Western Norway University of Applied Sciences

Proton Computed Tomography

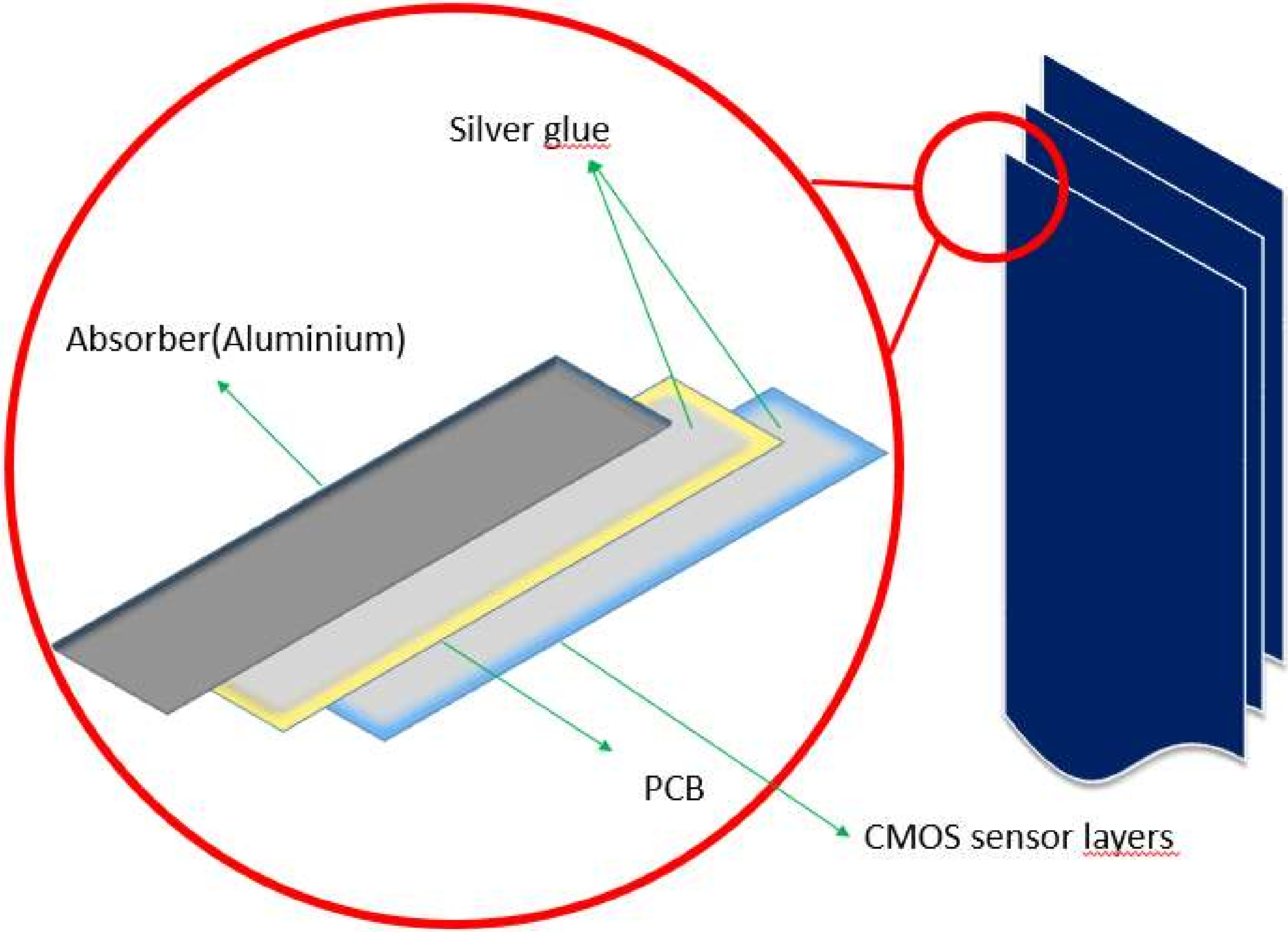
WP5,Mechanical:

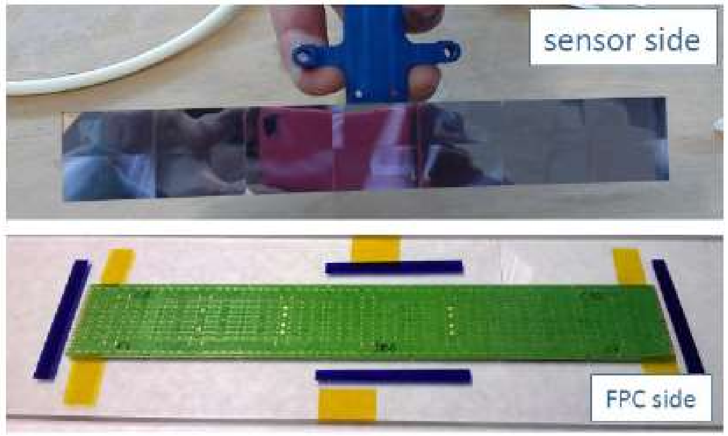
Detector cooling potential, Heat transfer approach

Hesam Shafiee

15.09.2017

Potential cooling schemes





Study and simulation analysis of heat distribution field:

- In plate heat distribution
  - ✓ Geometry effect (length-width proportion)

$q = k\, S\, \Delta T_{overall}$

S = Shape factor

2D Geometries

Very comprehensive summary of shape factors for a large variety of geometries is given by Rohsenow and Hahne and Grigull (Heat transfer books)

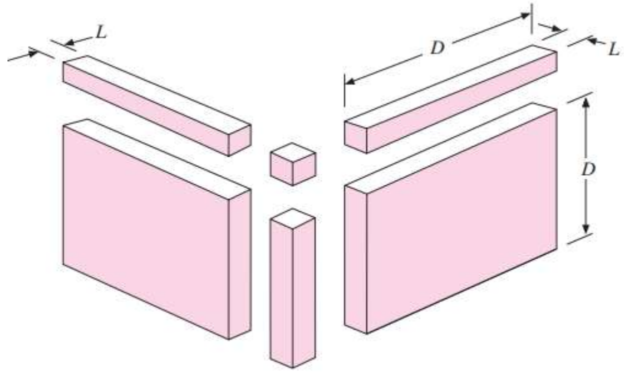
3D geometries

S_{wall} = A /L S_{edge} = 0.54D S_{corner} = 0.15L

A = Area of wall

L = Wall thickness

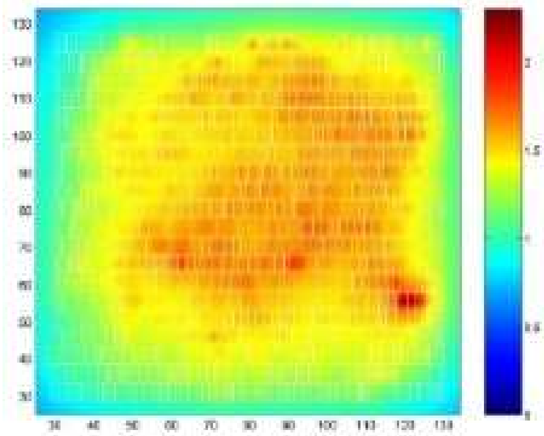
D = Length of edge



- ✓ Temperature gradient & heat transfer rate

  a. High energy proton beams colliding location

  - energy gradient causes
  - non-uniform temperature distribution



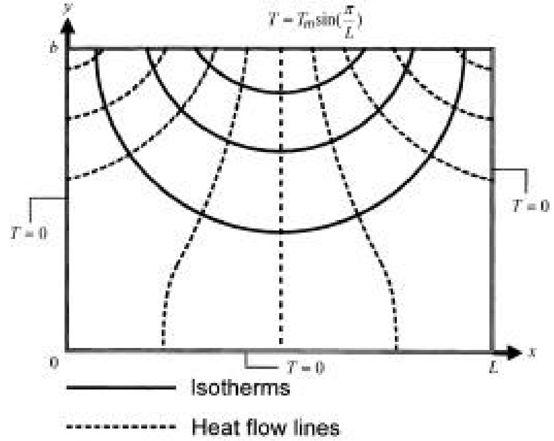
- ✓ Increasing conductivity of plate

  a. Material/Mechanical properties of PCB, Absorber:

  Higher conductivity (k) ⟺ Higher rate of heat transfer

- ✓ Heat spots and critical areas

- ✓ Effects of boundary conditions as cold sources



- Heat transfer through stave layers

  - ✓ Thermal conductivity of multilayer bodies(R_{Totall}):

    Sensors, PCB, Silver glue, absurber

    R=R1+R2+R3+R4+R5 = $\frac{L_1}{k_1A_1} + \frac{L_2}{k_2A_2} + \frac{L_3}{k_3A_3} + \frac{L_4}{k_4A_4} + \frac{L_5}{k_5A_5}$

    ↑ k , A ⟺ R ↓

  - ✓ Temperature gradient & rate of heat transfer

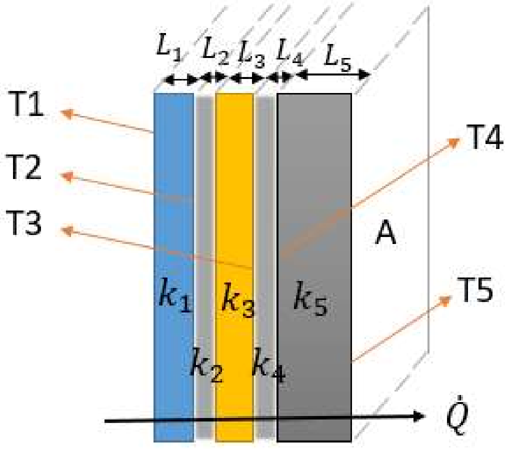
    $\dot{Q} = \frac{\Delta T}{R}$

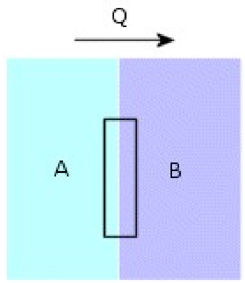
    ↑ ΔT ⟺ $\dot{Q}$ ↑

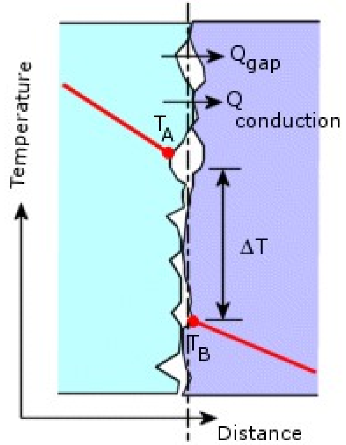
  - ✓ Thickness layers sensitivity

    ↑ L ⟺ $\dot{Q}$ ↓

  - ✓ Critical layer in case of mechanical properties and heat capasity, deformation?!
  - ✓ Thermal contact resistance challenge

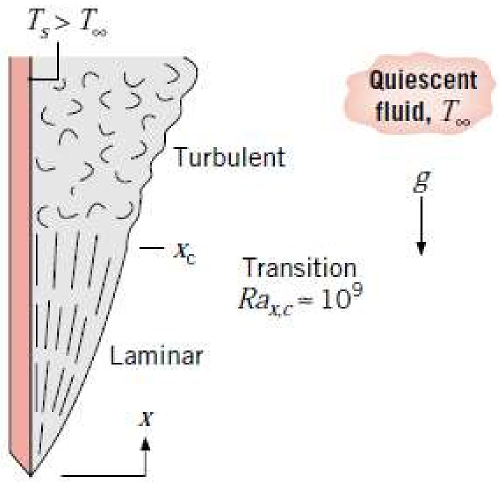


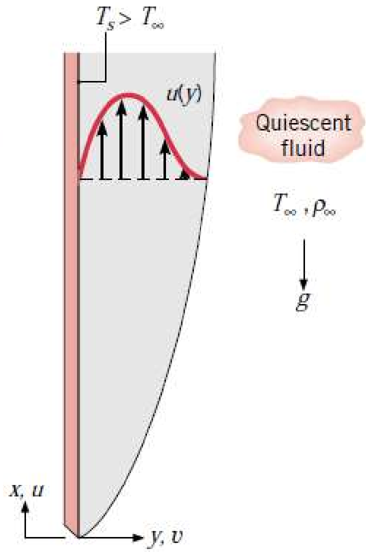


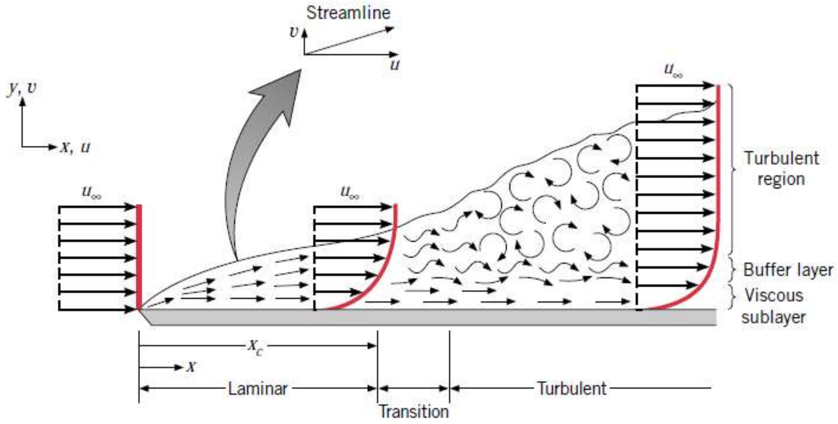


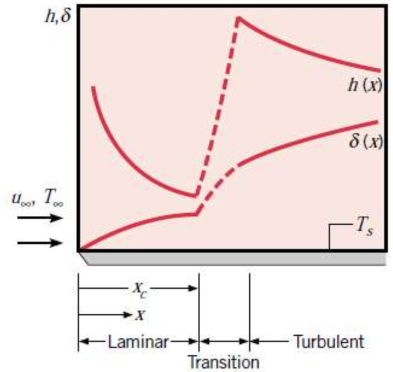
- Heat transfer between staves

  ✓ Feasibility of air cooling convection system









  ✓ Air gap sensitivity analysis → Boundary layer interaction

  ✓ Convection heat transfer rate, thermal gradient in air media between two stave

→ refsers to amount of proton particle stop at previous stave and amount of particles reach to new stave?Mont Carlo?

✓ Feasibility of various Convection heatr transfer:

a. Force convection $q = hA\,\Delta T$

- ➢ Reynolds Number(Re)- ratio of inertia to viscous force-
- ➢ Nusselt Number(Nu) – Thermal Boundary layer to velocity boundary layer

b. Free/Natural convection

b.1: Laminar Flow

- ➢ Bouyancy Forces
- ➢ Volumetric thermal expansion coeficient (β)
- ➢ Nusselt Number(Nu)

Nu=f(Gr,Pr) = $\frac{3}{4}\left(\frac{Gr_x}{4}\right)^{\frac{1}{4}} g(Pr)$

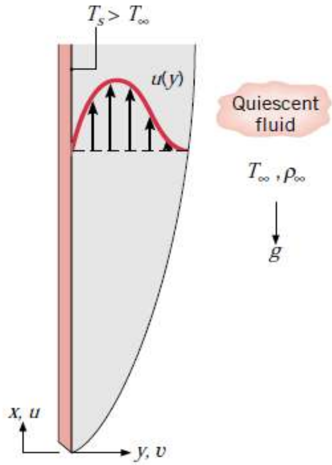
- ➢ Grashof Number (Gr)
- ➢ Prandtle Number (Pr)

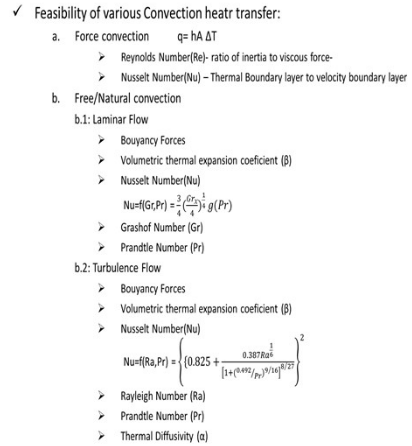
b.2: Turbulence Flow

- ➢ Bouyancy Forces
- ➢ Volumetric thermal expansion coeficient (β)
- ➢ Nusselt Number(Nu)

Nu=f(Ra,Pr) = $\left\{ \{0.825 + \frac{0.387Ra^{\frac{1}{6}}}{\left[1+\left({}^{0.492}/_{Pr}\right)^{9/16}\right]^{8/27}} \right\}^{2}$

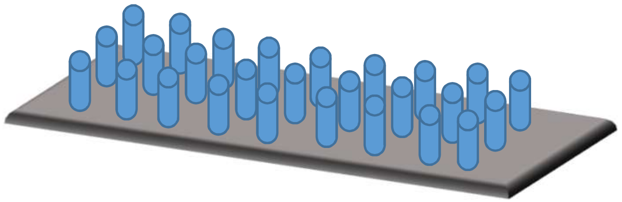
- ➢ Rayleigh Number (Ra)
- ➢ Prandtle Number (Pr)
- ➢ Thermal Diffusivity (α)

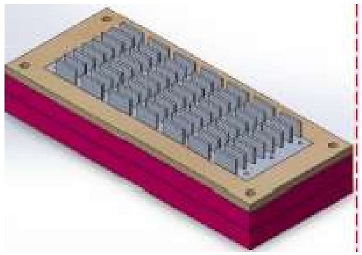


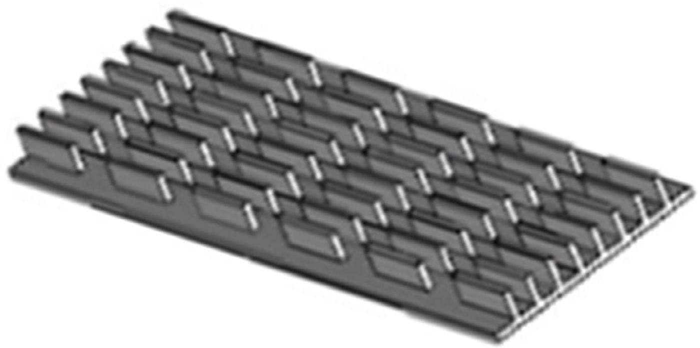


✓ Feasibility of various Convection heatr transfer:
a. Force convection q= hA ΔT
➢ Reynolds Number(Re)- ratio of inertia to viscous force-
➢ Nusselt Number(Nu) – Thermal Boundary layer to velocity boundary layer
b. Free/Natural convection
b.1: Laminar Flow
➢ Bouyancy Forces
➢ Volumetric thermal expansion coeficient (β)
➢ Nusselt Number(Nu)
Nu=f(Gr,Pr) = $\frac{3}{4}\left(\frac{Gr_x}{4}\right)^{\frac{1}{4}} g(Pr)$
➢ Grashof Number (Gr)
➢ Prandtle Number (Pr)
b.2: Turbulence Flow
➢ Bouyancy Forces
➢ Volumetric thermal expansion coeficient (β)
➢ Nusselt Number(Nu)
Nu=f(Ra,Pr) = $\left\{ \{0.825 + \frac{0.387Ra^{\frac{1}{6}}}{\left[1+\left({}^{0.492}/_{Pr}\right)^{9/16}\right]^{8/27}} \right\}^{2}$
➢ Rayleigh Number (Ra)
➢ Prandtle Number (Pr)
➢ Thermal Diffusivity (α)

- ✓ Ventilation feasibility between air gaps and sorrouding space inside calorimeter box
- ✓ Feasibility of microbodies (e.g rectangular or cylinderical) pin on absorber free side to work as heat sink to increase convection heat transfer rate







- ✓ Dual purpose design for calorimeter structure, with opportunity to work as support structure or stave rack/casing and also heat sink