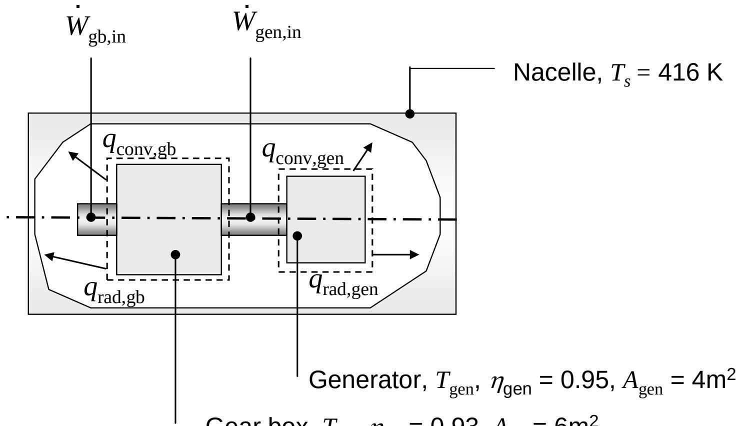
PROBLEM 1.38

KNOWN: Surface areas, convection heat transfer coefficient, surface emissivity of gear box and generator. Temperature of nacelle. Electric power generated by the wind turbine and generator efficiency.

FIND: Gear box and generator surface temperatures.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Interior of nacelle can be treated as large surroundings, (3) Negligible heat transfer between the gear box and the generator.

ANALYSIS: Heat is generated within both the gear box and the generator. The mechanical work into the generator can be determined from the electrical power, $P = 2.5 \times 10^6$ W, and the efficiency of the generator as

$$\dot{W}_{gen,in} = P/\eta_{gen} = 2.5\times10^6\,\text{W}/0.95 = 2.63\times10^6\,\text{W}$$

Therefore, the heat transfer from the generator is

$$q_{gen} = \dot{W}_{gen} - P = 2.63\times10^6\,\text{W} - 2.5\times10^6\,\text{W} = 0.13\times10^6\,\text{W}$$

The heat transfer is composed of convection and radiation components. Hence,

$$\begin{aligned} q_{gen} &= A_{gen}\left[h\left(T_{gen}-T_s\right)+\varepsilon\sigma\left(T_{gen}^4-T_s^4\right)\right] \\ &= 4\text{m}^2\times\left[40\frac{\text{W}}{\text{m}^2\cdot\text{K}}\left(T_{gen}-416\text{K}\right)+0.90\times5.67\times10^{-8}\frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\left(T_{gen}^4-\left(416\text{K}\right)^4\right)\right] \\ &= 0.13\times10^6\text{W} \end{aligned}$$

The generator surface temperature may be found by using a numerical solver, or by trial-and-error, yielding

T_{gen} = 785 K = 512°C <

Continued...

PROBLEM 1.38 (Cont.)

Heat is also generated by the gear box. The heat generated in the gear box may be determined from knowledge of the heat generated cumulatively by the gear box and the generator, which is provided in Example 3.1 and is $q = q_{\text{gen}} + q_{\text{gb}} = 0.33 \times 10^6$ W. Hence, $q_{\text{gb}} = q - q_{\text{gen}} = 0.33 \times 10^6\text{W} - 0.13 \times 10^6\text{W} = 0.20 \times 10^6\text{W}$ and

$$
\begin{aligned}
q_{\text{gb}} &= A_{\text{gb}}\left[h\left(T_{\text{gb}} - T_s\right) + \varepsilon\sigma\left(T_{\text{gb}}^4 - T_s^4\right)\right] \\
&= 6\text{m}^2 \times \left[40\frac{\text{W}}{\text{m}^2\cdot\text{K}}\left(T_{\text{gb}} - 416\text{K}\right) + 0.90 \times 5.67 \times 10^{-8}\frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\left(T_{\text{gb}}^4 - \left(416\text{K}\right)^4\right)\right] \\
&= 0.20 \times 10^6\text{W}
\end{aligned}
$$

which may be solved by trial-and-error or with a numerical solver to find

$T_{\text{gb}} = 791$ K = 518°C <

COMMENTS: (1) The gear box and generator temperatures are unacceptably high. Thermal management must be employed in order to generate power from the wind turbine. (2) The gear box and generator temperatures are of similar value. Hence, the assumption that heat transfer between the two mechanical devices is small is valid. (3) The radiation and convection heat transfer rates are of similar value. For the generator, convection and radiation heat transfer rates are $q_{\text{conv,gen}} = 5.9 \times 10^4$ W and $q_{\text{rad,gen}} = 7.1 \times 10^4$ W, respectively. The convection and radiation heat transfer rates are $q_{\text{conv,gb}} = 9.0 \times 10^4$ W and $q_{\text{rad,gb}} = 11.0 \times 10^4$ W, respectively, for the gear box. It would be a poor assumption to neglect either convection or radiation in the analysis.