CHAPTER (14)

TURBOMACHINARY

HOMEWORK (5)

14.2, 14.29, 14.42, 14.48, 14.60

Problem (14.2)

APPROACH

Apply the propeller thrust force equation and the propeller power equation.

ANALYSIS

Reynolds number

$$
\begin{aligned}
\mathrm{Re} &= V_0/nD \\
&= (80,000/3,600)/((1,400/60)\times 3) \\
&= 0.317
\end{aligned}
$$

From Fig. 14.2

$$C_T = 0.020$$

Propeller thrust force equation

$$
\begin{aligned}
F &= C_T \rho D^4 n_T^2 \\
&= 0.020 \times 1.05 \times 3^4 \times (1,400/60)^2 \\
& \boxed{F_T = 926 \ \mathrm{N}}
\end{aligned}
$$

From Fig. 14.2

$$C_p = 0.011$$

Propeller power equation

$$
\begin{aligned}
P &= C_p \rho n^3 D^5 \\
&= 0.011 \times 1.05 \times 3^5 \times (1400/60)^3 \\
& \boxed{P = 35.7 \ \mathrm{kW}}
\end{aligned}
$$

Problem (14.18)

PLAN

Apply discharge, head, and power coefficients. Use Fig. 14.6 to find the discharge, power, and head coefficients at maximum efficiency. Assume density is 1000 kg/m^3.

SOLUTION

From Fig. 14.6 at maximum efficiency, $C_Q = 0.64; C_p = 0.60$; and $C_H = 0.75$

$$\begin{aligned} D &= 0.5 \text{ m} \\ n &= 1,100 \text{ rpm}/60 \text{ s/min} = 18.33 \text{ rev/s} \end{aligned}$$

Discharge coefficient

$$\begin{aligned} Q &= C_Q n D^3 \\ &= 0.64 \times 18.33 \text{ rps} \times (0.5 \text{ m})^3 \end{aligned}$$

$$\boxed{Q = 1.46 \text{ m}^3/\text{s}}$$

Problem (14.18

Head coefficient

$$\begin{aligned}\Delta H &= C_H n^2 D^2/g \\ &= 0.75 \times (18.33 \text{ rps})^2 \times (0.5 \text{ m})^2 /9.81 \text{ m/s}^2 \\ &\boxed{\Delta H = 6.42}\end{aligned}$$

Power coefficient

$$\begin{aligned}P &= C_p \rho D^5 n^3 \\ &= 0.60 \times 1000 \text{ kg/m}^3 \times (0.5 \text{ m})^5 \times (18.33 \text{ rps})^3 \\ &= 115475 \text{ W} \\ &\boxed{P = 115.475 \, \text{kW}}\end{aligned}$$

Problem (14.29)

Situation: A pump operated at 1600 rpm.

Find: Discharge when head is 45 m

PLAN

Apply discharge coefficient. Calculate the head coefficient to find the corresponding discharge coefficient from Fig. 14.10.

SOLUTION

$$
\begin{aligned}
D &= 0.371 \text{ m} \\
n &= 1500/60 = 25 \text{ rps}
\end{aligned}
$$

Head coefficient

$$
\begin{aligned}
\Delta H &= C_H n^2 D^2 / g \\
C_H &= \frac{\Delta H g}{n^2 D^2} \\
C_H &= \frac{45 \text{ m} \times 9.81 \text{ m/s}^2}{(25 \text{ rps})^2 \times (0.371 \text{ m})^2} \\
&= 5.13
\end{aligned}
$$

Problem (14.29)

from Fig. 14.10

$$C_Q = 0.122$$

Discharge coefficient

$$Q = C_Q n D^3$$

$$= 0.122 \times 25 \text{ rps} \times (0.371 \text{ m})^3$$

$$\boxed{Q = 0.1557 \ \ \text{m}^3/\text{s}}$$

Problem (14.42)

Situation: A pump is required to pump water at 0.40 m^3/s at head of 70 m
rotational speed of 1100 rpm.

Find: Type of pump.

PLAN

Calculate the specific speed and use figure 14.12 to find the pump range to wh
corresponds.

SOLUTION

Specific speed

$$
\begin{aligned}
N &= 1,100 \text{ rpm} = 18.33 \text{ rps} \\
Q &= 0.4 \text{ m}^3/\text{sec} \\
h &= 70 \text{ meters} \\
n_s &= n\sqrt{Q}/[g^{3/4}h^{3/4}] \\
&= (18.33 \text{ rps})(0.4 \text{ m}^3/\text{s})^{1/2}/[(9.81 \text{ m/s}^2)^{3/4}(70 \text{ m})^{3/4}] \\
&= 0.086
\end{aligned}
$$

Then from Fig. 14.12 use a **radial flow pump.**

Problem (14.48)

<u>Situation</u>: A water-cooled centrifugal compressor compresses air from 100 kPa to 400 kPa at 1 kg/s. Inlet temperature is 15°C and efficiency is 50%.

<u>Find</u>: The shaft power.

<u>Properties</u>: From Table A.2 for air, $R = 287$ J/kg-K

SOLUTION

$$\begin{aligned} P_{th} &= p_1 Q_1 \ell n(p_2/p_1) \\ &= \dot{m} R T_1 \ell n(p_2/p_1) \\ &= 1 \text{ kg/s} \times 287 \text{ J/kg-K} \times 288 \text{ K} \times \ell n(400 \text{ kPa}/100 \text{ kPa}) \\ &= 114.6 \text{ kW} \\ P_{\text{ref}} &= 114.6 \text{ kW}/0.5 \\ & \boxed{P_{\text{ref}} = 229 \text{ kW}} \end{aligned}$$

Problem (14.60)

Situation: A conventional horizontal-axis wind turbine with 2.5 m diameter propeller in a 50 km/h wind.

Find: Maximum deliverable power.

Properties: $\rho = 1.2\ \mathrm{kg/m^3}$.

PLAN

Use equation for theoretical maximum power.

SOLUTION

The wind speed in m/s

$$V = 50\ \frac{\mathrm{km}}{\mathrm{h}} \times \frac{1000\ \mathrm{m}}{1\ \mathrm{km}} \times \frac{1\ \mathrm{h}}{3600\ \mathrm{s}} = 13.9\ \mathrm{m/s}$$

Maximum power

$$\begin{aligned} P_{\max} &= \frac{16}{27} \times \frac{1}{2} \rho V^3 A \\ &= \frac{8}{27} \rho V^3 A \\ &= \frac{8}{27} \times 1.2\ \mathrm{kg/s} \times (13.9\ \mathrm{m/s})^3 \times \frac{\pi}{4} \times (2.5\ \mathrm{m})^2 \end{aligned}$$

$$\boxed{\mathrm{P}_{\max} = 4.69\ \mathrm{kW}}$$

END OF HOMEWORK