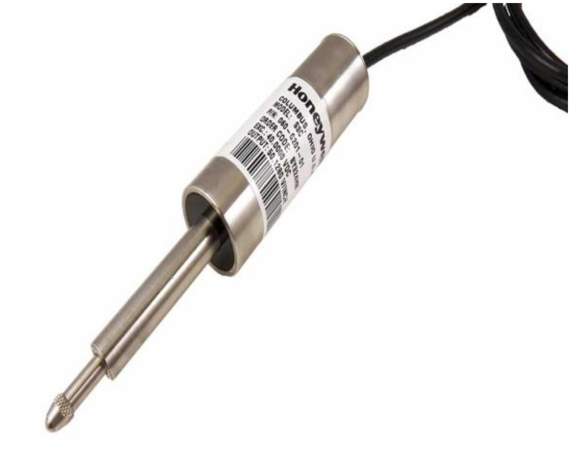
The LVDT is a highly accurate inductive displacement sensor.

Operation:

- ❑ AC excitation applied to primary coil
- ❑ Movable ferromagnetic core modifies magnetic coupling
- ❑ Differential voltage induced in secondary coils
- ❑ Output amplitude proportional to displacement

Characteristics:

- ❑ High linearity
- ❑ Frictionless operation
- ❑ Long service life



Applications:

- ❑ Joint angle measurement
- ❑ Muscle contraction monitoring
- ❑ Vibration measurement in medical devices

Electromagnetic Sensors

Definition:- Electromagnetic sensors operate according to Faraday’s Law of Electromagnetic Induction, where motion in a magnetic field induces voltage.

Fundamental Equation

$$E = B \cdot l \cdot v$$

Where:

E: Induced voltage

B: Magnetic flux density

l: Effective conductor length

v: Velocity

If a conductive fluid such as blood flows through a magnetic field, a voltage proportional to flow velocity is generated.

Biomedical Applications

- ❑ Blood flow measurement
- ❑ Cardiac output estimation
- ❑ Motion sensing systems

Signal Conditioning for Reactance Variation Sensors

Because reactance depends on frequency, these sensors require specialized AC-based conditioning circuits.

1. AC Excitation

- ❑ Stable sinusoidal source
- ❑ Frequency stability is essential
- ❑ Minimizes measurement error

2. AC Bridge Circuits

AC bridges are used to convert small changes in capacitance or inductance into measurable voltage differences.

Examples:

- ❑ Maxwell Bridge (inductance)
- ❑ Schering Bridge (capacitance)
- ❑ Wien Bridge

3. Demodulation

Since sensor outputs are AC-modulated:

- ❑ Rectification
- ❑ Synchronous detection
- ❑ Envelope detection

are used to obtain a DC signal proportional to the measurand.

4. Amplification and Filtering

- ❑ Instrumentation amplifiers increase signal level
- ❑ Low-pass filters remove carrier frequency
- ❑ Shielding reduces electromagnetic interference

Comparative Overview

Parameter	Capacitive	Inductive
Sensitivity	Very High	High
Linearity	Moderate	High
Environmental Sensitivity	High	Low
Size	Small (MEMS)	Medium
Complexity	Moderate	Moderate

Conclusion

- Reactance sensors measure physical quantities through variations in **capacitance or inductance** under AC excitation.
- Electromagnetic sensors operate based on **Faraday's Law of induction**.
- Capacitive sensing depends on geometric or dielectric changes; inductive sensing depends on magnetic field variation.
- Accurate measurement requires proper **AC signal conditioning** (bridge circuits, demodulation, amplification, filtering).
- These sensors enable **high-sensitivity, non-contact, and dynamic biomedical measurements**.

References

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