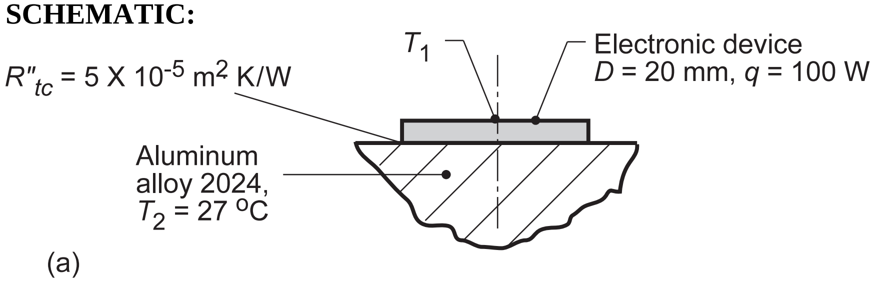
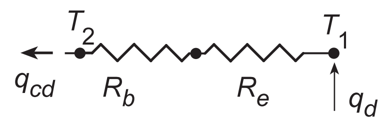
PROBLEM 4.35

KNOWN: Disc-shaped electronic devices dissipating 100 W mounted to aluminum alloy block with prescribed contact resistance.

FIND: (a) Temperature device will reach when block is at 27°C assuming all the power generated by the device is transferred by conduction to the block and (b) For the operating temperature found in part (a), the permissible operating power with a 30-pin fin heat sink.

SCHEMATIC:





ASSUMPTIONS: (1) Two-dimensional, steady-state conduction, (2) Device is at uniform temperature, T_1, (3) Block behaves as semi-infinite medium.

PROPERTIES: *Table A.1,* Aluminum alloy 2024 (300 K): k = 177 W/m·K.

ANALYSIS: (a) The thermal circuit for the conduction heat flow between the device and the block shown in the schematic where R_e is the thermal contact resistance due to the epoxy-filled interface,

$$R_e = R''_{t,c}/A_c = R''_{t,c}\Big/\left(\pi D^2/4\right)$$

$$R_e = 5\times10^{-5}\ \mathrm{K\cdot m^2/W}\Big/\left(\pi\left(0.020\,\mathrm{m}\right)^2\right)\Big/4 = 0.159\,\mathrm{K/W}$$

The thermal resistance between the device and the block is given in terms of the conduction shape factor, Table 4.1, as

$$R_b = 1/Sk = 1/\left(2Dk\right)$$

$$R_b = 1/\left(2\times0.020\,\mathrm{m}\times177\,\mathrm{W/m\cdot K}\right) = 0.141\,\mathrm{K/W}$$

From the thermal circuit,

$$T_1 = T_2 + q_d\left(R_b + R_e\right)$$

$$T_1 = 27^\circ\mathrm{C} + 100\,\mathrm{W}\left(0.141 + 0.159\right)\mathrm{K/W}$$

$$T_1 = 27^\circ\mathrm{C} + 30^\circ\mathrm{C} = 57^\circ\mathrm{C}$$ <

(b) The schematic below shows the device with the 30-pin fin heat sink with fins and base material of copper (k = 400 W/m·K). The airstream temperature is 27°C and the convection coefficient is 1000 $W/m^2 \cdot K$.

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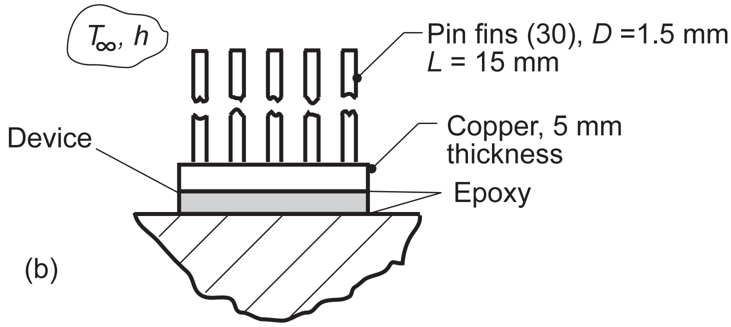

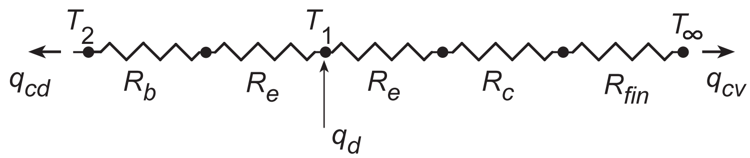

The thermal circuit for this system has two paths for the device power: to the block by conduction, q_{cd}, and to the ambient air by conduction to the fin array, q_{cv},

$$q_d = \frac{T_1 - T_2}{R_b + R_e} + \frac{T_1 - T_\infty}{R_e + R_c + R_{fin}} \tag{3}$$

where the thermal resistance of the fin base material is

$$R_c = \frac{L_c}{k_c A_c} = \frac{0.005\,\text{m}}{400\,\text{W/m}\cdot\text{K}\left(\pi 0.02^2/4\right)\text{m}^2} = 0.03979\,\text{K/W} \tag{4}$$

and R_{fin} represents the thermal resistance of the fin array (see Section 3.6.5),

$$R_{fin} = R_{t,o} = \frac{1}{\eta_o h A_t} \tag{5, 3.108}$$

$$\eta_o = 1 - \frac{N A_f}{A_t}\left(1 - \eta_f\right) \tag{6, 3.107}$$

where the fin and prime surface area is

$$A_t = N A_f + A_b \tag{3.99}$$

$$A_t = N\left(\pi D_f L\right) + \left[\pi D_d^2/4 - N\left(\pi D_f^2/4\right)\right]$$

where A_f is the fin surface area, D_d is the device diameter and D_f is the fin diameter.

$$A_t = 30\left(\pi \times 0.0015\,\text{m} \times 0.015\,\text{m}\right) + \left[\pi\left(0.020\,\text{m}\right)^2/4 - 30\left(\pi\left(0.0015\,\text{m}\right)^2/4\right)\right]$$

A_t = 0.00212 m^2 + 0.0002611 m^2 = 0.00238 m^2

Using the *IHT Model*, *Extended Surfaces*, *Performance Calculations*, *Rectangular Pin Fin*, find the fin efficiency as

$$\eta_f = 0.6769 \tag{7}$$

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Substituting numerical values into Equation (6), find

$$\eta_o = 1 - \frac{30 \times \pi \times 0.0015\,\mathrm{m} \times 0.015\,\mathrm{m}}{0.00238\,\mathrm{m}^2}(1 - 0.6769)$$

$$\eta_o = 0.712$$

and the fin array thermal resistance is

$$R_{fin} = \frac{1}{0.712 \times 1000\,\mathrm{W/m^2 \cdot K} \times 0.00238\,\mathrm{m}^2} = 0.590\,\mathrm{K/W}$$

Returning to Eq. (3), with T_1 = 57°C from part (a), the permissible heat rate is

$$q_d = \frac{(57-27)^\circ\mathrm{C}}{(0.141 + 0.159)\,\mathrm{K/W}} + \frac{(57-27)^\circ\mathrm{C}}{(0.159 + 0.03979 + 0.590)\,\mathrm{K/W}}$$

$$q_d = 100\,\mathrm{W} + 38\,\mathrm{W} = 138\,\mathrm{W}$$ <

COMMENTS: In calculating the fin efficiency, η_f, using the IHT Model it is not necessary to know the base temperature as η_f depends only upon geometric parameters, thermal conductivity and the convection coefficient.