Lecture 4
Chapter 4 Basic Principles of Transducers

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Reminder: Simulink tutorials 9:00-11:00 am on Thursdays (Weeks 4 & 5 only) – G37

# Chapter 4

- Learning Outcomes: p. 4-3
- Contents of Chapter 4:
  - resistance transducers
  - capacitance transducers
  - inductance transducers and linear variable differential transformer (lvdt)
  - piezo-electrical transducers

# Chapter 4 - Definitions

- **Transducer** is a device that converts one form of energy or physical quantity to another. Often this energy or physical quantity is "*in form*" or *the same*. The energy or stimulus determines the quantity of the signal (R.G. Seippel, 1983).
- Sensor, Actuator, Detector, Transmitter:
  - A ***sensor*** is a device that detects or measures a physical quantity – a very simple measuring system
  - An ***actuator*** (an opposite device of a sensor) is a device that converts a signal (usually electrical) to some action, usually mechanical (Sinclair 2001).

# Chapter 4 - Definitions

- A ***detector*** is a device used to sense the presence of a physical quantity or physical phenomenon (heat, radiation, etc.)
- A ***transmitter*** is a device used to convert an output from a primary element into a useable signal, which is then transmitted either to an indicating instrument or to a controller.

- The difference between sensor, detector, transmitter and transducer is very slight

# Chapter 4

- Transducer sensitivity: $K_t = \frac{\Delta y}{\Delta u}$
  - **Example 5.1** Loaded spring (p. 4-5)

$$\Delta y = x\,[m] \quad \Delta u = F\,[kN]$$

$$K_t = \frac{x}{F} = \frac{0.05\,[m]}{10\,[kN]} = 0.005\left[\frac{m}{kN}\right]$$

$$F = \frac{x}{K_t} = \frac{0.075\,[m]}{0.005\,[m/kN]} = 15\,[kN]$$

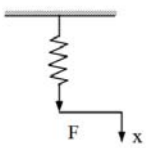
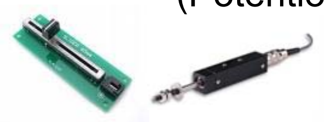



**Figure 2** Loaded spring

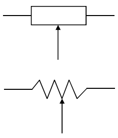
# Chapter 4

- Functions of transducer: measurement and control
- Characteristics of an ideal transducer:
  - P.4-5: fidelity, linear relationship
- Classification of transducers: electrical, mechanic, pneumatic
  - Electrical transducers: resistance (potentiometer, resistance temperature transducer), capacitance, inductance (lvdt), piezo-electric

## Chapter 4 - Resistance type (Potentiometer)




- Linear


- Carbon film

Symbol

- Rotary

## Chapter 4

- Resistance type – Potentiometer
  - Principle

$$v_o = f(x, R_T, x_T, V)$$

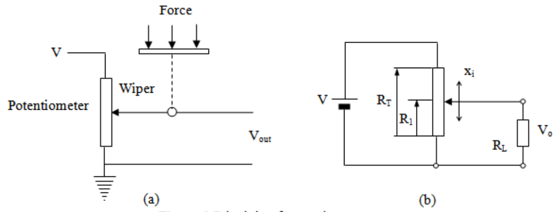
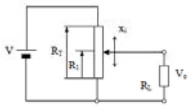



**Figure 3** Principle of potentiometer

## Chapter 4

- Resistance type – Potentiometer
  - Unloaded $v_o = V\frac{R_i}{R_T} = V\frac{x_i}{x_T}$



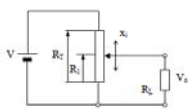

  - Maximum supply voltage:

$$V_{max} = \sqrt{PR_T}$$

  - **Example 2**: $R_T$ = 10kΩ, P = 40 mW, $X_T$ = 4 cm, x = 1.2 cm. What is $v_o$?

## Chapter 4

- Resistance type – Potentiometer:
  - Loaded condition



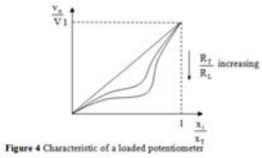




**Figure 4** Characteristic of a loaded potentiometer

$$v_o = V\left[\frac{x_T}{x_i} + \frac{R_T}{R_L}\left(1 - \frac{x_i}{x_T}\right)\right]^{-1}$$

  - **Example 3**: p. 4-7

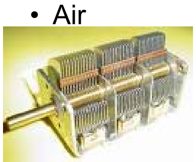
## Chapter 4

- Use of potentiometer:
  - To measure displacement (linear, angular)
  - To measure level
  - To measure force (as in strain gauges)
  - To measure pressure
  - To detect error in a control system (a comparator, or a comparison circuit)

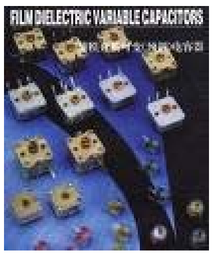
**Note:** Thermal resistance transducers (RTDs, Thermistors): Chapter 5 Temperature Measurement

## Chapter 4 - Capacitance transducers

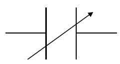
- Air



- Multi-Band




Film Dielectric



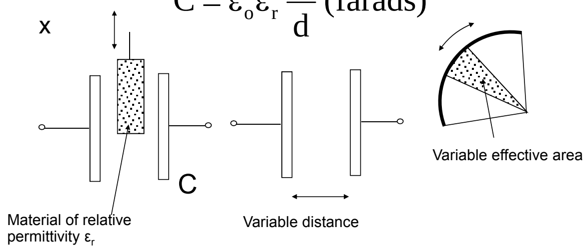
Symbol

D/P Cell

http://www.inotek.com/

# Chapter 4 – Capacitance

Principle: $$C = \varepsilon_o \varepsilon_r \frac{A}{d} \text{ (farads)}$$




Examples of Capacitive Devices

# Chapter 4

- Capacitance transducers:
  - Characteristics

$$\frac{dC}{dd} = -\frac{\varepsilon_0 \varepsilon_1}{d^2}$$

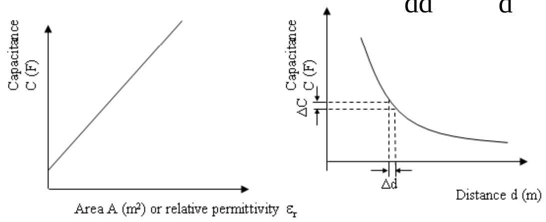
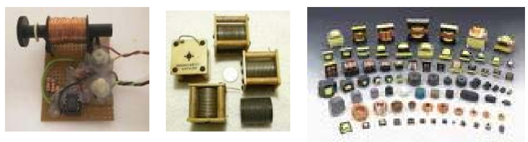



**Figure 9** Characteristics of capacitive transducers

# Chapter 4

- **Example 6:** how to calculate the sensitivity of a capacitance device $$\frac{dC}{dd} = -\frac{\varepsilon_0 \varepsilon_1}{d^2}$$
- Use of capacitance transducers:
  - To measure level, displacement
  - To measure pressure, differential pressure, forces and moments
  - To measure flow rate
  - To measure acceleration

# Chapter 4 – Inductance transducers (variable inductor and l.v.d.t)

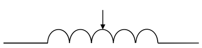


Variable inductors  Inductors and transformers


Linear Variable Differential Transformers

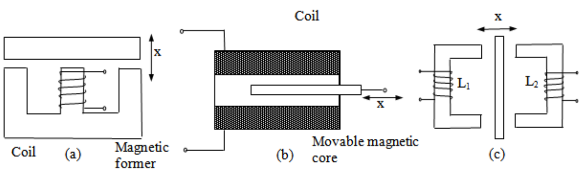
# Chapter 4

- Inductance transducers:
  - Principle



Symbol

$$L = \frac{\mu_0 \mu_r N^2 A}{l} \qquad L = \frac{N^2}{S}$$




# Chapter 4

- Inductance transducers:
  - **Example 7**: how to determine the sensitivity of a single coil inductive transducer:
    - (a) variation in relative permeability

$$\frac{dL}{d\mu} = \frac{\mu_0 N^2 A}{l}$$

    - (b) variation in length of magnetic circuit

$$\frac{dL}{dl} = -\frac{\mu_0 \mu_r N^2 A}{l^2}$$

## Chapter 4

- Inductance transducers
- Advantages:
  - Large displacement can be measured
  - Friction between plunger and body is insignificant, thus giving a long life
- Disadvantages:
  - Not quite as linear as the potentiometer or the linear variable differential transformer (lvdt)
  - Frequency range is limited to 0.1 of the excitation frequency of the a.c. bridge (not applicable to the FM system)

## Chapter 4

- Inductance transducers
  - LVDT = Linear Variable Differential Transformer

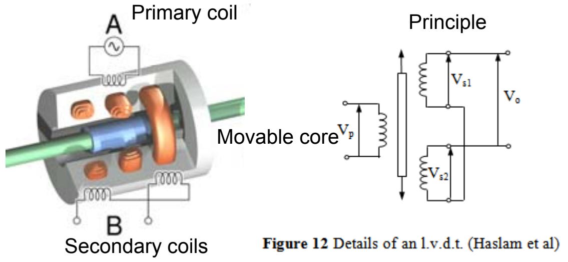



**Figure 12** Details of an l.v.d.t. (Haslam et al)

http://www.rdpe.com/displacement/lvdt/lvdt-principles.htm

## Chapter 4

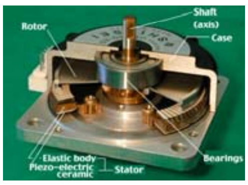
- Inductance transducers - LVDT
- Advantages:
  - There is no frictional contact between the core and the coils and therefore inductive device has long life than potentiometer
  - Infinite resolution
- Disadvantages:
  - Displacement frequencies of only up to 0.1 of the excitation frequency can be measured
  - Complex electronic circuitry is required, including an oscillator for frequencies other than main frequency.

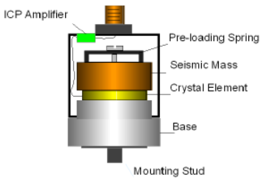
## Chapter 4

- Use of inductance transducers:
  - To measure displacement
  - To measure level
  - To measure acceleration
  - To pressure (differential pressure transmitter)
  - To measure forces, moments and strain

## Chapter 4

- 2.5 Piezo-electric Transducers:
  - Construction: using crystal materials: ceramic, quartz




http://www.tky.3web.ne.jp/

- Piezo-electric transducer

## Chapter 4

- 2.5 Piezo-electric Transducers:
  - Principle

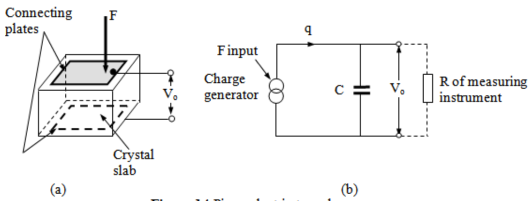



**Figure 14** Piezo-electric transducer

- **Example 8** pp.4-13

## Chapter 4

- Piezo-electric transducers:
  - Applications:
    - Pressure
    - Forces and moment
    - Acceleration

## Chapter 4

- Other types of transducer:
  - Force-to-displacement transducers:
    - Spring
    - Cantilever
  - Pressure-to-displacement transducers:
    - Diaphragms
    - Bellows
  - Displacement-to-pressure transducers:
    - Nozzle-flapper system
    - Nozzle-flapper with bellows
  - Piezo-resistive transducers

## Chapter 4

- Summary of Chapter 4
- Four common types of transducer
  - Resistance
  - Capacitance
  - Inductance
  - Piezo-electric
- Other types of transducer:
  - Self-study

## References


- http://www.rdpe.com/displacement/lvdt/lvdt-principles.htm
  http://www.analog.com/library/analogDialogue/archives/42-08/lvdt.html
- http://www.piezomaterials.com/
- http://content.honeywell.com/sensing/sensotec/lvdt.asp


## Activities

- Activity 1 Capacitance displacement sensor

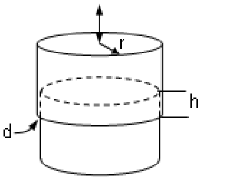
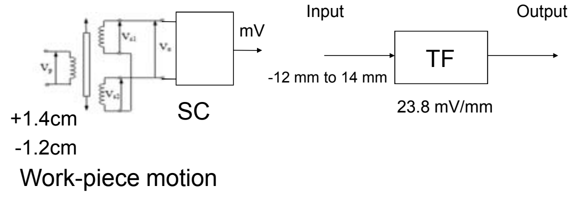



**Figure 1** Capacitance displacement sensor

## Activities

- Activity 2 LVDT
  - An LVDT has a maximum core motion of 1.5 cm with a linearity of 0.3% over that range. The transfer function is 23.8 mV/mm. If used to track work-piece motion from –1.2 to + 1.4 cm, what is the expected output voltage? What is the uncertainty in position determination due to nonlinearity?



## Activities

- Activity 3 Capacitance level sensor

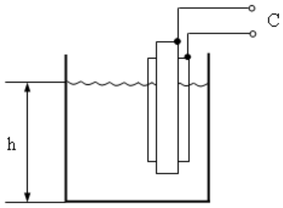



**Figure 2** Capacitance level sensor

## Any Questions?