Earlier Topics

• Introduction to Cryogenic Engineering
• Properties of Cryogenic Fluids
• Properties of Materials at Cryogenic Temperature
• Gas Liquefaction and Refrigeration Systems
• Gas Separation
• Cryocoolers
• Cryogenic Insulations
• Vacuum Technology
Current Topic

Topic: Instrumentation in Cryogenics

- Need of Cryogenic Instrumentation
- Measurement of Thermophysical Properties
- Various Sensors

- The current topic will be covered in 3 lectures.
- Tutorials and assignments are also included.
Outline of the Lecture

Topic: Instrumentation in Cryogenics

• Need of Cryogenic Instrumentation

• Measurement of Thermo physical Properties
  • Temperature
Introduction

• In the earlier lecture, we have seen that the cryogenic vessels are insulated, closed containers.

• Instrumentation is needed
  • To monitor the vacuum in insulation, as there is a continuous gas in leak.
  • To monitor the liquid level so as to avoid any over flow of the cryogen.
  • To monitor a sample’s temperature.
Introduction

• This justifies the need for instrumentation for a safe Cryogenic operation.

• It is clear that conventional methods like bourdon pressure gauge or thermometer cannot be used due to the following reasons.
  • Working at extremely low temperatures.
  • Sustainability to thermal and mechanical fatigues.
  • Calibration at low temperatures.
Special Requirements

• There are a few special requirements that are to be qualified by the sensors, to use them in Cryogenic Technology. They are

• **Remote Arrangements** : Cryogenic vessels are closed containers. The sensors should be capable of remote operation from outside.

• **Vacuum** : The sensors should be able to withstand low pressures prevalent in vacuum.

• **Cryogen** : The sensors should be chemically inert towards the cryogen under use.
Special Requirements

• **Magnetic Field**: The property of the sensor should be intact even in magnetic atmospheres.

• **Accuracy**: The accuracy, the calibration are very important at such low temperatures.

• **Losses**: The heat release, for example, $i^2R$ losses, conduction via leads should be very low.

• **Material Properties**: Thermal, mechanical properties of sensors must be in allowable limits.
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.
Temperature

• The various measuring units of temperature are Kelvin, degree Centigrade, degree Fahrenheit etc.

• The measurement of temperature is based on zeroth law of thermodynamics. It states that when two bodies are in thermal equilibrium, they are at the same temperature.

• Temperature is measured to monitor thermal expansion and most importantly pressure rise.

• The calibration of a temperature sensor is done using some fixed points.
Temperature Scales

• The international temperature scale is defined up to the triple point of $H_2$. Its value is 13.84 K.

• Recently, various scales are developed to measure much lower temperatures.

• Germanium Resistance Thermometer – 4.2 K to 13.84 K.

• He$^4$ Vapor Pressure Scale – 1.5 K to 4.24 K. It was invented in 1958 and it is often called as $T_{58}$ (He$^4$).
Temperature Scales

- He\(^3\) Vapor Pressure Scale – 0.8 K to 1.5 K. This scale is also called as T\(_{62}\) (He\(^3\)).

- For the temperatures between 0.006 K to 0.8 K, the scale is based on the properties of Cerium magnesium nitrate (salt).

- The variations in magnetic susceptibility of this salt are calibrated in terms of temperature.
Temperature Measurement

- Various sensors that are often used in Cryogenics to measure temperature are

- Thermocouples
- Metallic Resistance Thermometer
- Semiconductor Resistance Thermometer
- Constant Volume Gas Thermometer
- Vapor Pressure Thermometer
- Magnetic Thermometer
Thermocouple

- Consider two conducting wires of different materials, A and B.
- These metal wires are joined together as shown above.
- The left and right joints are LJ and RJ respectively. A voltmeter V is in series with wire B.
• Consider a situation, in which left and right joints are maintained at \( T_1 \) and \( T_2 \) respectively. (\( T_1 \neq T_2 \))

• Due to the temperature difference, a net voltage or an electromotive force is developed in the loop. This is called as **Seebeck** effect.

• It is named after a German physicist, Thomas Johann Seebeck (1821).
Thermocouple

- The voltage \((e, \text{mV})\) is directly proportional to the temperature difference \((t, ^\circ\text{C})\).

- Mathematically, we have \(e = f(t)\).

- Rearranging, we can also express it as \(t = g(e)\).

- Here, \(f\) and \(g\) are some functional correlations.
In practice, reference point like ambient temperature or ice point is maintained at left end.

The temperature at the right end is calculated using the functional correlations.

These functional correlations are also dependent on wire materials, wire dimensions and reference point.
Some approximate values for different types of thermocouples are as given below.

**T type**
- Cu and Cu – Ni alloy (Copper – Constantan).
- Range: 3 K to 673 K.
- Sensitivity: 4.6 µV/K at 20 K.

**K type**
- Ni – Cr and Ni – Al alloys (Chromel – Alumel).
- Range: 3 K to 1543 K.
- Sensitivity: 4.1 µV/K at 20 K.
Thermocouple

- The different types of thermocouples in use are
- **E type**
  - Ni – Cr and Cu – Ni alloys (Chromel – Constantan).
  - Range: 3 K to 953 K.
  - Sensitivity: 68 μV/K at 20 K.
  - This combination produces the highest Seebeck effect.
The adjacent figure shows the variation of Seebeck coefficient with temperature for E, K and T type thermocouples.

For any given temperature, E type thermocouple has more Seebeck coefficient than T type thermocouple.

It is important to note that the sensor should have maximum coefficient for greater accuracy.
Hence, **E** type thermocouple has more accuracy than the **T** type thermocouple.

From the figure, it is clear that for the temperatures below **50 K**, the curves are steep.

It is undesirable to use these sensors in this temperature range.
Thermocouple

- The disadvantages of a thermocouple are
  - The emf or the voltage generated is very small, typically in the order of milli volts. A series combination of various thermocouples is used.
  - The voltage drop across the length of the lead wires induces substantial error in measurement.
  - The thermal conduction along the lead wires contribute to the heat in leak.
Resistance Temp. Detectors

• Resistance of a conductor or a semiconductor changes with the change in temperature.

• Resistance Temperature Detectors, also called as RTDs, use this property to measure the temperature.

• Platinum, copper, lead or indium wires are used in metallic RTDs.

• Non metallic RTDs use GaAlAs diodes, Carbon glass and Ruthenium Oxide.
Resistance Temp. Detectors

- The schematic of a Platinum RTD is as shown in the figure.

- A conducting wire, say a platinum wire, of very long length is wound on a notched mica insulator.

- This assembly is housed inside a closed platinum sheath.

- An ohm meter is used to measure the resistance, thereby, the corresponding temperature.
Resistance Temp. Detectors

- The photograph of a RTD is as shown.

- The typical size of a RTD is 3 mm x 1.84 mm x 0.98 mm.
The choice of the wire material is dependent on the variation of resistance with temperature.

The adjacent figure shows the variation of $R_t/R_o$ with the temperature.

Here, $R_t$ and $R_o$ are the resistances at temperatures $T_\circ C$ and $0^\circ C$ respectively.
It is desirable to choose a material whose resistance varies linearly with temperature.

From the adjacent figure, it is clear that the sensor is most preferred up to 30 K, due to its linear variation.
• The correlation for the adjacent graph is

\[
\frac{R_t}{R_o} = 1 + At + Bt^2 + Ct^3 \left( t - 100 \right)
\]

• The constants \( A, B, C \) are found by calibration of RTD at any three standard temperatures.
The term Sensitivity is defined as the rate of change of electrical resistance with the change in temperature.

Mathematically, it is expressed as

\[ S = \frac{dR}{dT} \]

The adjacent figure shows the sensitivity of a Platinum resistance thermometer.
Resistance Temp. Detectors

- The advantages of a RTD are
  - These sensors exhibit a very high repeatability and accuracy in their operating range.

- Few typical values are
  - Repeatability : ±10 mK in 77 K to 305 K.
  - Accuracy : ±250 mK in 77 K to 305 K.

- The effect of magnetic field is very low for the operating temperatures above 40 K.
Resistance Temp. Detectors

• It is important to note that, proper care has to be taken while mounting a RTD.

• The unwanted mechanical and thermal strains causes a change in the electrical resistance.

• These changes induce error in the measurement.
Resistance Temp. Detectors

• The effect of lead wire resistance is very crucial in the accuracy of a RTD.

• In order to minimize this error, two different wiring arrangements are used.

• They are,
  • Two wire arrangement
  • Four wire arrangement
Resistance Temp. Detectors

- The schematic of a Two wire arrangement is as shown.

- Let the resistance of each of the lead wires be \( R \) ohms.

- The ohmmeter \( V \), across the ends of lead wires, measures the combined resistance of RTD + leads.

- It is clear that this extra lead wire resistance is the direct error in measurement.
Resistance Temp. Detectors

- Hence, the lead wire resistance should be as low as possible.

- In such arrangements, wires of short length are used to minimize the resistance.
Resistance Temp. Detectors

- The schematic of a Four wire arrangement is as shown.

- An external constant current source \((i)\), typically in mA, is used to power the RTD.

- The measurement leads are connected in parallel across the RTD.

- In this arrangement, the current flowing across the measuring leads is negligibly small.
Resistance Temp. Detectors

- The current being negligibly small, the voltage drop offered is also very small.

![Diagram of Resistance Temp. Detectors](image)

- The output of the sensor, either voltage drop or resistance is directly proportional to the RTD resistance.

- Therefore, the reading of the sensor is insensitive to lead resistance.
Resistance Temp. Detectors

- Some of the commonly used metallic RTDs are
  - PT 100
  - PT 1000
  - PT 100 implies the sensor has 100 ohms resistance at 0°C.
Summary

- In Cryogenics, there is a need to monitor various properties like pressure, temperature, liquid level, etc for safe operation.

- Thermocouple works on Seebeck effect.

- Different types of thermocouples are
  - **T type**: Cu and Cu – Ni alloy, 3 to 673 K.
  - **K type**: Ni – Cr and Ni – Al alloys, 3 to 1543 K.
  - **E type**: Ni – Cr and Cu – Ni alloys, 3 to 953 K.
Summary

• PT 100, PT 1000 are some of the commonly used RTDs in Cryogenics.

• In order to minimize errors due to lead resistance, Four wire arrangement is preferred over Two wire arrangement.
• A self assessment exercise is given after this slide.

• Kindly assess yourself for this lecture.
1. Cryogenic Instrumentation should be capable of _____ operation from outside.
2. The heat release in sensors is due to _____.
3. Measurement of temperature is based on ___ of thermodynamics.
4. Thermocouple works on ______ effect.
5. The Seebeck effect is highest for ______ type.
6. Resistance of a conductor _____ with a decrease in temperature.
7. RTDs are preferred upto ____, due to linear variation.
8. Errors are less in _____ arrangement, as compared to Two wire arrangement.
Answers

1. Remote
2. $i^2R$ losses
3. Zeroth law
4. Seebeck
5. E
6. Decreases
7. 30 K
8. Four wire
Thank You!