11/8/22. Sensors & Transducers: 18ECO1337.

INTRO: Sensor or transducer is a device which provides a usable output in response to a specific measurant. here the output is defined as the electrical quantity & measurant as a physical quantity property or the condition which is measured.

Principles:
Piezoelectric crystal.
Sensing principle - physical /chemical.

Signals: Measurants

1. Mechanical - Length area, vol, force etc.
2. Thermal - Temperature, heat flow, entrophy.
3. Electrical - charge, I, V, R, L, C, etc.
4. Magnetic - field intensity flux, density, permeability.
5. Radiant - Intensity, phase, refractive index, wavelength.
6. Chemical - Concentration composition, PH, Oxidation /reduction.

classification:

1. Transduction principle.
2. primary I/P quantity.
3. Material & technology.
4. property.
5. Energy & power supply requirements
6. Application.

Industrial — process control.

Non-Industrial — 1. Automobile. 2. Medical products 3. Aircrafts 4. Consumer electronics 5. Other server.

7. Technology Based Sensors.
   Eg: MEMS, CMOS image Sensors.

16/8/22 Static characteristics: (char of sensors that will not change.)

10m 1. Accuracy: $E_a = \frac{x_m - x_t}{x_t} \times 100$

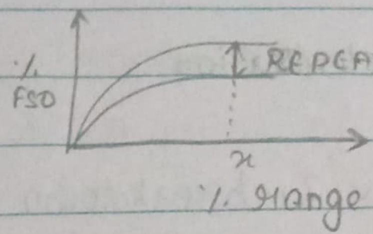
t - true value

m - measured value

x - measurand

* for Multiple - error S/m.
  performance is assessed through.
  (i) worst case approach.
  (ii) RMS approach $E_0 = \sqrt{\sum_t (E_i)^2}$

2. Precision:



Same instrument many times the Precision shd not change.

3. Resolution:

$$MR = x_{max} - x_{min}$$

x - measurant

$$R_{max}(\%) = \frac{100(\Delta x)}{M.R}$$

MR → Measured Range.

Δx → small change in o/p

(Avg) $$R_{avg}(\%) = 100 \sum_{1}^{n} \frac{\Delta x_i}{n.MR}$$

n → no. of times used.

4. Sensitivity: (true value)

$$S = \frac{\Delta y}{\Delta x} \; ; \; S_n = \frac{\Delta y / \Delta x}{y / x}$$

S_n → normalised the Sensitivity

5. Threshold:

6. Selectivity & Specificity (false value represented false)

Dynamic characteristics: (in respect to time changes)
fidelity, Speed of response.

Environmental Parameter:
(also. Affect the char of Sensors)
External variables.

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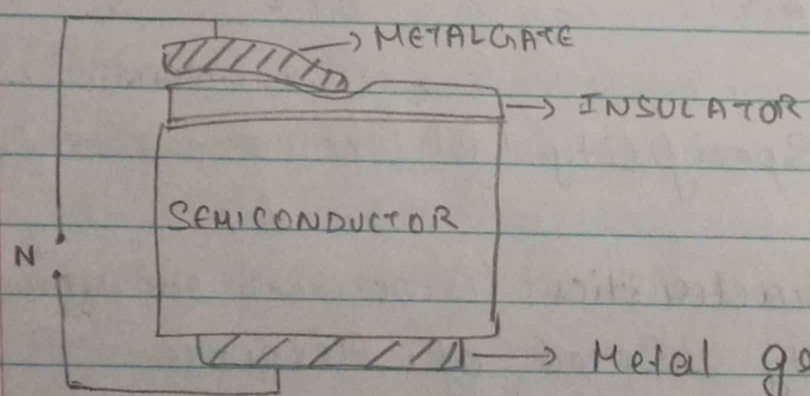
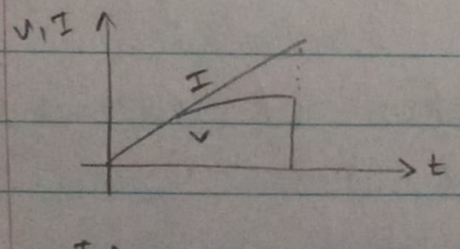
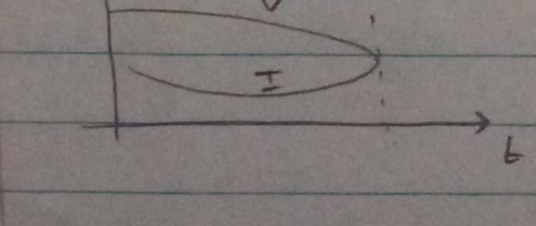
10^m Electrical Characterization

* Parameters → Z, V, I, breakdown Vge & fields,
(of Sensor) noise, crosstalk
* I/P impedance of measuring equipment - high for Vge Sensors
O/P impedance of sensors. - low for I sensors.

* Breakdown:
→ dielectric strength → current induced breakdown
→ wear out







Electrical char { Leakage current (Depends on insulation)
Noise. (unwanted info)
Crosstalk (work on with only one and occurs when another one also interrupts)

Mechanical & Thermal :

* Reliability & integrity of transducer
* Testing

failure analysis

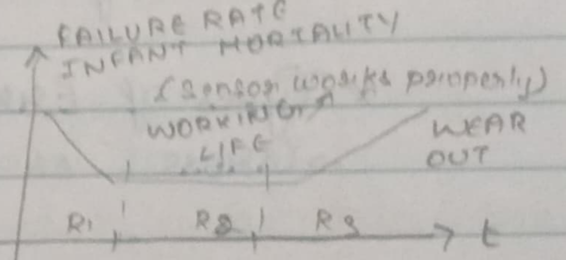
→ Catastrophic early life failures (Beginning failures)

→ Short term drifts (Short term usage & failures)

→ Long term drifts (long term)

Reliability func → $R(x) = 1 - F(x) \Rightarrow \int_x^\infty f(t)\,dt$ → continuity func (failures)

(F(x): failure; R(x) can take any distribution)



(BATCH wise testing) * → high temperature burn in.

→ -125 °c for 48 hrs.

* high temp. storage bake (to check installation)

→ Baked as 250°c in

→ Silicon integrated type sensor.

* Electrical overstress test. to check for breakdown in sensor (and overload stress)

→ larger vge (voltage) upto 50% in excess are applied.

* Thermal shock test (to check defect) to check packaging sensor good or not. (if defective then removed)

→ Packaging, -65°c to 125°c for 10 secs

→ 10 min & repeated 10 times.

* Mechanical Shock Test : (Same like THERMAL SHOCK)

→ Dropping from 3-10m height

→ Shaking the unit

* optical characteristics : (if sensor related to light)

Chemical / Biological (sensor is corrosive or not)

(refractive index ... checks the sensor)

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10th Errors & its classification.

* Errors occurs because of
  - → parallax error Analog Device with pointer, user shd read the value properly
  - → Calibration shd be calibrated properly
  - → Zero shd pt exactly to zero state.
  - → Damage Damaged sensor used without knowing
  - → Limit of reading of the measurement

classification

* Types of Errors:
  - → Gross error made by humans.
  - → Systematic (errors related to instruments)
    - ↳ Instrumental → Short coming of instrument (how many I/O)
      - misuse, loading effects
    - ↳ Environmental → temp. pressure, Dust (impacts to sensor)
    - ↳ Observational → parallax, wrong scale reading.
    - (mismatch in conversion) → Incorrect conversion of units
* Random Errors. Beyong human assumption

10M Selection of Transducers → (Sensors used for particular Application)

Operating principle → transducer is resistive Based → wat form to wat form

Sensitivity → Medical Application- Sensitivity shd be high → Depends on sensitivity

Operating range → certain condition, shd work in corrosive range too.

Accuracy → imp for specified Application Eg → Drugs, medicines, dosage

Cross sensitivity → measurand - one plane → transducer - another plane

(Time) Transient & frequency response → Peak time, rise time.
↓
flat graph → so sensor works crtly.

Loading effects. high I/P impedance & low of O/P impedance
↓ depends on no. of loads entering

Environmental compatibility. → I/P & O/P relationship.

Usage & Ruggedness → Ruggedness Vs Size & weight
↳ mechanical sensors

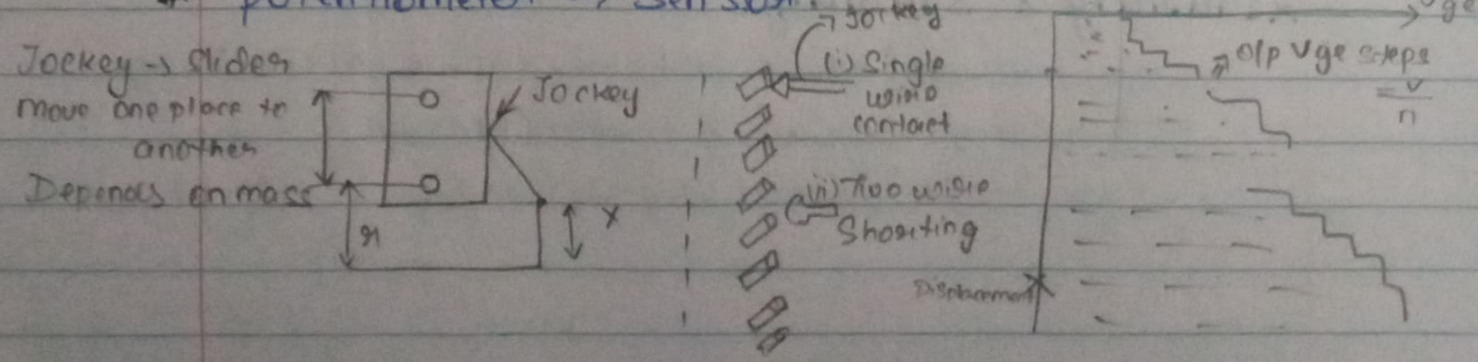
Electrical aspects → types & length of cables to be used
signal ↑ noise ↓ → SNR (signal to noise ratio)

Reliability & Stability.
→ Shd be reliable, work accordingly
→ Some are use & throw (sensors)
high stable & reliable → sensors shd be

23/8/22 Mechanical Sensors:

* Mech. quantity - i/p
[Motion, force, speed etc]
Electrical optical - o/p
Magnetic thermal.
* Sensors may be categorized under more than one category without being inappropriate
How sensors are formed & Developed
Select the sensors accordingly
* Eg: Mechanical Variables are secondary in nature Such as motion of the tip of bimetallic tip → (Thermocouple) primary measurement - temp
mechanical Sensors always Secondary → movement of needle.
* Direct measurement - poor accuracy & low resol.
(Can't be measured Directly) (can be measured only indirectly)

Resistive potentiometer:
* Variable resistance transducer
* precision wire - wound.
* potentiometer ⇒ Sensor. → resistivity change



⇒ Case (i): for voltage resolution $\Delta V = \frac{V}{n}$.
(step size proportional to $\frac{V}{n}$)

⇒ case (ii):
Voltage Resolution $\Delta V_m = V_p \left[\frac{1}{n-1} - \frac{1}{n} \right]$

* Loss in resolution:

$$\Delta V - \Delta V_m = \frac{V}{n} - V_p \left[\frac{1}{1-n} - \frac{1}{n} \right]$$

* To reduce loss in resolution:
→ Jockey shape.
→ Jockey radius
wire radius
→ geometry of wire
winding for reducing ΔV_m.

⇒ (Jockey size can be varied)
when the jockey placed on potentiometer,
it makes maximum.

noise in resistive potentiometer - (Random noise)
Thermal motion of molecule that come
in Σ with random motion of e^-
giving rise to white / johnson noise.

Contact non-uniformity mainly produced due to change in contact area & hence contact resistance.

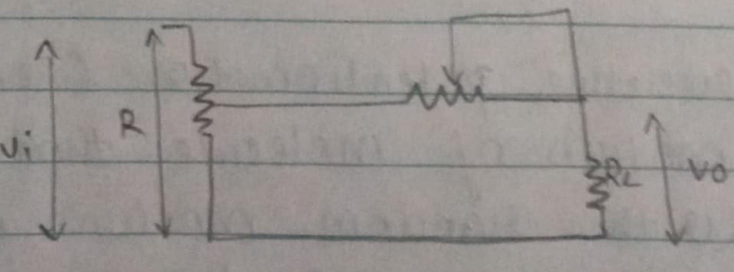
Rubbing action bet the jockey & the wire

Thermoelectric action specifically at high temp & DC operation.

Sensitivity under ideal unloaded condition of the potentiometer is the O/P voltage per unit travel of the jockey.

Irregularities occur at the potentiometer ends & due to power dissipiation & corresponding rise in resistance of the potentiometer.

The performance of the Potentiometer changes in the specific condition



R_L - Load resistance

R_i - instantaneous tapped resistance

R_s - variable series resistance.

$$\frac{V_o}{v_i} = \frac{R_i/R}{1 + \frac{R_i}{R_L}\left(1 - \frac{R_i}{R}\right)}$$

efficiency Calculation

$$E = \left[\frac{\frac{V_{oi}}{v_i} - \frac{V_o}{V_i}}{V_{oi}/V_i}\right] \times 100$$

error Calculation.

for ideal condition.

$$\frac{V_{oi}}{v_i} = \frac{R_i}{R} = e$$

$$E = \left[1 - \frac{1}{(1 + \lambda p(1-e))}\right] \times 100$$

$$\frac{R}{R_L} = \lambda$$

10M // Strain Gauge:

Basic principle:

Change in resistance of metallic wire in response to strain produced in it

Strain gauge are of 2 types

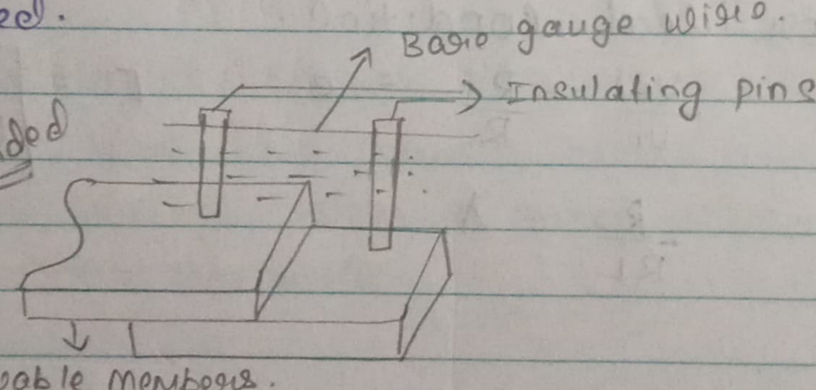
* resistive type
* semi-conductor type

Resistance Strain Gauge:

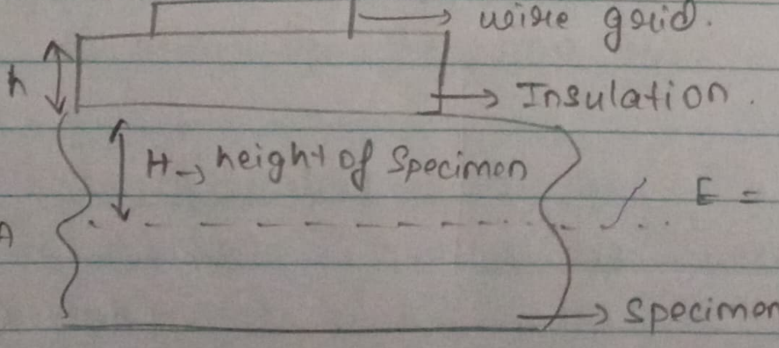
Unbonded.

Bonded.

UnBounded



Bonded



$E = E_m \frac{H}{h+H}$

According to strain, height changes

Depending upon implementation the resistance gauges can be classified as unbounded metal wire & Bounded metal wire, Bounded metal foil, thin metal film by vaccum, thin metal film by sputter deposition

UNBOUNDED DERIVATION:

Considering a circular cross section metal resistance wire of length l & crossection area A,
with resistivity ρ of the material, the unstrained resistance of the wire is given by

(Resistivity) $\rightarrow R = \frac{\rho l}{A} \rightarrow$ (1) If the wire is uniformly stressed along its length & if stress is given by 'σ'.

($d = \partial$)

$$\frac{dR}{d\sigma} = \frac{d}{d\sigma}\left(\rho \frac{l}{A}\right) \rightarrow (2)$$

Which gives

$$\left(\frac{1}{R}\right)\frac{dR}{d\sigma} - \left(\frac{1}{l}\right)\frac{dl}{d\sigma} - \left(\frac{1}{A}\right)\frac{dA}{d\sigma} + \left(\frac{1}{\rho}\right)\frac{d\rho}{d\sigma} \rightarrow (3)$$

Eliminating σ terms.

$$\frac{dR}{R} = \frac{dl}{l} - \frac{dA}{A} + \frac{d\rho}{\rho} \rightarrow (4)$$

W.K.T $\frac{\Delta d}{d} = \frac{1}{2}\left(\frac{dA}{A}\right)$, $\epsilon = \frac{\Delta l}{l}$

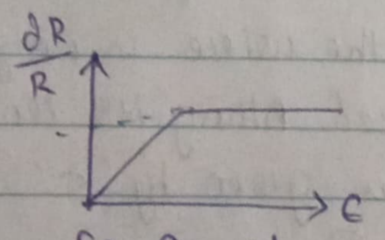
$$\therefore \frac{d}{d} = -\frac{\mu \Delta l}{l} \longrightarrow (5)$$

$$(4) \Rightarrow \frac{\Delta R}{R} = (1+2\mu)\frac{\Delta l}{l} + \frac{\Delta \rho}{\rho}$$

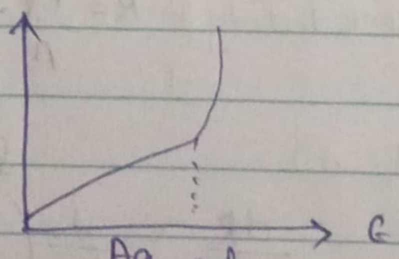
Strain Resistivity.

$$\lambda = \frac{\Delta R/R}{\Delta l/l} = 1 + 2\mu + \frac{\Delta \rho/\rho}{\Delta l/l}$$

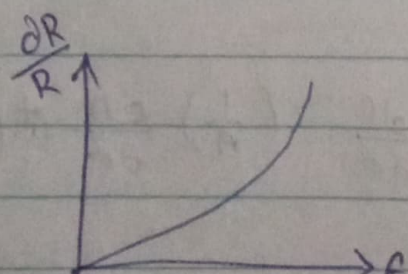
where $\frac{\Delta \rho/\rho}{\Delta l/l} = \psi \epsilon$ (Piezo electric)



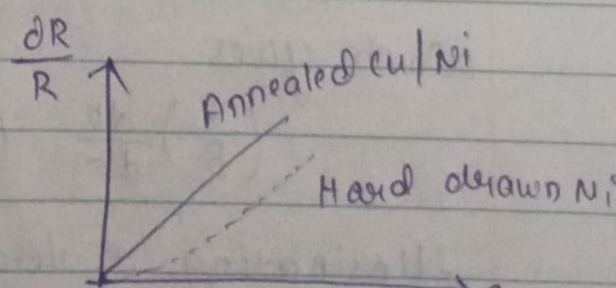
Fe, Ag, pt



Ag, pd



min alpha



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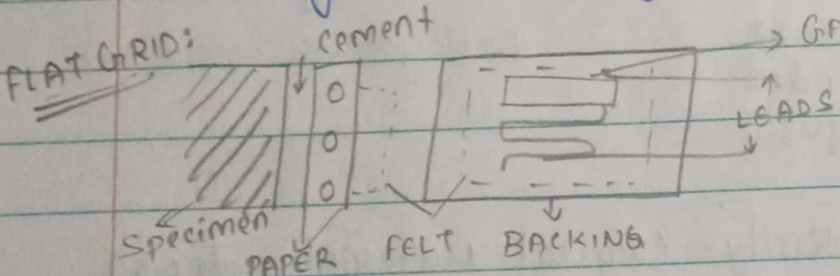
BOUNDED STRAIN GAUGE

→ flat grid
→ wrap around
→ woven

Gauge - Resistance element, gauge backing, cement, connection leads & protective coating.

Etched foil - Commonly used.

FLAT GRID:



cement → dielectric

* Small hyst , more accurate
Better strain transmission from member to wire grid
* Foil gauges - higher surface area to cross-section ratio
* wire gauges - drawn & annealed
foil - Photoetching process (In the form of light)
* Vaccum deposition → elastic metal element in chamber with dielectric material
→ Heat → vapourizes thin layer ↓ condensed
thin layer ← formed.
→ template is placed, gauge is formed.

Instead of using cement we can use these methods.

* Sputtering - deposition
→ 1st step is same
→ Sputtered patter → (ii) etching → (iii) removal of impurities

Semiconductor Strain gauge:

* Produced from single crystal of Si/Ge by cutting thin Strips
* High gauge factors
* Much inferior to resistive types in terms of linearity & temperature stability
* Smart Sensors — Doping → with impurities
* 2 types < Bonded / Diffused

* Strain Sensitivity - Crystal Material, doping Material (Crystal cut - axis orientation
* for intrinsic S.C - Gauge factor ↓, Doping ↑
  $\lambda = 1 + 2\mu + \psi e$ (Derived Already)
* Piezoresistive coefficients - fundamental (property) (PCF)
  - Types:
    - ↳ longitudinal PCF - Stress & current in Same direction
    - ↳ transverse PCF - Stress & Current $\perp^r$ to each Other
* Bonding - epoxy Based adhesives / diffusion process [photolithographic (with light) + impurity diffusion)
  ↓ help to form
  Gauge
* Change in resistivity $\frac{\Delta R}{R} = \sum_{j=1}^{2} k_j \epsilon$ → stress applied.

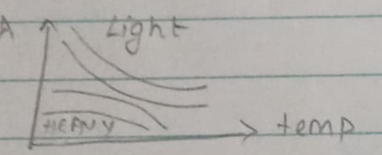
kj - constant dep on materials & doping levels.

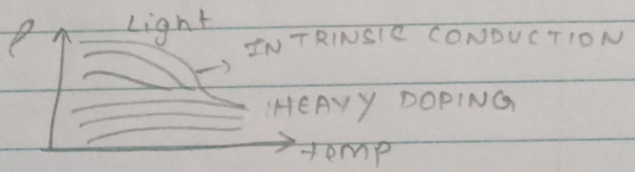
* By heavy doping - non linearity can be improved but strain sensitivity ↓
* $j = 2$ is good for practical use
* for n-Si gauge $\rho = 3.1 \times 10^{-4} \Omega$, $\lambda = -110 + 10^5 \epsilon$

  p-Si $\rho = 0.2 \times 10^{-3} \Omega$, $\lambda = 120 + 4 \times 10^4 \epsilon$

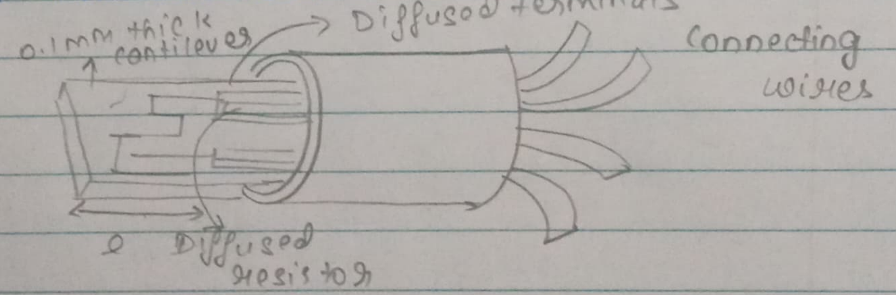
  $\rho = 78 \times 10^{-3}$, $\lambda = 175 + 7.26 + 10^4 \epsilon$

Summarize ⇒ * ↑ doping ↓ sensitivity, changes gauge resistance as well.





* Pressure Transducers



* With Beam under stress the resistors on the two side of the Beam undergoes different changes becoz of compression on one side & its extension other.
* Deformation of diaphram is transmitted to the Canti-lever & hence to the Diffused resistance gauges