**PRACTICE PROBLEMS**

1. Two centrifugal pumps used in a water pumping application have the characteristic curves shown. The pumps operate in parallel and discharge into a common header against a head of 40 ft. What is most nearly the discharge rate of the pumps operating in parallel?

(A) 30 gpm  
(B) 50 gpm  
(C) 75 gpm  
(D) 130 gpm

2. An electric motor drives a pump in a gasoline transfer network. The system and pump curves are defined by the points in the given table. The gasoline has a specific gravity of 0.7. What is most nearly the minimum horsepower for the motor?

<table>
<thead>
<tr>
<th>head (ft)</th>
<th>system curve (gpm)</th>
<th>pump curve (gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>1500</td>
</tr>
<tr>
<td>20</td>
<td>500</td>
<td>1200</td>
</tr>
<tr>
<td>30</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>40</td>
<td>1200</td>
<td>500</td>
</tr>
<tr>
<td>50</td>
<td>1500</td>
<td>0</td>
</tr>
</tbody>
</table>

(A) 4.0 hp  
(B) 5.3 hp  
(C) 5.5 hp  
(D) 7.6 hp

3. A pump intended for occasional use in normal ambient conditions has an overall hydraulic efficiency of 0.85 and is required to develop a hydraulic horsepower of 4.5 hp. The pump is driven by an electric motor with a service factor of 1.80 and an electrical efficiency of 90%. The smallest NEMA standard motor size suitable for this application is

(A) 3 hp  
(B) 5 hp  
(C) 8 hp  
(D) 10 hp

4. In a valve test bed, the fluid flow rate was measured as 800 gpm. The specific gravity of the fluid was 1.2. The pressure of the fluid one pipe diameter upstream of the valve was measured as 10 psig. The pressure ten pipe diameters downstream of the valve was measured as 0.1 psig. The pressure at the vena contracta was measured as −3 psig. The valve’s pressure recovery factor for liquids is most nearly

(A) 0.3  
(B) 0.6  
(C) 0.8  
(D) 0.9

5. 2000 gal/min of 60°F thickened sludge with a specific gravity of 1.2 flows through a pump with an inlet diameter of 12 in and an outlet diameter of 8 in. The centerlines of the inlet and outlet are at the same elevation. The inlet pressure is 8 in of mercury (vacuum). A discharge pressure gauge located 4 ft above the pump discharge centerline reads 20 psig. The pump efficiency is 85%. All pipes are schedule-40. The input power of the pump is most nearly

(A) 26 hp  
(B) 31 hp  
(C) 37 hp  
(D) 53 hp
(e) If the effective head is 225 ft (70 m), the flow rate will most nearly be

- (A) 25 ft\(^3\)/sec (700 L/s)
- (B) 38 ft\(^3\)/sec (1100 L/s)
- (C) 56 ft\(^3\)/sec (1600 L/s)
- (D) 64 ft\(^3\)/sec (1800 L/s)

**SOLUTIONS**

1. Theoretically, when operating in parallel, each pump performs as if the other pump is not present. The capacities of each pump at a 40 ft discharge head are cumulative: 50 gpm for pump 2 and 75 gpm for pump 1.

\[
Q_{\text{parallel}} = Q_2 + Q_1 = 50 \frac{\text{gal}}{\text{min}} + 75 \frac{\text{gal}}{\text{min}}
\]

\[
= 125 \text{ gpm (130 gpm)}
\]

*The answer is (D).*

2. The system and pump curves intersect at 1000 gpm and 30 ft. From Table 18.5, the hydraulic horsepower is

\[
WHP = h_4 Q(SG) = \frac{(30 \text{ ft})(1000 \frac{\text{gal}}{\text{min}})(0.7)}{3956 \text{ ft-gal hp-min}}
\]

\[
= 5.31 \text{ hp (5.3 hp)}
\]

This is the minimum power that the electric motor can produce.

*The answer is (B).*

3. The motor efficiency is not used because NEMA motor power ratings are motor power output ratings. The motor is intended for occasional use, so the service factor should be included.

From Eq. 18.11, the smallest suitable motor size is

\[
BHP = \frac{WHP}{\eta_p(SF)} = \frac{4.5 \text{ hp}}{(0.85)(1.80)} = 2.94 \text{ hp}
\]

From Table 18.7, the smallest NEMA standard motor size with a rating greater than 2.94 hp is 3 hp.

*The answer is (A).*
4. The lowest pressure will usually be found at the vena contracta. The liquid pressure recovery factor, $F_L$, of a valve is the square root of the ratio of the actual pressure loss to the maximum pressure loss.

\[
F_L = \sqrt{\frac{p_1 - p_2}{(p_1 - p_{\text{vena contracta}})SG}}
\]

\[
= \sqrt{\frac{10 \text{ lbf/in}^2 - 0.1 \text{ lbf/in}^2}{(10 \text{ lbf/in}^2 - 3 \text{ lbf/in}^2) (1.2)}}
\]

\[
= 0.796 (0.8)
\]

**The answer is (C).**

5. The flow rate is

\[
\dot{V} = \frac{2000 \text{ gal/min}}{(7.4805 \text{ gal/ft}^3)(60 \text{ sec/min})} = 4.456 \text{ ft}^3/\text{sec}
\]

From App. 16.B,

12 in: $D_1 = 0.99483$ ft $\quad A_1 = 0.7773$ ft$^2$

8 in: $D_2 = 0.6651$ ft $\quad A_2 = 0.3474$ ft$^2$

\[
p_1 = \left(14.7 \text{ lbf/in}^2 - (8 \text{ in})(0.491 \text{ lbf/in}^2)\right)(12 \text{ in/ft})^2
\]

\[
= 1551.2 \text{ lbf/ft}^2
\]

\[
p_2 = \left(14.7 \text{ lbf/in}^2 + 20 \text{ lbf/in}^2\right)(12 \text{ in/ft})^2
\]

\[
+ (4 \text{ ft})(1.2)(62.4 \text{ lbf/ft}^3)
\]

\[
= 5296.3 \text{ lbf/ft}^2
\]

\[
v_1 = \frac{\dot{V}}{A_1} = \frac{4.456 \text{ ft}^3}{0.7773 \text{ ft}^2} = 5.73 \text{ ft/sec}
\]

\[
v_2 = \frac{\dot{V}}{A_2} = \frac{4.456 \text{ ft}^3}{0.3474 \text{ ft}^2} = 12.83 \text{ ft/sec}
\]

From Eq. 18.8, the total heads (in feet of sludge) at points 1 and 2 are

\[
h_{t,1} = \frac{p_1}{\gamma} + \frac{v_1^2}{2g} = \frac{1551.2 \text{ lb/ft}^2}{62.4 \text{ lb/ft}^3} (1.2) + \left(\frac{5.73 \text{ ft/sec}}{2g}\right)^2
\]

\[
= 21.23 \text{ ft}
\]

\[
h_{t,2} = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} = \frac{5296.3 \text{ lb/ft}^2}{62.4 \text{ lb/ft}^3} (1.2) + \left(\frac{12.83 \text{ ft/sec}}{2g}\right)^2
\]

\[
= 73.29 \text{ ft}
\]

The pump must add 73.29 ft $- 21.23$ ft $= 52.06$ ft of head (sludge head).

The power required is given in Table 18.5.

\[
P_{\text{ideal}} = \frac{\Delta p \dot{V}}{\gamma} = \frac{\Delta h(SG)\gamma \dot{V}}{550} = \frac{(52.06 \text{ ft})(1.2)(62.4 \text{ lb/ft}^3)(4.456 \text{ ft}^3)}{550 \text{ ft-lbf/ hp-sec}}
\]

\[
= 31.58 \text{ hp}
\]

The input horsepower is

\[
P_{\text{in}} = \frac{P_{\text{ideal}}}{\eta} = \frac{31.58 \text{ hp}}{0.85} = 37.15 \text{ hp (37 hp)}
\]

**The answer is (C).**

6. When operated in series, the second pump receives water at the rate of the first pump’s discharge, so both pumps experience the same flow rate. The second pump adds pressure head to the first pump’s pressurization, so the discharge heads are cumulative. At 50 gpm, the discharge heads are 60 ft for pump 1 and 40 ft for pump 2, respectively.

\[
h_{A,\text{series}} = h_{A,1} + h_{A,2} = 60 \text{ ft} + 40 \text{ ft} = 100 \text{ ft}
\]

**The answer is (D).**
# 41 Determinate Statics

## PRACTICE PROBLEMS

1. Two towers are located on level ground 100 ft (30 m) apart. They support a transmission line with a mass of 2 lbm/ft (3 kg/m). The midpoint sag is 10 ft (3 m).
   (a) The midpoint tension is most nearly
      
      (A) 125 lbf (0.55 kN)
      (B) 250 lbf (1.1 kN)
      (C) 375 lbf (1.6 kN)
      (D) 500 lbf (2.2 kN)
   
   (b) The maximum tension in the transmission line is most nearly
      
      (A) 170 lbf (0.70 kN)
      (B) 210 lbf (0.86 kN)
      (C) 270 lbf (1.2 kN)
      (D) 330 lbf (1.4 kN)
   
   (c) If the maximum tension is 500 lbf (2200 N), the sag in the cable is most nearly
      
      (A) 1.3 ft (0.4 m)
      (B) 3.2 ft (1.0 m)
      (C) 4.0 ft (1.2 m)
      (D) 5.1 ft (1.5 m)

2. Two legs of a tripod are mounted on a vertical wall. Both legs are horizontal. The apex is 12 distance units from the wall. The right leg is 13.4 units long. The wall mounting points are 10 units apart. A third leg is mounted on the wall 6 units to the left of the right upper leg and 9 units below the two top legs. A vertical downward load of 200 is supported at the apex. What is most nearly the reaction at the lowest mounting point?

   (A) 120
   (B) 170
   (C) 250
   (D) 330

3. The ideal truss shown is supported by a pinned connection at point D and a roller connection at point C. Loads are applied at points A and F. What is most nearly the force in member DE?

   (A) 1200
   (B) 2700
   (C) 3300
   (D) 3700
12. A 30 ft × 10 ft box-shaped 9000 lbf piece of machinery is lifted using a three-cable hoist ring, as shown. Two cables of the hoist are connected to opposite corners of the 10 ft side, and the other cable is connected to the center of the other 10 ft side. The hoist ring is 20 ft directly above the center of the machinery. What are most nearly the forces in hoist cables \( C_1 \), \( C_2 \), and \( C_3 \), respectively?

(A) 2300 lbf, 2300 lbf, and 6800 lbf
(B) 2500 lbf, 2700 lbf, and 3900 lbf
(C) 2900 lbf, 2900 lbf, and 5600 lbf
(D) 3000 lbf, 3000 lbf, and 3000 lbf

**SOLUTIONS**

1. **Customary U.S. Solution**

(a) Use Eq. 41.68 to relate the midpoint sag, \( S \), to the constant, \( c \).

\[
S = \frac{g}{c} \left( \cosh \left( \frac{a}{c} \right) - 1 \right)
\]

\[
10 \text{ ft} = \frac{g}{c} \left( \cosh \left( \frac{50 \text{ ft}}{c} \right) - 1 \right)
\]

Solve by trial and error.

\( c = 126.6 \text{ ft} \)

Use Eq. 41.52(b) and Eq. 41.70 to find the midpoint tension.

\[
H = wc = m \left( \frac{g}{g_c} \right) c
\]

\[
= \left( 2 \frac{\text{lbm}}{\text{ft}} \right) \left( \frac{32.2 \text{ ft sec}^2}{32.2 \frac{\text{lbm-ft}}{\text{lbf-sec}^2}} \right) (126.6 \text{ ft})
\]

\[
= 253.2 \text{ lbf} \quad (250 \text{ lbf})
\]

The answer is (B).

(b) Use Eq. 41.72 to find the maximum tension.

\[
T = wy = w(c + S) = m \left( \frac{g}{g_c} \right) (c + S)
\]

\[
= \left( 2 \frac{\text{lbm}}{\text{ft}} \right) \left( \frac{32.2 \text{ ft sec}^2}{32.2 \frac{\text{lbm-ft}}{\text{lbf-sec}^2}} \right) (126.6 \text{ ft} + 10 \text{ ft})
\]

\[
= 273.2 \text{ lbf} \quad (270 \text{ lbf})
\]

The answer is (C).

(c) From \( T = wy \),

\[
y = \frac{T}{w} = \frac{500 \text{ lbf}}{2 \frac{\text{lbm}}{\text{ft}}} = 250 \text{ ft} \quad \text{[at right support]}
\]

\[
250 \text{ ft} = c \left( \cosh \left( \frac{50 \text{ ft}}{c} \right) \right)
\]

By trial and error, \( c = 245 \text{ ft} \).
Substitute into Eq. 41.68.

\[
S = c \left( \cosh \left( \frac{a}{c} \right) - 1 \right) = (245 \text{ ft}) \left( \cosh \left( \frac{50 \text{ ft}}{245 \text{ ft}} \right) - 1 \right) = 5.1 \text{ ft}
\]

The answer is (D).

**SI Solution**

(a) Use Eq. 41.68 to relate the midpoint sag, \( S \), to the constant, \( c \).

\[
S = c \left( \cosh \left( \frac{a}{c} \right) - 1 \right)
\]

\[
3 \text{ m} = c \left( \cosh \left( \frac{15 \text{ m}}{c} \right) - 1 \right)
\]

Solve by trial and error.

\[c = 38.0 \text{ m}\]

Use Eq. 41.52(a) and Eq. 41.70 to find the midpoint tension.

\[
H = wc = m g c = \left( 3 \frac{\text{ kg}}{\text{ m}} \right) \left( 9.81 \frac{\text{ m}}{\text{s}^2} \right) (38.0 \text{ m}) = 1118.3 \text{ N} \ (1.1 \text{ kN})
\]

The answer is (B).

(b) Use Eq. 41.72 to find the maximum tension.

\[
T = wy = w(c + S) = m g (c + S)
\]

\[
= \left( 3 \frac{\text{ kg}}{\text{ m}} \right) \left( 9.81 \frac{\text{ m}}{\text{s}^2} \right) (38.0 \text{ m} + 3.0 \text{ m}) = 1206.6 \text{ N} \ (1.2 \text{ kN})
\]

The answer is (C).

(c) From \( T = wy \),

\[
y = \frac{T}{w} = \frac{2200 \text{ N}}{\left( 3 \frac{\text{ kg}}{\text{ m}} \right) \left( 9.81 \frac{\text{ m}}{\text{s}^2} \right)} = 74.75 \text{ m} \ [\text{at right support}]
\]

\[74.75 \text{ m} = c \left( \cosh \left( \frac{15 \text{ m}}{c} \right) \right)\]

By trial and error, \( c = 73.2 \text{ m} \).

Substitute into Eq. 41.68.

\[
S = c \left( \cosh \left( \frac{a}{c} \right) - 1 \right) = (73.2 \text{ m}) \left( \cosh \left( \frac{15 \text{ m}}{73.2 \text{ m}} \right) - 1 \right) = 1.54 \text{ m} \ (1.5 \text{ m})
\]

The answer is (D).

2. step 1: Draw the tripod with the origin at the apex.

\[\text{step 2: By inspection, the force components are } F_x = 0, F_y = 200, \text{ and } F_z = 0.\]

\[\text{step 3: First, from triangle EBO, length BE is}\]

\[
BE = \sqrt{(13.4 \text{ units})^2 - (12 \text{ units})^2} = 5.96 \text{ units} \ [\text{use 6 units}]
\]

The \((x, y, z)\) coordinates of the three support points are

- point A: \((12, 0, 4)\)
- point B: \((12, 0, -6)\)
- point C: \((12, 9, 0)\)

\[\text{step 4: Find the lengths of the legs.}\]

\[
AO = \sqrt{(x_A - x_O)^2 + (y_A - y_O)^2 + (z_A - z_O)^2} = \sqrt{(12 \text{ units})^2 + (0 \text{ units})^2 + (4 \text{ units})^2} = 12.65 \text{ units}
\]

\[
BO = \sqrt{(x_B - x_O)^2 + (y_B - y_O)^2 + (z_B - z_O)^2} = \sqrt{(12 \text{ units})^2 + (0 \text{ units})^2 + (-6 \text{ units})^2} = 13.4 \text{ units}
\]

\[
CO = \sqrt{(x_C - x_O)^2 + (y_C - y_O)^2 + (z_C - z_O)^2} = \sqrt{(12 \text{ units})^2 + (9 \text{ units})^2 + (0 \text{ units})^2} = 15.0 \text{ units}
\]