ME343 Lecture Note 5

Temperature Measurements and Sensor Characteristics

Objectives:

- Temperature Measurement by TC
- Sensor Characteristics
    - Sensitivity
    - Signal drifting
    - Response time
- Other methods for Temperature Measurement
    - RTD
    - Thermistor
    - Infrared Thermometer
- Lab Report Requirement of Lab 2

  (See Lecture note 3 for geeral format requirement and Grading Criteria of Lab 2 for special requirement)

- Resistance Thermometer (RTD)

$$R(T) = R_0[1 + A(T - T_0) + B(T - T_0)^2] \quad (1)$$

Where, R_0 is resistance at T_0; A and B are coefficients.

or

$$R(T) = \alpha + \beta T + \gamma T^2 \quad (2)$$

Thus, given some calibrated oints (R_1, T_1), (R_2, T_2), (R_3, T_3), α, β, γ are determined from equation (2).

$$\therefore sensitivity = \frac{dR}{dT} = \beta + 2\gamma T \quad (3)$$

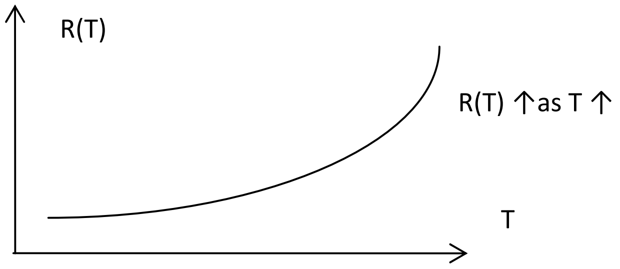
For small temperature span or at low temperature

$$R(T) \doteq R_0[1 + A(T - T_0)] = \alpha + \beta T$$

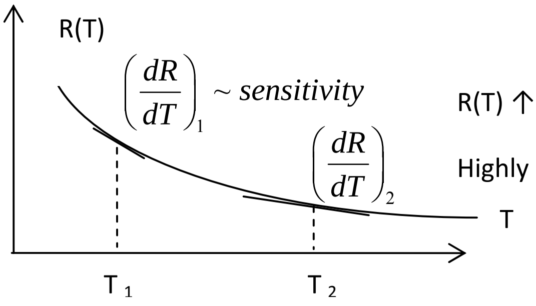
Table 16.2 Typical RTD's

	T (^{o}c)	R_0 (Ω)	A	Response time
Platinum (Lab)	-190~540	25@0 ^{o}c	0.0039	
Platinum (Ind.)	-200~125 -18~540	25@0 ^{o}c	0.0039	10-30
Copper	-70~120	10@0 ^{o}c	0.0038	20-60
nickel	0~120	100@0 ^{o}c	0.0067	20-60

Most RTD's are metal alloys



- Thermistor
  - Ceramic- type materials:



R(T) ↑as T ↓

Highly non-liner!

$$R(T) = R_0 EXP\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

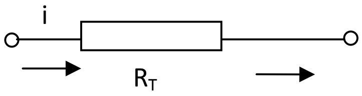
Where β is a constant.

OR. $R(T) = \alpha \exp(\frac{\beta}{T})$

Thus, given two or more calibration points → α, β

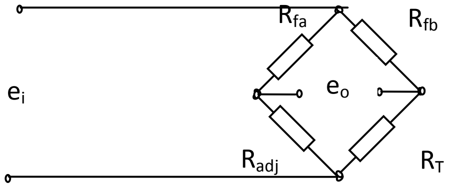
  - Various forms of thermistors (See Fig. 16.7 and Table 16.3)
  - Self-heating (drifting in R)

Concept:



$$\dot{q} = i^2 R = T_R \uparrow \Rightarrow R_T \downarrow$$
$$(\therefore \; from \;\; \Delta R_T \Rightarrow \Delta T)$$

Testing:



(1) Initially balanced by adjusting R_{adj} ($e_o \approx 0$)

(2) R_T is changed by changing e_i (or i)

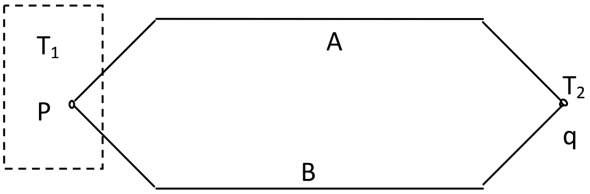
(3) "self-heating" → $e_o \neq 0$

$$\frac{e_o}{e_i} = \left[\frac{R_{fa}}{R_{adj} + R_{fa}} - \frac{R_{fb}}{R_T + R_{fb}} \right]$$

$$\therefore \frac{de_o}{e_i} = e_i \frac{R_{fb}(dR_T)}{(R_T + R_{fb})^2} = \frac{R_{fa}^2 dR_T}{\left(R_{adj} + R_{fa}\right)^2 R_{fb}}$$

$$From \left.\left(\frac{dR}{dT}\right)\right|_{balanced\ point} \Rightarrow dT \doteq dR_T \cdot \left.\left(\frac{dR}{dT}\right)\right|_{balanced\ point}$$

- Thermocouple (TC)



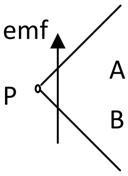
* A, B are two dissimilar metals:

(1) Peltier effect: electromotive force at junction (emf)

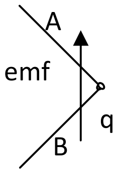
(2) Thomson effect: electromotive fore by tempereature gradient

(Themoson effect << Peltier effect)

* A, B junction at p:



A, B junction at q:



If $T_1 = T_2$, $(\text{emf})_p = (\text{emf})_q$

If $T_1 \neq T_2$, $(\text{emf})_p \neq (\text{emf})_q \rightarrow i_{TC} \neq 0$

If T_1 is a cold (or reference) junction (e.g. icy point.)

$i_{TC} = f(T_2)$

* Typical Type of TC (See Table 16.4)

	Type T (Cu/Const)	Type J (Iron/ Const)	Type K (Chrom/Al)
T range (°c)	-180~260	-180~540	-180~1370
mV range	-5.3~19	-7.5~29.5	-5.6~54.8

All output are in mV

Need " pre-amplifier" to do data-acquisition

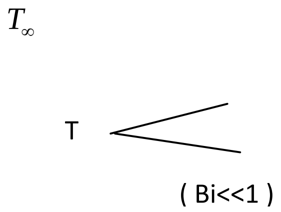
Empirical relations (see Table 16.6)

Standard TC data base (e.g. TC manuals)

* Transient Temperature Measurement by TC

$$\rho c \frac{dT}{dt} = hA(T_\infty - T)$$

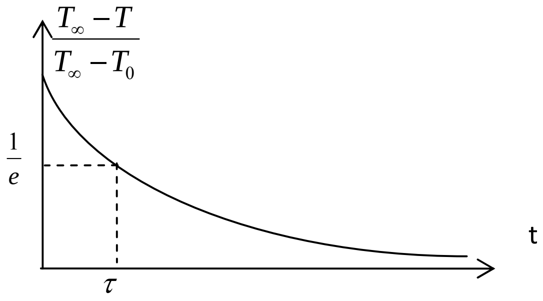
$$\therefore \begin{cases} \dfrac{d(T_\infty - T)}{dt} = -\dfrac{hA}{\rho c}(T_\infty - T) \\ T\big|_{t=0} = T_0 \end{cases}$$



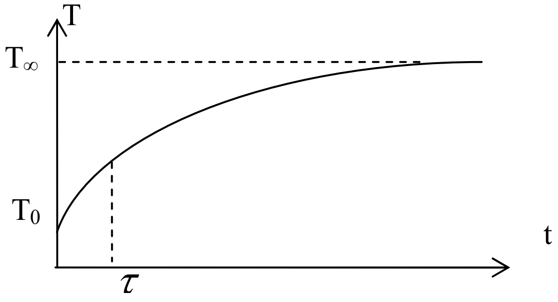
$$\therefore \frac{T_\infty - T}{T_\infty - T_0} = \exp(-\frac{hA}{\rho c} t)$$

$$Let\ \ \tau \equiv \frac{\rho c}{hA} \qquad (response\ time)$$

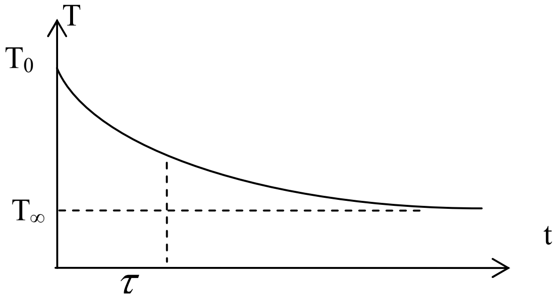
$$\therefore \frac{T_\infty - T}{T_\infty - T_0} = \exp(-\frac{t}{\tau})$$



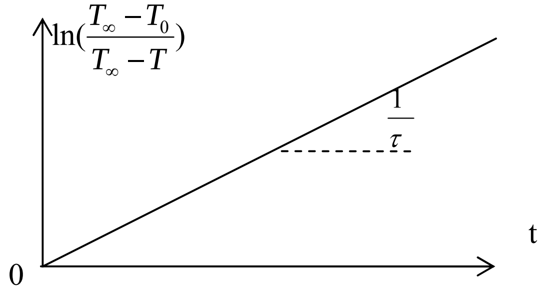
Or (1) $T_\infty > T_0$



(2) $T_\infty < T_0$



(3) $\ln(\frac{T_\infty - T_0}{T_\infty - T}) = \frac{t}{\tau}$



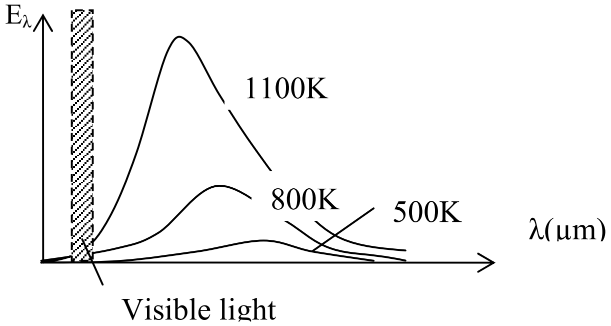
- Infrared Thermometer (IR Pyrometry)
  - Thermal Radiation

(1) Monochrometic (single wavelength)

Planck's law: $E_\lambda = \dfrac{C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)}$

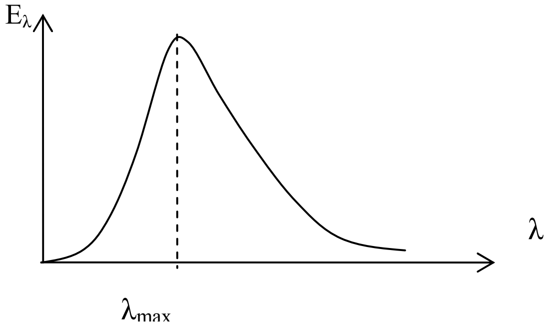
Where, $E_\lambda (w/m^2 \cdot \mu m)$; $T(K)$; $\lambda(\mu m)$

$C_1 = 374.18 MW \mu m^4 / m^2$; $C_2 = 14388 \mu m K$



(2) Wien displacement law ($\dfrac{dE_\lambda}{d\lambda} = 0$)

$\lambda_{\max} \cdot T = 2897.8 \mu m K$



(3) Total radiation

$\dot{q}_r = \int_0^\infty E_\lambda d\lambda = \sigma T^4$ (Stefan-Boltzmann)

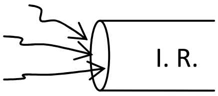
- IR Pyrometry

(1) IR region: λ=0.75~ 1000 μm (non-visible)

T °c	λ_{max}
25 °c	9.7 μm
1100 °c	2 μm
-100°c	~15 μm

(2) Area-averaged (not point-measurement !)

(poor focusing!)



(3) High-temperature (>1000 °c)

Distinct peak → good sensitivity

(4) Cryogenic-temperature (say < -50 °c)

a. Less distinctive peak

but can go to very low temperature

b. Important for outer-space applications