CEP Workshop "Low Cost High-tech Automation with Applications",
Course Coordinator: Prof N Ramakrishnan, IIT Bombay, 30/08/07 to 03/09/07

SENSORS

P. C. Pandey

EE Dept, IIT Bombay
[pcpandey@ee.iitb.ac.in, www.ee.iitb.ac.in/~pcpandey]

Sept '07

References

EO Doeblin: Measurement Systems: Application and Design.
CS Rangan, GR Sarma, & VSV Mani: Instrumentation: Devices & Systems.
WD Cooper & AD Helfrick: Electronic Instruments & Measurement Techniques.

1. INTRODUCTION

Sensor: device for measuring a physical variable

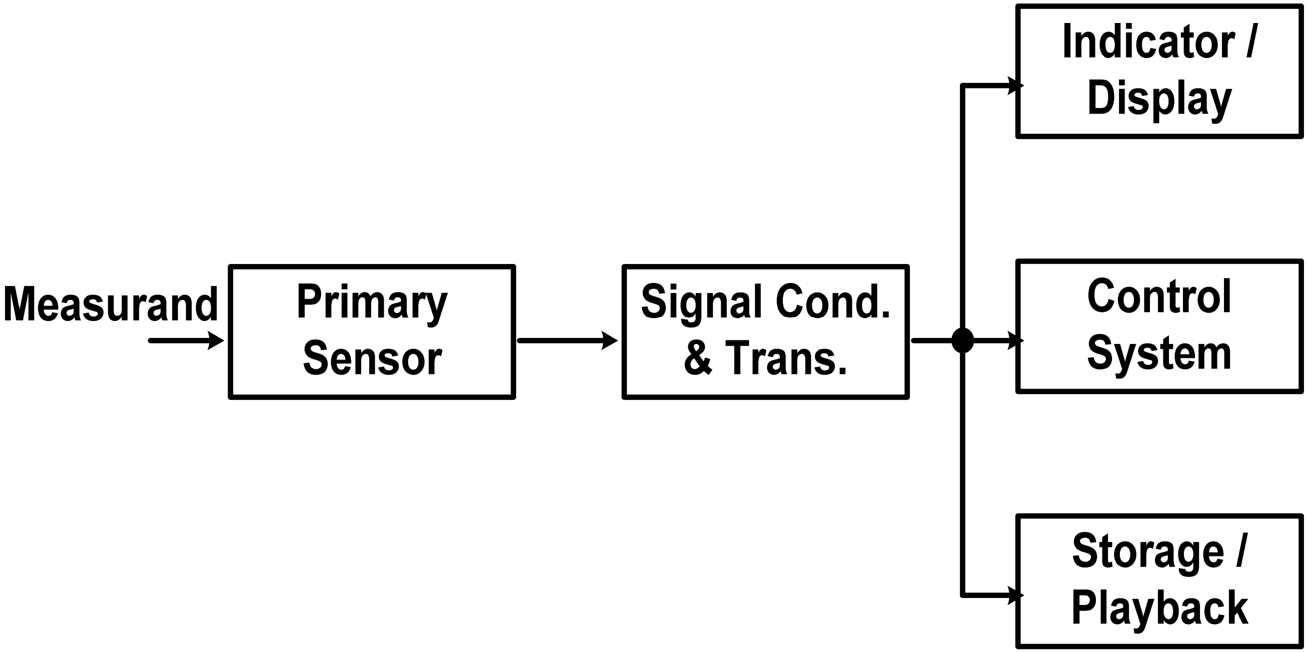
Transducer: an energy conversion device

Active transducers (involving energy conversion): Output related to the input without any external energizing source. Examples: thermoelectric, piezoelectric, photovoltaic, electrodynamic, electromagnetic, etc

Passive transducers (involving energy control): Parameter variation caused by the measurand sensed by using energy from an external source. Examples: piezoresistive, photoconductive, thermo-resistive, capacitive, Hall effect, etc.

Sensor Applications

- Monitoring of process & operations (indication and display)
- Feedback control of processes & operations
- Experiment analysis & testing



Signal: Waveform (function of time or space variables) containing information (e.g. voltage, current, resistance, pressure, temperature, etc.)

Type of Signals

- *Analog*: Continuous time & continuous amplitude
- *Quantized:* Continuous time & quantized amplitude
- *Discret- time or sampled*: Sampled time & continuous amplitude
- *Digital:* Sampled time & quantized amplitude

Signal Conditioning

Amplification, preliminary filtering, compensation

Signal Processing

Interference reduction, information extraction

Sensors with Electronic Signal Conditioning

- Less loading of the measurand
- Higher flexibility

Digital Measurement / Control / Indication System

Analog signal
↓ A-to-D conversion
Digital signal
↓ Digital signal processing
Digital output
↓ Display / Digital control / D-to-A converter

Digital Signal Processing (DSP)

- Digital operations on data sequence to retrieve the information of interest.
- Cost effective for complex processing operations
- Time sharing of the hardware possible
- Easier realization of new processing algorithms
- Free from the effects of component value drifts.
- Problems:
  - Signal quantization errors
  - Coefficient quantization errors
  - Overflow and underflow during operations

Basic Sensor Requirements:

- ♦ Minimal disturbance in the measurand quantity
- ♦ Sensitive to the specific measurand and insensitive to other varying parameters

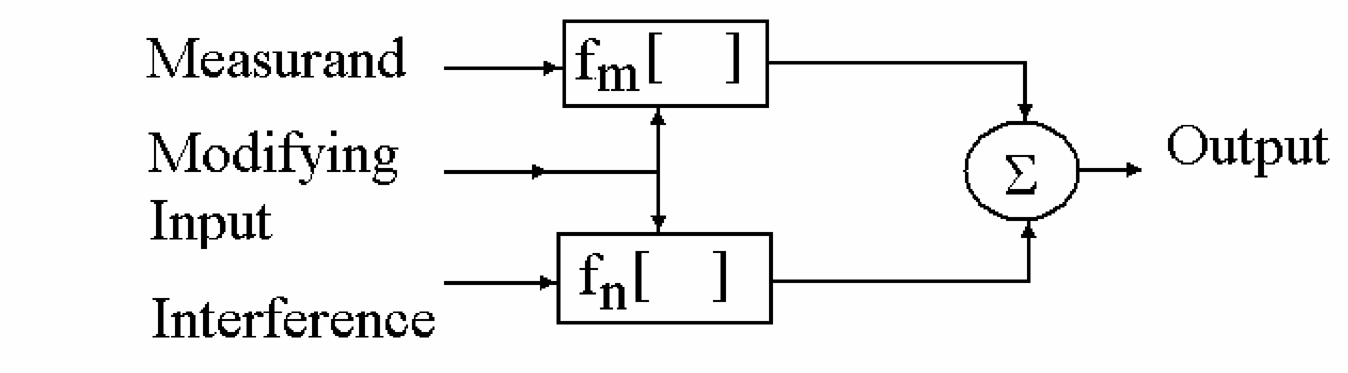
Desirable Sensor Characteristics

- Ruggedness
- Linearity
- Repeatability (under same environmental conditions)
- Calibration stability w.r.t. environment variations)
- Dynamic response: Faithfulness of output to input as a function time → Good frequency response
- Freedom from hysteresis

Sensing Methods

- ***Deflection method:*** **Output related to the measurand**
- ***Null method:*** **Output brought to zero by a balancing effect**
  - **High sensitivity**
  - **High accuracy**
  - **Less convenient**
  - **Poor dynamic response**

Input Output Relation



Corrective Actions

- ♦ **Linearization, offset and gain corrections**
- ♦ **Compensation:**
  - ▪ **response compensation (static)**
  - ▪ **compensation (dynamic) by sensing the modifying input**
- ♦ **Interference cancellation**

Different Types of Sensors

♦ **Linear Displacement:** length, position, thickness, surface quality, strain, velocity, acceleration

♦ **Linear Velocity:** speed, rate of flow, vibration

♦ **Linear Acceleration:** Vibration, jerk, motion

♦ **Angular Acceleration:** Torque, angular vibration, moment of inertia

♦ **Force:** Weight, stress, vibration, acceleration, pressure, flow, sound intensity

♦ **Temperature:** fluid expansion, heat flow, radiation pressure, sound velocity

♦ **Light:** Light flux, density, temperature, frequency

♦ **Time:** Frequency, no. of events

2. DISPLACEMENT SENSORS

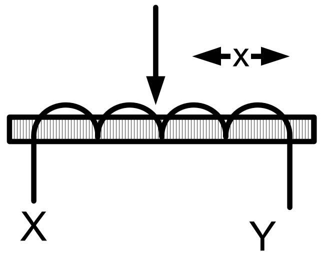
- Linear and angular displacement
- Derived quantities: force, stress, pressure, velocity, acceleration
- Mechanical linkage by sensing shaft or spring-loaded shaft.
- No linkage for electromagnetic, optical encoders, etc.

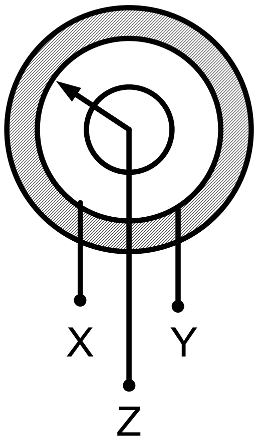
Types:

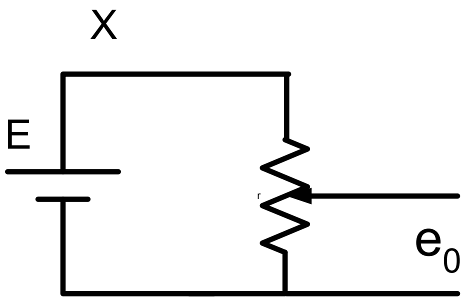
- Variable resistance: potentiometric, strain gauge
- Variable inductance: LVDT
- Variable capacitance transducer
- Synchros & resolvers
- Electro optical devices
- Digital encoders
- Radio-active devices

2.1 Variable Resistance Sensor

- **Winding wire**: precision drawn, 25 to 50 μ
- **Resistivity**: 0.4 μΩ.m to 1.3 μΩ.m
- **Wiper contact**: spring contact
- **Former**: good dimensional stability & surface insulation
- **Resolution achievable**: 0.1 % of full scale (generally not better than 5 %). Continuous R variation with plastic film.





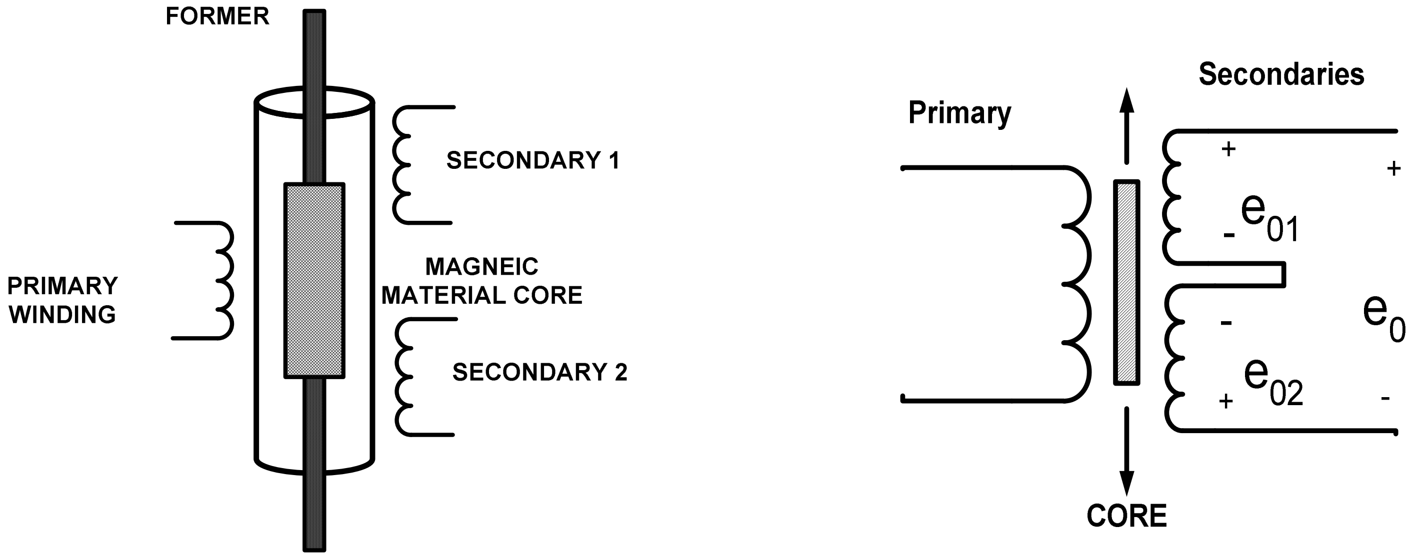


Translational or rotary displacement

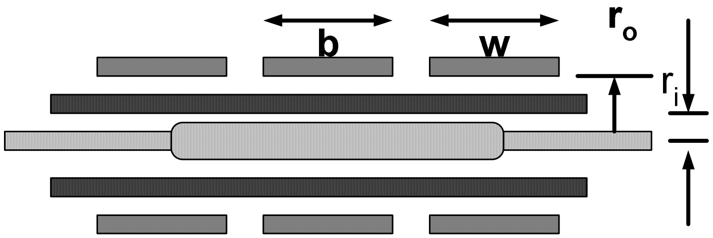
→ Motion of contact point

→ Output voltage variation

2.2 Linear Variable Differential Transformer (LVDT)



- **Transformer with a primary coil & two identical secondary coils (axially spaced on same former)**
- **Fine resolution, good stability**



$$e_o = \frac{16\pi^3 f.I_p.n_s}{10^9 \ln\left(\frac{r_o}{r_i}\right)}.\frac{2^b}{3w}.x\left(1-\frac{x^2}{2b^2}\right)$$

f = excitation frequency,
n_p, n_s = no. of turns in primary and secondary,
w = width of secondary coil,
x = core displacement

I_p = primary current
b = primary coil width
r_o, r_i = outer and inner radii of the coil

For $|x| \ll b$, $e_o \propto x$

I_b **should be large, without causing core saturation**

f **should be large, but should not cause errors due to stray capacitances.**

Coil former: non magnetic material with dimensional stability (phenolic or ceramic)
Coil wire: enameled Cu
Moving core: ferromagnetic, with high permeability
Casing: Ferromagnetic, for electrostatic & electromagnetic shielding
Frequency: 50 Hz, 2 kHz-10 kHz
Excitation voltage: ~ 1 V

Varying displacement : variation in amplitude of output carrier
Phase sensitive detector: for polarity & magnitude of displacement
Dynamic response : 0.1 carrier frequency
Resolution : 10 μ
Linearity: 0.25 % (depends on length of the coil)

2.3 Variable Capacitance Transducer

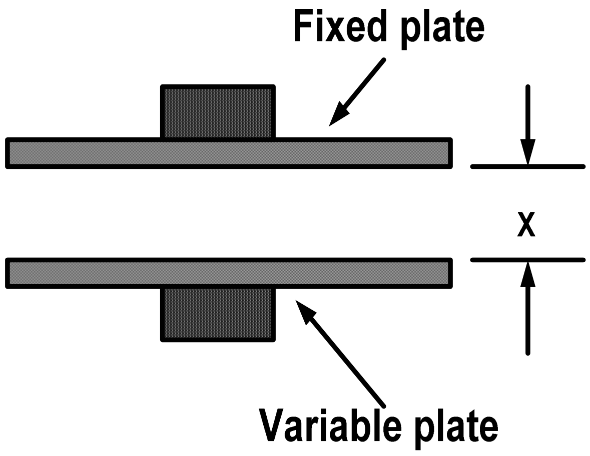
- Non-contact, dynamic, small size, small mechanical loading, suitable for small displacements

- Sensing of
  - change in air gap between parallel plates
  - change in common area

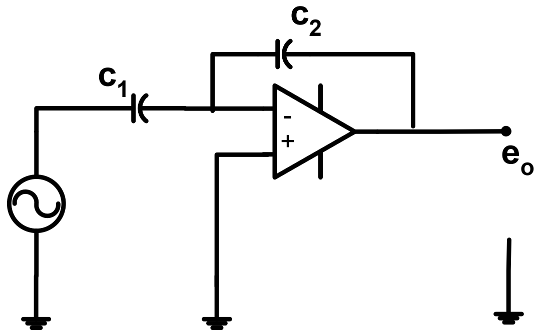
$$C = \varepsilon_0 \frac{kA}{x}$$

ε = permittivity of free space

k = relative permittivity



$$A = A_0 - \Delta A$$



$$e_0 = -\left(\frac{j\omega C_1}{j\omega C_2}\right)e_i = -\frac{C_1}{C_2}e_i$$

Variable gap capacitor

$$dC/dx = -\varepsilon_0\frac{kA}{x^2} = -C/x$$

$$dC/C = -dx/x$$

With C_1 fixed, C_2 varying, $e_0 = -\frac{C_1 e_i}{\varepsilon_0 \frac{kA}{x}} = -\frac{C_1}{\varepsilon_0 kA}e_i x$ **& therefore** $e_0 \propto x$

Variable area capacitor

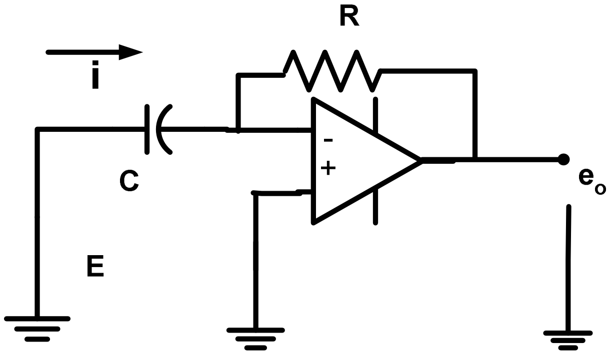
$$dC/dA = \varepsilon_0\frac{k}{x} = \frac{C}{A}$$

$$dC/C = -\frac{dA}{A}$$

With C_1 varying, C_2 fixed

$$e_0 = -\frac{kA}{xC_2}e_i \Rightarrow e_0 \propto A$$

Velocity Sensor



$$Q = EC, \; i = \frac{dQ}{dt} = E\frac{dC}{dt}$$

$$i = E\frac{d}{dt}\left(\varepsilon_0 k\frac{A}{x}\right) = -E\varepsilon_0\frac{A}{x^2}\frac{dx}{dt}$$

$$= E\left(\varepsilon_0 k\frac{A}{x}\right)\left(-\frac{1}{x}\frac{dx}{dt}\right) = -EC\frac{\dot{x}}{x}$$

$$e_o = -iR = ECR\frac{\dot{x}}{x}$$

For small displacements, about a mean displacement

$e_0 \propto \dot{x}$ ⇒ **velocity sensor**

3. STRAIN SENSORS

Stress (force per unit area) → **Strain** (mechanical deformation) $\frac{\Delta l}{l}$

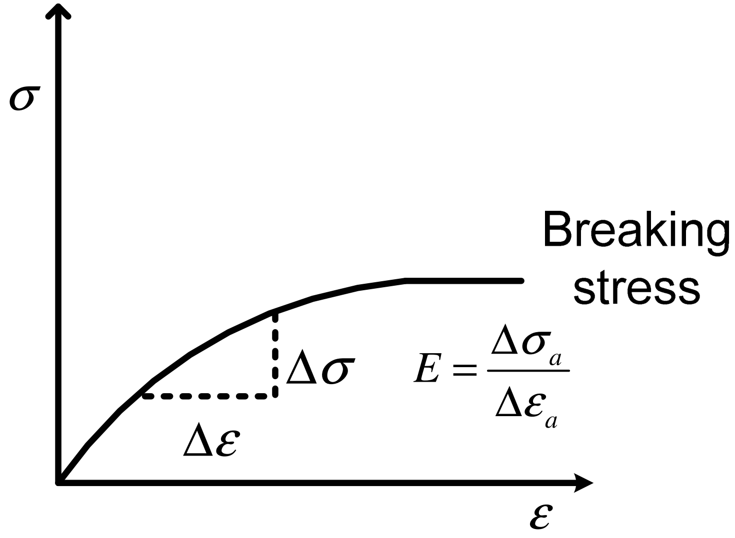
Stress-strain relationship
during compression or tension:

$$\varepsilon_a = \frac{\Delta l}{l} = E^{-1}\sigma_a, or$$

$$\sigma_a = E\varepsilon_a$$

where E =Young’s modulus,

σ_a = axial stress and ε_a = strain (axial).



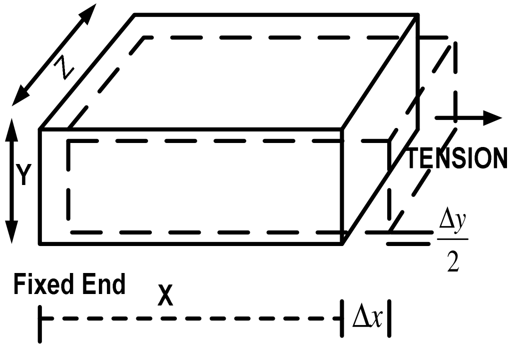
Relationship is linear if the stress applied is below the elastic limit.
Axial tension → increase in length, decrease in cross section

Three strains, for tension stress σ_x along x-axis, and Poisson’s ratio = ν (~=0.3),

$$\varepsilon_x = \frac{\Delta x}{x} = \frac{\sigma_x}{E}$$

$$\varepsilon_y = -\frac{\Delta y}{y} = -\nu\frac{\sigma_x}{E}$$

$$\varepsilon_z = -\frac{\Delta z}{z} = -\nu\frac{\sigma_x}{E}$$



For stress applied in all dimensions, with components $\sigma_x, \sigma_y, \sigma_z$

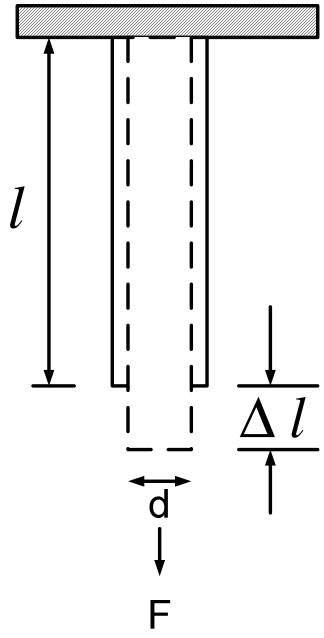
$$\varepsilon_x = \frac{\sigma_x}{E} - \nu\frac{\sigma_y}{E} - \nu\frac{\sigma_z}{E}$$

$$\varepsilon_y = -\nu\frac{\sigma_x}{E} + \frac{\sigma_y}{E} - \nu\frac{\sigma_z}{E}$$

$$\varepsilon_z = -\nu\frac{\sigma_x}{E} - \nu\frac{\sigma_y}{E} + \frac{\sigma_z}{E}$$

Units of strain: micro strain. Typical strains µm/m → displacements too small for direct m/s.

3.1 Resistance Strain Gauges



Lord Kelvin (1856): Resistance of Cu wire changes when subjected to tension or compression

Wire of length l and uniform cross section A, $R = \rho \dfrac{l}{A}$

ρ **= specific resistivity of the wire material**

Axial stress σ → change in all the three parameters ρ, l, A

$$\frac{dR}{d\sigma} = d\frac{\left(\rho\, {}^{l}\!/\!{}_{A}\right)}{d\sigma} = \frac{\partial R}{\partial \rho}.\frac{\partial \rho}{\partial \sigma} + \frac{\partial R}{\partial l}.\frac{\partial l}{\partial \sigma} + \frac{\partial R}{\partial A}.\frac{\partial A}{\partial \sigma}$$

$$\frac{dR}{d\sigma} = \frac{l}{A}.\frac{\partial \rho}{\partial \sigma} + \frac{\rho}{A}\frac{\partial l}{\partial \sigma} - \frac{\partial l}{A^2}\frac{\partial A}{\partial \sigma} \Rightarrow \frac{1}{R}\frac{dR}{d\sigma} = \frac{1}{\rho}\frac{\partial \rho}{\partial \sigma} + \frac{1}{l}\frac{\partial l}{\partial \sigma} - \frac{1}{A}\frac{\partial A}{\partial \sigma}$$

Therefore $$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta l}{l} - \frac{\Delta A}{A}$$

Under tension, the wire length increases, & the wire diameter contracts

$$\frac{\Delta d}{d} = -\nu \frac{\Delta l}{l}$$

$$A = \pi\left(\frac{d}{2}\right)^2 \Rightarrow \frac{\Delta A}{A} = 2.\frac{\Delta d}{d}$$

Therefore $$\frac{\Delta R}{R} = \frac{\Delta\rho}{\rho} + \frac{\Delta l}{l} + 2\nu\frac{\Delta l}{l}$$

Gauge factor $$G = \frac{\Delta R}{R}\bigg/\frac{\Delta l}{l} = \frac{\Delta\rho}{\rho}\bigg/\frac{\Delta l}{l} + 1 + 2\nu$$

In the purely elastic region, volume of the wire does not change and for most metals, $G \approx 2$

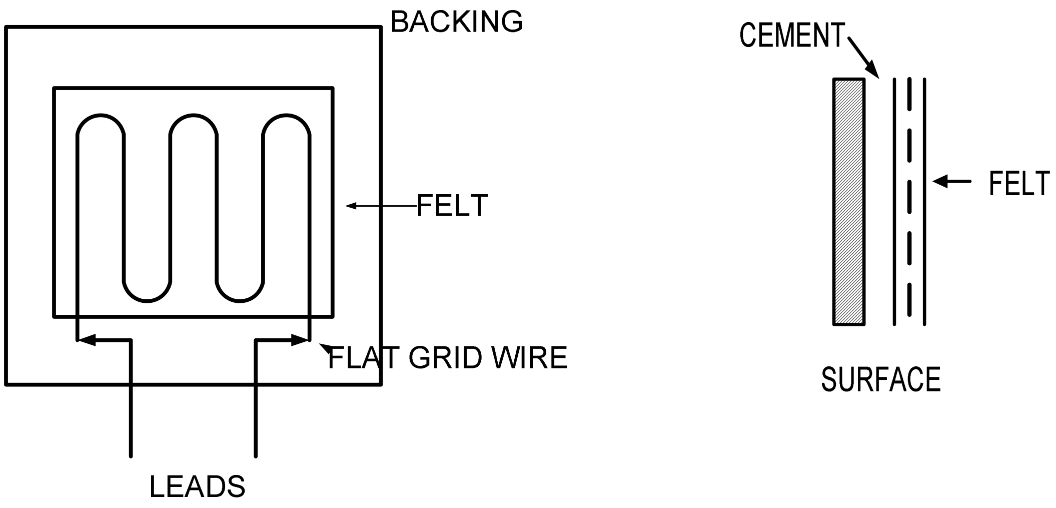
Types of gauges: Bonded wire, unbonded, foil, semiconductor (piezoresistive)

3.2 Bonded Wire Strain Gauges

Wire is bonded to the surface being tested with a thin layer of adhesive cement (cement: transmits strain to the wire, provides electrical insulation)

- **Flat grid**
- **Wrap around**
- **Single wire**
- **Woven**

Flat Grid



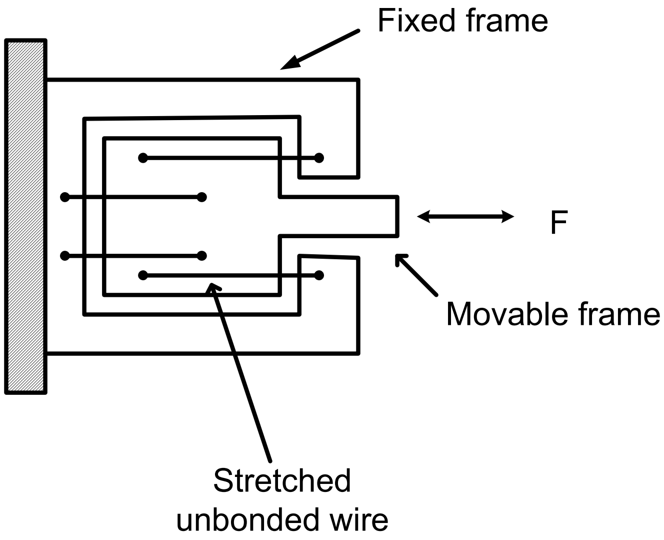
3.3 Unbonded Wire Strain Gauges

- Free filament sensing element: strain transferred to resistance wire directly without backing

- Loops of high tensile strength resistance wire between insulated pins, one attached to a stationary frame and the other to a movable frame.

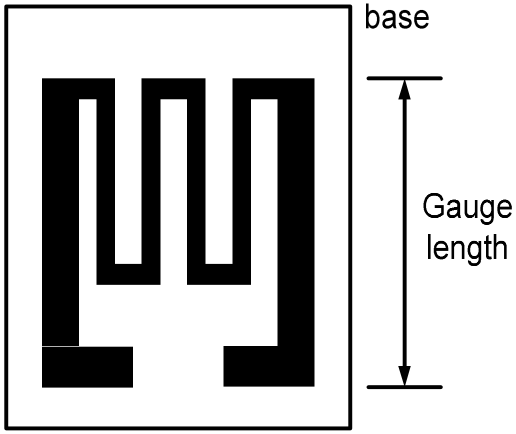
- Winding experiences change in stress due to the applied force.

- No hysteresis and creep (lack of bonding)



3.4 Foil Gauges

- Thin foil of resistive material bonded to a backing material
- Better thermal stability due to longer ratio of surface area to cross-sectional area
- No joints, no stress concentration
- Thick perpendicular sections, insensitive to transverse strain
- Fabrication by photochemical etching to get the desired pattern.



3.5 Semiconductor Strain Gauges

Piezoresistive property of doped Si or Ge crystals, and strain sensitivity is mainly due to resistivity changes.

Gauge factor $$G = \frac{\Delta R/R}{\Delta l/l} = 1 + 2v + m$$

where piezoresistive coefficient $$m = \frac{\Delta\rho/\rho}{\Delta l/l}$$

Features

- **High gauge factor G (100 to 140)**
- **Chemical inertness**
- **Freedom from hysteresis & creep**
- **Very low cross sensitivity**

Common semiconductor gauge

- **Doped Si, $\rho_0 = 2\times10^{-4}\,\Omega m$**
- **Filaments of 150μ thickness**
- **Electrodes formed by vapor deposition**
- **Nominal resistance obtained by electrolytic etching**
- **Embedded on film, backing of phenolic, backelite, or epoxy**

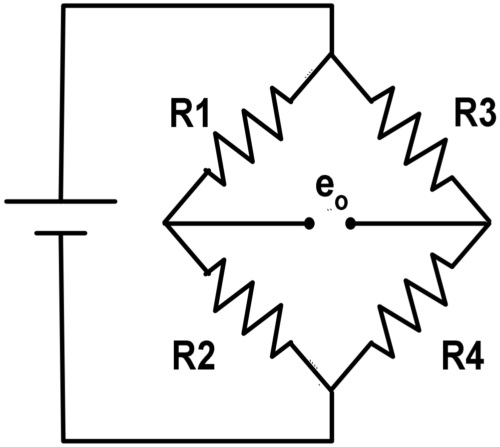
G.F is +ve for p-type and –ve for n-type doped material.

Temperature effects

- **Temperature dependence of unstrained resistance**
- **Temperature dependence of gauge factor**

Temperature independence can be obtained by very high doping levels $\rho_0 < 10^{-5}\,\Omega m$

3.6 Strain Gauge Bridge Circuits



$$e = \left(\frac{R_2}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right) E = \frac{R_2 R_3 - R_1 R_4}{(R_1 + R_2)(R_3 + R_4)} E$$

= 0, if $R_2 R_3 = R_1 R_4$

If all the four resistances are active strain gauges with unstrained value of R and $R_1 = R + \Delta R_1$, etc, then we have

$$e = \frac{\left(1+\frac{\Delta R_2}{R}\right)\left(1+\frac{\Delta R_3}{R}\right)-\left(1+\frac{\Delta R_1}{R}\right)\left(1+\frac{\Delta R_4}{R}\right)}{\left(2+\frac{\Delta R_1}{R}+\frac{\Delta R_2}{R}\right)\left(2+\frac{\Delta R_3}{R}+\frac{\Delta R_4}{R}\right)}E$$

Ignoring higher degree non-linearity terms, we get

$$e \approx \frac{\frac{\Delta R_2}{R}+\frac{\Delta R_3}{R}-\frac{\Delta R_1}{R}-\frac{\Delta R_4}{R}}{4\left(1+\frac{\Delta R_1}{2R}+\frac{\Delta R_2}{2R}+\frac{\Delta R_3}{2R}-\frac{\Delta R_4}{2R}\right)}E \qquad \Rightarrow e \approx \frac{1}{4}\left(\frac{\Delta R_2}{R}-\frac{\Delta R_1}{R}+\frac{\Delta R_3}{R}-\frac{\Delta R_4}{R}\right)E$$

If the gauge factors are G1, G2 …and strains are $\varepsilon_1, \varepsilon_2 \cdots$ then

$$e = \frac{1}{4}\left(G_2\varepsilon_2 - \varepsilon_2.\varepsilon_1 + G_3\varepsilon_3 - G_4\varepsilon_4\right)E$$

Bridge configurations

Quarter bridge: **one arm of the bridge, say R2 is active and others are fixed resistances.**

$$e = \frac{E}{4} G\varepsilon 1$$

Half bridge: **R1 and R2 are strain gauges, one in tension and other in compression & other two are fixed resistances.** $\varepsilon_1 = -\varepsilon_2 = \varepsilon$ **. Further if G1=G2=G, then** $e = \frac{E}{2} G\varepsilon$

Full bridge: **R1 and R4 are in tension & R2 and R3 are in compression**

$$e = E.G.\varepsilon$$

Half bridge with gauges in transverse direction

$$e = \frac{E}{4}\left(G\varepsilon - Gv(-\varepsilon)\right) = \frac{E}{4}(1+v)G\varepsilon$$

Temperature compensation

$$\frac{\Delta R}{R} = \left(\frac{\Delta R}{R}\right)_t + \left(\frac{\Delta R}{R}\right)_\varepsilon$$

Following may change with change in temperature

- **R value of the gauge**
- **Gauge factor itself**
- **Different expansions of the gauge & the surface it is bonded to.**

Compensation (to certain extent) possible by using dummy gauges in the bridge configuration.

$$e = \frac{1}{4}\left(\frac{\Delta R_2}{R} - \frac{\Delta R_1}{R} + \frac{\Delta R_3}{R} - \frac{\Delta R_4}{R}\right)E$$

Let
R2: an active strain gauge,
R1: dummy strain gauge exposed to same temperature variation as R2.
R3 and R4: fixed resistors of value R

$$e = \frac{1}{4}\left(\left(\frac{\Delta R_2}{R}\right)_t + \left(\frac{\Delta R_2}{R}\right)_\varepsilon - \left(\frac{\Delta R_1}{R}\right)_t\right)E$$

$$= \frac{1}{4}\left(\frac{\Delta R_2}{R}\right)_\varepsilon E$$

because $\left(\frac{\Delta R_2}{R}\right)_t = \left(\frac{\Delta R_1}{R}\right)_t$

4. TEMPERATURE SENSORS

Temperature

- ♦ A physical condition of matter, related to its ability of transferring heat to its surroundings.
- ♦ A measure of mean of the kinetic energy of the molecules of the substance
- ♦ Potential of heat flow

Effects of temperature change

- ♦ Change in physical or chemical state
- ♦ Change in physical dimensions
- ♦ Variation in electrical properties
- ♦ EMF generation at the junction of two dissimilar metals
- ♦ Change in the intensity of radiation emitted

Thermodynamic temperature scale

$$\frac{T_2}{T_1} = \left[\frac{P}{P_{273.15}}\right]_{\text{constant V}}$$

For an ideal gas as thermometric substance,

P = pressure at temperature T_2

$T_1 = 273.15\ K$ = triple point of water

ITS – 90 scale

9 reproducible fixed points as temperature standards, along with interpolating instruments.

Type of Sensors

A) Thermocouples

Cu - Constantan : 73 – 673 K (0.75%)
Fe – Constantan : 73 – 973 K (0.75%)
Chromel – Alumel: 273 – 1273 K (0.75%)
PtRh$_{30}$ – PtRh$_{6}$: 273 – 1773 K (0.50%)
PtRh$_{13}$ -Pt : 273 – 1573 K (0.50%)
Tungsten - Rhenium : 273 – 3033 K (1.00%)

B) Resistance Thermometer

Pt: 91 – 903 K (0.5% f.s.)
Ni: 213 – 423 K (0.2 – 0.2^{o})
Thermistor: 173 – 573 K (0.2^{o})
Semiconductor: 173 – 453 K (0.5 - 1.5^{o})

C) Crystal Transducer : **273 – 573 K (0.03 – 1^{o})**

D) Semiconductor Junction Voltage Transducer : **223 – 423 K (0.1 – 0.5^{o})**

Metal Resistance Thermometer

$$R_t = R_0(1 + at + bt^2)$$

where $T = T_O + t$, R_O = resistance at T_O

$$\frac{dR_t}{dt} = aR_0 t \Rightarrow \frac{1}{R_0} . \frac{dR_t}{dt} = Q$$

♦ **Bridge m/s & lead compensation**
♦ **Self heating should be minimized.**

Thermistor

Made of sintered ceramics (mixtures of oxides of Iron, Manganese Ni, Co, Cu) as beads or discs.

$$R_T = a.e^{b/T} \Rightarrow \frac{dR_T}{dT} = ae^{\frac{b}{T}}.\left(-\frac{b}{T^2}\right)$$

$$R_{T_1} = a.e^{b/T_1} \Rightarrow \frac{dR_T}{dT}.\frac{1}{R_T} = -\frac{b}{T^2}$$

$$R_{T_2} = a.e^{b/T_2}$$

$$\frac{R_{T_1}}{R_{T_2}} = e^{b\left(\frac{1}{T_1}-\frac{1}{T_2}\right)}$$

$$R_{T_1} = R_{T_2}\, e^{b\left(\frac{1}{T_1}-\frac{1}{T_2}\right)}$$

Thanks

*5 Days Workshop on LOW COST HI-TECH AUTOMATION WITH APPLICATIONS *
30-08 to 3-09-2007, *IIT Bombay*

INTRODUCTION
Under the present regime of globalization and liberalization, quality enhancement and cost reduction are two major steps to enhance productivity- when many factors make heavy investment not pragmatic (Uncertaintities in market, low volume- customized products, severe competition etc). One of the very practical, safe, economical and rewarding strategies is the application of Low Cost Automation. LCA has been widely practiced during the last four decades for many simple applications. Microelectronics with microchips made it possible to make, LCA very sophisticated. Prof. Ramakrishnan (IITB) has coined the term LCHA to highlight this current development. India is poised to be major global power in manufacturing and our manufacturing industries have opportunities which were never there in the past. LCHA is probably one of the best tool/ technique that can help in tapping fully this opportunity.

WHAT IS LOW COST HI-TECH AUTOMATION ?
Low Cost High Tech Automation is a technology that creates some degree of automation around the existing equipment, tools, methods and people, using mostly standard components available in the market and using microelectronics & information technology to enhance the system capability. India has the right mix of Low cost and high technology with adequate skilled manpower. India is one of the best countries for LCHA.

PAYOFFS
~U Investment required is low, hence risk involved is low. Faster throughput
~U Technologies used are easy and simple to understand , maintain and upgrade, losses will be minimal in case of breakdowns
~U The hardware components are flexible and reusable and very adaptable to changes in product, market conditions etc.
~U Labor resistance will be minimal since fatigue and drudgery of work get eliminated and they can be made to feel "involved" in the developments.
~U Development cost will be a fraction of what it will be elsewhere in the world
~U LCHA is equally useful for a process or a product
~U It is beneficial to any type of industry or any size of industry

SCOPE
The course is aimed at developing the right perspective and understanding of this attractive aid to competitiveness. Apart from clarifying the basics, case studies will be used from different types of industries to highlight the applications potential. It is expected to provide a systematic approach to LCHA with gradually increasing sophistication. After discussing the basic concepts to form a strong foundation in LCHA, applications in three important areas ~V material handling, assembly & testing and inspection will be covered in problem- solving mode.

PROGRAM OVERVIEW
The course is of 5 days duration. It will have 4 modules each day (20 modules totally). Each module will be of 1½ hrs and there will be 2 modules pre-lunch and 2 modules post lunch per day. Details of modules are given below;

SESSION 1
Introduction to LCHA
Mechanization and automation, Rigid and flexible automation, Degree of automation, Manufacturing cycles, productivity, favorable conditions for automation.

SESSION 2
Technologies for LCHA
Mechanical, Pneumatics, Hydraulics, Electrical, Hybrid, etc. Comparative merits and limitations.

SESSION 3
System synthesis, developing mechanical systems, elements, synthesis, Illustrative examples

SESSION 4
Pneumatics, types of actuators, pressure, flow and direction, control valves, auxiliaries, symbols, synthesis of circuit
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SESSION 5
Hydraulics, pumps and power packs, actuators, valves, accumulators and intensifiers, oil and filtration, symbols, synthesis of simple circuits, hydraulic servo mechanism.

SESSION 6
Illustrative examples for various industrial applications

SESSION 7
Illustrative examples for various industrial applications

SESSION 8
Introduction to Mechatronics

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SESSION 9
Sensor Technology- Prof.P.C.Pande

SESSION 10
Intelligent Control for LCHA, Hardware Components, Stepper motor, interfacing with Actuators, Signal Conditioners, Control Strategies, Popular Controllers.

SESSION 11
Introduction to material handling - Concepts of material handling, Traditional material handling systems.

SESSION 12
New trends in material handling - Storage & retrieval/ AGVs/ Intelligent conveyors. Pick & place units. System integration.

SESSION 13
Basics of assembly engineering - Precedence diagram. Motion Economics. Assembly line for mass production.

SESSION 14
Modular Flexible Assembly Lines ~V advantages, areas of applications, examples.

SESSION 15
Introduction to inspection & Testing. Standards & Tests. Indigenous, custom-built testing.

SESSION 16
Product design
Design for manufacturing and assembly. Design for customer delight using Mechatronics.

SESSION 17
Laboratory work

SESSION 18
Laboratory work

SESSION 19
Case Study from Industries

SESSION 20
Case Study from Industries

WHO CAN BE BENEFITED?*
LCHA is universal, and useful for all kinds of industries. (consumer durables, FMCGs, pharmaceuticals, metallurgical, automobiles. etc.) Hence, anyone having a degree or diploma in any of the engineering disciplines is expected to find this beneficial because of its multi-disciplinary nature. Irrespective of the basic area of expertise anyone will find it applicable.

FACULTY
Dr. N. Ramakrishnan, IIT Bombay, Mechanical Engineering Department has more than thirty five years of experience in developing Low Cost Automatic systems with close interaction with many industries. He has been involved in many projects in companies like L&T Mumbai, Godrej & Boyce Mumbai, Bajaj Auto Pune, Cadilla Labs Ahmedabad, IFB Bangalore, etc.
Dr. D.K.Sharma, Electrical engineering department, IIT Bombay, has been helping him in areas of micro-electronics and micro-controller. He will be also assisted by colleagues from IIT Bombay for different modules.
Experts from industries like L & T, M & M, Feedtech Automation,Tata Motors etc with long experience will be giving illustrative examples & joining in the Brainstorming sessions.

VENUE
CONFERENCE HALL
IIT Guest House, IIT Bombay, Powai, Mumbai - 400 076
DATE : 30-08 to 3-09-2007
TIME : 9.00 AM to 5.00 PM