# BFF3302 SENSOR AND INSTRUMENTATION SYSTEM

## Transducer Elements

By

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# Chapter Description

- Aims
  - Obtain basic knowledge about transducer.

- Expected Outcomes
  - Determine general treatment of instrument elements and their characteristic
  - Analyse transducer elements, intermediate elements, and data acquisition system (DAQ)
  - Determine principles of the work and derive mathematical model of sensors for measuring motion and vibration, dimensional metrology, force, torque and power, pressure, temperature, flow and acoustics

- References

  - B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.
  - Introduction to signal processing, instrumentation, and control : an integrative approach / Joseph Bentsman Hackensack, NJ : World Scientific Pub., 2016
  - Transducers for instrumentation / M. G. Joshi, New Delhi, India : Infinity, 2017
  - Instrumentation and measurement in electrical engineering / editor : Harinirina Randrianarisoa, New York : Arcler Press, 2017

# What is a Sensor?

- A sensor is a device that r**eceives a signal and responds with an electrical signal**.
- It detects the parameter

* Eg. Thermocouple to sense/detect the changing of temperature.

**What is Transducer?**

- A transducer is a **converter of one type of energy to another**.
- OR
- A device that converts non electrical parameters into electrical signals (voltages or currents) or vice versa that are proportional to the value of the physical parameter being measured.

# Introduction

## Transducer

| Analog | Digital |
| --- | --- |
| variation of input and produce a continuous variation of output | variation of input and produce a digital or discrete output. |

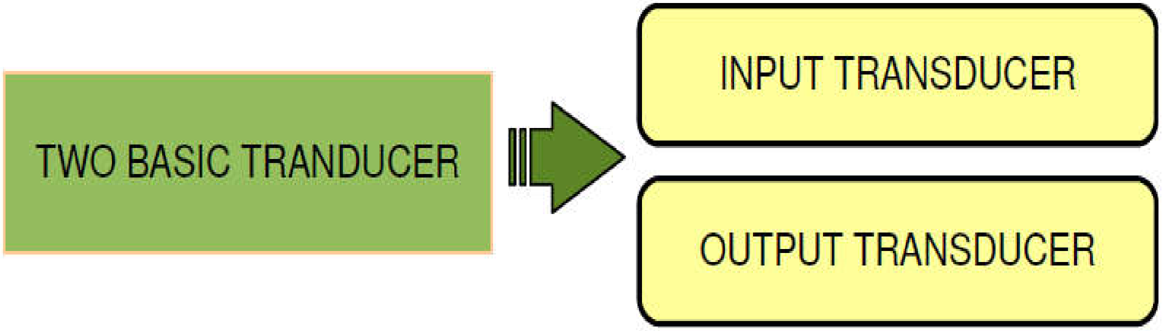
**Analog**

- Electromechanical types, potentiometric resistance type, inductance, capacitive, piezoelectric, resistance strain gauge, ionisation and mechano-electronic types.
- transducers, comprising photo-emissive, photo-conductive and photo-voltaic

**Digital**

- Digital encoder types
- Frequency generating types

# Introduction




- **INPUT TRANSDUCER**
- * **Also called sensors**
- * Convert physical quantity → proportional electrical signal.

**OUTPUT TRANSDUCER**

- Convert an electrical signal → physical quantity that can detect or use externally.

# Introduction

Example of transducer in everyday life:

| | |
|---|---|
| Thermostat in lecture room | Input tranduser that sense room temperature and is used to control air conditioning |
| Streetlight | Equipped with photo sensor that are used to turn the lights on when sun goes down |
| Speaker | Output transducer that converts electrical signal into sound energy |

* Extra notes can be read at:
http://en.wikipedia.org/wiki/Transducer
http://www.kpsec.freeuk.com/transduc.htm

# Introduction

- A transducer's output can be voltage, current or resistance.

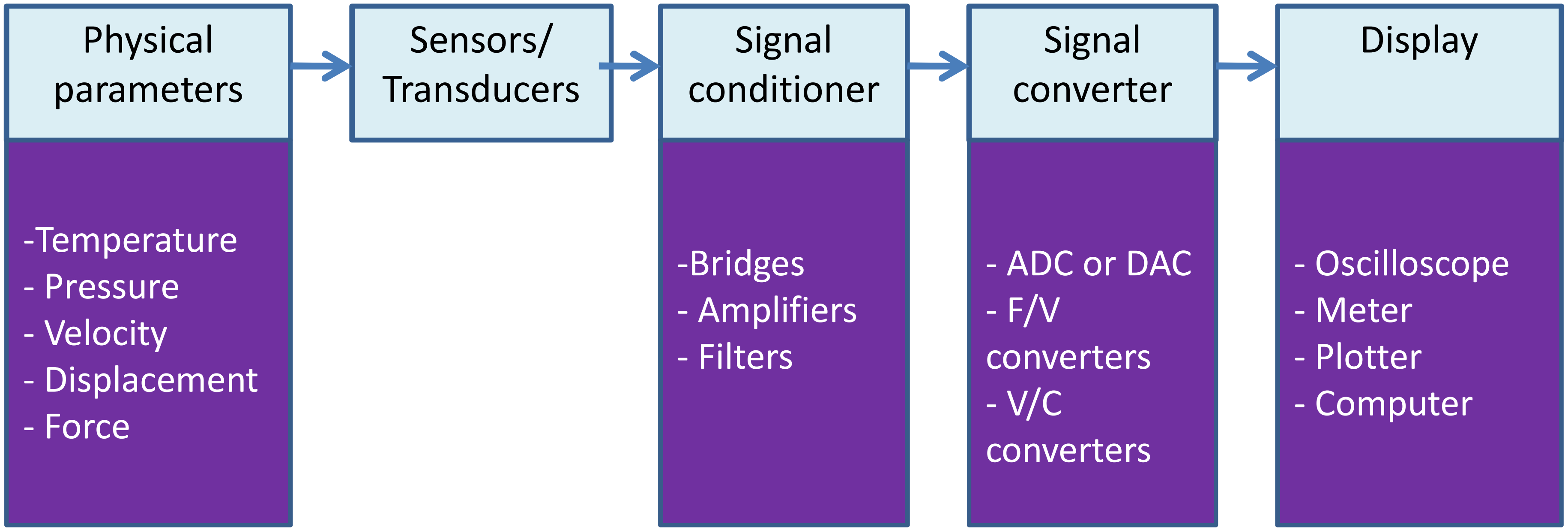
| Output | Example of transducer |
|---|---|
| Voltage | Thermocouple |
| Current | IC temperature transducer |
| Resistance | Resistance Temperature Detector (RTD)<br>Thermistor<br>Strain gauge |

# Electrical transducer

- ➔ sensing device that transform physical, mechanical or optional quantity into an (e.g.) electrical voltage/current proportional to the input measurement.

- Electrical transducer should have following parameter:
  - Linearity – input changes directly proportional to output
  - Sensitivity – small changes results in changes of output voltage (e.g.)
  - Dynamic range – small scale to bigger scale
  - Repeatability – produce similar output for same input value
  - Physical size – compact, easy to carry/used

# Instrumentation systems




- In a nutshell, an instrumentation system should have sensors, signal conditioners, signal converters and a display.

# Electromechanical types

- An electrical output is produced due to an input of mechanical displacement or strain.

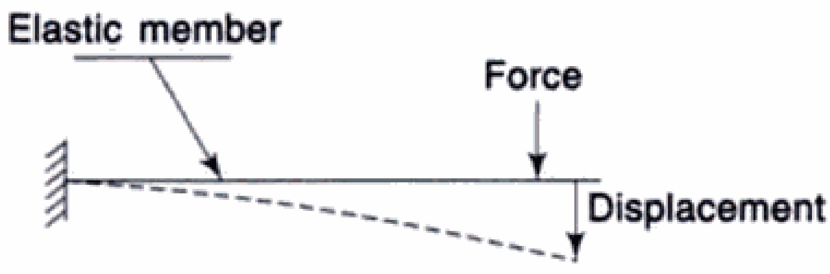
- The mechanical displacement or strain input in turn may be produced by a primary sensor due to the input physical variable which may be pressure, flow, etc.

# Electromechanical types

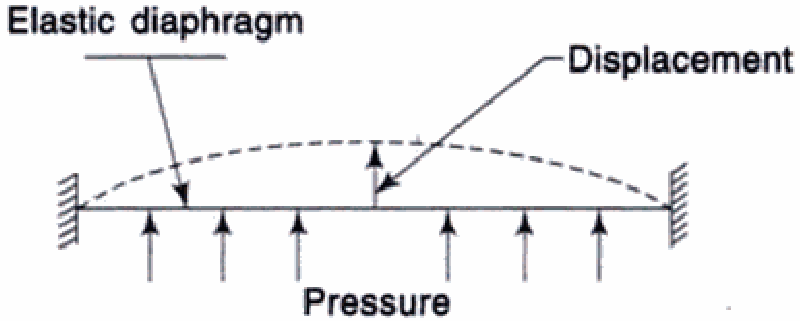
Scheme for measurement using electromechanical transducer:


B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

# Electromechanical types

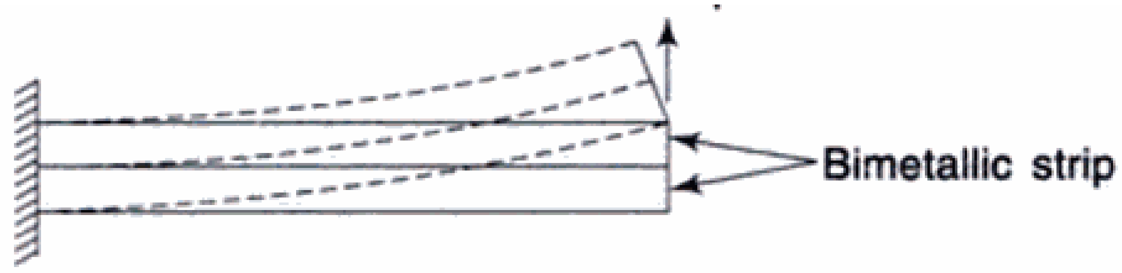



(a) Primary sensor for force input




(b) Primary sensor for pressure input

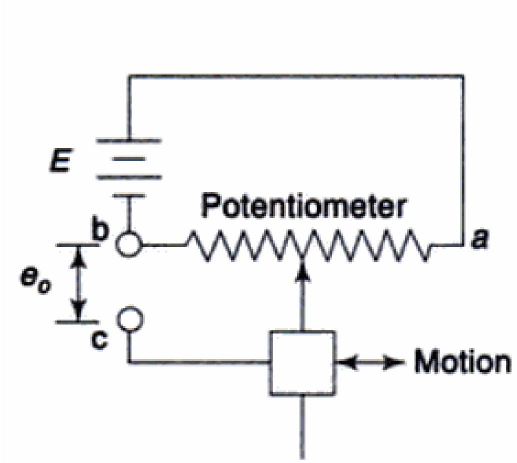
Displacement Due to temperature

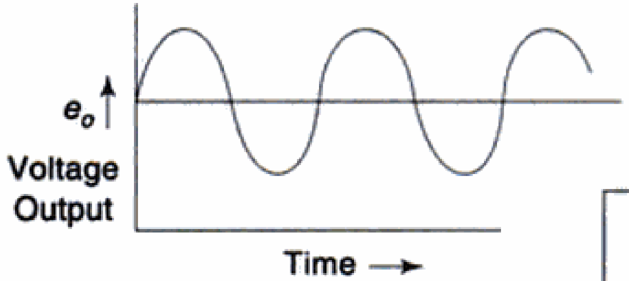


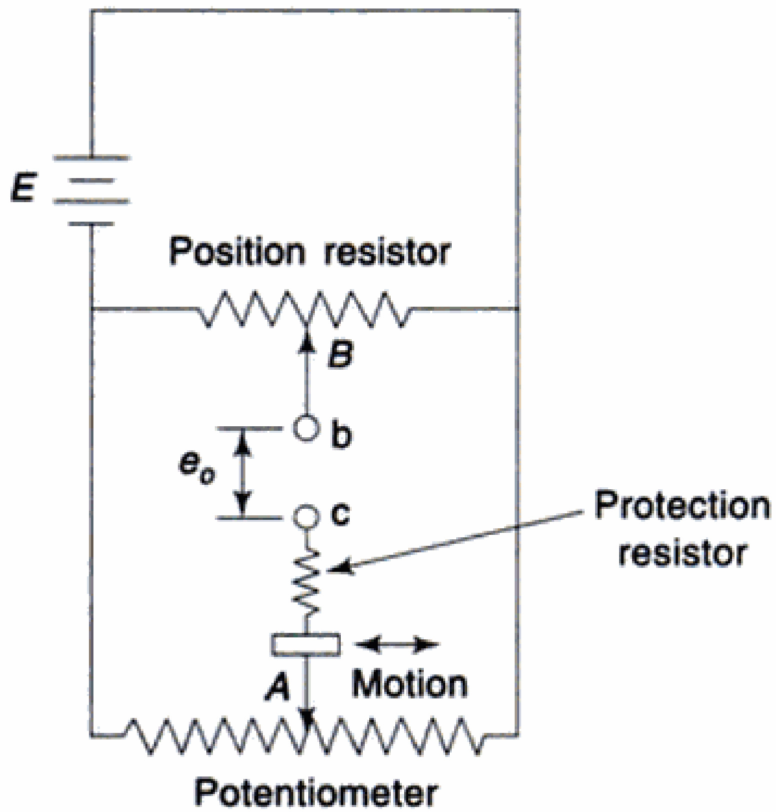

(c) Primary Sensor for Temperature Input

B.C.Nakra and K.K. Chaudhry, 2012.
Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

# Potentiometric resistance-type transducer




B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

# Inductive-type transducers

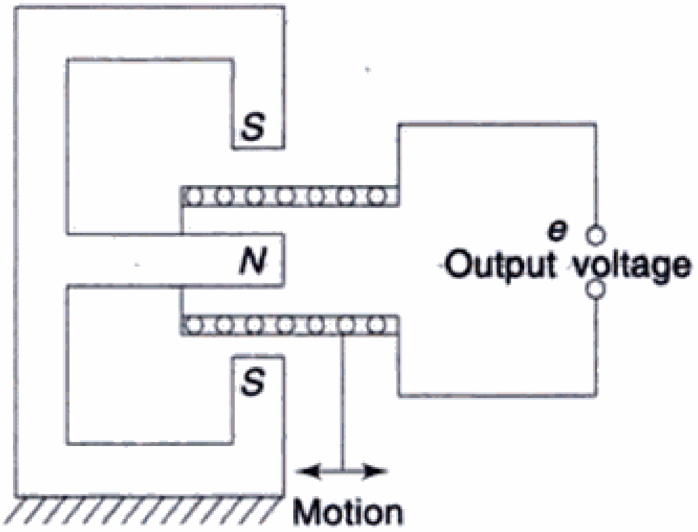



**Fig. 4.5** *Electrodynamic transducer*

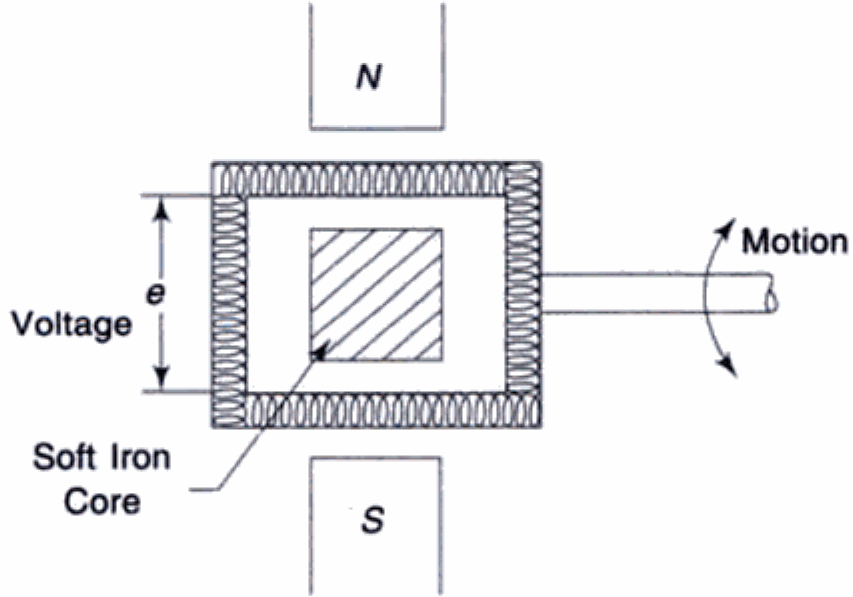



**Fig. 4.6** *Electrodynamic transducer for rotary motion*

B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

# Inductive-type transducers

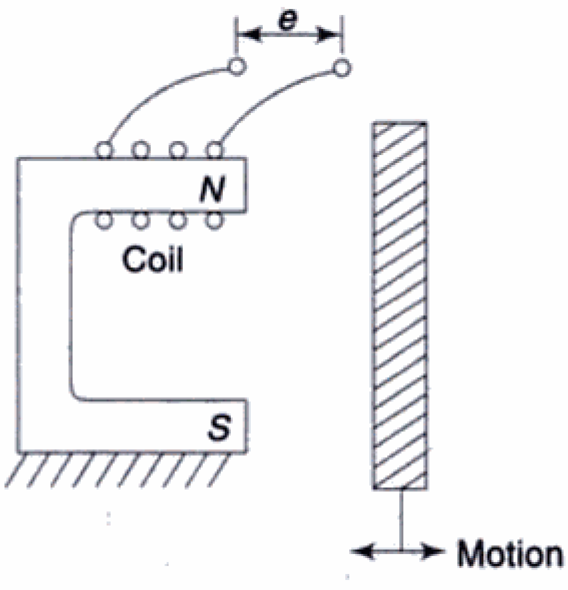



Fig. 4.7 *Electromagnetic transducer*

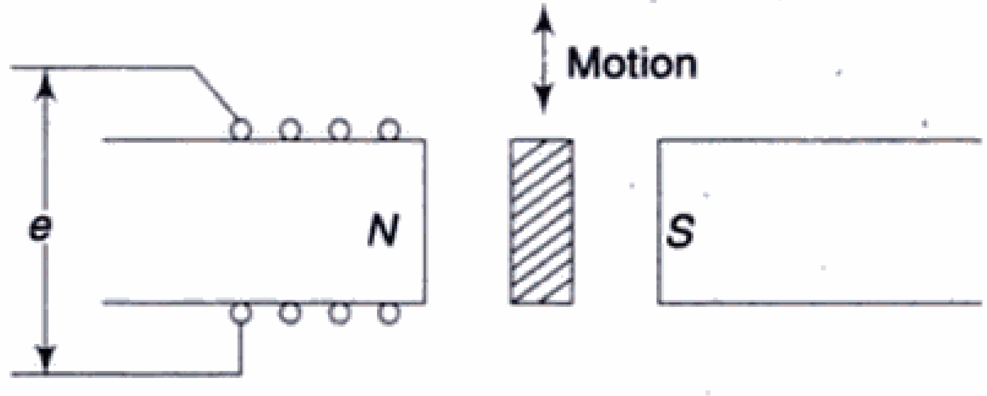
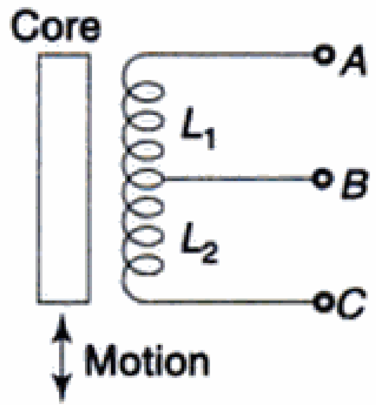



Fig. 4.8 *Eddy current transducer*




B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

# Inductive-type transducers

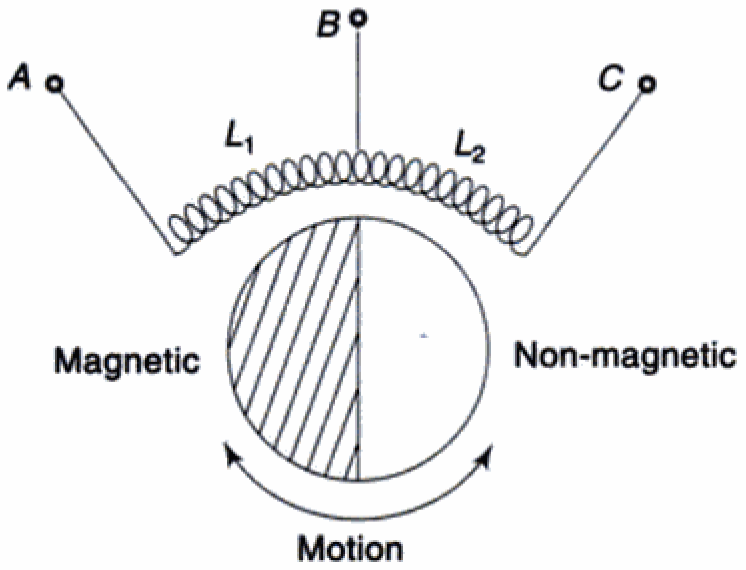



**Fig. 4.10** *Variable inductance transducer for rotary motion*

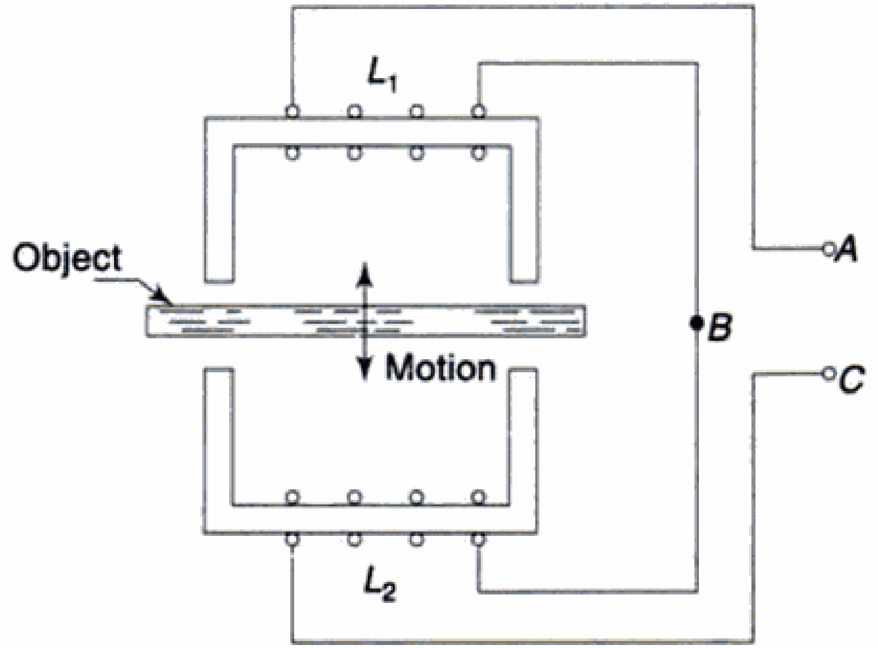



**Fig. 4.11** *Proximity type inductance transducer*

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# Inductive-type transducers

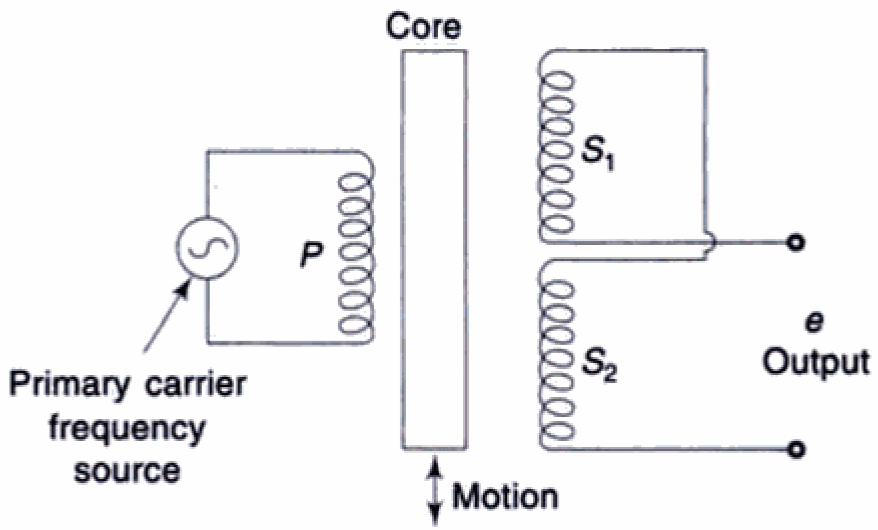


**Fig. 4.12** *LVDT (Linear motion type)*

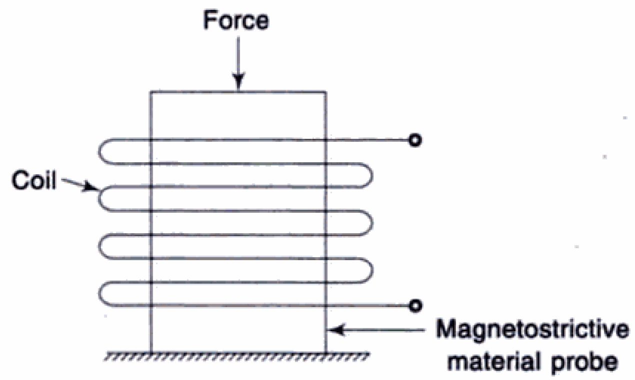


**Fig. 4.14** *Magnetostrictive transducer*

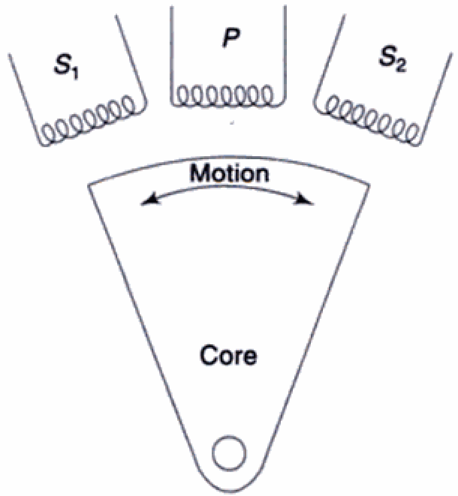


**Fig. 4.13** *LVDT (Rotary motion type)*

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# Capacitive type transducer

The capacitance $C$ between two plates is given by

$$C = \frac{1}{3.6\pi}\,\varepsilon\,\frac{A}{d} \qquad (4.1)$$

where $C$ is capacitance, µF
$A$ is area of plates, $cm^2$
$d$ is distance between plates, cm
$\varepsilon$ is dielectric constant of the medium between the plates (= 1 for air).

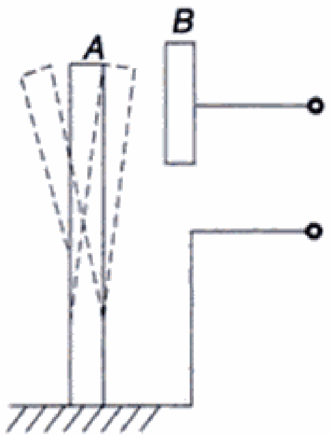


**Fig. 4.15** *Gap-change type capacitive transducer*

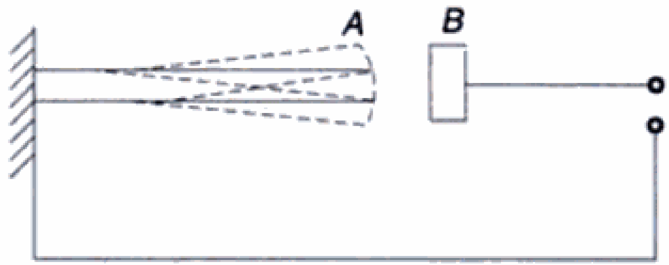


**Fig. 4.16** *Area-change type capacitive transducer*

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# Piezo-electric transducer

$C$ being the capacitance of the crystal ($\mu F$), $\varepsilon$ the dielectric constant of the crystal material, $A$ its area ($cm^2$) and t its thickness (cm). If $A$ is in square metre ($m^2$), $t$ in metre (m) and $C$ in farads ($F$), Eq. (4.8) becomes:

$$C = \frac{\varepsilon A}{1.31 \times 10^{11}\, t} \tag{4.9}$$

Relation between force $P$ and deformation $x_i$ is:

$$P = EA\frac{x_i}{t} \tag{4.10}$$

$E$ being the Young's modulus of the crystal material.

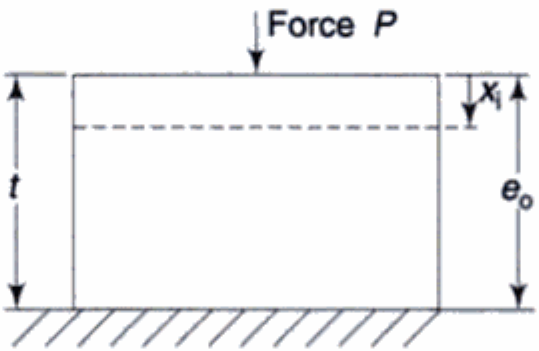



**Fig. 4.21** *Piezo-electric crystal subjected to force P*

B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

# Piezo-electric transducer

**Table 4.2** Properties of some Piezo-electric Materials

| *S.No.* | *Material* | *Charge sensitivity pC/N* | *Dieelectric constant ε* | *Young's modulus N/m²* |
|---|---|---|---|---|
| 1. | Quartz | 2.0 | 4.5 | $9 \times 10^{10}$ |
| 2. | Tourmaline | 1.9 | 6.6 | $16 \times 10^{10}$ |
| 3. | Barium titanate | 150 | 1380 | $12 \times 10^{10}$ |
| 4. | Lead zirconate titanate | 265 | 1500 | $7.9 \times 10^{10}$ |

B.C.Nakra and K.K. Chaudhry, 2012.
Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

# Resistance strain gauges

Strain gauge transducers are of two types:

1. Unbonded strain gauge
2. Bonded strain gauge

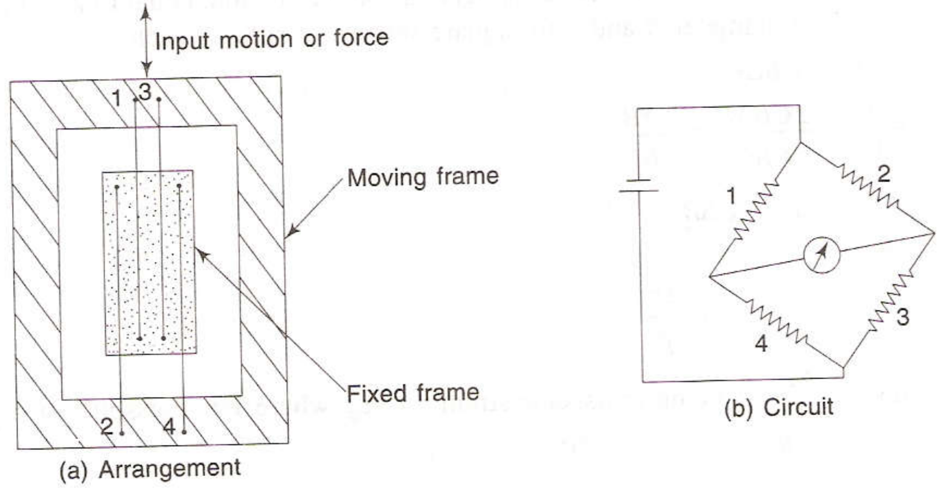



Fig. 4.28 *Unbonded strain gauge*

B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

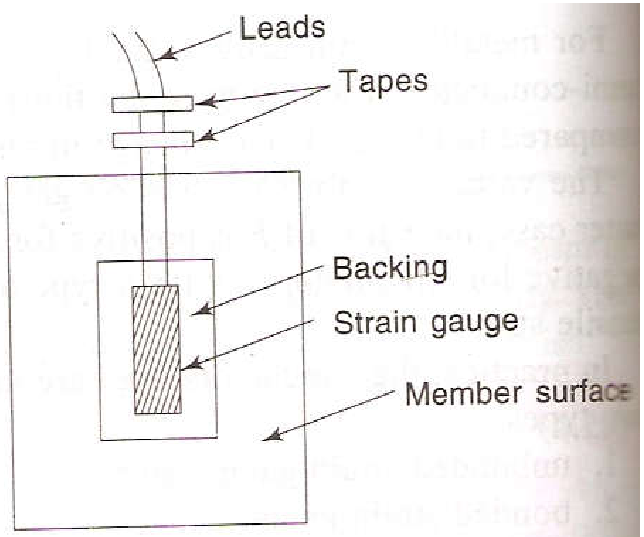



Fig. 4.30 *Strain gauge in bonded position*

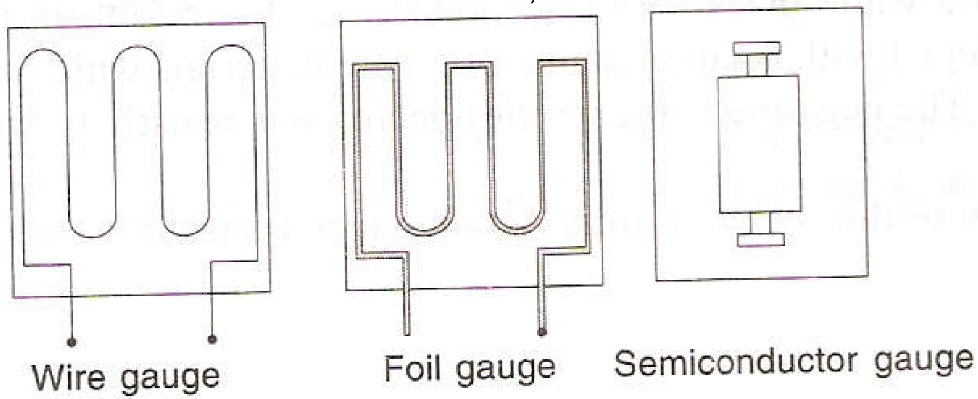
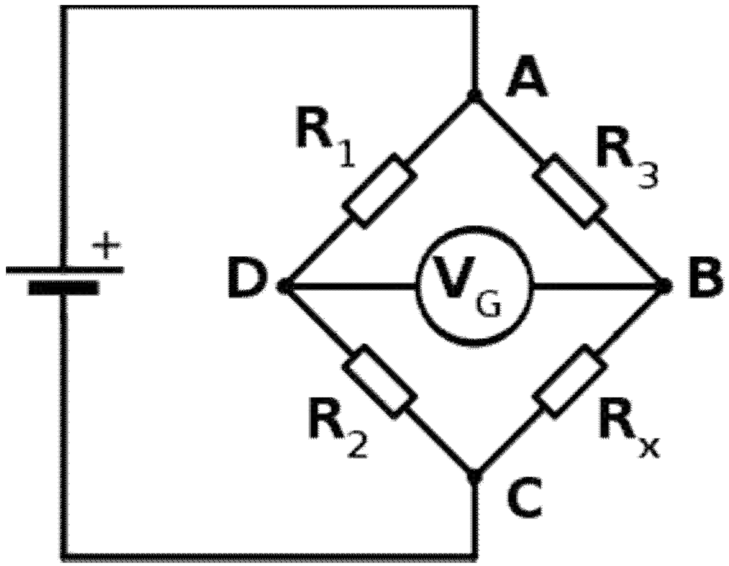



Fig. 4.29 *Types of resistance strain gauges*

# Wheatstone Bridge

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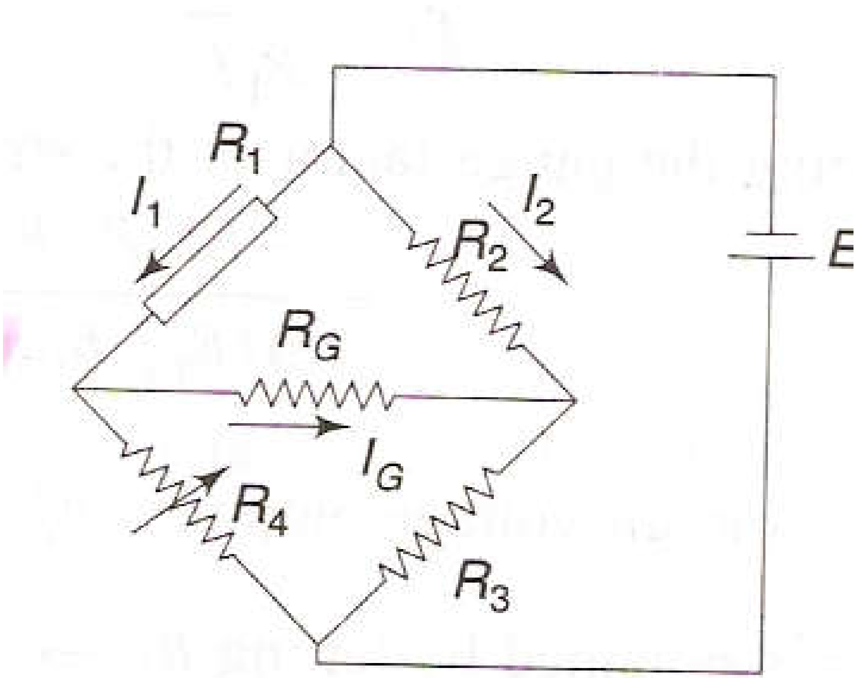


**Fig. 4.31** *Balanced strain gauge*

# Analysis of Bridge Circuits

- When the bridge is balanced, $V_o = 0$

$$V_o = V_c\left[\frac{R_2}{R_1 + R_2}\right] - V_c\left[\frac{R_x}{R_3 + R_x}\right] = 0$$

$$V_c\left[\frac{R_2}{R_1 + R_2}\right] - V_c\left[\frac{R_x}{R_3 + R_x}\right] = 0$$

$$\left[\frac{R_2}{R_1 + R_2}\right] - \left[\frac{R_x}{R_3 + R_x}\right] = 0$$

$$\left[\frac{R_2}{R_1 + R_2}\right] = \left[\frac{R_x}{R_3 + R_x}\right]$$

$$R_2 R_3 + R_2 R_x = R_x R_1 + R_x R_2$$

$$R_2 R_3 = R_x R_1$$

$$\boxed{\boldsymbol{R_x = \frac{R_2 R_3}{R_1}}}$$