CHAPTER 1: INSTRUMENTATION EQUIPMENT

MODULE 6: Temperature Instrumentation

MODULE OBJECTIVES:

At the end of this module, you will be able to:

1. Briefly describe how a typical "J" type thermocouple is constructed.
2. State the type, and magnitude of the signal which a thermocouple generates and describe briefly its relationship with temperature.
3. Define the terms measurement junction and reference junction in relation to a thermocouple.
4. Explain the need for extension grade wires in a thermocouple installation.
5. State where thermocouples are used in typical industrial applications, and why they are used in these areas.
6. Explain the construction and principle of operation of a Resistance Temperature Detector (RTD).
7. State the type of signal a RTD generates.
8. Explain the need for three wire RTDs in temperature measurement.
9. State the functions of a thermal well.

Temperature Instrumentation

Temperature measurement is divided into two different types - local and control room (remote) measurement Often local measurement is used when no control function is required. It is for indication purposes only.

Local Temperature Measurement

In most industrial application the majority of local temperature measurements are made by <u>bimetalic thermometers</u>.

A bimetalic strip is constructed by bonding two metals with different coefficients of thermal expansion (Figure 1 (a)). If heat is applied to one end of the strip, the metal with the higher coefficient of expansion will expand more readily than the lower one. As a result, the whole metallic strip will bend in the direction of the metal with the lower coefficient. (Figure 1(b)).

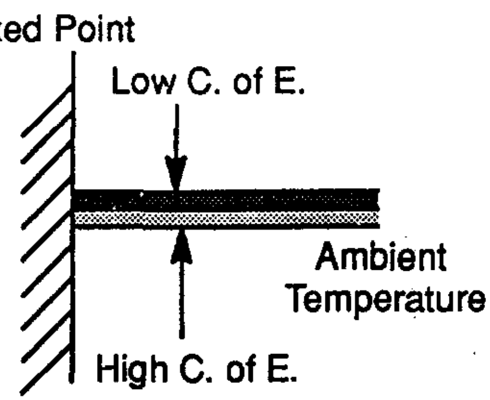

Figure 1 (a): A Bimetalic Strip

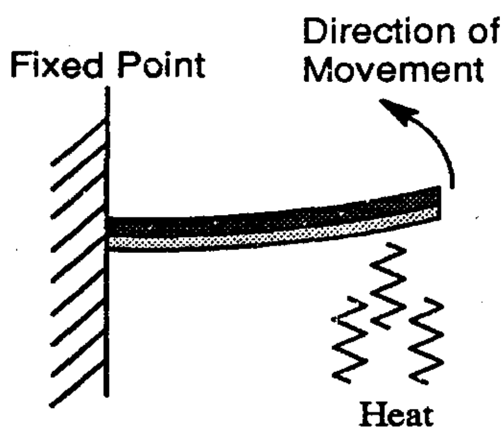

Figure 1 (b): Bimetalic Strip Bent After Heat is Applied

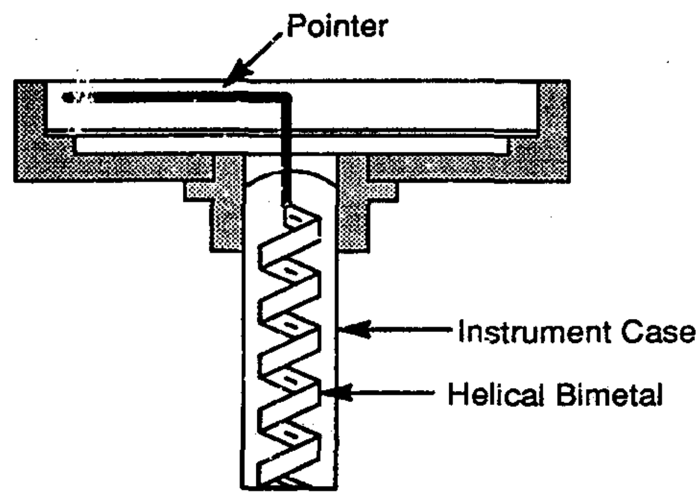

Figure 2: A Helical Bimetalic Thermometer

Thermocouple (TC) - Principle of Operation

- A thermocouple consists of two pieces of dissimilar metals with their ends joined together.
- When heat is applied to the junction, a voltage, in the range of millivolts (mV), is generated.
- A thermocouple is self-powered.
- The voltage (or emf) generated at each junction depends on junction temperature.
- The net voltage (circuit emf) shown on the galvanometer depends on the relative magnitude of the voltages at the two junctions.

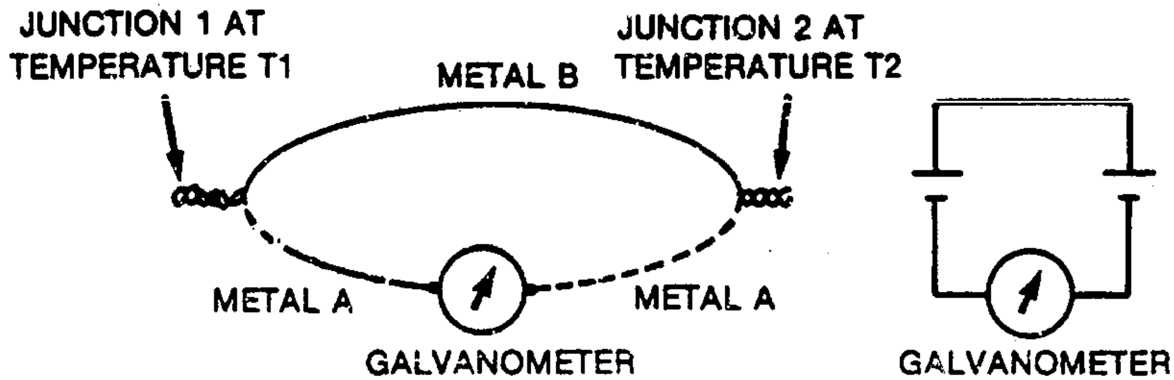

Figure 3: Thermocouple Circuit.

- To use a thermocouple to measure process temperature, one end of the thermocouple has to be kept in contact with the process while the other end has to be kept at a constant temperature.
- The end that is in contact with the process is called the <u>hot</u> or <u>measurement junction</u>. The one that is kept at constant temperature is called <u>cold</u> or <u>reference junction</u>.
- The relationship between circuit emf and junctions emf is:

  Circuit emf = Measurement emf - Reference emf

If circuit emf and reference emf are known, measurement emf can be calculated.

Temperature Transmitter

- To convert the emf generated by a thermocouple to the standard 4-20 mA signal, a transmitter is needed.
- The temperature measurement circuit consists of a thermocouple which is connected directly to the temperature transmitter.
- There are two junctions in the circuit - a measurement junction and a reference junction which is kept at control room temperature.
- There are two additional junctions formed by the metal C, which is the metal used inside the transmitter, and metal A.
- Circuit emf = Measurement emf + A-C emf - A-C emf - reference emf

  = Measurement emf - reference emf

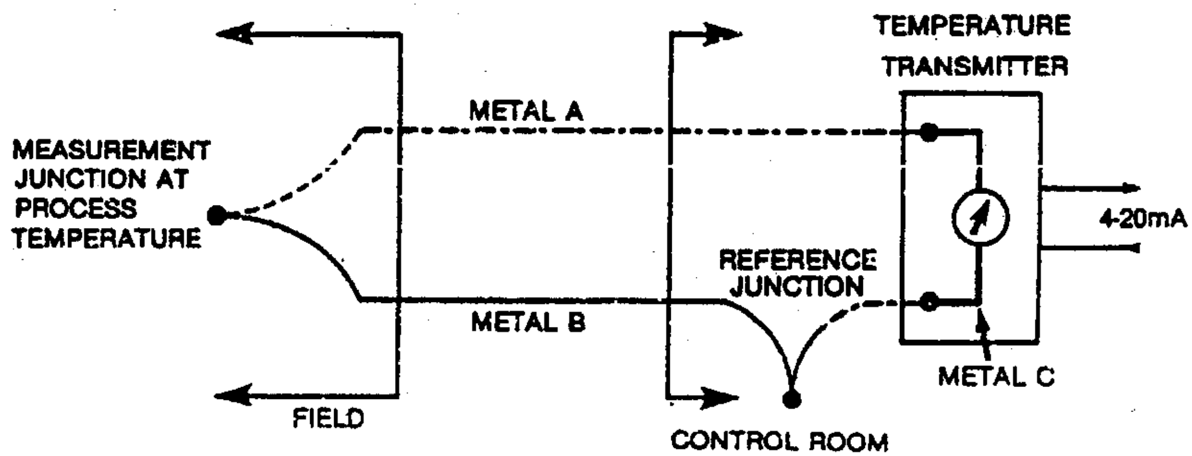

Figure 4: A Simplified Thermocouple Temperature Transmitter.

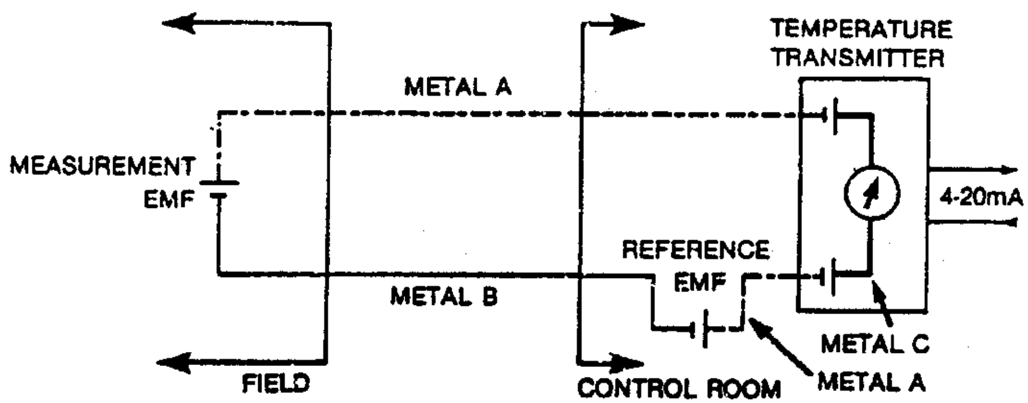

Figure 5: Equivalent Thermocouple Circuit Diagram.

The emf generated by the junctions of the third metal is equivalent to the emf that would be generated by the reference junction at the same temperature. The transmitter itself in effect becomes the reference junction. (Figure 6).

In practice, the transmitter is often installed in a constant temperature environment (usually inside the control room) to help maintain the reference emf constant.

Since we know the total circuit emf and the reference junction emf, the measurement junction emf can easily be obtained by the relationship:

Measurement emf = Total Circuit emf + Reference emf

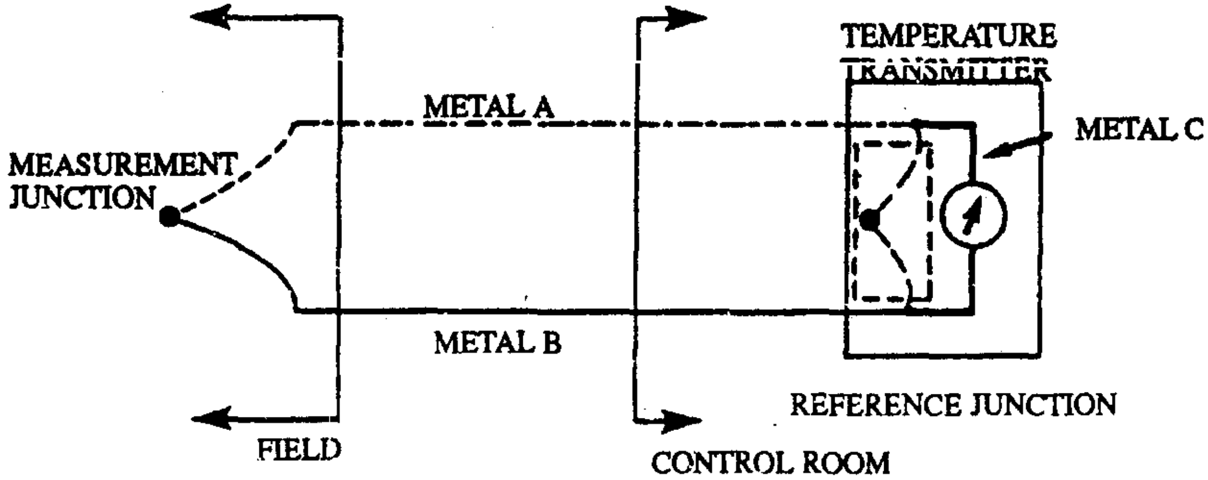

Figure 6: Thermocouple Circuit With Transmitter Terminals Acting As The Reference Junction.

The transmitter, when properly calibrated, will output a 4-20 mA signal that is directly proportional to the measurement emf and hence the process temperature.

Thermocouple Construction

- **The materials used for thermocouple construction depend on the temperature range to which the thermocouple will be subjected.**
- **A popular type of thermocouple is the "J" type. It consists of iron and constantan (a nickel-copper alloy) wires with very high purity.**
- **The "J" type thermocouple has a fairly linear relationship between temperature and millivolt output in the range of 0 to 300°C, which suits many industrial applications.**
- If the thermocouple is located some distance away from the transmitter, a connection between the thermocouple and the transmitter has to be made.
    - Using high purity thermocouple wires for connection will be expensive.
    - If ordinary copper wires are used, additional junctions would be formed where the wires are joined.
    - To eliminate this problem, extension grade thermocouple wires or compensating cables have to be used.
- Extension grade wires are made of the same, or with the same characteristic, materials as the thermocouple wires they are connected to.
- In general, thermocouples are used exclusively around the turbine hall because of their rugged construction and low cost.
- **Thermocouples are not used in areas where high radiation fields are present (for example, in the reactor vault). Beta radiation (from neutron activation), essentially electrons, will induce a voltage in the thermocouple wires. Since the signal from thermocouple is also a voltage, the induced voltage will cause an error in the temperature transmitter output.**

Resistance Temperature Detector (RTD) - Principle of Operation

- **The Resistance Temperature Detector or RTD can be regarded as a high precision wire wound resistor whose resistance varies with temperature.**

  For metals, resistance is given by:

  $$R = \rho\, l/A$$

  where, R = resistance (Ω)

  P = resistivity (Ω-M)

  l = length (m)

  A = cross-sectional area (m^2)

- **When the temperature of the metal changes, its physical dimensions also change (e.g. length increases, cross-sectional area decreases). Metals have a positive temperature coefficient of resistance, i.e. as temperature increases, resistance increases. By measuring the resistance of the metal, its temperature can be determined.**

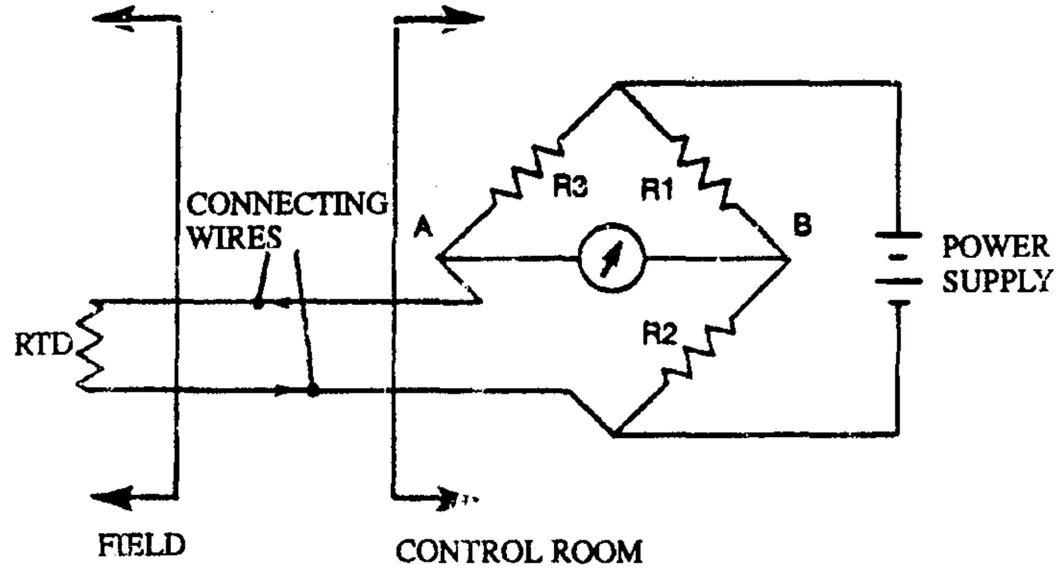

Figure 7: A Wheatstone Bridge Temperature Detector For RTD.

- **Several different pure metals (such as platinum, nickel and copper) can be used in the manufacture of RTDs. A typical RTD probe contains a coil of very fine metal wire, allowing for a large resistance change without great space requirement.**
- **In applications that require high accuracy and linearity, platinum RTDs are used as process temperature monitors. To detect the variations of resistance of the RTD, a temperature transmitter in the form of a Wheatstone bridge can be used. (Figure 7).**

In a Wheatstone bridge circuit, when the current flow in the galvanometer is zero (the voltage at point "A" equals the voltage at point "B") the bridge is said to be in <u>null balance</u>. A set ratio exists between the resistive elements.

When the galvanometer in the Wheatstone ridge detector reads null, when

$$\frac{R_1}{R_2} = \frac{R_3}{RTD}$$

- By keeping R_1, R_2 and R_3 constant, the resistance of the RTD can be determined by the reading of the galvanometer.
- If the galvanometer is replaced by a detector circuit, a 4 - 20 mA signal which is proportional to the temperature range being monitored can be generated.
- As with the case of a thermocouple, a problem arises when the RTD is installed some distance away from the transmitter.
- To eliminate the problem of variations in wire resistance, a three-wire RTD is used.
- From Figure 8, it can be seen that the resistances of the wires cancel and therefore the effect of the connecting wires is eliminated.

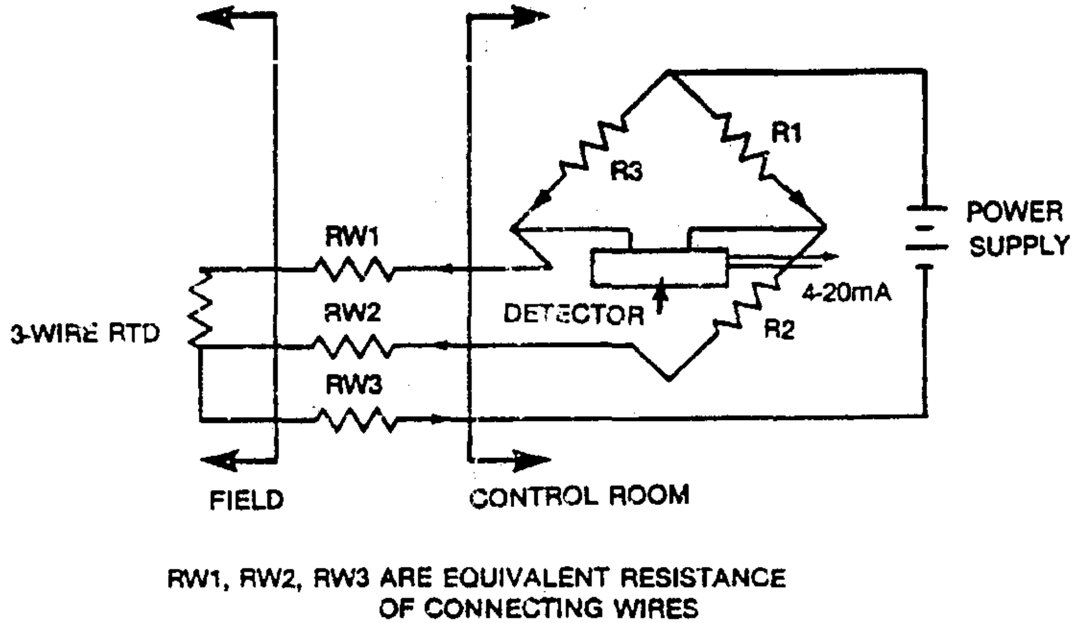

Figure 8: Three Wired RTD.

Thermal Wells

Used to protect temperature sensors in process environments that are pressurized and possibly chemically corrosive and/or radioactive.

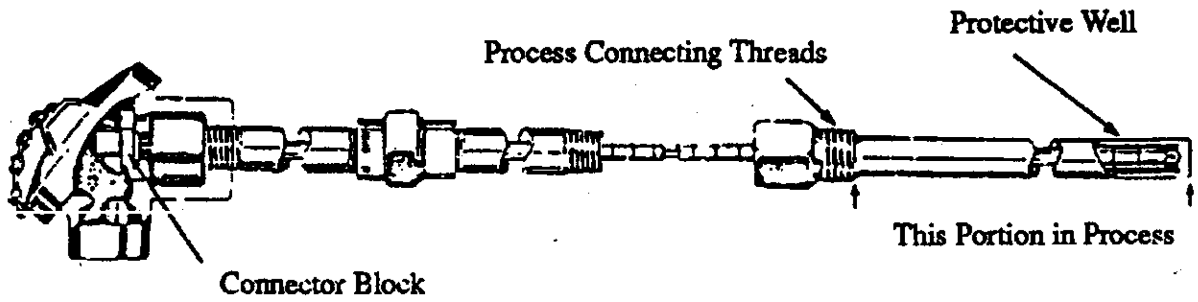

Figure 9: A Typical Thermal Well Installation.

- **A thermal well is basically a hollow metal tube with one end sealed. It is usually mounted permanently in the pipe work.**
- **The sensor is inserted into the well and makes contact with the sealed end.**
- **A drawback to thermal wells is their long response time because heat must be transferred through the well to the sensor.**
- **An example of the temperature response for bare and thermal well installed sensors is shown in Figure 10.**
- **The thermal lag can be decreased by minimizing the air space between the sensor and the well.**

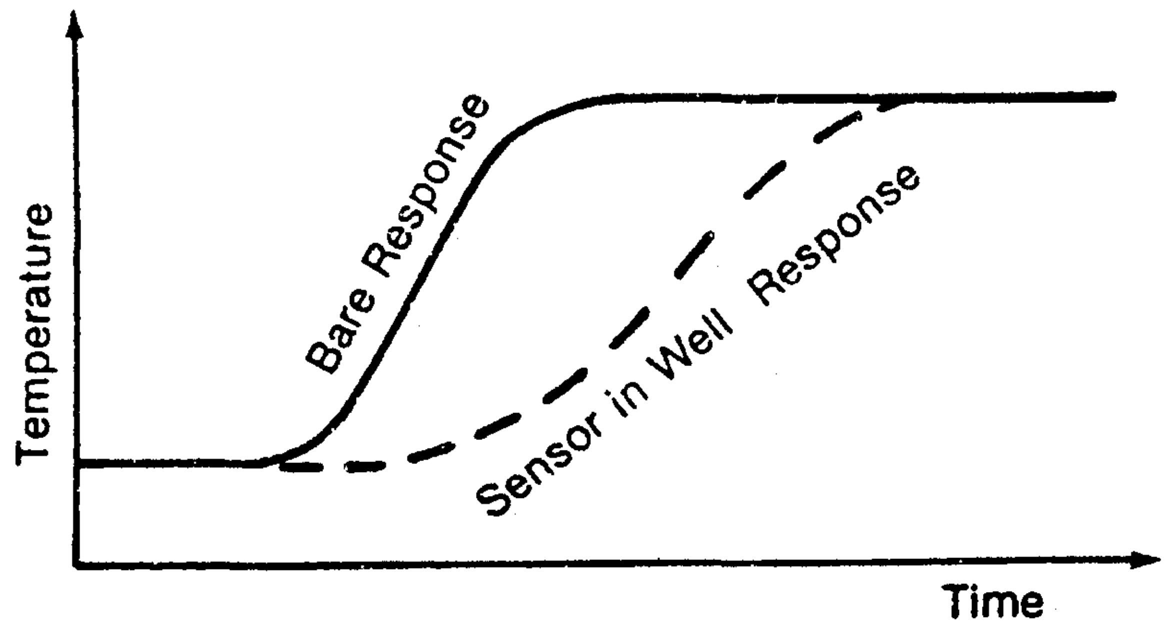

Figure 10: Response Curves of Bare and Thermal Well Installation.