Sensors and transducers:

UNIT – 1

Part – B:

1. Illustrate the different types of sensor static characteristics.

The static accuracy of a sensor indicates how much the sensor signal correctly represents the measured quantity after it stabilizes (i.e., beyond the transient period.) Important static characteristics of sensors include sensitivity, resolution, linearity, zero drift and full-scale drift, range, repeatability and reproducibility.

Sensitivity is a measure of the change in output of the sensor relative to a unit change in the input

Resolution is the smallest amount of change in the input that can be detected and accurately indicated by the sensor.

Linearity is determined by the calibration curve. The static calibration curve plots the output amplitude versus the input amplitude under static conditions.

Drift is the deviation from a specific reading of the sensor when the sensor is kept at that value for a prolonged period of time

The range of a sensor is determined by the allowed lower and upper limits of its input or output.

Repeatability is defined as the deviation between measurements in a sequence when the object under test is the same and approaches its value from the same direction each time.

Reproducibility is the same as repeatability, except it also incorporates long time lapses between subsequent measurements.

2. Demonstrate about electrical characterization [pg. – 10, 11]

3. Discuss the dynamic characteristics of sensor. [pg. – 9]

4. Explain briefly "semiconductor strain gauge" with their principle of operation

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Semiconductor strain gauges can be divided into two classes:

(i) Bonded semiconductor

(ii) Diffused semiconductor depending on their implementation.

The bandgaps of both intrinsic and extrinsic semiconductors are affected by temperature variations.

For intrinsic semiconductors, gauge factors are larger decreasing with increasing degrees of doping, the thermal coefficients of resistivity also decrease.

As has been shown, the gauge factor of strain gauge is given by the relation

$$\lambda = 1 + 2\mu + \psi E$$

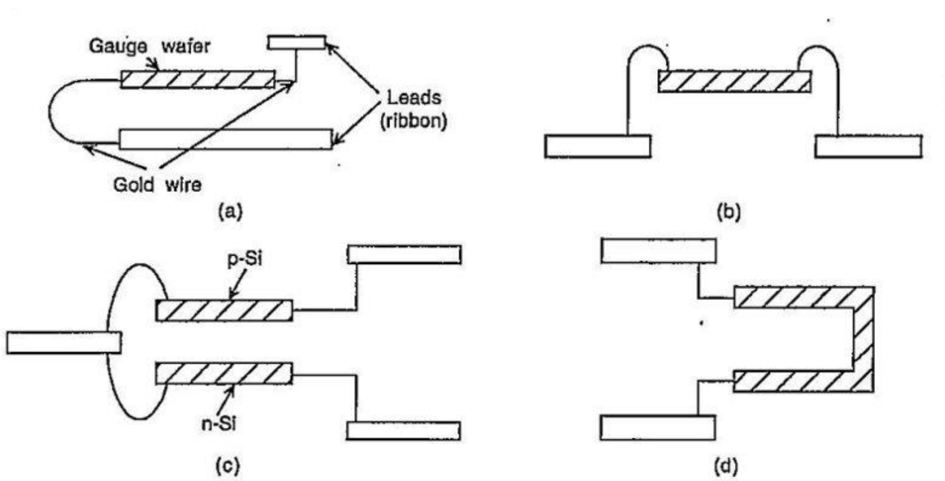


Fig. 2.12 Semiconductor gauges of different shapes and mountings.

Part – C:

1. Briefly describe sensors and classify it based on measurands and technology?

SENSORS:

Instrument Society of America defines sensor or transducer as a device which provides a usable output in response to a specified measurand. Here, the Output is defined as an 'electrical quantity' and Measurand is defined as the Physical quantity, property or condition which is being measured.'

This definition can be generalized by extending 'electrical quantity' to any type of signal such as mechanical and optical and extending 'Physical quantity, property or condition which is being measured' to those of nature – chemical and biochemical and so on.

PRINCIPLES:

Sensor as an element that senses a variation in input energy to produce a variation in another or same form of energy is called a sensor.

Transducer uses transduction principle to convert a specified measurand into usable output.

Thus, a properly cut piezoelectric crystal can be called a sensor whereas it becomes a transducer with appropriate electrodes and input/output mechanisms attached to it.

The principles can be grouped according to the form of energy in which the signals are received and generated.

CLASSIFICATION BASED ON MEASURAND:

Mechanical: Length, area, volume, force, pressure, acceleration, torque, mass flow, acoustic intensity, and so on.

Thermal: Temperature, heat flow, entropy, state of matter.

Electrical: Charge, current, voltage, resistance, inductance, capacitance, dielectric constant, polarization, frequency, electric field, dipole moment, and so on.

Magnetic: Field intensity, flux density, permeability, magnetic moment, and so forth.

Radiant: Intensity, phase, refractive index, reflectance, transmittance, absorbance, wavelength, polarization, and so on.

Chemical: Concentration, composition, oxidation/reduction potential, reaction rate, pH, and the like.

TECHNOLOGY BASED CLASSIFICATION:

Conventional sensors are now aptly supported by technologies which have yielded Micro Electro Mechanical Sensors (MEMS), CMOS image sensors, displacement and motion detectors and biosensors.

Similarly, Coriolis, magnetic and ultrasonic flowmeters, photoelectric, proximity, Hall effect, infrared, integrated circuit (IC), temperature, radar-based level sensors are also relatively modern.

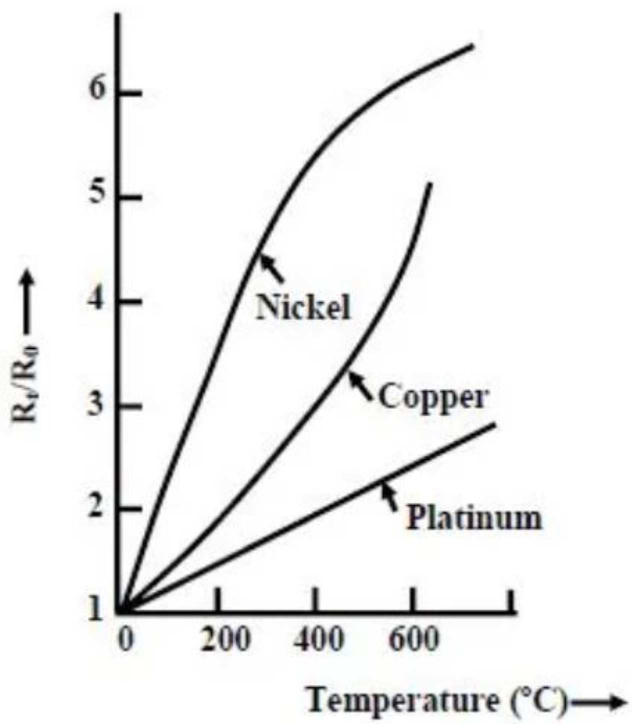
shows the emerging sensor technologies with current and future application schedules as a chart.

Table 1.4 Emerging sensor technologies

Sensors	*Image sensors* *Technology: CMOS-based*	*Motion detectors* *Technology: IR, ultrasonic, microwave/radar*	*Biosensors* *Technology: electrochemical*	*Accelerometers* *Technology: MEMS-based*
Applications	Traffic and security surveillance, blind-spot detection as autosensors (robots etc.), video conferencing, consumer electronics, biometrics, PC imaging	Obstruction detection (robots, auto), security detection (intrusion), toilet activation, kiosks videograms and simulations, light activation	Water testing, food testing (contamination detection), medical care device, biological warfare agent detection	Vehicle dynamic system (auto), patient monitoring (including pace makers etc.)

2. **Explain the working principles of RTD along with the necessary equations and its different types in detail.**

- A Resistance Temperature Detector (also known as a Resistance Thermometer or RTD) is an electronic device used to determine the temperature by measuring the resistance of an electrical wire.
- This wire is referred to as a temperature sensor.
- The variation of resistance of the metal with the variation of the temperature is given as
  - $R_t = R_o[1 + (t - t_0) + \beta(t - t_0)^2 + \cdots]$
- Where, R_t and R_0 are the resistance values at t°C and t_0°C temperatures. α and β are the constants depends on the metals.
- This expression is for huge range of temperature. For small range of temperature, the expression can be,
  - $R_t = R_o[1 + (t - t_0)]$



CONSTRUCTION:

The construction is typically such that the wire is wound on a form (in a coil) on notched mica cross frame to achieve small size, improving the thermal conductivity to decrease the response time and a high rate of heat transfer is obtained.

In the industrial RTD’s, the coil is protected by a stainless-steel sheath or a protective tube.

The physical strain is negligible as the wire expands and increase the length of wire with the temperature change.

If the strain on the wire is increasing, then the tension increases. Due to that, the resistance of the wire will change which is undesirable. So, we don't want to change the resistance of wire by any other unwanted changes except the temperature changes.

Mica is placed in between the steel sheath and resistance wire for better electrical insulation.

Due less strain in resistance wire, it should be carefully wound over mica sheet.

SIGNAL CONDITIONING:

In RTD the change in resistance value is very small with respect to the temperature.

So, the RTD value is measured by using a bridge circuit.

By supplying the constant electric current to the bridge circuit and measuring the resulting voltage drop across the resistor, the RTD resistance can be calculated.

Temperature is determined by converting the RTD resistance value using a calibration expression.

TWO WIRE RTD BRIDGE:

In two wires RTD Bridge, the dummy wire is absent.

The output taken from the remaining two ends as shown in fig

If wires A and B are matched properly in terms of length and cross section area, then their impedance effects will cancel because each wire is in opposite position.

In order to overcome that 3 wire RTD is introduced, which is done by adding a dummy wire

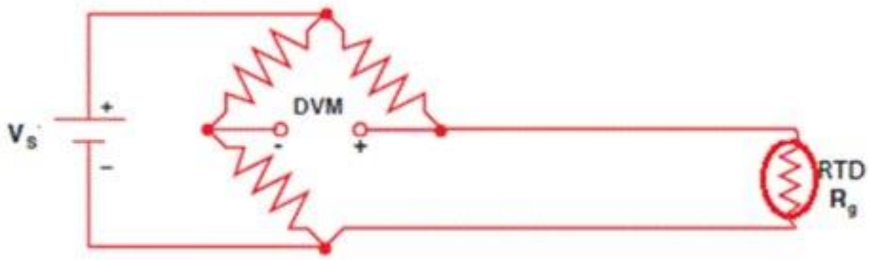


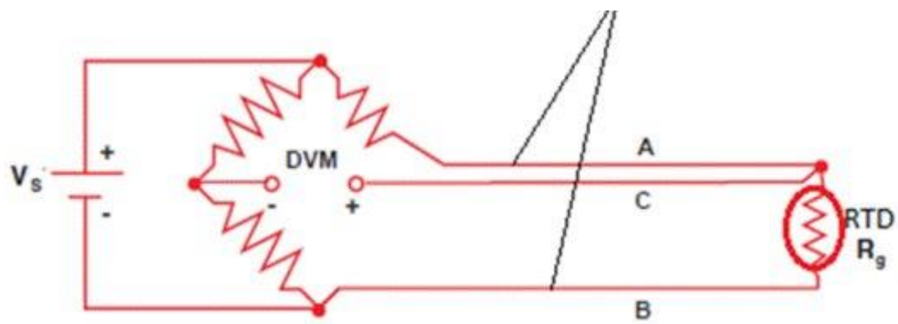
Fig.3. Two wires RTD Bridge

THREE WIRE RTD BRIDGE:

If wires A and B are matched properly in terms of length and cross section area, then their impedance effects will cancel because each wire is in opposite position.

So that, the dummy wire C acts as a sense lead to measure the voltage drop across the RTD resistance and it carries no current

In these circuits, the output voltage is directly proportional to the temperature. So, we need one calibration equation to find the temperature.



FOUR WIRE RTD:

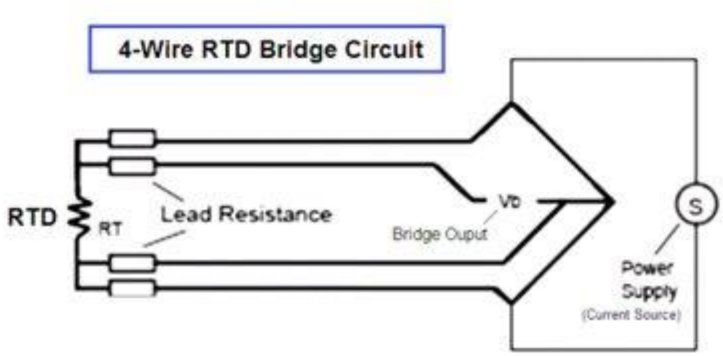
The most accurate lead wire configuration is the “true” 4-wire configuration.

In a true 4- wire configuration, the resistance of the lead wires does not contribute to the resistance of the sensor.

4-wire construction is used primarily where close accuracy is required.

The true 4-wire measurement uses the current-potential method.

A current of known value (I+) is passed through the sensor along the “current” lead wires.



MATERIALS USED IN RTD:

Platinum Resistance Temperature Detectors:

Platinum RTDs are the most common type of RTD used in industrial applications.

This is because platinum has excellent corrosion resistance, excellent long-term stability, and measures a wide range of temperature, (-200…+850°C)

Nickel Resistance Temperature Detectors:

Nickel RTDs are less expensive than platinum and have good corrosion resistance.

However, nickel ages more rapidly over time and loses accuracy at higher temperatures. Nickel is limited to a measurement range of -80…+260°C.

Copper Resistance Temperature Detectors:

Copper RTDs have the best resistance to temperature linearity of the three RTD types, and copper is a low-cost material.

However, copper oxidizes at higher temperatures. Copper is limited to a measurement range of -200…+260°C

3. Explain in detail about various types of errors associated in measurement and how these errors can be minimized

The error which occurs during the measurement is known as measurement error.

Errors occur because of:

- Parallex error (which is due to incorrect sighting)
- Calibration error (occurs when scale is not accurately drawn)
- Damage (if the measuring instrument is damaged)
- Zero error (Which occurs if zero is not present in the device)
- Limit of reading of the measurement device.

The three types of error which we will look after are,

- Gross error
- Systematic error
- Random error

GROSS ERROR:

The error which occurs due to human mistakes in reading the instruments and recording and calculating the measurements.

This kind of errors occurs due to oversighting of a human.

For e.g., Due to oversight, a human reads a value of 21.5 whereas the actual value is 31.5

Gross errors can be any amount and then their mathematical analysis is impossible. These types of errors can be avoided by following the given steps.

- Great care is must in reading and recording the data
- Two or three or more number of readings must be taken for the quantity under same measurement.

SYSTEMATIC ERROR:

Under systematic error, there are three types.

- Instrumental error
- Environmental error
- Observational error

* INSTRUMENTAL ERROR:

The instrumental error is mainly caused due to three things.

- Due to inherent shortcoming of the instrument.

For example, the spring in the permanent magnet instrument has become weak, so the instrument will always read high. This is caused due to hysteresis, gear backlash or friction.

- Due to misuse of the instrument.
- Due to loading effects of the instrument.

* ENVIRONMENTAL ERROR:

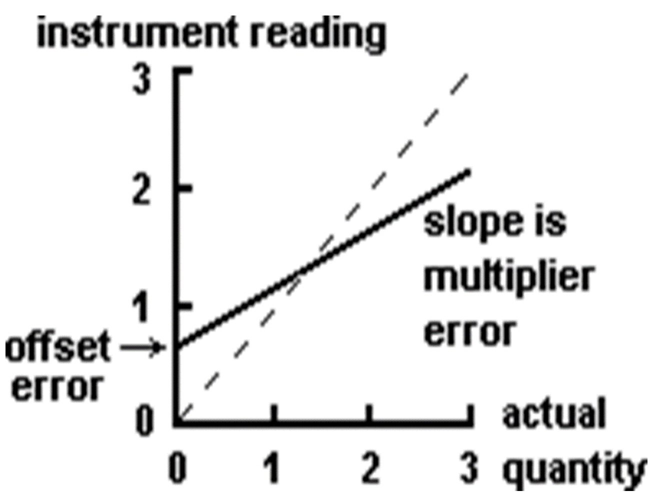
This error arises due to the condition that are external to the measuring instrument, these conditions also include the surrounding of the instrument.

The measuring instrument can be influenced due to temperature, pressure, humidity, dust, vibrations or due to external magnetic or electro static fields.

* OBSERVATIONAL ERROR:

There are many sources of observational errors: -

- Parallax, i.e., Apparent displacement when the line of vision is not normal to the scale.
- Inaccurate estimate of average reading.
- Wrong scale reading and wrong recording the data.
- Incorrect conversion of units between consecutive reading.



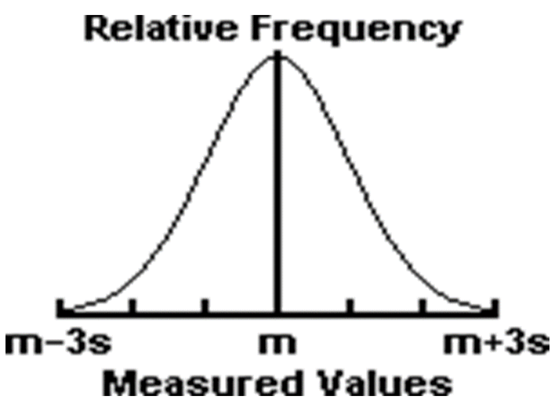
Here in Graph, Full Line shows the systematic Error in non Linear Instrument.

While Broken Line shows response of an ideal instrument without Error.

RANDOM ERROR:

The quantity being measured can be affected by any happenings in the universe. The errors which are caused due to the happenings or disturbances which we are totally unaware of is known as random error. This error is also known as residual error.

Example of random error.



The Gaussian normal distribution. m = mean of measurements. s = standard deviation of measurements. 68% of the measurements lie in the interval $m - s < x < m + s$; 95% lie within $m - 2s < x < m + 2s$; and 99.7% lie within $m - 3s < x < m + 3s$.

4. Describe the different criteria for selection of transducer for a particular application

There are many ways to measure a physical quantity. While selecting a transducer, how to select a transducer that is suitable for a particular application, the following points should be kept in the mind.

Unfortunately, transducers are not sensitive to just one quantity. If a measurement has to be made under certain conditions, there is likelihood that more than one input quantities will be influencing the transducer, it is desirable to select a transducer which is sensitive to a particular desirable quantity and insensitive to another unwanted quantity.

If not, we have to find other means or ways to compensate the effects that are caused by unwanted quantities.

The transducers are selected based on the following criteria,

- Operating principle
- Sensitivity
- Operating range
- Accuracy
- Cross sensitivity
- Loading effects
- Environmental compatibility
- Usage and ruggedness
- Electrical aspects
- Stability and reliability

* Operating principle:

The transducers are many times selected based on the operating principle used by them. The operating principle may be resistive, inductive, capacitive, optoelectronic, piezoelectric etc.

* Sensitivity:

The transducers must be sensible enough to produce deductible outputs.

* Operating range:

The transducers should maintain the range requirements and it should have good resolution over its specified range. The rating of the transducer must be sufficient enough so that it won't breakdown while operating in its specified range.

* Accuracy:

High degree of accuracy is assured if the transducer does not require frequent calibration and has a small value for repeatability. In most of the industry application, repeatability is often considered more important than the absolute accuracy.

- Cross sensitivity

Cross sensitivity is a further factor to be taken into account when measuring mechanical quantities.

There are situations where the actual quantity is being measured is in one plane and the transducer is subjected to variations in another plane.

More than one promising transducer design has had to be abandoned because the sensitivity to variations of the measured quantity in a plane perpendicular to the required plane has been such as to give completely erroneous results when the transducer has been used in practice.

- Transient and Frequency Response

The transducer should meet the desired time domain specifications like peak overshoot, rise time, settling time and small dynamic error.

It should ideally have a flat frequency response curve. In practice, however, there will be cutoff frequencies and higher cut off frequency should be high in order to have a wide bandwidth.

- Loading Effects.

The transducer should have a high input impedance and a low output impedance to avoid loading effects.

- Environmental Compatibility

It should be assured that the transducer selected to work under specified environmental conditions maintains its input-output relationship and does not break down.

For example, the transducer should remain operable under its temperature range.

It should be able to work in corrosive environments (if the application so requires), should be able to withstand pressures and shocks and other interactions to which it is subjected to.

Insensitivity to Unwanted Signals in the sense the transducer should be minimally sensitive to unwanted signals and highly sensitive to desired signals.

- Usage and Ruggedness

The ruggedness both of mechanical and electrical intensities of transducer versus its size and weight must be considered while selecting a suitable transducer.

- Electrical aspects.

The electrical aspects that need consideration while selecting a transducer include the length and type of cable required.

Attention also must be paid to signal to noise ratio in case the transducer is to be used in conjunction with amplifiers.

Frequency response limitations must also be taken into account.

- Stability and Reliability

The transducer should exhibit a high degree of stability to be operative during its operation and storage life.

In general, the transducer should maintain the expected input output relationship as described by its transfer function so as to avoid errors in transducers.