무소음 환경을 위한 Fin 설계

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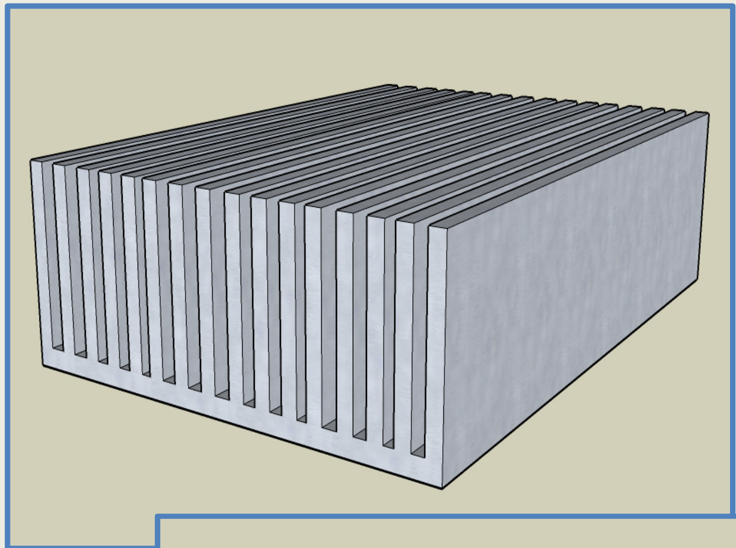
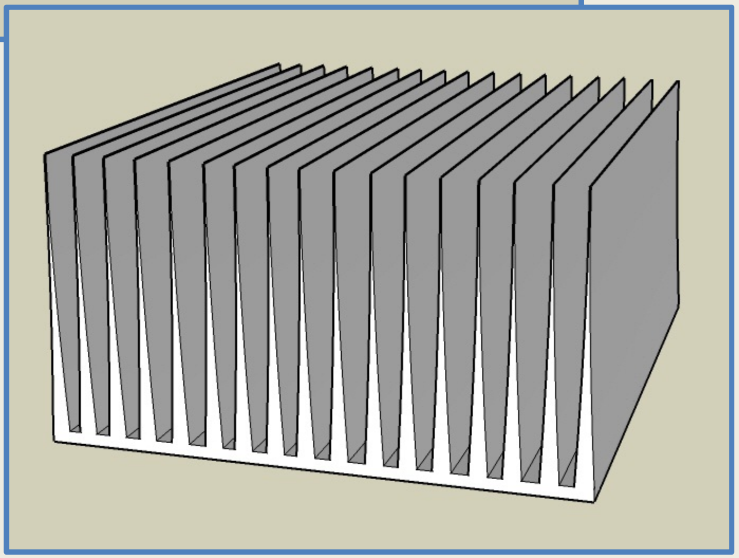
Design Object





Previous Model

2004, "Fin design" - 김민태

- Geometrical : Rectangular
- Convection : Natural Convection
  Bar-Cohen, Rohsenow(1984)
- Objective of design
  Maximize fin effectiveness
  Minimize volume

Advanced Model

- Geometrical : Concave Parabolic
- Convection : Natural Convection
  Yovanovich, Culham(1994)
- Objective of design
  Minimize mass
  Power consumption of CPU(65W)

Assumptions

The Murray-Gardner assumptions

- Steady state
- 1-Dimesional heat transfer
- Homogeneous and uniform characteristics of materials.
- Temp. of surrounding the fin is uniform
- Temp. at the base of the fin is uniform
- No heat source within the fin itself

Assumptions

- Neglect radiation effect
- All heat transfer through the heat sink
- No temp. gradient between CPU and the fin base

Data and Design Variables

Properties of Air

- Temp of air is 35°C
- Prandtl number, Pr=0.7202
- Kinematic viscosity, $\nu = 1.896 \times 10^{-5}\ \mathrm{m}^2 / s$
- Thermal expansion coefficient, $\beta = 3.0 \times 10^{-3}\ {}^\circ\mathrm{C}^{-1}$

Fin material

- Pure aluminum
- Density, $\rho = 2702\ \mathrm{kg/m^3}$
- Thermal conductivity, $k = 237\ \mathrm{W/m} \bullet K$

Data and Design Variables

Intermediate Variable

- H (Height of a heat sink) = $\delta_p + b$ [m]

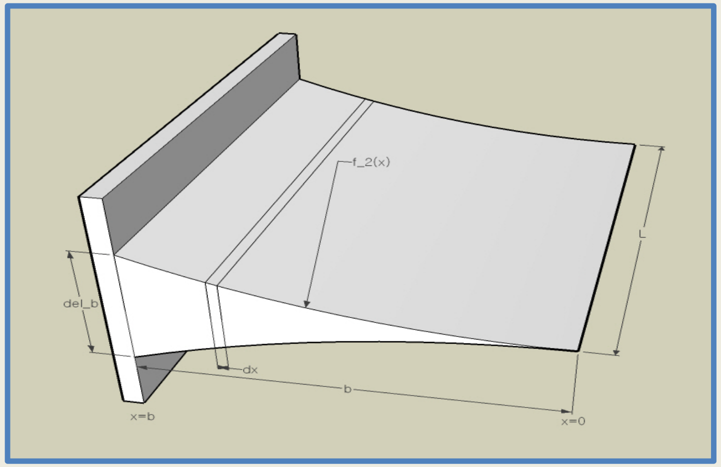
Design Variables

- δ_b (Thickness of a fin) [m]
- b (height of Fin) [m]
- n (Number of fins) [EA]

Parameters

- Q (Power Consumption of CPU) = 65 W
- L (Length of a Heat sink) = 0.075 m
- W (Width of a heat sink) = 0.075 m
- T_a (Temp. of air) = 35°C
- T_b (Temp. of base) = 60°C
- δ_p (Thickness of plate) = 0.001 m

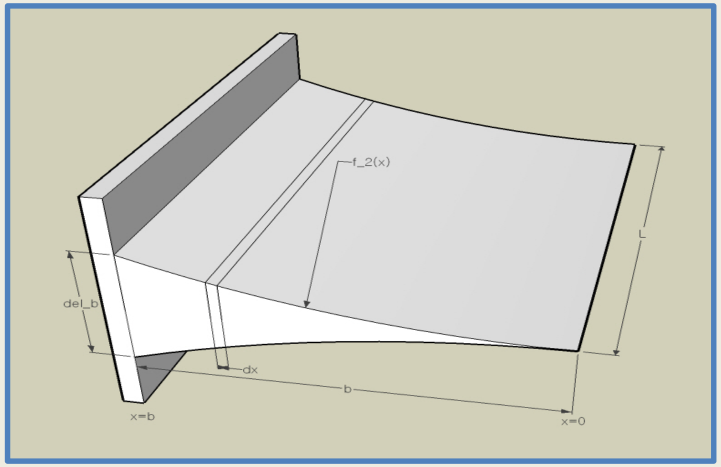
Objective Function



Minimize mass of the heat sink(fins).

$$f(n, \delta_b, b) = \frac{n\delta_b b^2}{3}\rho$$

Formulation - Heat transfer



- Generalized Differential Equation

$$2Lf_2(x)\frac{d^2\theta}{dx^2}+\frac{2Ldf_2(x)}{dx}\frac{d\theta}{dx}-\frac{2h}{k}\theta=0$$

- Geometry function

$$f_2(x)=\frac{\delta_b}{2}(\frac{x}{b})^2$$

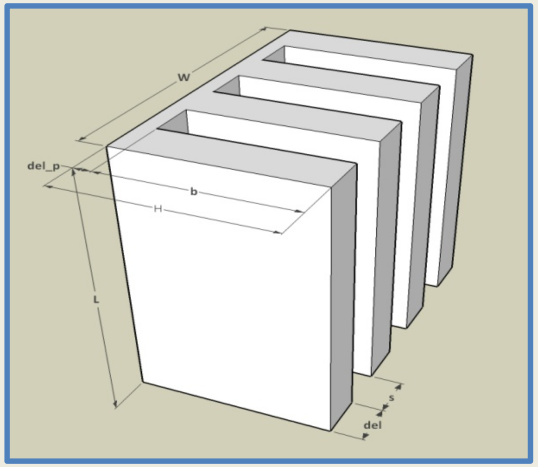
- Solution of temp. distribution

$$\theta(b,h,\delta_b,x)=\theta_b(\frac{x}{b})^{\alpha},\ \text{where}\ \alpha=-\frac{1}{2}+\frac{1}{2}(1+4m^2b^2)^{1/2},\ m=(\frac{2h}{k\delta_b})^{1/2}$$

- Heat transfer through base of fin

$$\dot{Q}(b,h,\delta_b)=\frac{k\delta_b L\theta_b}{2b}(-1+\sqrt{1+(2mb)^2})$$

Formulation - Natural Convection
Yovanovich et al (1994)



- Nusselt numbers, $\mathrm{Nu}_{\sqrt{A}} \equiv \dfrac{h\sqrt{A}}{k} = \mathrm{Nu}_{\sqrt{A}}^{\infty} + f(\mathrm{Pr})\mathrm{G}_{\sqrt{A}}\mathrm{Ra}_{\sqrt{A}}^{0.25}$

- Diffusive limit, $\mathrm{Nu}_{\sqrt{S}}^{\infty} = \dfrac{3.192 + 1.868(H/L)^{0.76}}{\sqrt{1 + 1.189(H/L)}}$

- Universal Prandtl number, $f(\mathrm{Pr}) = \dfrac{0.67}{[1 + (0.5/\mathrm{Pr})^{9/16}]^{4/9}}$

- Body gravity function

$$G_{\sqrt{S}} = 1.0904\left[\frac{L\Lambda^2}{(n\delta_b b + \delta_b W + L\Lambda)^{3/2}}\right]^{1/4}, \text{ where } \Lambda = nb + \delta_p + W$$

- Rayleigh numbers, $\mathrm{Ra}_{\sqrt{A}} \equiv \dfrac{g\beta \mathrm{Pr}\Delta T(\sqrt{A})^3}{\nu^2}$

Constraints

g1. Heat transfer

$$\dot{Q}-\dot{Q}_{total}=65-\left[n\times\frac{k\delta_b L\theta_b}{2b}\left(-1+\sqrt{1+(2mb)^2}\right)+\left(W-n\delta_b\right)Lh\theta_b\right]=0$$

g2. 1-Dimensional heat transfer

$$\frac{h\delta}{k}\le 0.2,\ (\delta\le\delta_b)\rightarrow\ \delta_b-\frac{0.2k}{h}\le 0$$

g3. Fin efficiency

$$\frac{2}{1+\sqrt{1+(2mb)^2}}\ge 0.6\ \rightarrow\ \frac{b^2h}{0.96k}-\delta_b\le 0$$

Constraints

g4. Laminar flow

$$Ra_{\sqrt{A}} - 10^9 \leq 0$$

g5. Geometry

n : natural number

$$-\delta_b \leq 0 \qquad 0.001 - \delta_b \leq 0$$

$$-b \leq 0 \qquad b - 0.1 \leq 0$$

$$n\delta_b - W \leq 0$$

Graphical Solution

Design Variables

- n : number of fins
- δ_b : thickness of fin base

Fixed Variables

- b : fin height = 0.075 m

Constraints

g1. Heat transfer

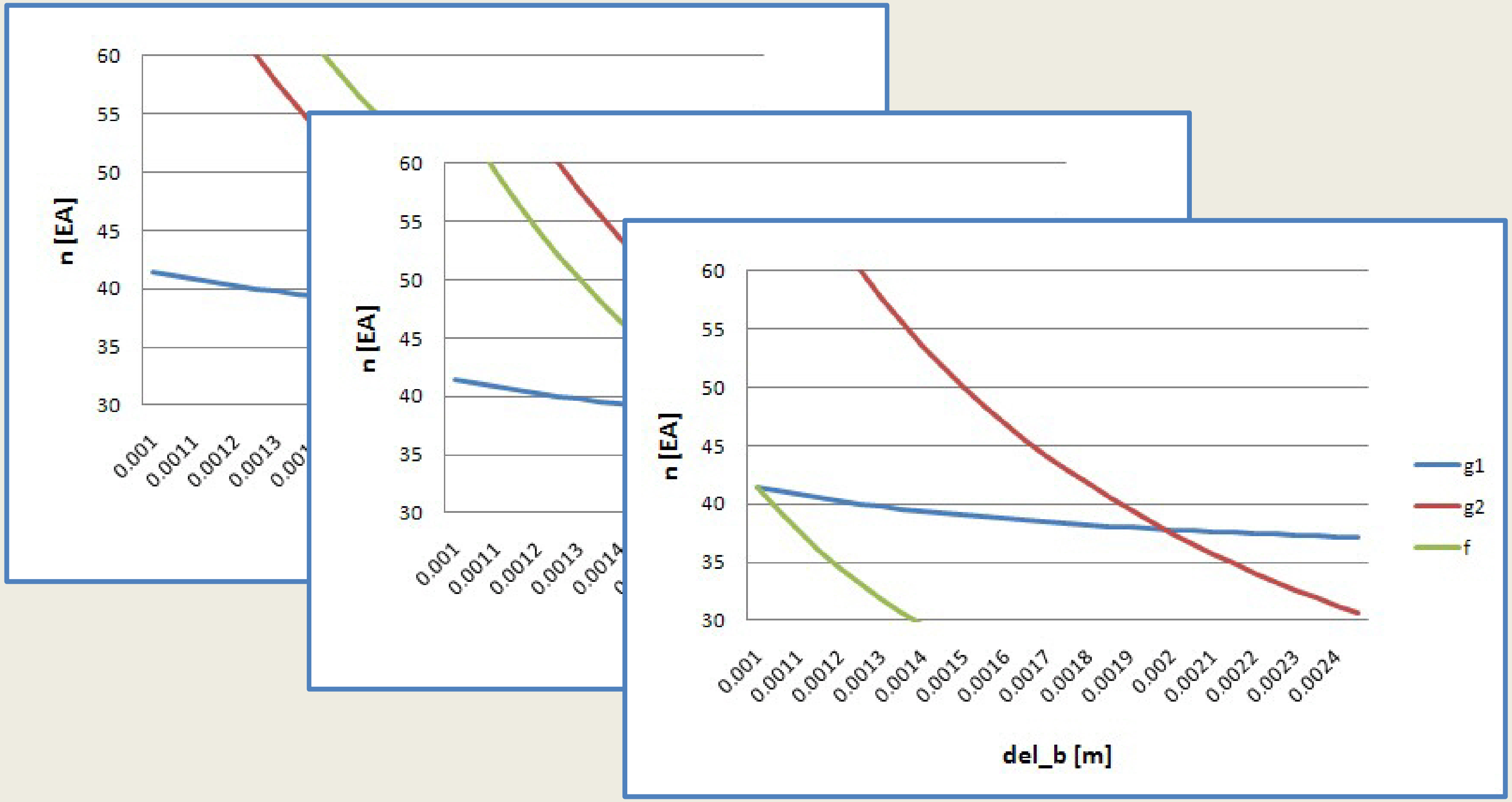
$$\dot{Q}-\dot{Q}_{total}=65-\left[n\times\frac{k\delta_b L\theta_b}{2b}\left(-1+\sqrt{1+(2mb)^2}\right)+\left(W-n\delta_b\right)Lh\theta_b\right]=0$$

g5. Geometry

$$-\delta_b\le 0 \quad 0.001-\delta_b\le 0 \quad 1-n\le 0 \quad n\delta_b-W\le 0$$

n : natural number

Graphical Solution



Graphical Solution

Properties			Temperature			Solutions			
k	237	W/m·℃	Base Temp.	60	℃		Initial value	Solver	
h	7	W/㎡·℃	Air Temp.	35	℃	Thickness	0.001	0.0010646	m
Density	2702	kg/㎥				Number of fins	41.45078	41	EA
Geometry			Input			Mass	0.21	0.2211407	kg
Width	0.075	m	CPU power	65	W	Volume	7.772E-05	8.184E-05	㎥
Length	0.075	m				g1	0.0496669	2.329E-07	=0
Height	0.075	m				g2	0.0335492	0.0313502	≥0

References

Heat transfer : A practical Approach 2nd
Yunus A. Cengel
2004, McGraw-Hill

Extended Surface Heat Transfer
Allan D. Kraus, Abdul Aziz, James Welty
2001, Willy Inter-Science

Questions
&
Answers

Thank
You

Appendix #1

The temp. gradient both of fin plate sides

$$\dot{Q} = k\frac{\Delta T}{L}$$

$$\Delta T = \frac{\dot{Q}L}{k} = \frac{65\ W \times 0.001\ m}{237\ \mathrm{W/m \cdot {}^{\circ}C}} = 0.000274\,{}^{\circ}\mathrm{C}$$