CRYOGENIC ENGINEERING

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Lecture No - 40
Earlier Lecture

• In the earlier lecture, we have seen the importance of instrumentation in Cryogenic Engineering.

• Various properties like pressure, temperature, liquid level, etc are monitored for safe operation.

• We discussed about the thermocouples and the metallic RTDs in the previous lecture.

• T, K, E are the different types of thermocouples. PT 100, PT 1000 are some of the commonly used RTDs in Cryogenics.
Outline of the Lecture

Topic: Instrumentation in Cryogenics

• Measurement of Thermo physical Properties
  • Temperature (continued)

• Measurement of Liquid level
Introduction

• In the earlier lecture, we have seen a metallic RTD, in which, the resistance of a conductor changes with temperature.

• Similarly, non – metallic sensors like silicon diode, Cernox and Ruthenium Oxide exhibit this property.

• A diode is a two terminal electronic component, which is most commonly made of silicon.

• The $i - V$ variation of a diode can be changed by adding impurities or dopants like germanium, arsenic etc.
Introduction

• In these sensors, a constant current supply, typically in micro amps, is fed across the sensor.

• With the decrease in temperature, the resistance of the device increases.

• It is important to note that, this property is in reverse to the characteristic of a metallic RTD.

• This resistance change is calibrated against the temperature change.
Non – metallic Sensors

• Few of the commonly used non – metallic sensors are
  • Silicon Diodes – The sensor consists of a small silicon chip with a repeatable resistance – temperature property.
  • Cernox – Cernox is a sputter deposited thin film resistor. Cernox is the trade name for zirconium oxynitride, manufactured by Lake Shore, USA.
Non – metallic Sensors

- Ruthenium Oxide – It is a thick film resistor which is widely used in magnetic field applications.
Silicon Diodes

- The adjacent photograph shows a casing which houses the silicon diode.

- The packing is a ceramic, hermetically sealed casing with the lowest self heating errors.

- The casing is designed to withstand the mechanical fatigue, occurring due to the temperature change.
Silicon Diodes

- The four wire connection is recommended for accurate sensor readings.

- Very often, these sensors are provided with signal conditioner and display/temperature controller.
Silicon Diodes

- The adjacent figure shows the variation of voltage with temperature for a silicon diode.

- It is clear that the gradient of the curve is very steep for temperatures below 30 K.

- Therefore, it is most preferred in this range for its good accuracy.
Silicon Diodes

- The figure shows the variation of sensitivity \( \frac{dV}{dT} \) with temperature for a silicon diode.

- The sensitivity remains constant up to 30 K.

- It increases with the decrease in temperature, below 30 K. Hence, it is most preferred for low temperatures.
Silicon Diodes

The following table gives some of its properties.

<table>
<thead>
<tr>
<th>Specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>1.4 K to 475 K</td>
</tr>
<tr>
<td>Excitation Current</td>
<td>10μA ±0.1 %</td>
</tr>
<tr>
<td>Repeatability</td>
<td>10mK @ 4.2K</td>
</tr>
<tr>
<td></td>
<td>16mK @ 77K</td>
</tr>
<tr>
<td></td>
<td>75mK @ 273K</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±50mK or better</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>-33.6 mV/K @ 4.2 K</td>
</tr>
<tr>
<td></td>
<td>-1.91 mV/K @ 77 K</td>
</tr>
</tbody>
</table>

•
Silicon Diodes

- The advantages of a silicon diode are
  - The activation current is in the order of $\mu A$. The $i^2R$ losses are negligibly small.
  - It exhibits a linear response over the entire operating range with repeatability and accuracy.

- The disadvantages of a silicon diode are
  - Errors are induced in magnetic fields and these diodes are very costly.

<table>
<thead>
<tr>
<th>Price (INR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibrated</td>
</tr>
<tr>
<td>Non-calibrated</td>
</tr>
</tbody>
</table>
Cernox

- As mentioned earlier, Cernox is a thin film RTD. It is manufactured by Lake Shore, USA.

- It exhibits a good temperature sensitivity over a wide range of operating temperatures.

- One of the most important characteristics of this sensor is its accuracy in magnetic fields. Also, these sensors exhibit a fast response time at low temperatures.

- Cernox are packaged in a robust, hermetically sealed casing similar to silicon diodes.
Cernox

- The following table gives some of its properties.

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<thead>
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<tbody>
<tr>
<td>Range</td>
<td>0.3 K to 325 K</td>
</tr>
<tr>
<td>Excitation</td>
<td>10 µA</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±5mK @ 10 K</td>
</tr>
<tr>
<td>Repeatability</td>
<td>±3 mK at 4.2 K</td>
</tr>
</tbody>
</table>
The advantages of a Cernox are

- These RTDs offer excellent stability over the entire operating range.

- Similar to silicon diodes, Cernox exhibits a linear response for temperatures.

- Cernox diodes are not affected by the magnetic field.
Non – metallic Sensors

• The three important differences between a non – metal and a pure metal sensor are
  • **Sensitivity** : Sensitivity of a non – metal sensor is more than pure metal at any temperature.
  • **Temperature Coefficient** : The coefficient of temperature resistivity of a non – metal sensor is negative, whereas that of pure metal is positive.
  • **Resistivity** of a non – metal sensor is very high. As a result, a non – metal sensor has a small length and relatively a large area.
# A Comparison

<table>
<thead>
<tr>
<th>Silicon Diode</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Range</td>
<td>1.4 K to 475 K</td>
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<tr>
<td>Excitation</td>
<td>$10 \mu A \pm 0.1%$</td>
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<tr>
<td>Accuracy</td>
<td>$\pm 50 mK$ or better</td>
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<tr>
<td>Repeatability</td>
<td>$10 mK @ 4.2 K$</td>
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<td>Range</td>
<td>0.3 K to 325 K</td>
</tr>
<tr>
<td>Excitation</td>
<td>10 $\mu A$</td>
</tr>
<tr>
<td>Accuracy</td>
<td>$\pm 5 mK$ @ 10 K</td>
</tr>
<tr>
<td>Repeatability</td>
<td>$\pm 3 mK$ at 4.2 K</td>
</tr>
</tbody>
</table>
Thermo physical Properties

• There are various thermo physical properties that are measured or monitored in Cryogenics. They are:
  - Temperature
  - Liquid Level
  - Pressure
  - Mass Flow Rate
  - Viscosity and Density
  - Electrical and Thermal Conductivity

• In this topic, only the first three properties are covered, which are very important.
Liquid Level Measurement

• It is important to monitor the liquid level in a closed cryogenic container
  • To avoid the overflow of cryogen.

• To know the amount of cryogen at any time.

• Various electronic measuring devices/techniques are available in order to monitor the liquid level.

• The level of liquid inside a container is often expressed as the percentage of the total volume.
Liquid Level Measurement

- The measuring devices/techniques that are used in Cryogenics are

  - Dipstick (old technique)
  - Hydrostatic gauge
  - Electric Resistance gauge
  - Capacitance liquid gauge
  - Thermodynamic liquid level gauge
  - Superconducting LHe level gauge
Dip Stick Technique

• It is one of the oldest and a simplest way to check the liquid level.

• A bubbling sound or a boil off is the indication, when a thin open tube is dipped into the liquid.

• The following video demonstrates this technique for liquid nitrogen.
Hydrostatic Gauge

- Consider a closed cryogenic vessel as shown in the figure.

- Let $L_f$ and $L_g$ be the heights of liquid and gas columns respectively. We have, $L = L_f + L_g$.

- Pressure tapings are provided at top and bottom of the vessel as shown.

- The tapings are connected across a differential pressure measurement device.
Hydrostatic Gauge

• As the name suggests, the hydrostatic differential pressure is calibrated in terms of the liquid level.

• Therefore, the pressure difference ($\Delta p$) can be written as

$$\Delta p = \rho_f L_f g + \rho_g L_g g$$

• Using $L = L_f + L_g$, the above equation can be rearranged as

$$\Delta p = \left(\rho_f - \rho_g\right) L_f g + \rho_g L_g$$
Hydrostatic Gauge

- The density of vapor is negligible as compared to that of liquid.

- Therefore, we have

\[ \Delta p = (\rho_f - \rho_g) L_f g + \rho_g L_g \]

\[ \Delta p = \rho_f L_f g \]

\[ L_f = \frac{\Delta p}{\rho_f g} \]

\[ L_f \propto \Delta p \]

- The pressure gauge is directly calibrated in terms of height of liquid.
Hydrostatic Gauge

- The sensitivity of this gauge is directly proportional to the difference in liquid and vapor densities.

<table>
<thead>
<tr>
<th>Densities (kg/m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen ( \rho_L = 808, \rho_g = 4.65 )</td>
</tr>
<tr>
<td>Hydrogen ( \rho_L = 70.8, \rho_g = 1.33 )</td>
</tr>
<tr>
<td>Helium ( \rho_L = 124.8, \rho_g = 16.7 )</td>
</tr>
</tbody>
</table>

- In the case of \( H_2 \) and \( He \), \( \rho_g \) cannot be neglected in comparison to \( \rho_L \). Hence, these gauges cannot be used.
Elec. Rest. Gauge (Movable)

- The schematic of a movable electrical resistance gauge is as shown in figure.

- In this arrangement, a movable resistor is connected across a voltmeter.

- This movable resistance element is heated by using a very small current.

- It is clear that the wire temperature is high, when it is above the liquid level.
The heat transfer coefficient of the liquid is nearly twice that of vapor.

As a result, when the wire is dipped into the liquid, the temperature of the wire drops momentarily.

The electrical resistance, thereby the voltmeter reading, undergoes a sudden change.

This sudden change is the indication of the liquid vapor interface.
Elec. Rest. Gauge (Immovable)

- This method was first devised by Wexler and Cox in the year 1956.

- Unlike in the earlier arrangement, this arrangement has a fixed resistor along the total height of the container.

- The resistor is connected across a voltmeter as shown in the figure.

- The resistance element is fed by a very small current.
Elec. Rest. Gauge (Immovable)

- With the change in the level of the liquid, the resistance of the wire changes.

- This change in resistance, thereby the change in voltmeter reading, is calibrated as a function of liquid level.
Elec. Rest. Gauge (Immovable)

- The advantages are
  - The system does not involve any moving components.
  - The gauge has a continuous indication of liquid level.

- The disadvantage is
  - Continuous energy is dissipated leading to excess boil – off.
Capacitance Liquid Gauge

- In this arrangement, the level probe consists of two concentric cylindrical electrodes, placed vertically as shown.
- The dielectric constants of liquid and vapor are different. Let them be denoted by $C_f$ and $C_g$ respectively.
- The net capacitance ($C_{\text{Net}}$) is a function of $C_f$ and $C_g$, which, in turn are functions of liquid and vapor heights.
Capacitance Liquid Gauge

- With the change in liquid level, the net capacitance ($C_{\text{Net}}$) changes.

- This property is used to calibrate the liquid level inside the vessel.

- The advantages are
  - The system does not involve any moving components.
  - The gauge has a continuous indication of liquid level.
Thermodynamic Liquid Gauge

• The schematic of a thermodynamic level gauge is as shown in the figure.

• It works on a principle that liquid undergoes a large change in the volume, when it is evaporated.

• The probe consists of a thin capillary tube and a pressure gauge via a buffer volume.
Thermodynamic Liquid Gauge

- The capillary is attached to a pressure gauge through a dead volume at an ambient temperature.

- The gauge is charged with a measured amount of gas of the same type, as that in the storage vessel.

- As the capillary tube is immersed into the liquid, the gas in the immersed portion of the tube is condensed.
Thermodynamic Liquid Gauge

• The change in the volume of the gas during condensation reduces the gas pressure within the capillary and the dead volume.

• This drop in pressure is used as an indication of the liquid level inside the container.
**SC LHe level gauge**

- The schematic of a SC LHe level gauge is as shown in figure.

- In this arrangement, an immovable SC element is dipped into the LHe.

- The sensor is connected to a voltmeter and is fed with a small current.

- These sensors measure the liquid level by measuring the resistance of the measuring filament.
SC LHe level gauge

- This superconducting filament is housed inside a Teflon protective tube.

- The portion of filament in liquid remains in the superconducting state and exhibits zero resistance.

- Therefore, the resulting voltage along the sensor filament is proportional to the length of filament above the liquid helium.
SC LHe level gauge

- This sensor provides a continuous measure of the helium depth.
- Four wire technique is used to eliminate the errors resulting in variations in the length of the leads.
- The small amount of heat generated in the probe is dissipated primarily in the helium gas rather than in the liquid helium.
Summary

• Some of the commonly used non-metallic sensors are Silicon diode, Cernox and Ruthenium Oxide.

• Silicon diodes have negligible $i^2R$ losses, exhibit a linear response, good repeatability and accuracy.

• Cernox RTDs offer high response time and have low magnetic field induced errors.

• Sensors used to monitor liquid level are Dipstick, Hydrostatic gauge, Electric Resistance/Capacitance level gauge, Thermodynamic level gauge and Superconducting LHe level gauge.
• A self assessment exercise is given after this slide.

• Kindly assess yourself for this lecture.
Self Assessment

1. In a silicon diode, sensor consists of a _____ with resistance – temperature property.
2. Voltage in silicon diode ___ with decrease in temperature.
3. For a silicon diode, the sensitivity _____ 30 K.
4. _____ diodes are accurate in magnetic fields.
5. In hydrostatic gauge, pressure gauge is directly calibrated in terms of _____.
6. In hydrostatic gauge, sensitivity is dependent on _______ densities.
7. The heat transfer coefficient of liquid is _____ that of vapor.
8. SC LHe level gauge has an immovable _____.
Answers

1. Silicon chip
2. Decreases
3. Increases
4. Cernox
5. Height
6. Liquid and vapor
7. Twice
8. SC element
Thank You!