Module 5: Sensors.

1) Sensor: They sense the physical change in the System in the surrounding. They convert that into an electric or digital signal.

2) Actuator: (A special type of transducer). In response to the sensor's input, Actuator performs an output task. It can be used to switch voltages or current. Specifically, they convert energy into motion or mechanical energy.

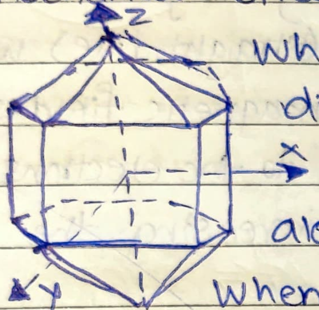
3) Piezoelectric effect: It is a property of certain materials to generate an electric charge in response to the applied physical stress. (Piezo: greek word for push). This effect is reversible (electric to stress). When stress is applied on such material, the shifting of the +ve & -ve charge centeres in the material takes place. It creates an external electric field. Applications: Detection of sound, high voltage generation, electronic frequency generation, ultrafine focusing of optical assemblies etc.

3.1.1) Use in sensors: A physical dimension, transformed into a force, acts on two opposing faces of the sensing material/element. Detection of pressure variation in the form of sound is the most common sensor application. (Piezoelectric microphone). This sensor is also used in ultrasonic transducers with high frequency sounds for medical imaging & industrial non-destructive testing.

3.1.2) Piezoelectric motors: Piezo crystals are used in these motors. When an electric pulse is provided to the crystal, it applies a directional force to an opposing ceramic plate. Motion is generated when this force acts against ceramic strips.

3.1.3) Piezoelectric crystals.

In a quartz crystal, if an electric voltage is applied in the dirn of the electrical axis, (here x), mechanical stress is produced in the Y axis.



When alternating voltage is applied in the dirn of electrical axis, alternating stresses & strains are produced along its thickness & length. & vice-versa.

When voltage's frequency = natural vibration frequency of the plate, resonance occurs. (Large amplitude of oscillation)

f (freq. of thickness vibration) = $\frac{1}{2t}\sqrt{\frac{Y}{\rho}}$ (along x-axis).

where, Y = young's modulus, t = thickness of the crystal,
ρ = Density of the crystal.

4) Magnetostriction effect : Magnetostriction is a property of ferromagnetic materials which cause them to change their shape or size ~~when~~ during magnetization. When the magnetic feild is applied, small magnetic domains in the magnetostrictive material try to allign themselves wrt to the applied field. Usually, they are present non-oriented. As the intensity of the magnetic field increases, magnetostriction increases as the strain field increases. Magnetostriction coefficient = λ

$\lambda = \delta L / L$. Frequency of oscillation (f) = $\frac{1}{2L}\sqrt{\frac{Y}{\rho}}$.

4.1.1) Magnetostriction Transducer : Used to convert mechanical energy into magnetic energy & vice-versa.

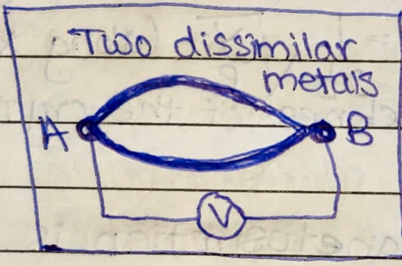
4.2) Magnetoresistance : Resistance of some of the metals & semiconductor varies in a magnetic field. These are known as magnetoresistors. Used to determine the presence, strength & dirn of force of a magnetic fied. Made up of Indium antimonide or Indium arsenide semiconductor material.

Magnetoresistance $\propto$ Intensity of ~~m~~ magnetic field.

Used in computer hard disks, ~~e~~ electronic compass, for measuring of the current etc.

Explanation: In absence of any magnetic field, electrons move in a specific fashion (Straight line) when voltage is nonzero. But, when a magnetic field is applied, it produces a resisting force to the electrons resisting the flow of electrons, hence increasing the magnetoresistance.

5) Seebeck effect.



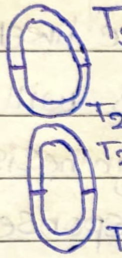
When two metals wires (of different properties) are joined at their ends to form Hot & Cold Junctions, a thermocouple is formed. An emf is generated in such circuit. Reason being the charge carriers in such circuits (typically electrons or holes) being more energetic in the hotter region (& therefore having ~~more~~ higher velocities) tend to travel towards the cold junction. Diffusion stops when the field created because of moving charges becomes strong enough to stop their movement.

6) Peltier effect: It is the inverse of Seebeck effect. When a circuit is formed containing a junction of two dissimilar conductors, thermal energy is absorbed from one ~~junction~~ metal, while its emitted in the other one. It is because of the fact, that average energy of electrons involved in the transfer of electric current is different for different conductors. (eg: concentration of e^- in the conductor, scattering of e^- upon applied voltage etc.) Hence, resulting in absorbing thermal energy from one metal while emitting it in another.

2·6·1) Laws of thermocouple :

i) Law of intermediate metals: Addition of a metal into any circuit does not change the emf of the circuit provided that the metal is at the same temperature as that of the point where it's added.

ii) Law of intermediate temperatures:



$e[1-3] = e[1-2] + e[2-3]$

given metal of T_2 is the same & is at the same temperature. In this way it will not show peltier effect at the junction T_2.

iii) Variation of emf with temperature:

In a thermocouple, if we keep increasing the temperature of hot junction keeping cold junction at 0°C, thermo emf increases till it reaches the max value (at T_N: neutral temp.) & then decreases to zero. Thermo emf $(E) = at + \frac{bt^2}{2}$, at saturation,

$dE/dt = 0 \Rightarrow a + bt = 0 \quad \therefore t = -a/b$

T_i : inversion temperature (dir^n of emf is reversed).

$T_N = (T_C + T_i)/2$.

7) Biological Sensors: This sensor integrates the biological elements with the physiochemical transducer to produce an electronic signal. Biosensors are used to determine the concentration of substances & other parameters of biological interests.

7.1) Environmental Sensing by plants: (Tropism).

Tendancy of plants to grow towards or away from the environmental stimuli. (eg: Sunlight, gravity, objects to climb, moisture in soil etc.).

Tropism are caused by differential growth. Tropisms begin within 30 minutes after a plant is exposed to the stimulus & are completed within approx 5 hours.

7.1.1) Phototropism: It is the growth response of plants towards light coming from one direction. positive phototropism is growth of stems etc. towards the light as cells in the exposed region grow faster.

7.1.2) Gravitropism: Growth response to gravity. Positive gravitropism involves root cap (tiny thimble shaped organ). Such roots are more likely to encounter water & minerals and stems, leaves will be better able to interpret light for photosynthesis.

7.1.3) Thigmotropism: Growth response to touch. Common example is coiling exhibited by specialized organs called Tendrils. (Plant eg: Morning glory, bindweed)

7.1.3) Hydrotropism & Heliotropism:

Growth of roots towards soil moisture is called hydrotropism. (root capped roots prefer this.).

Heliotropism is a process by which plant organs track the relative position of sun in the sky & move accordingly. "Compass plants" in deserts orient their leaves ~~to~~ parallel to sunlight decreasing the leaf temperature.

7.2) Environmental sensing in animals:

Sharks have their sense of smell much developed than their other senses. Water enters through two forward facing nostrils. That water enters nasal passage & moves past folds of skins covered with sensory skills. They can detect the prey by smell even over long distances. They can even detect electrical fields produced by other animals. Around the head they have small holes (ampullae). They are connected to jelly filled bulbs below the skin. External electric signals are transmitted to jelly filled bulbs where they strike the nerves & signal the brain. This is usefull in dark at depths. They can also navigate the globe with the help of earth's electromagnetic field.

8) MEMS : Micro-electromechanical system.

These devices/systems combine electrical & mechanical components. They are fabricated using IC batch processing techniques & range from few µm to mm. Its formation needs expertise from wide range of technical areas eg: IC fabrication, Mech. engineering, material science, electrical engineering, chemical engineering, fluid engineering, optics etc.

Applications: Accelerometers for airbag sensors, inkjet printer heads, computer disk drive read/write heads, blood pressure sensors, biosensors etc.

Because of interdisciplinary nature & micromachining techniques of MEMS, it has resulted in a very wide range of devices & synergies. (eg: Biology & microelectronics). Also, because of its batch fabrication techniques, components of high performance ~~of~~ & reliability, small physical size as well as small volume, weight & cost can be manufactured.

8.1) NEMS: Nano-electromechanical Systems:

They have dimensions ~~of~~ few hundred nanometers. These devices can have fundamental frequencies of 100GHz, mechanical quality factor in tens & thousands, low energy dissipation, active mass in the femtogram range, force sensetivity at attonnewton level, mass sensetivity upto atto & subattogram, power consumption in orders of 10 attowatts, approaching 1012 elements per square centimeters. Hence, it finds uses in force, chemical & biological sensors as well as high frequency resonators.

Its active parts are made up of silicon, silicon carbide, carbon nanotubes, gold & platinum. Whereas, ultra small silicon based NEMS fail to work because of surface oxidation, thermo-elastic clamping. Hence, carbon nanotubes are used in their place as they have nearly one dimensional structure, high aspect ratio & excellent electrical & mechanical properties. Similar to them, nano-wires are also another type of one dimensional nanostructure which can be electrically controlable and are used in NEMS.

8.2) MEMS/NEMS fabrication: usually for MEMS, using vapour deposition, ~~sut~~ material is deposited on the substrate (here silicon), lithography involves patterning of a chemically resistant polymer and material is removed by a chemical. Fabrication of soft materials utilizes glass/plastic substrate and polymerization of poured monomer material is done using UV-radiation.

9) Other Sensors:

9.1) IR sensors: IR sensors sense the characteristics of ~~their~~ their surrounding either by emitting or recieving IR signals. They are also capable of detecting movements and heat being emitted by objects. They have require low power, simple circuitry & portable features. Their physics is based on three laws viz. planck's radiation law, Stephan boltzmann law, wein's displacement law. All objects over 0°K emit energy & are sources of IR as a result.

9.2) UV Sensors: used to detect & measure intensity of incident UV radiation. These sensors can create outputs, generally electrical which can be directed to an electrical meter for observation & recording or to a computer using ADC's (Analog to digital converters) to plot graphs & study.

10) Magnetic-Sensors: Detects the magnitude of magnet field in a region. Based on link betn currents and Magnetic fields. Main noise is earth's Magnetic field (30-40 μT).

Range: Low field / High sensitivity: $\leq$ 0.1nT.
Earth field / Med. sensitivity: 0.1nT to 100 μT.
Bias field / Low Sensitivity: above 100 μT.

10.1) Fluxgate Magnetometer: Based on coil induction. Driver coil operates the ferromagnetic core into saturation while sensor coil detects the change in current. sensitivity: 10^{-2} nT.

10.2) Hall effect Sensor: Based on Lorentz force. DC current is set up in a thin semi conductor film. Magnetic field at right angles creates Hall voltage. $V_H = R_H \frac{I.B.d}{A}$.

10.2) Magnetoresistance: Based on the principle of change in size / length of material due to magnetic field. Hence, electrons take longer paths & scatter more. Increased scattering, hence increased resistance. $R \propto B^2$ (for small fields), $R \propto B$ (for very high fields).

[For radiation sensors, refer to PPT given in notes]

- Atharvmmmm.