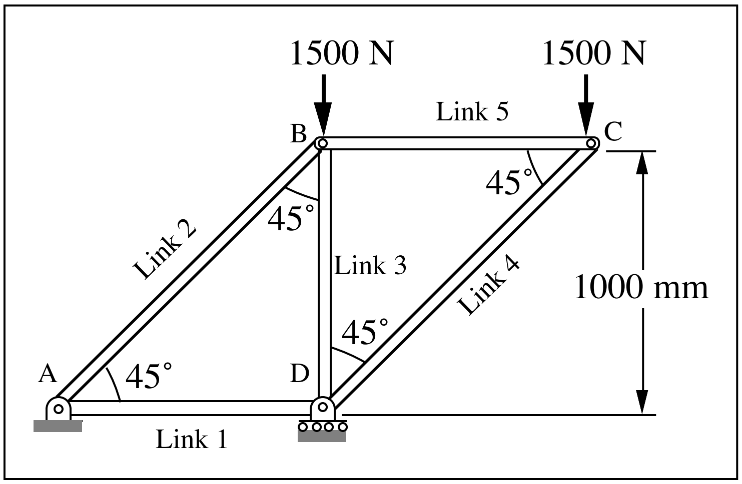
SOLUTION (2.14new)
Known: The geometry and the loads acting on a pinned assembly are given.

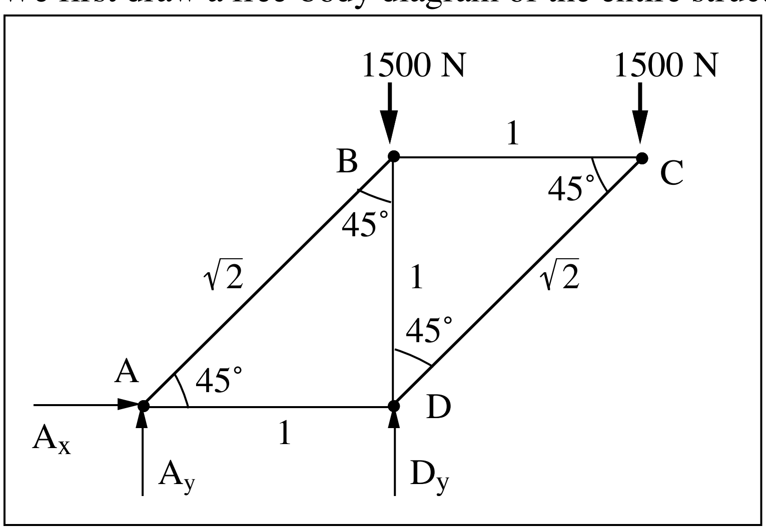
Find: Draw a free-body diagram for the assembly and determine the magnitude of the forces acting on each member of the assembly.

Schematic and Given Data:



Assumptions:
1. The links are rigid.
2. The pin joints are frictionless.
3. The weight of the links are negligible.
4. The links are two force members and are either in tension or compression.

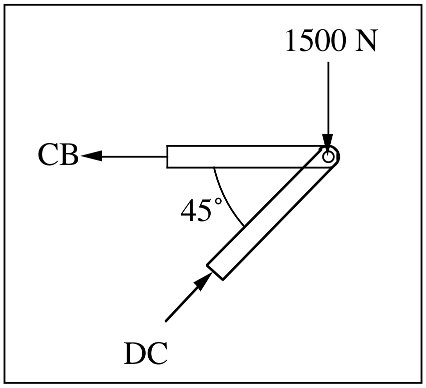
Analysis:
1. We first draw a free-body diagram of the entire structure.



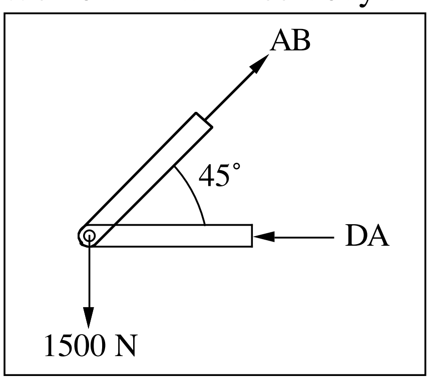
2. Taking moments about point A and assuming clockwise moments to be positive,
$$\sum M_A = 0 = 1500(2) + 1500(1) - D_y(1)$$
3. Solving for D_y gives $D_y = 4500$ N.
4. Summation of forces in the y-direction and assuming vertical forces positive,
$$\sum F_y = 0 = A_y + D_y - 1500 - 1500 = A_y + D_y - 3000.$$

5. Since, $D_y = 4500$ N, $A_y = 3000 - D_y = -1500$ N.

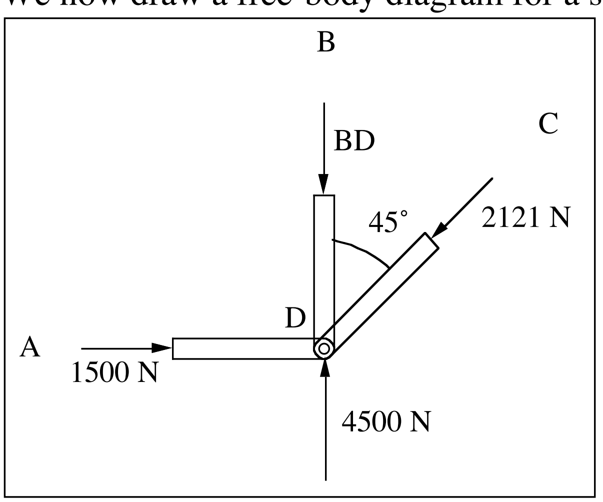
6. $\sum F_x = 0$ gives, $A_x = 0$.
7. We now draw a free-body diagram for a section at C.



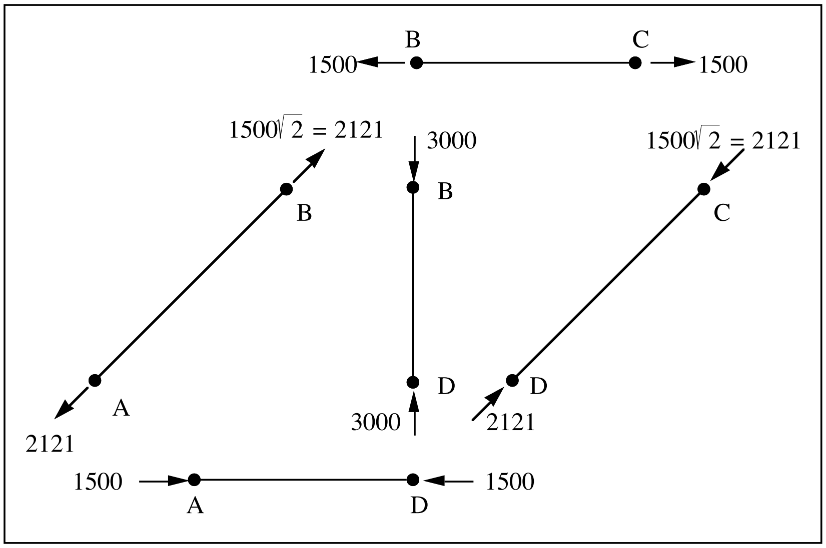
8. $\sum F_x = 0 = -CB + DC \sin 45°$ and
   $\sum F_y = 0 = DC \sin 45° - 1500$
9. Solving simultaneous equations gives DC = 2121 N, CB = 1500 N.
10. We now draw a free-body diagram for a section at A.



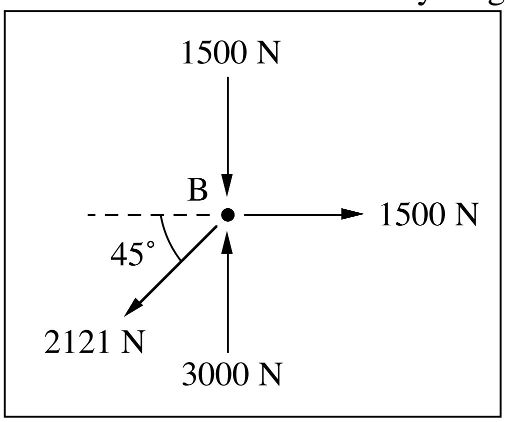
11. $\sum F_y = 0 = AB \sin 45° - 1500$
    $\sum F_x = 0 = AB \cos 45° - DA$
12. Solving simultaneous equations gives AB = 2121 N, DA = 1500 N.
13. We now draw a free-body diagram for a section at D.



14. $\sum F_y = 0 = 4500 - BD - 2121(\sin 45°)$
    Hence, BD = 3000 N.
15. The free-body diagrams for links DC, BC, AB, AD, and BD are:



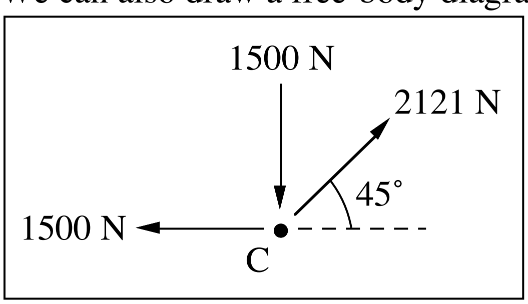
16. We can now draw a free-body diagram of pin B:



17. Checking for static equilibrium at pin B gives:

$$\sum F_x = 2121 \cos 45° - 1500 = 0$$
$$\sum F_y = 1500 + 2121 \sin 45° - 3000 = 0$$

18. We can also draw a free-body diagram for pin C:



19. Checking for static equilibrium at pin C gives:

$$\sum F_x = 1500 - 2121 \cos 45^\circ = 0$$
$$\sum F_y = 1500 - 2121 \sin 45^\circ = 0$$

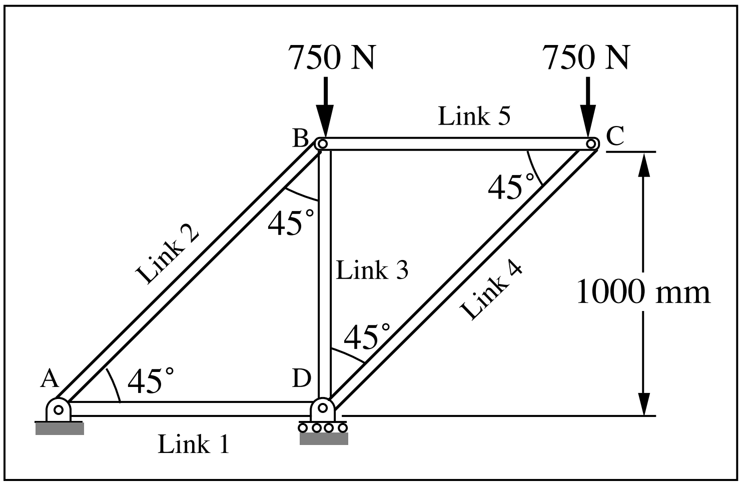
Comment: From force flow visualization, we determine that links 1, 3, and 4 are in compression and that links 2 and 5 are in tension.

SOLUTION (2.15new5e)

Known: The geometry and the loads acting on a pinned assembly are given.

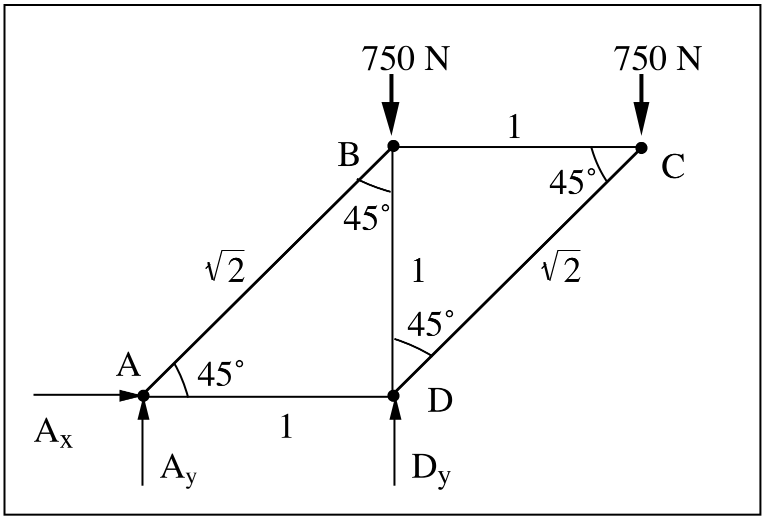
Find: Draw a free-body diagram for the assembly and determine the magnitude of the forces acting on each member of the assembly.

Schematic and Given Data:

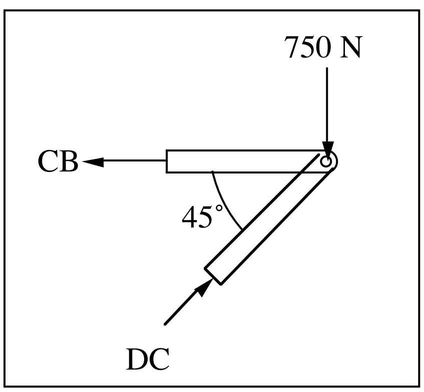


Assumptions:
1. The links are rigid.
2. The pin joints are frictionless.
3. The weight of the links are negligible.
4. The links are two force members and are either in tension or compression.

Analysis:
1. We first draw a free-body diagram of the entire structure.

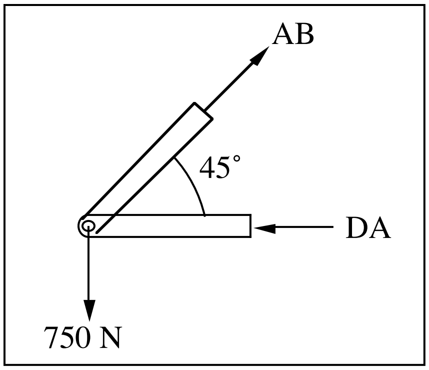


2. Taking moments about point A and assuming clockwise moments to be positive, $\sum M_A = 0 = 750(2) + 750(1) - D_y(1)$
3. Solving for D_y gives $D_y = 2250$ N.
4. Summation of forces in the y-direction and assuming vertical forces positive, $\sum F_y = 0 = A_y + D_y - 750 - 750 = A_y + D_y - 1500$.
5. Since, $D_y = 2250$ N, $A_y = 1500 - D_y = -750$ N.
6. $\sum F_x = 0$ gives, $A_x = 0$.
7. We now draw a free-body diagram for a section at C.



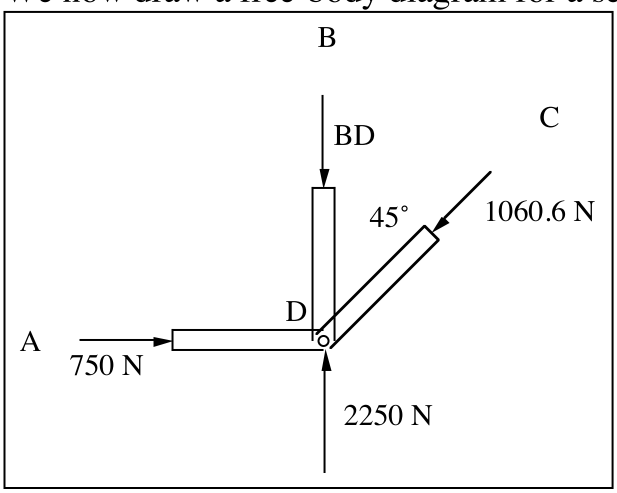
8. $\sum F_x = 0 = - CB + DC \sin 45^\circ$ and $\sum F_y = 0 = DC \sin 45^\circ - 750$

9. Solving simultaneous equations gives DC = 1060.6 N, CB = 750 N.
10. We now draw a free-body diagram for a section at A.



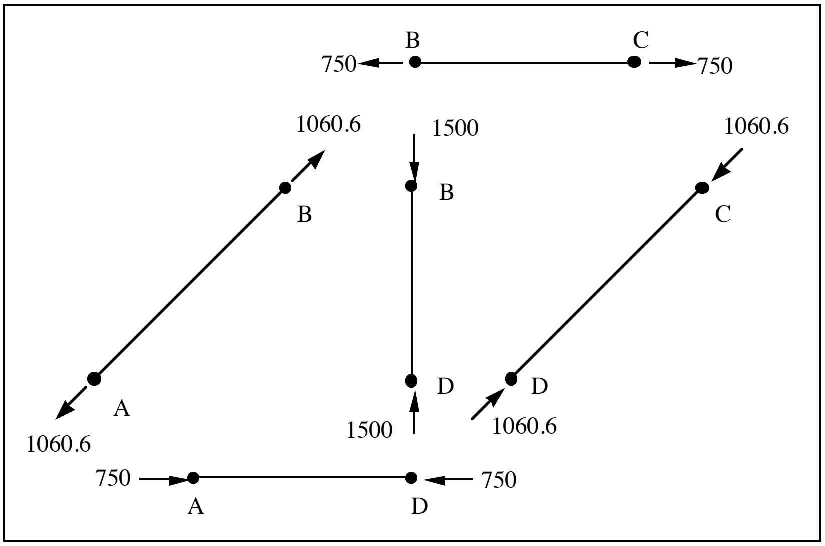
11. $\sum F_y = 0 = AB \sin 45° - 750$
    $\sum F_x = 0 = AB \cos 45° - DA$

12. Solving simultaneous equations gives AB = 1060.6 N, DA = 750 N.
13. We now draw a free-body diagram for a section at D.

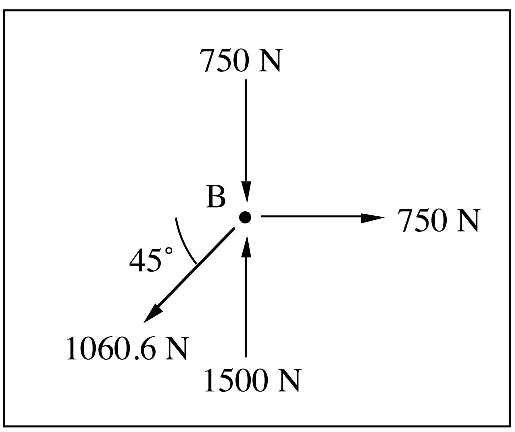


14. $\sum F_y = 0 = 2250 - BD - 1060.6(\sin 45°)$
    Hence, BD = 1500 N.

15. The free-body diagrams for links DC, BC, AB, AD, and BD are:



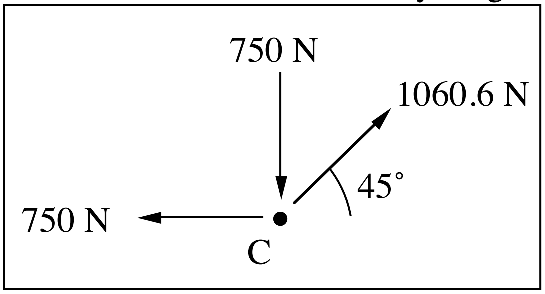
16. We can now draw a free-body diagram of pin B:



17. Checking for static equilibrium at pin B gives:

$$\sum F_x = 1060.6 \cos 45^\circ - 750 = 0$$
$$\sum F_y = 750 + 1060.6 \sin 45^\circ - 1500 = 0$$

18. We can also draw a free-body diagram for pin C:



19. Checking for static equilibrium at pin C gives:

$$\sum F_x = 750 - 1060.6 \cos 45^\circ = 0 \sum$$
$$\sum F_y = 750 - 1060.6 \sin 45^\circ = 0$$

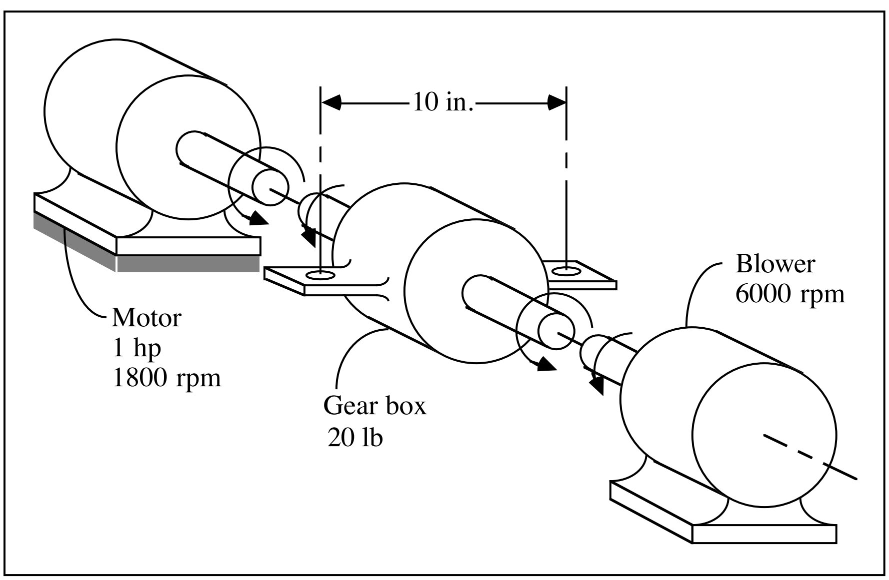
Comment: From force flow visualization, we determine that links 1, 3, and 4 are in compression and that links 2 and 5 are in tension.

SOLUTION (2.16new)

Known: A 1800 rpm motor is rotating a blower at 6000 rpm through a gear box having a known weight.

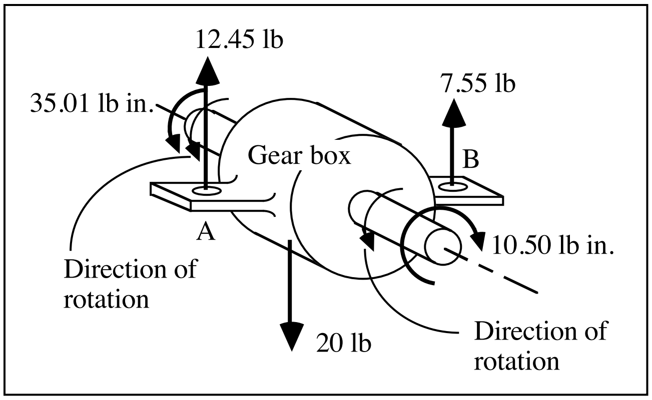
Find: Determine all loads acting on the gear box when the motor output is 1 hp, and sketch the gear box as a free-body in equilibrium.

Schematic and Given Data:



Assumption: The friction losses in the gear box are negligible.

Analysis:



1. From Eq. (1.3), $T = \frac{5252 \cdot \dot{W}}{n} = \frac{5252(1)}{1800}$
   T = 2.92 lb·ft = 35.01 lb·in. (motor shaft)

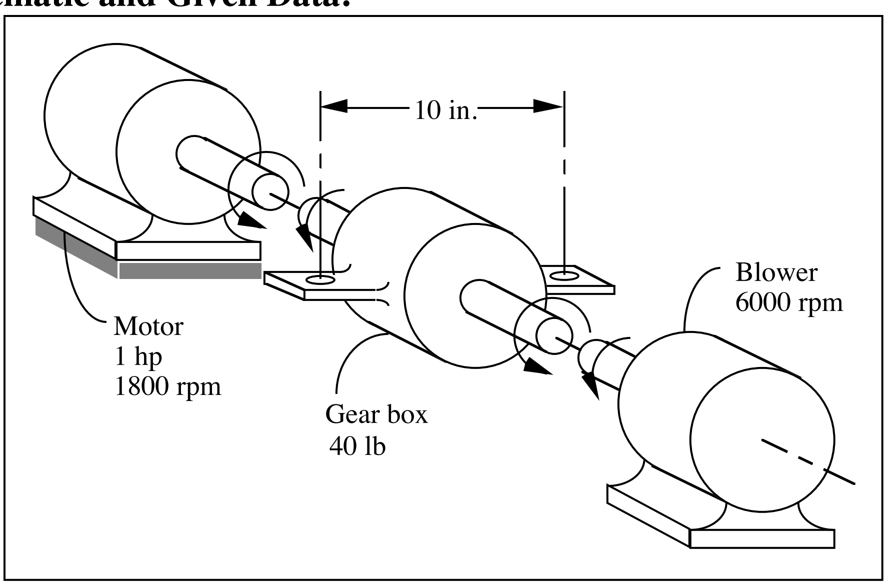
2. To the blower, $T = 35.01\left(\frac{1800 \text{ rpm}}{6000 \text{ rpm}}\right)$ = 10.50 lb·in. (to blower)
3. Mounting torque reaction = 35.01 - 10.50 = 24.51 lb·in.
4. Mounting forces = 24.51 lb·in./ 10 in. = 2.45 lb. The mounting force acts upward at A and downward at B.
5. Add 10 lb acting upward at A and B to support the gravity load, giving 12.45 lb upward at A and 7.55 lb upward at B.

SOLUTION (2.17new5e)

Known: A 1800 rpm motor is rotating a blower at 6000 rpm through a gear box having a weight of 40 lb.

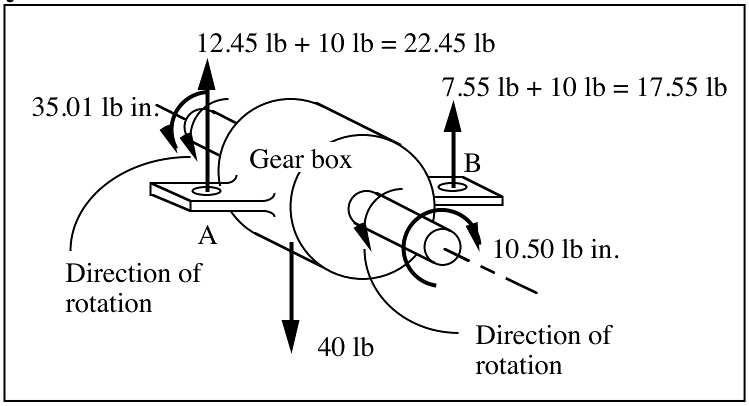
Find: Determine all loads acting on the gear box when the motor output is 1 hp, and sketch the gear box as a free-body in equilibrium.

Schematic and Given Data:



Assumption: The friction losses in the gear box are negligible.

Analysis:



1. From Eq. (1.3), $T = \frac{5252 \cdot \dot{W}}{n} = \frac{5252(1)}{1800}$

   $T = 2.92$ lb·ft = 35.01 lb·in. (motor shaft)

2. To the blower, $T = 35.01\left(\frac{1800 \text{ rpm}}{6000 \text{ rpm}}\right) = 10.50$ lb·in. (to blower)

3. Mounting torque reaction = 35.01 - 10.50 = 24.51 lb·in.

4. Mounting forces = 24.51 lb·in./ 10 in. = 2.45 lb. The mounting force acts upward at A and downward at B.

5. Add 20 lb acting upward at A and B to support the gravity load, giving 22.45 lb upward at A and 17.55 lb upward at B.

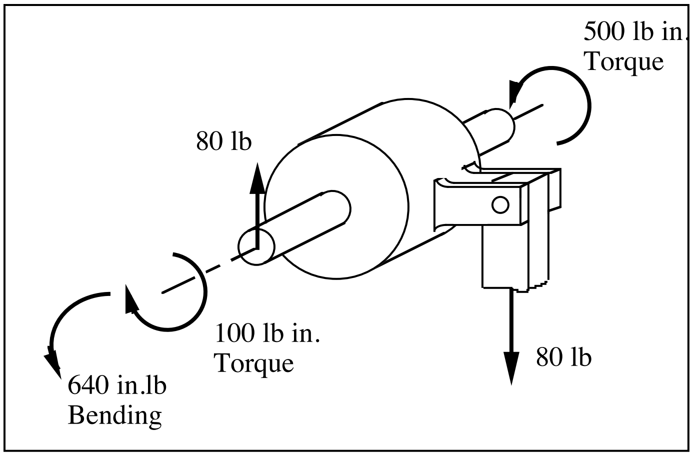
Comment: In textbook problem 2.16, the gear box weights 20 lb.

SOLUTION (2.18new)

Known: The motor operates at constant speed and develops a torque of 100 lb-in. during normal operation. A 5:1 ratio gear reducer is attached to the motor shaft; i.e., the reducer output shaft rotates in the same direction as the motor but at one-fifth the motor speed. Rotation of the reducer housing is prevented by the "torque arm," pin-connected at each end as shown in Fig. P2.18. The reducer output shaft drives the load through a flexible coupling. Gravity and friction can be neglected..

Find: Determine the loads applied to (a) the torque arm, (b) the motor output shaft, and (c) the reducer output shaft.

Schematic and Given Data:



Assumption: The friction losses in the gear box are negligible.

Analysis:
1. The force in the torque arm is 80 lb tension.
2. The loads on the reducer input shaft are 100 lb in. torque, plus 80 lb vertical load and 640 in lb bending moment in the plane of the motor face.
3. The load on the reducer output shaft is 500 lb in. torque.

SOLUTION (2.26)

Known: An engine and propeller rotate clockwise viewed from the propeller end. A reduction gear housing is bolted to the engine housing through the bolt holes shown. The power and angular velocity of the engine are known.

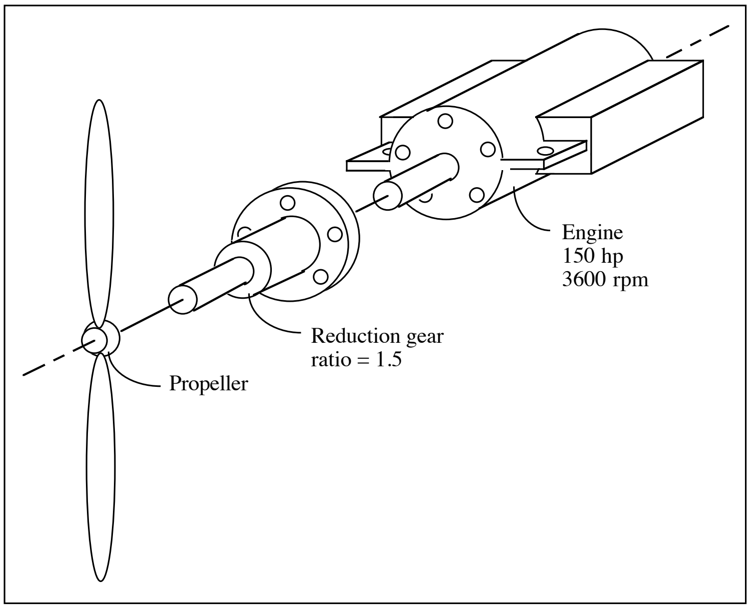
Find:

(a) Determine the direction and magnitude of the torque applied to the engine housing by the reduction gear housing.

(b) Determine the magnitude and direction of the torque reaction tending to rotate (roll) the aircraft.

(c) Find an advantage of using opposite-rotating engines with twin-engine propeller-driven aircraft.

Schematic and Given Data:

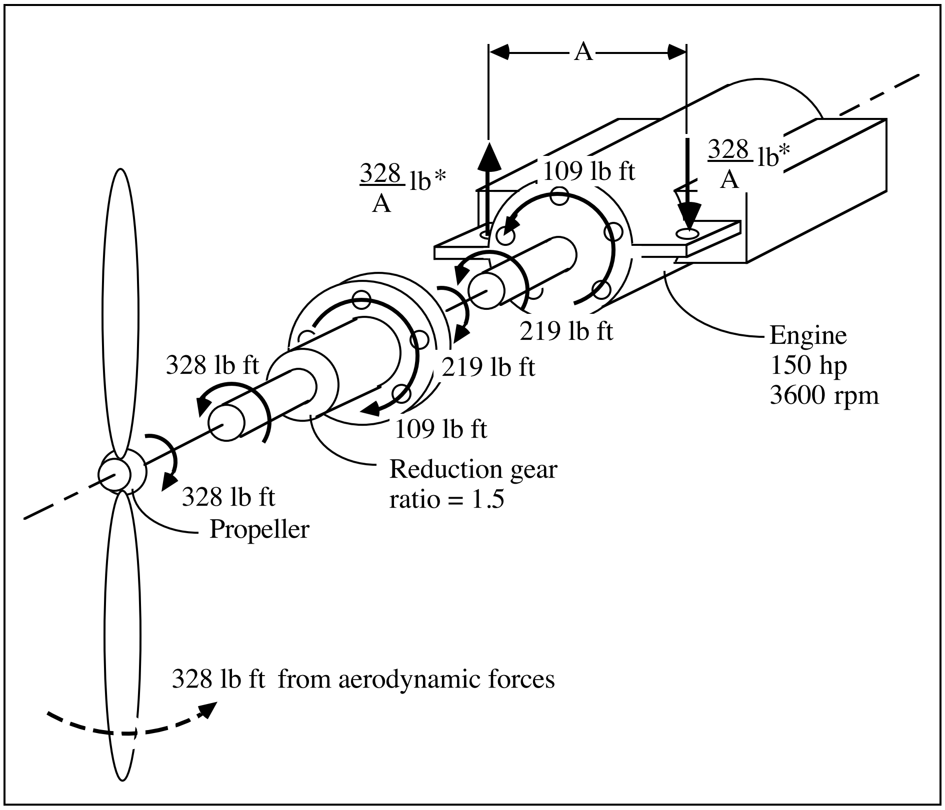


Assumption: The friction losses are negligible.

Analysis:

1. From Eq. (1.3), engine torque, $T = \frac{5252 \cdot \dot{W}}{n} = \frac{5252(150)}{3600} = 219$ lb ft

2. Reduction gear torque, T = 219(1.5) = 328 lb ft

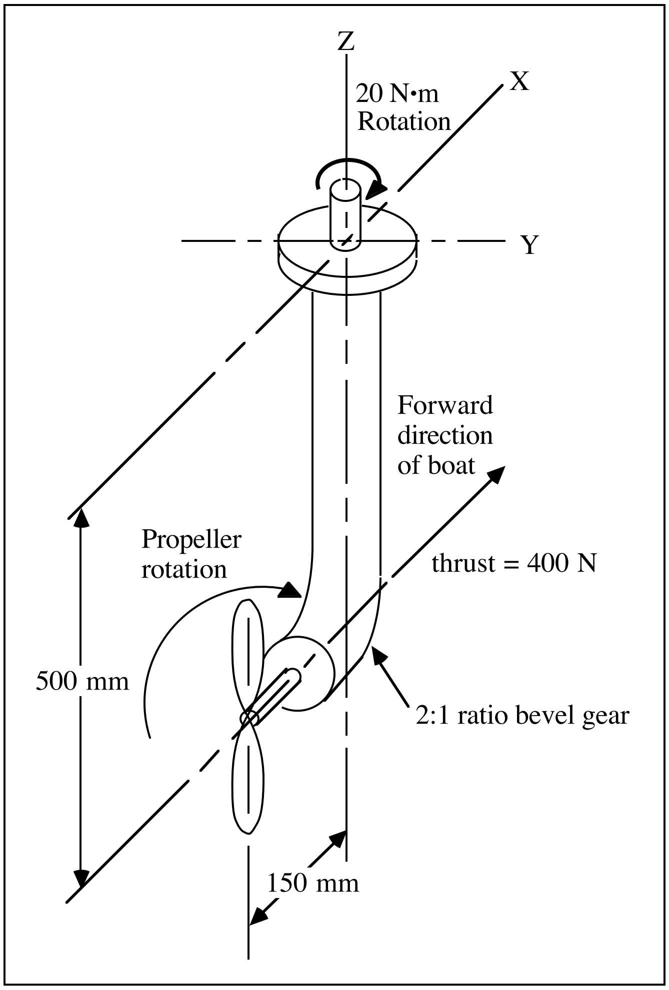


3. The attachment forces apply an equal and opposite torque of 328 lb•ft ccw tending to "roll" the airplane--see (*) in the above figure.
4. Thus, the torque applied to the engine housing by the reduction gear housing is 109 lb ft counter-clockwise, and the torque reaction tending to rotate the aircraft is 328 lb ft counter-clockwise. ■
5. Torque reactions applied to the air frame by the two engines cancel. (This produces bending in the connecting structure, but does not require a compensating roll torque from the aerodynamic control surfaces.) ■

SOLUTION (2.31)
Known: A gear reduction unit and a propeller of an outboard boat operate with a known motor torque and a known thrust.

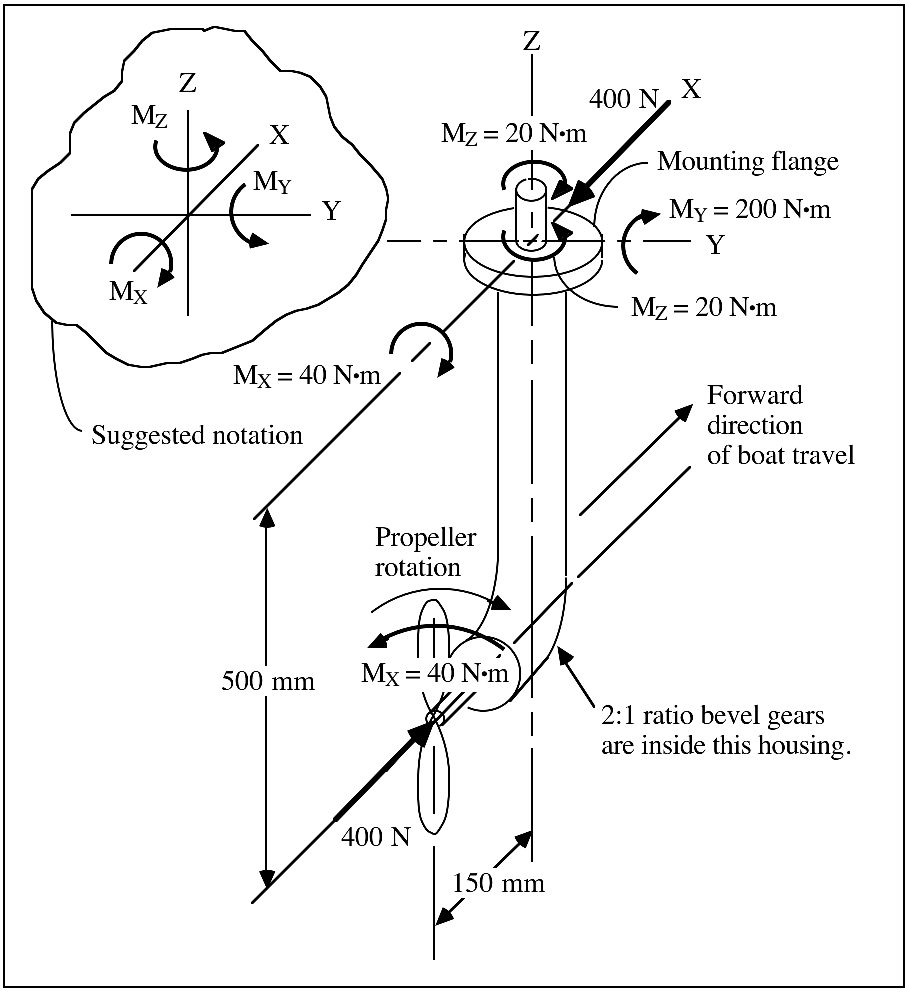
Find: Show all external loads acting on the assembly.

Schematic and Given Data:



Assumption: The effects of gravity and friction are negligible.

Analysis:

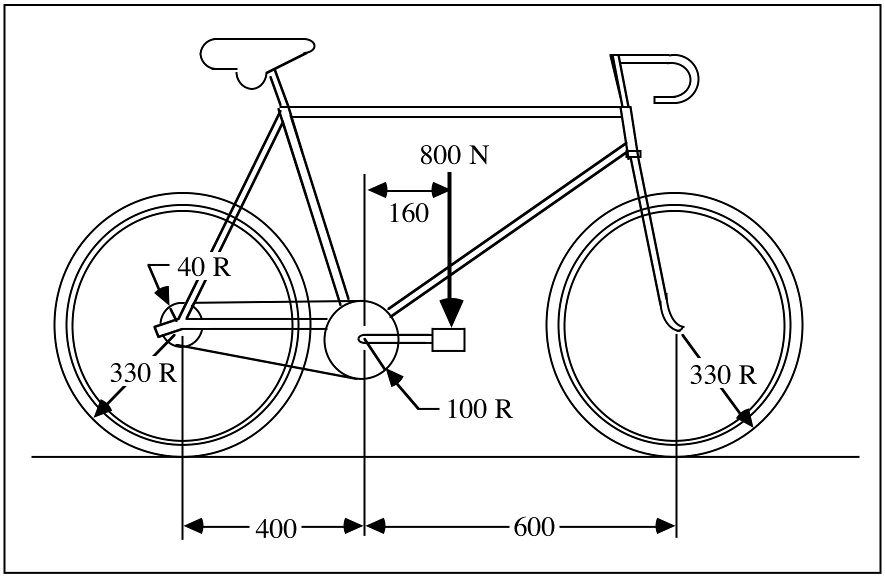


Z
Z
M_Z
X
M_Y
Y
M_X
400 N
X
M_Z = 20 N•m
Mounting flange
M_Y = 200 N•m
Y
M_Z = 20 N•m
M_X = 40 N•m
Suggested notation
Forward
direction
of boat travel
Propeller
rotation
500 mm
M_X = 40 N•m
2:1 ratio bevel gears
are inside this housing.
400 N
150 mm

SOLUTION (2.32)
Known: A rider is applying full weight to one pedal of a bicycle.

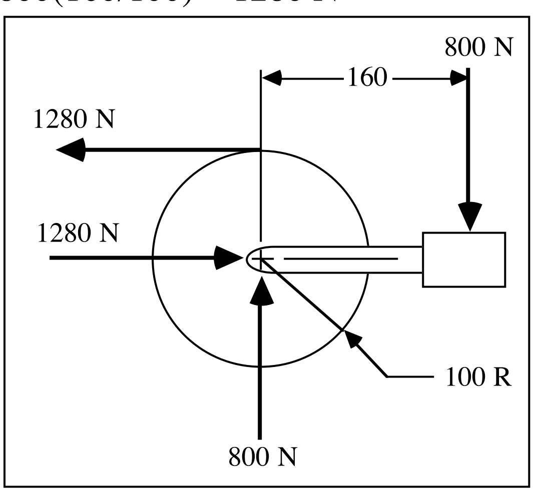
Find: Draw as free-bodies in equilibrium:
(a) The pedal, crank, and pedal sprocket assembly.
(b) The rear wheel and sprocket assembly.
(c) The front wheel.
(d) The entire bicycle and rider assembly.

Schematic and Given Data:



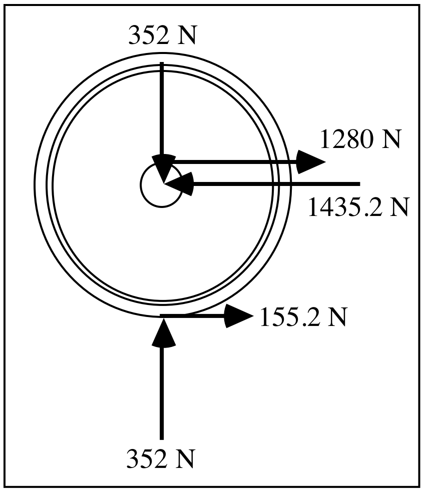
Assumptions:
1. The bicycle can be treated as a two-dimensional machine.
2. The bicycle weight is negligible.

Analysis:
1. For the pedal, crank, and pedal sprocket assembly, the chain force is F = 800(160/100) = 1280 N

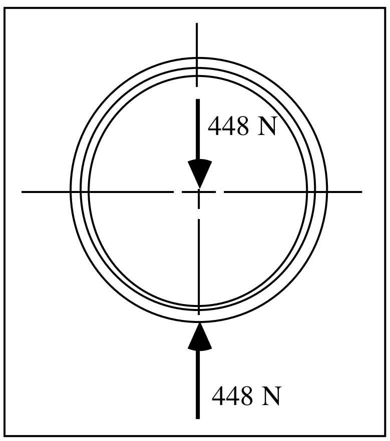


2. For the rear wheel and sprocket assembly,
rear wheel gravity load = 800(440/1000) = 352 N

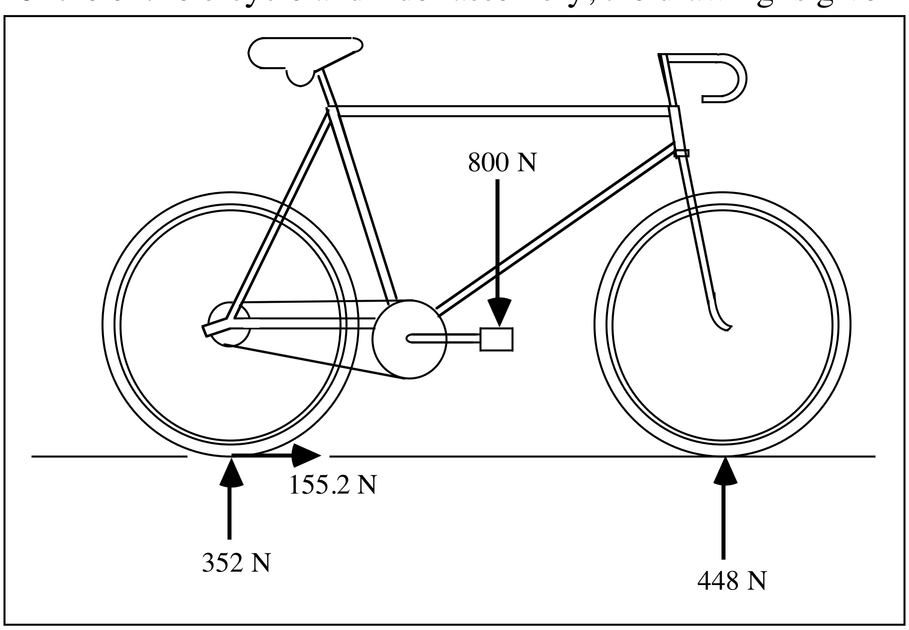
rear wheel friction force = 1280(40/330) = 155.2 N
horizontal bearing force = 1280 + 155.2 = 1435.2 N



3. For the front wheel, front wheel gravity load = 800(560/1000) = 448 N



4. For the entire bicycle and rider assembly, the drawing is given below.



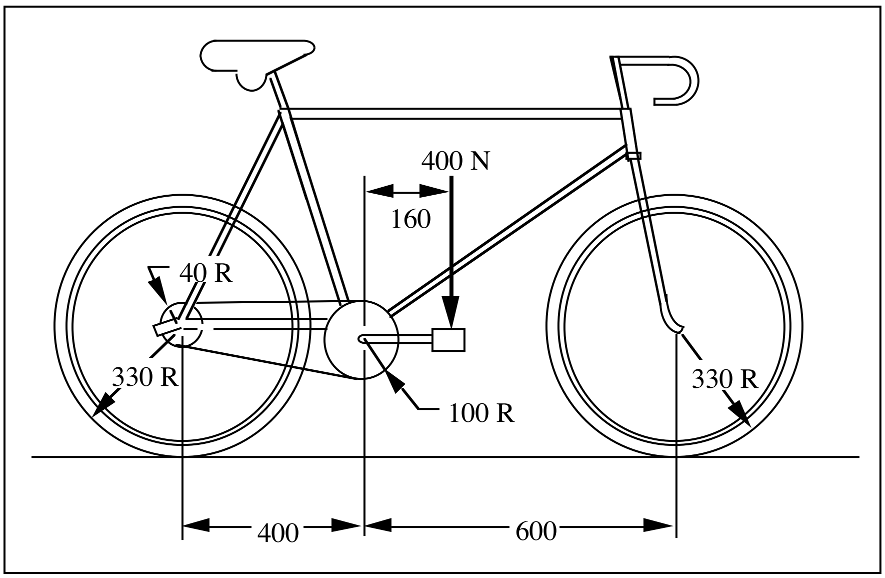
Comments: The drawing does not show the rearward 155.2 N inertia force necessary to establish $\sum F_H = 0$. It would be located thru the center of gravity of the cycle-plus-rider, the location of which is not given. Since this vector would be at some distance "h" above the ground, the resulting counter clockwise couple, 155.2 h, would be balanced by decreasing the vertical force on the front wheel and increasing the vertical force on the rear wheel, both by (155.2 h/1000) N.

SOLUTION (2.33new)

Known: A small rider is applying full weight to one pedal of a bicycle.

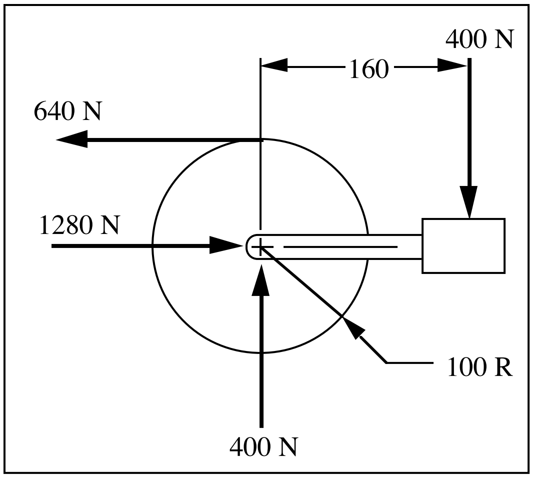
Find: Draw as free-bodies in equilibrium:
(a) The pedal, crank, and pedal sprocket assembly.
(b) The rear wheel and sprocket assembly.
(c) The front wheel.
(d) The entire bicycle and rider assembly.

Schematic and Given Data:

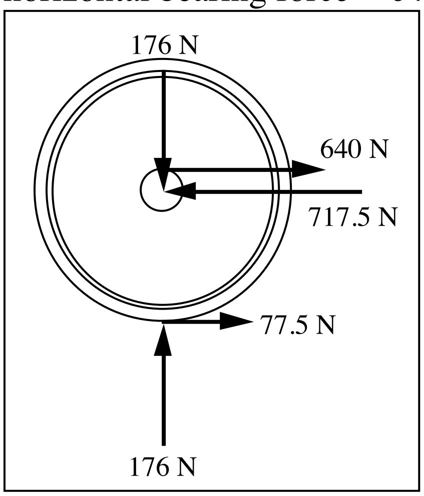


Assumptions:
1. The bicycle can be treated as a two-dimensional machine.
2. The bicycle weight is negligible.

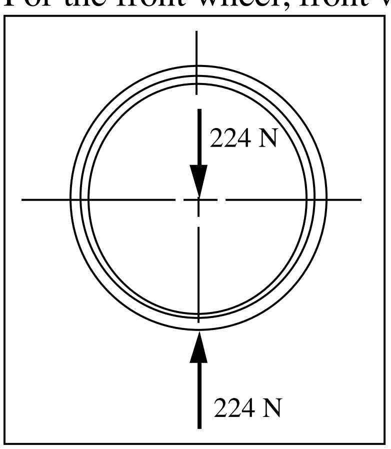
Analysis:
1. For the pedal, crank, and pedal sprocket assembly, the chain force is F = 400(160/100) = 640 N



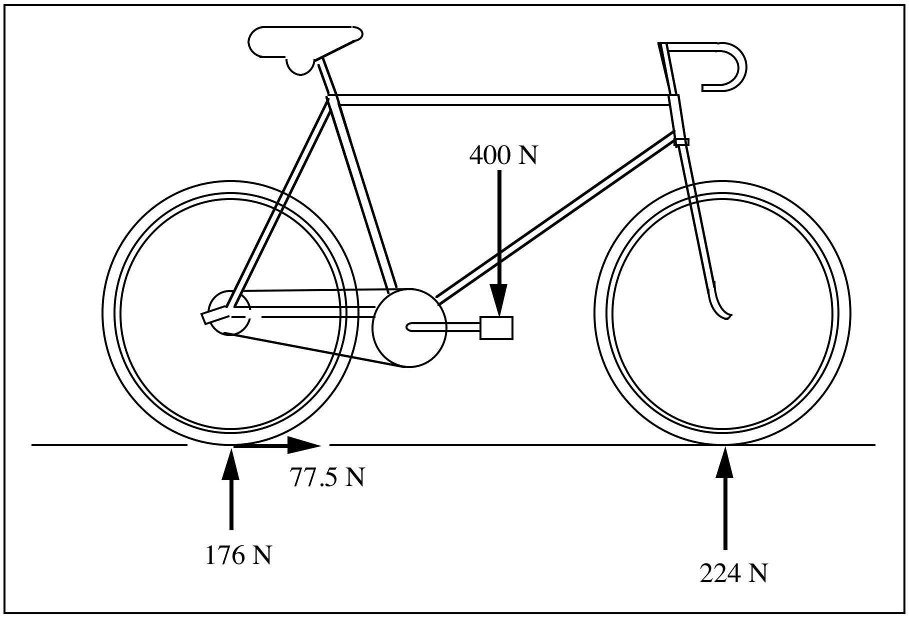
2. For the rear wheel and sprocket assembly,
   rear wheel gravity load = 400(440/1000) = 176 N
   rear wheel friction force = 640(40/330) = 77.5 N
   horizontal bearing force = 640 + 77.5 = 717.5 N



3. For the front wheel, front wheel gravity load = 400(560/1000) = 224 N



4. For the entire bicycle and rider assembly, the drawing is given below.



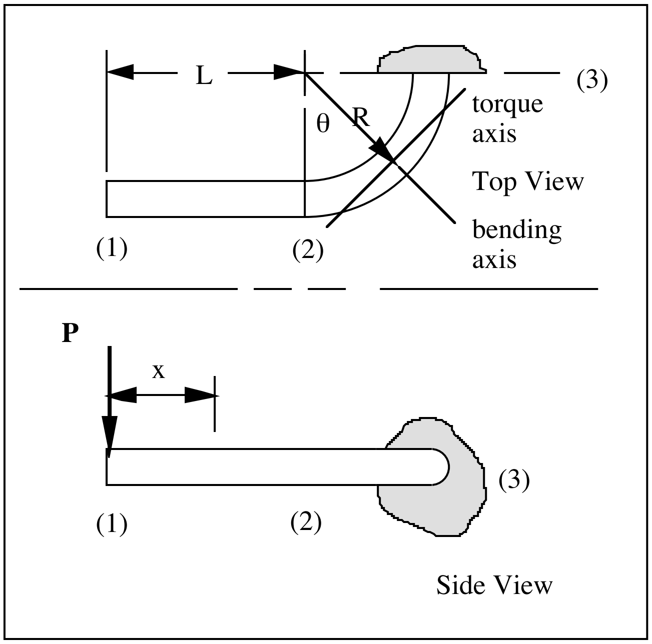
Comments: The drawing does not show the rearward 77.5 N inertia force necessary to establish $\sum F_H = 0$. It would be located thru the center of gravity of the cycle-plus-rider, the location of which is not given. Since this vector would be at some distance "h" above the ground, the resulting counter clockwise couple, 77.5 h, would be balanced by decreasing the vertical force on the front wheel and increasing the vertical force on the rear wheel, both by (77.5 h /1000) N.

SOLUTION (2.34)

Known: A solid continuous round bar is shown in Fig. P2.34 and can be viewed as comprised of a straight segment and a curved segment – segments 1 and 2. We are to neglect the weight of the member.

Find: Draw free body diagrams for segments 1 and 2. Also, calculate the force and moments acting on the ends of both segments.

Schematic and Given Data:



Assumption: The weight of the round bar is negligible.

Analysis:

1. For section 1 to 2, $M = Px$

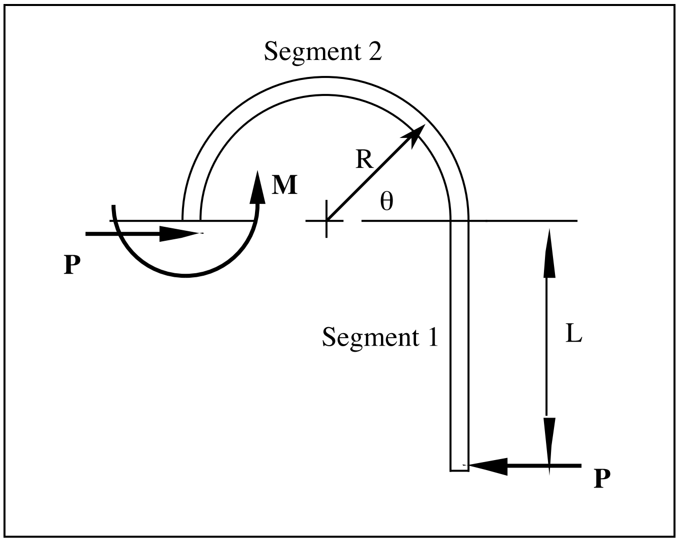
2. For section 2 to 3, $M = P(L \cos \theta + R \sin \theta)$ and $T = P[L \sin \theta + R(1 - \cos \theta)]$.

SOLUTION (2.35)

Known: The spring clip shown in Fig. P2.35 has a force P acting on the free end. We are to neglect the weight of the clip.

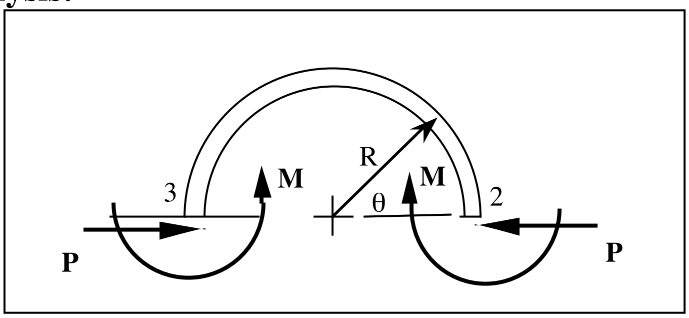
Find: Draw free-body diagrams for segments 1 and 2 – straight and curved portions of the clip. Also, determine the force and moments acting on the ends of both segments.

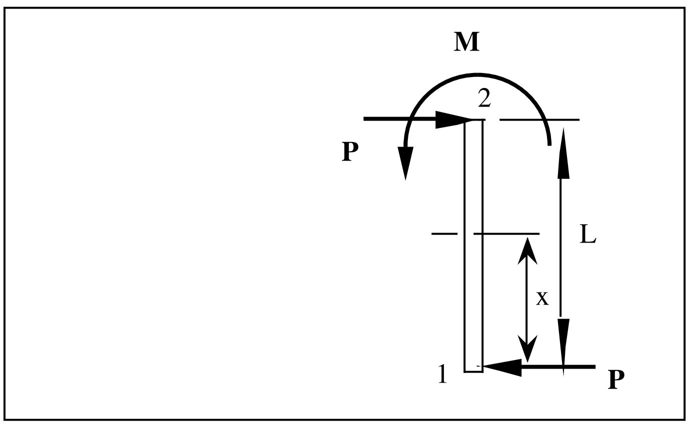
Schematic and Given Data:



Assumption: The weight of the clip is negligible.

Analysis:





1. In the straight section 1 to 2, M = Px, and the shear force V = P. At section 2, M = PL.
2. In the curved section 2 to 3, M = P(L + R sin θ). The shear force V = P and the moment M = PL at section 2 and at section 3.

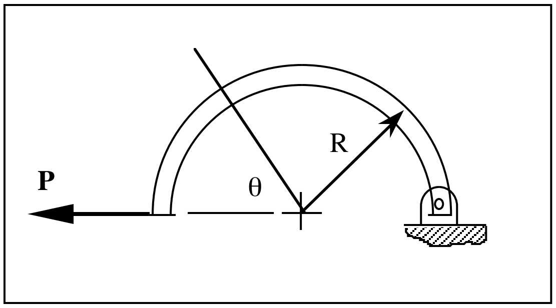
Comment: Note that at the top of the curved section the member is in axial compression.

SOLUTION (2.36)

Known: A semicircular bar of rectangular cross section has one pinned end -- see Fig. P2.36. The free end is loaded as shown.

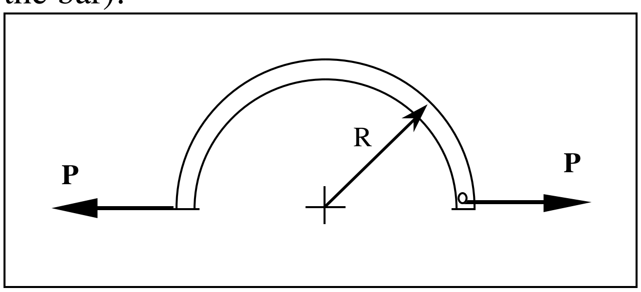
Find: Draw free-body diagrams for the entire semicircular bar and for a left portion of the bar. Discuss what influence the weight of the semicircular bar has on this problem.

Schematic and Given Data:

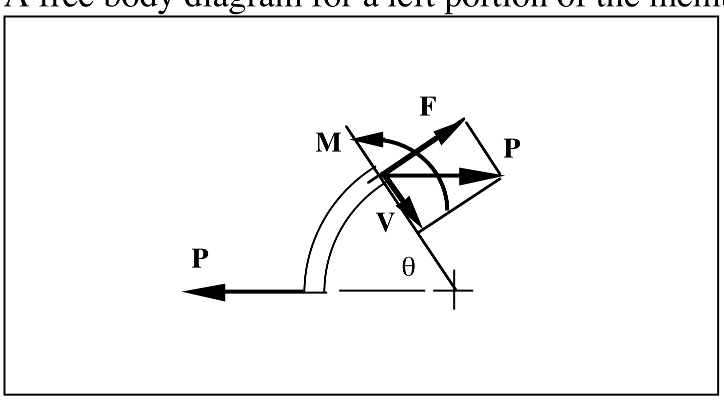


Assumptions:
1. Deflections are negligible.
2. The friction forces at the pinned end are negligible.
3. The semicircular bar is in static equilibrium.
4. The weight of the semicircular bar is negligible except where we address the effect of weight, then the force of gravity is the only body force.

Analysis:
1. A free body diagram for the entire member is shown below (ignoring the weight of the bar).



2. A free body diagram for a left portion of the member is shown below.



3. At any section, θ, the loads are $M = PR \sin\theta$, $F = P \sin\theta$, and $V = P \cos\theta$.

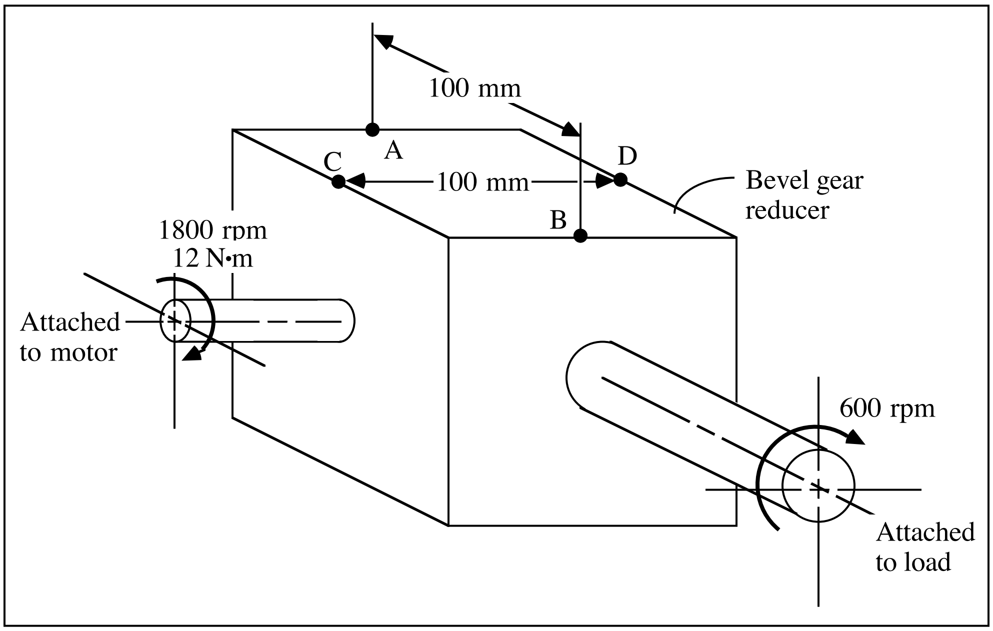
Comments: The weight for each small segment can be added in the free body diagram at the segment center of mass. An application of the equations of force equilibrium will establish the forces F, V and P, and the moment M at section θ.

SOLUTION (2.37)

Known: A bevel gear reducer with known input and output angular velocity is driven by a motor delivering a known torque of 12 N•m. The reducer housing is held in place by vertical forces applied at mountings A, B, C and D.

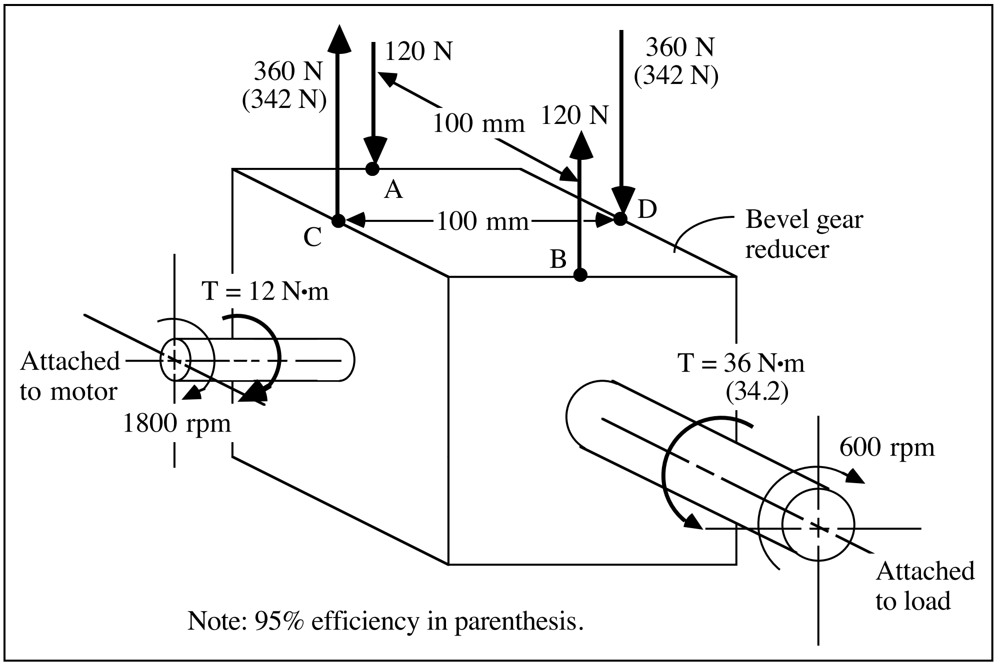
Find: Determine the forces applied to the reducer at each of the mountings:
(a) Assuming 100% reducer efficiency.
(b) Assuming 95% reducer efficiency.

Schematic and Given Data:



Assumption: The bevel gear reducer is in static equilibrium.

Analysis:


360 N
(342 N)
120 N
100 mm
120 N
360 N
(342 N)
A
D
C
100 mm
B
Bevel gear
reducer
T = 12 N•m
Attached
to motor
1800 rpm
T = 36 N•m
(34.2)
600 rpm
Attached
to load
Note: 95% efficiency in parenthesis.

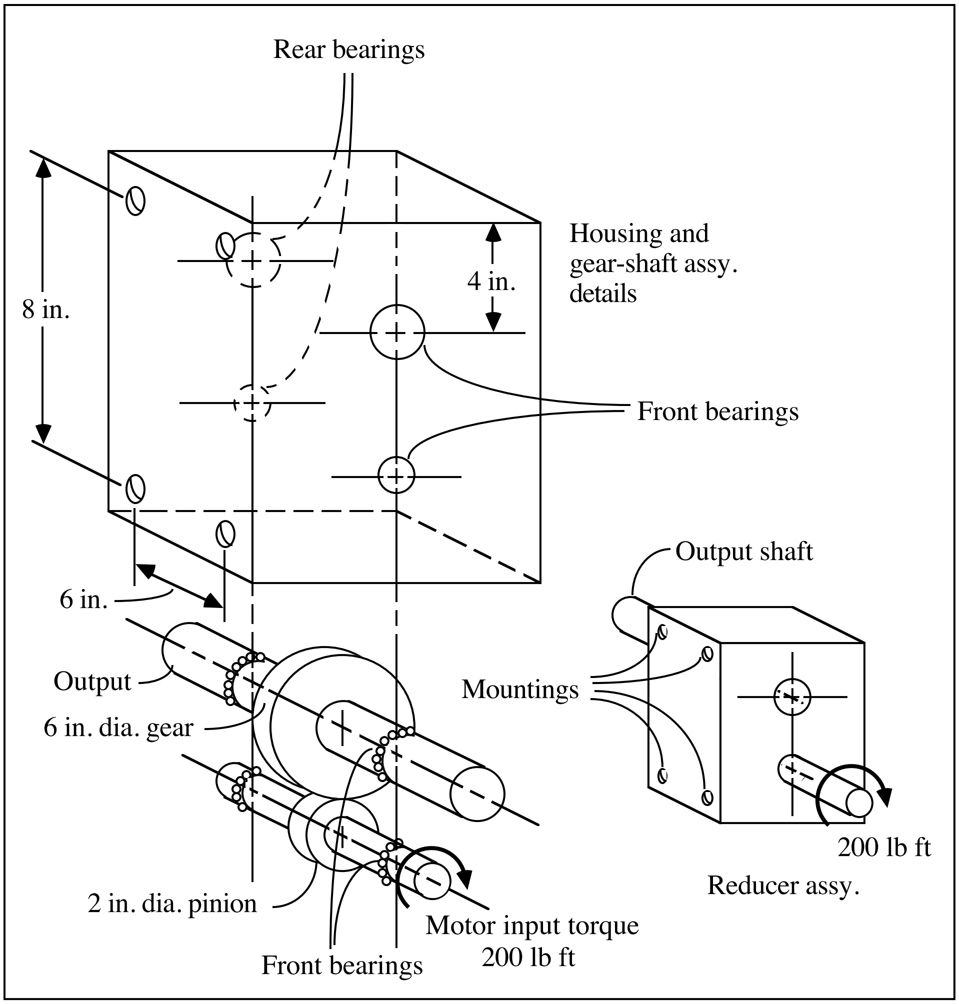
1

SOLUTION (2.40)

Known: A motor applies a known torque to the pinion shaft of a spur gear reducer.

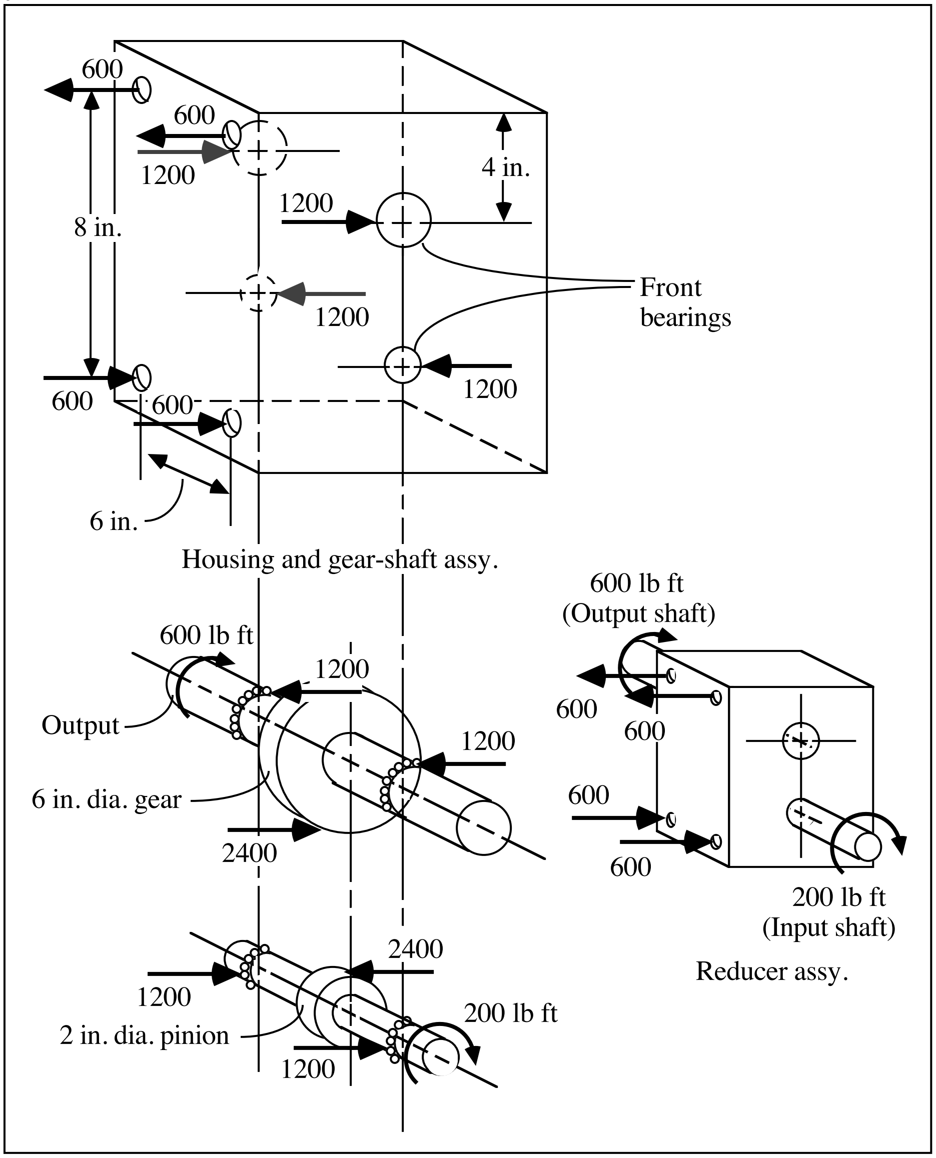
Find: Sketch free-bodies in equilibrium for
(a) The pinion and shaft assembly.
(b) The gear and shaft assembly.
(c) The housing.
(d) The entire reducer assembly.

Schematic and Given Data:



Assumptions:
1. The effect of gravity is negligible.
2. The forces between the gears act tangentially.

Analysis:



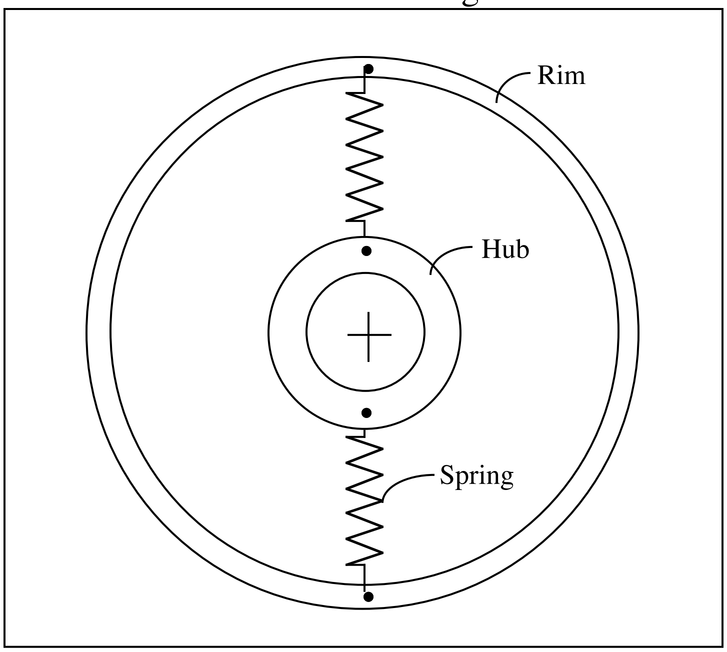
600
600
1200
4 in.
1200
8 in.
Front
bearings
1200
600
600
1200
6 in.
Housing and gear-shaft assy.
600 lb ft
(Output shaft)
600 lb ft
1200
Output
1200
6 in. dia. gear
2400
600
600
600
600
200 lb ft
(Input shaft)
Reducer assy.
2400
1200
2 in. dia. pinion
200 lb ft
1200

SOLUTION (2.41new)

Given: A rim and hub are connected by spokes (springs) as shown in Figure P2.41. The spokes are each tightened to a tension of 20 lb.

Find: Draw a free body diagram of (a) the hub, (b) the rim, (c) one spring, and (d) one-half (180°) of the rim.

Schematic and Given Data: See Figure P2.41.



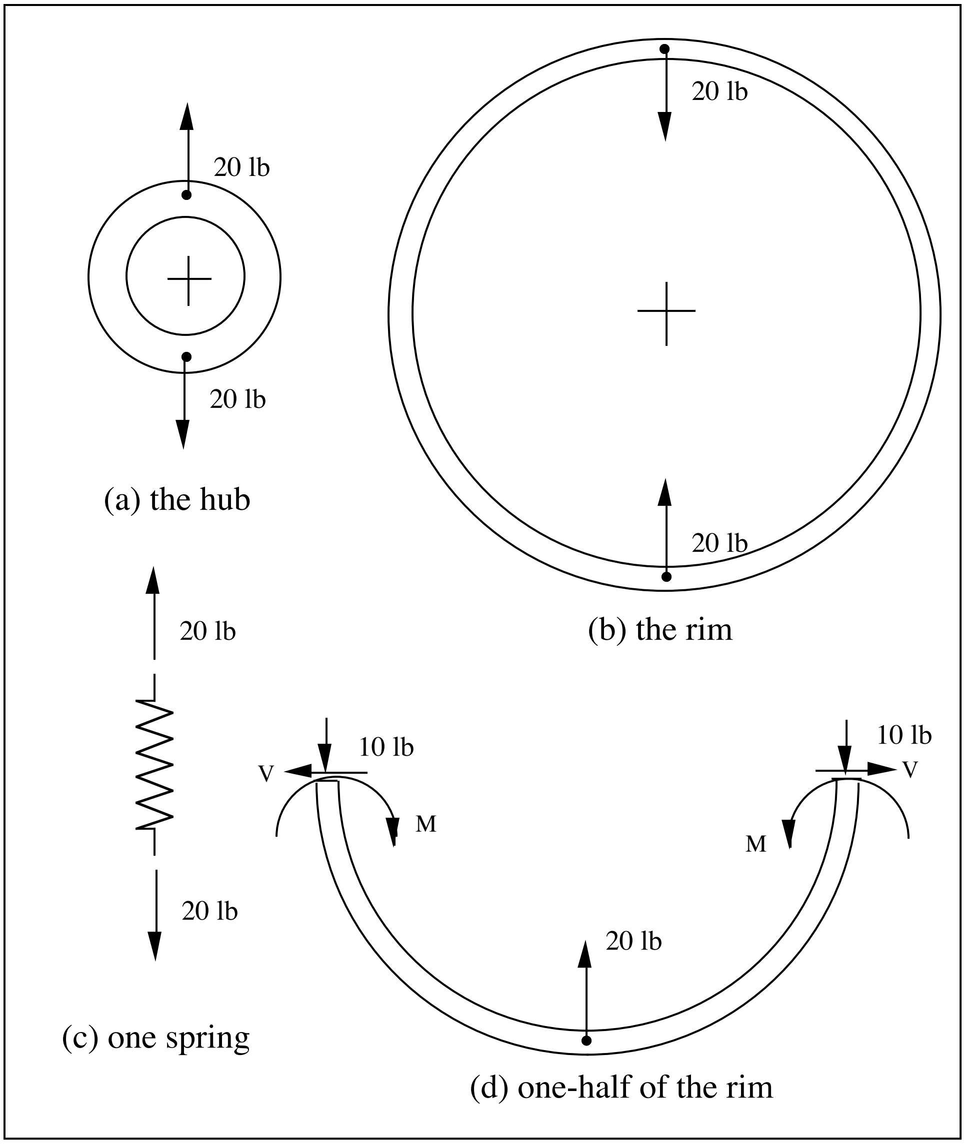
Assumption:
1. The weight of each component can be ignored.
2. The rim and hub change from circular shapes to oval shapes when the spokes are tightened.
3. The rim and hub are of homogeneous material that has the same modulus of elasticity in tension and compression.
4. The cross section of the rim and hub are each uniform.
5. The maximum stress does not exceed the proportional limit.

Analysis:
1. The hub has two opposed radial 20 lb forces pulling it apart.

2. The ring had two opposed radial 20 lb forces pulling inward.

3. Each spring has a 20 lb force on each end placing the spring in tension.

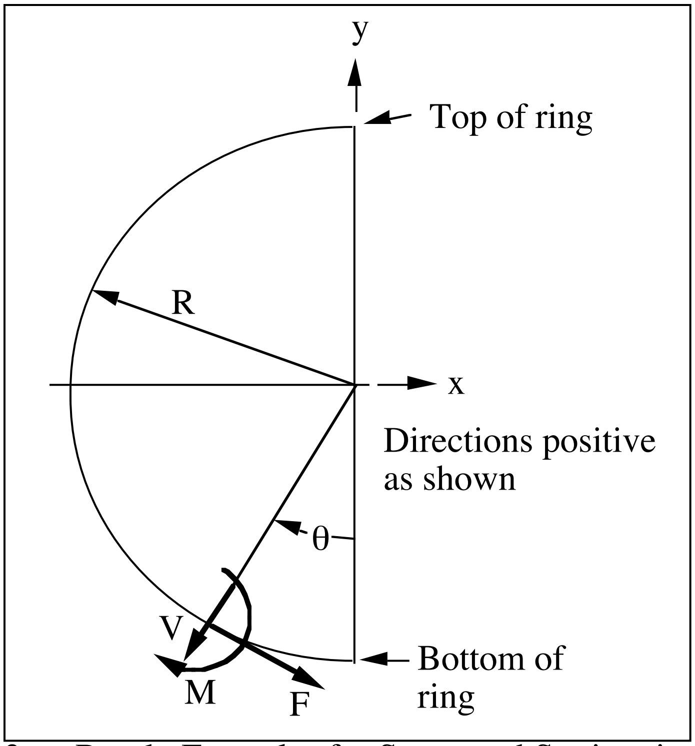
4. A free body diagram of half (180°) of the rim shows a 20 lb force pulling radially inward and a compressive force of 10 lb acting on each "cut" end of the half (180°) ring. At each cut end we show unknown moment M and shear force V.



Comments:

1. The circular ring may be regarded as a statically indeterminate beam, and can be analyzed by Castigliano's method – see Section 5.8 and 5.9 of the textbook. Section 5.9 discusses the case of redundant reactions -- a statically indeterminate problem.

2. The compressive force in the ring is given by $F = - \frac{1}{2} W \sin \theta$, where W is the force in the spring (the inward force exerted by the spring on the ring), and where θ is defined in the figure below. The shear force in the ring is given by $V = - \frac{1}{2} W \cos \theta$. See the figure below for terminology.



3. Roark, Formulas for Stress and Strain, gives the following equations obtained apparently by using Castigliano's method:

$$M = WR(0.3183 - ½^{\sin\theta}) = WR(0.3183 - [1/(2^{\sin\theta})]$$

$$\delta_x = + 0.137\ WR^3/EI \quad \text{(increase in diameter in the x-direction)}$$

$$\delta_y = - 0.149\ WR^3/EI \quad \text{(decrease in diameter in the y-direction)}$$

4. In the above equations, W= inward force of the spring on the ring, I = moment of inertia of ring cross section, E = modulus of elasticity, M = bending moment, F = circumferential tension, V = radial shear at an angular distance θ from the bottom of the ring, δ_x = change in horizontal diameter, and δ_y = change in vertical diameter.

5. Note that:

max (+M) = 0.3183WR at bottom and top (θ = 0, θ = 180)

max (-M) = - 0.1817WR at sides (θ = π/2, θ = - π/2)

F (at bottom and top) = 0

V (at bottom and top) = - ½ W

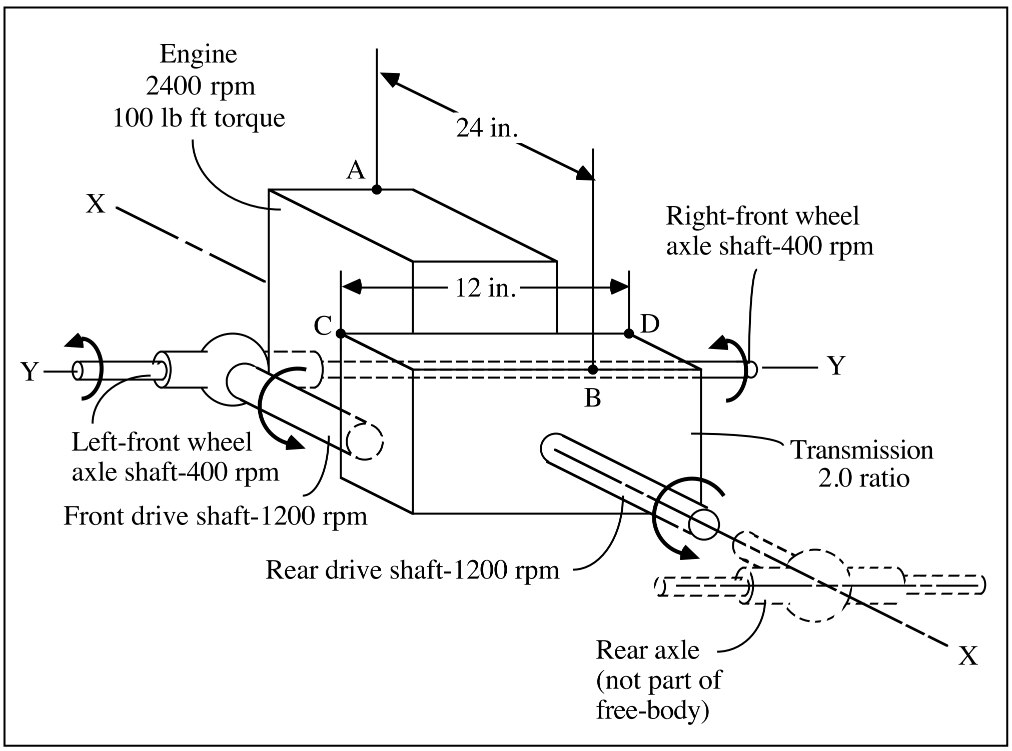
6. If the ring is connected to the hub by N spokes rather than with two spokes, Roark points out that the formulas can be combined by superposition so as to cover almost any condition of loading and support likely to occur.

SOLUTION SOLUTION (2.42)

Known: An engine rotates with a known angular velocity and delivers a known torque to a transmission which drives a front and rear axle.

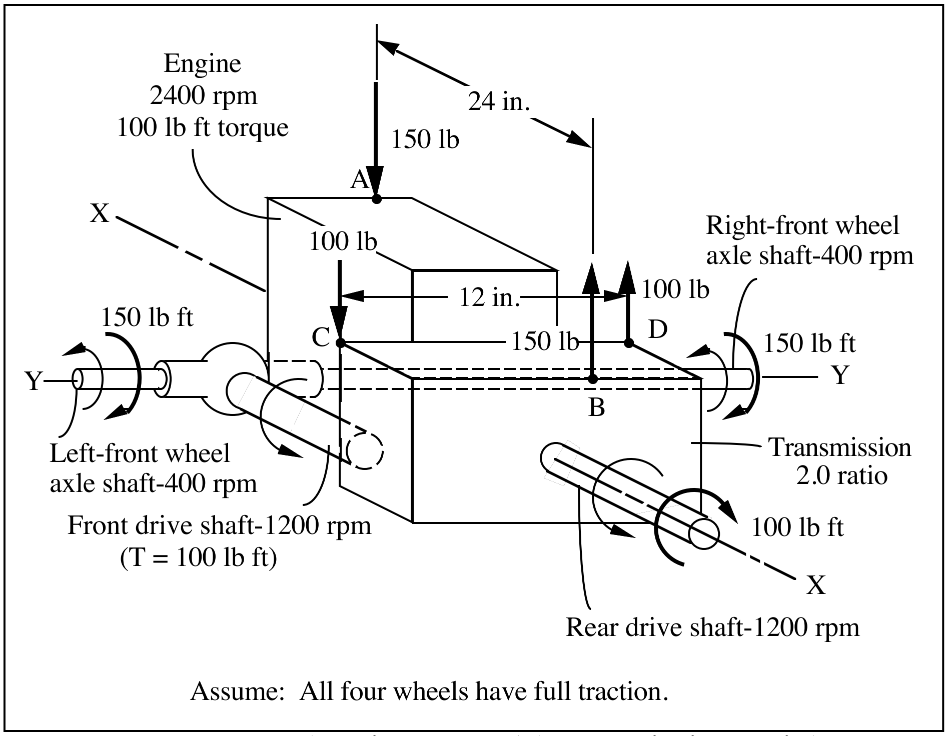
Find: Determine the forces applied to the free-body at A, B, C, and D.

Schematic and Given Data:



Assumptions:
1. The friction and gravity forces are negligible.
2. The mountings exert only vertical forces.
3. All four wheels have full traction.

Analysis:



1. Drive shaft torque = $\dfrac{\text{(Engine torque)(Transmission ratio)}}{\text{Number of drive shafts}}$
   = (100)(2)/2 = 100 lb ft

2. Wheel torque = $\dfrac{\text{(Drive shaft torque)(Axle ratio)}}{\text{Number of wheels per drive shaft}}$
   = (100)(3)/2 = 150 lb ft

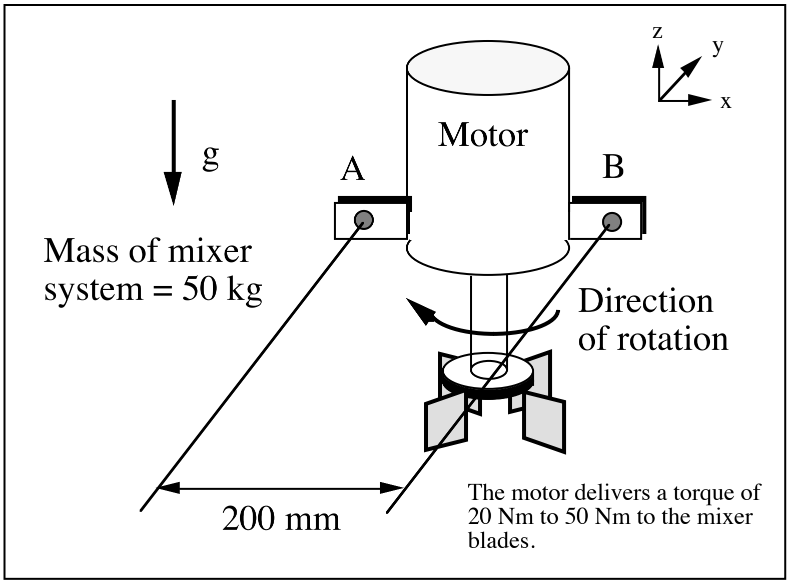
3. Therefore, A: 150 lb down ■
   B: 150 lb up ■
   C: 100 lb down ■
   D: 100 lb up ■

SOLUTION (2.43D)

Known: A mixer is supported by symmetric mounts at A and B. The motor torque should be 20 N·m to 50 N·m. The motor delivers a torque to mixing paddles which, in turn, stir a fluid to be mixed.

Find: Determine the forces acting on the mixer. Sketch a free-body of the mixer.

Schematic and Given Data:



Decision: A motor with a maximum torque output of 50 N·m is selected for analysis.

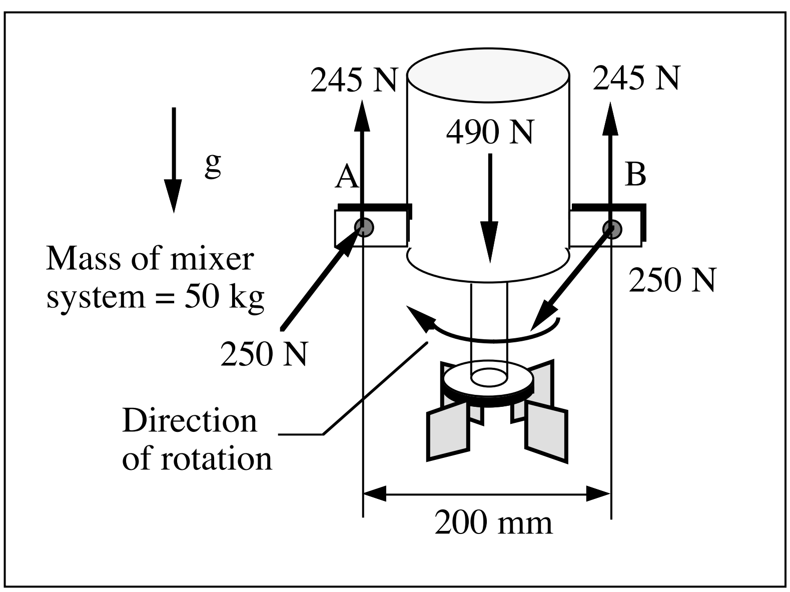
Assumption: The fluid forces on the paddles create a torque to oppose the rotation of the paddles. Other fluid forces can be neglected (e.g. the paddles are buoyed up by the weight of the displaced fluid).

Analysis:

1. The torque exerted on the paddles by the fluid is 50 N·m maximum.

2. Mounting forces to resist torque = (50 N·m)/(0.2 m) = 250 N. Thus, a force of 250 N is exerted at A and at B.
3. Gravitational forces apply F = ma = (50 kg)(9.8 m/s^2) = 490 N. Thus, there is a 245 N force upward at A and at B.

4. The forces are shown on the free body diagram for the maximum motor torque of 50 N·m.



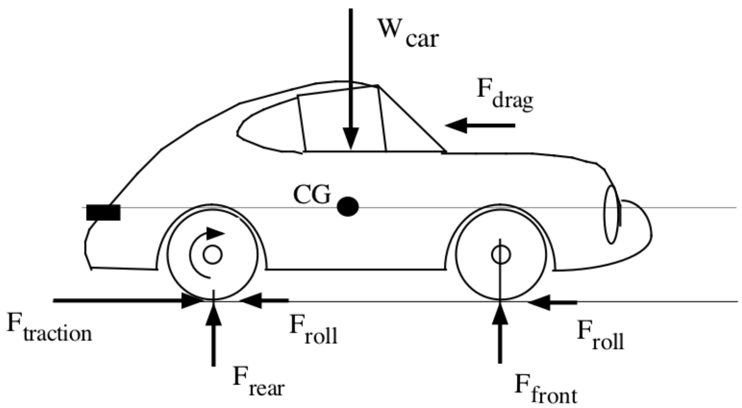
Comment: For torques less than 50 N·m, the resultant mounting forces will be smaller.

SOLUTION (2.44new)

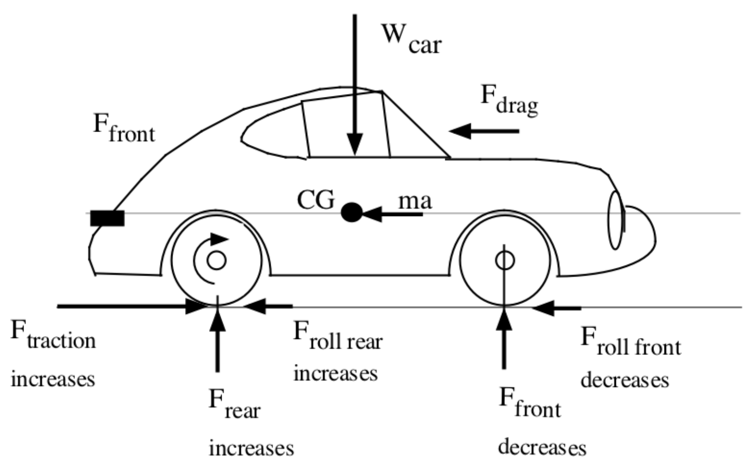
Known: A rear wheel driven vehicle travels at a steady speed. The forces opposing the motion of the vehicle are (i) the drag force, F_d, imposed on a vehicle by the surrounding air, (ii) the rolling resistance force on the tires, F_r , and (iii) the forces of the road acting on the tires. The vehicle has a weight W.

Find: Draw a free body diagram of the rear wheel driven vehicle. Describe how the free body diagram changes if the accelerator pedal is pushed and the vehicle starts accelerating.

Schematic and Given Data:



Rear Wheel Drive



Car Starts Accelerating

Assumptions: The vehicle is operating initially at steady state conditions.

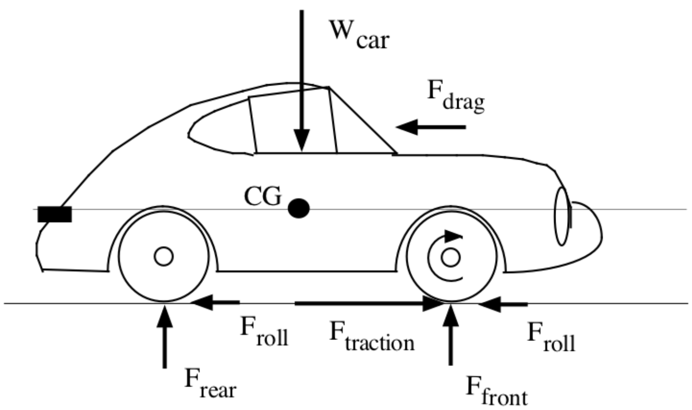
Comment: The acceleration of the vehicle results from an increase in traction force, and the additional force to acceleration the vehicle is directly related to its mass and its acceleration; i.e., F = ma. ■

SOLUTION (2.45new)

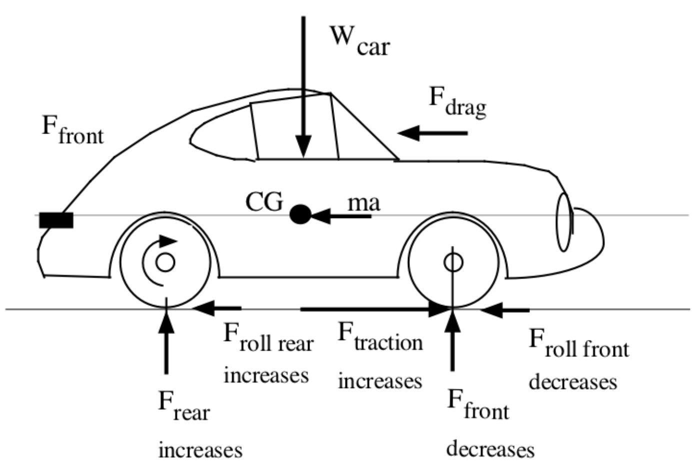
Known:
A front wheel driven vehicle travels at a steady speed. The opposing forces are the (i) drag force, F_d, imposed on a vehicle by the surrounding air and the (ii) rolling resistance force on the tires, F_r, opposing the motion of the vehicle, and (iii) the forces of the road acting on the tires. The vehicle has a weight W.

Find: Draw a free body diagram for a front wheel driven vehicle. Describe how the free body diagram changes if the accelerator pedal is pushed and the vehicle starts accelerating.

Schematic and Given Data:



Front Wheel Drive



Car Starts Accelerating

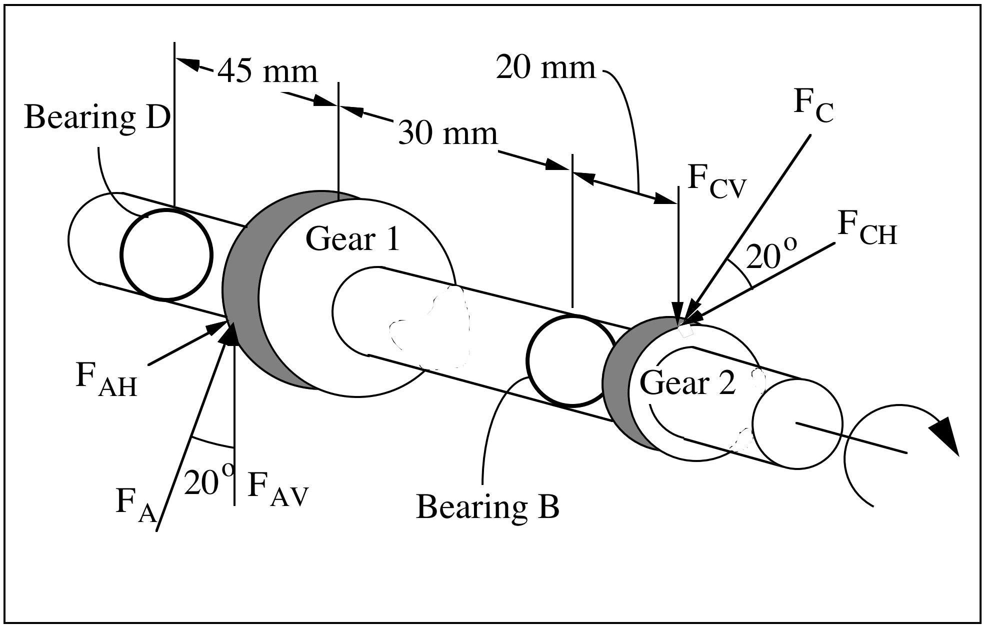
Assumptions: The vehicle is initially operating at steady state conditions.

Comment: Free body diagrams are shown above. Although the front tire force(s) decreases with acceleration, this is only a traction problem if the front wheel(s) loses a grip on the road. ■

SOLUTION (2.48)
Known: The geometry and dimensions of the gear and shaft assembly are known.

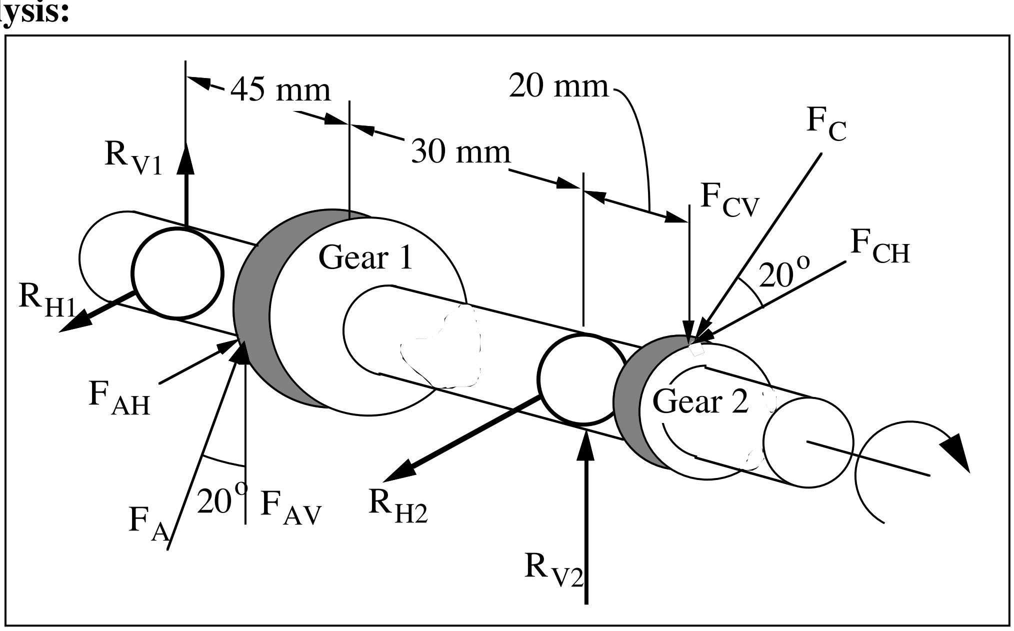
Find: Draw a free-body diagram of the assembly. Also draw the free-body diagrams for gear 1, gear 2 and the shaft.

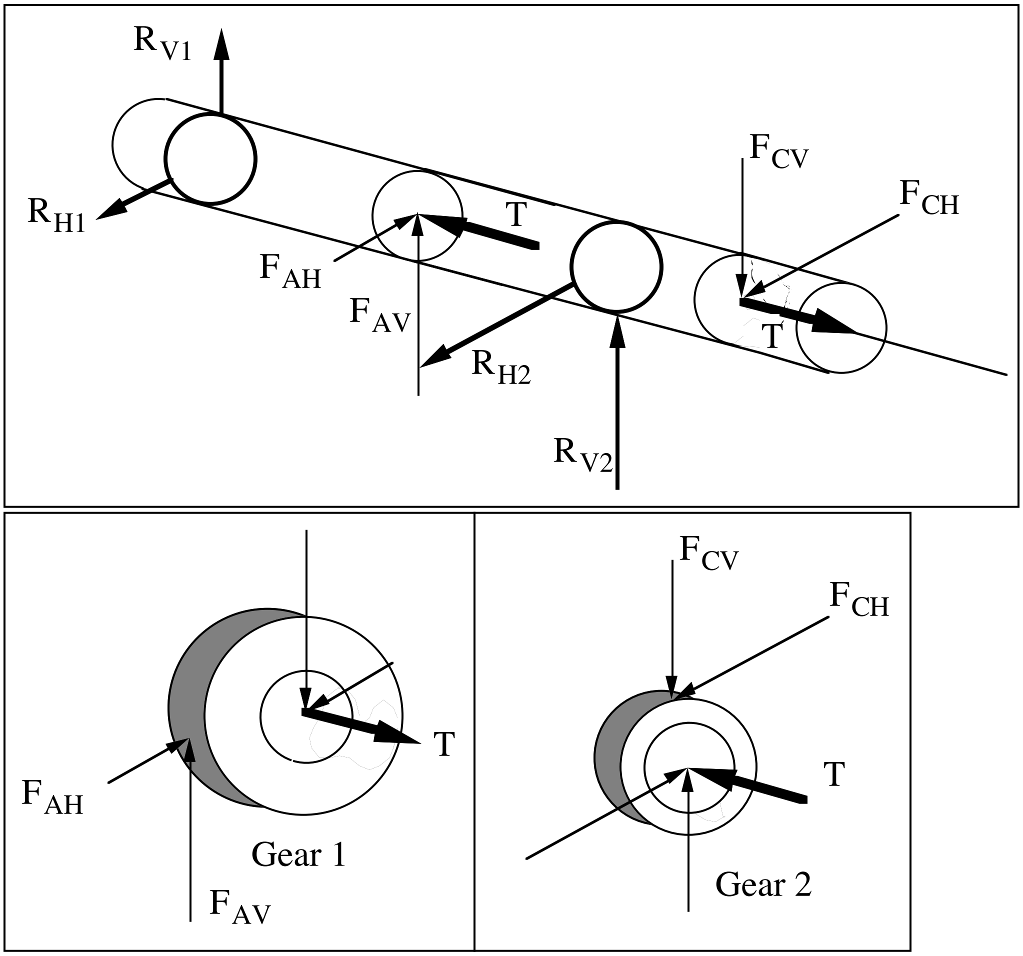
Schematic and Given Data:



Assumption: Gravity forces are negligible.

Analysis:




R_{V1}
R_{H1}
F_{AH}
F_{AV}
T
R_{H2}
R_{V2}
F_{CV}
F_{CH}
T
F_{AH}
F_{AV}
T
Gear 1
F_{CV}
F_{CH}
T
Gear 2

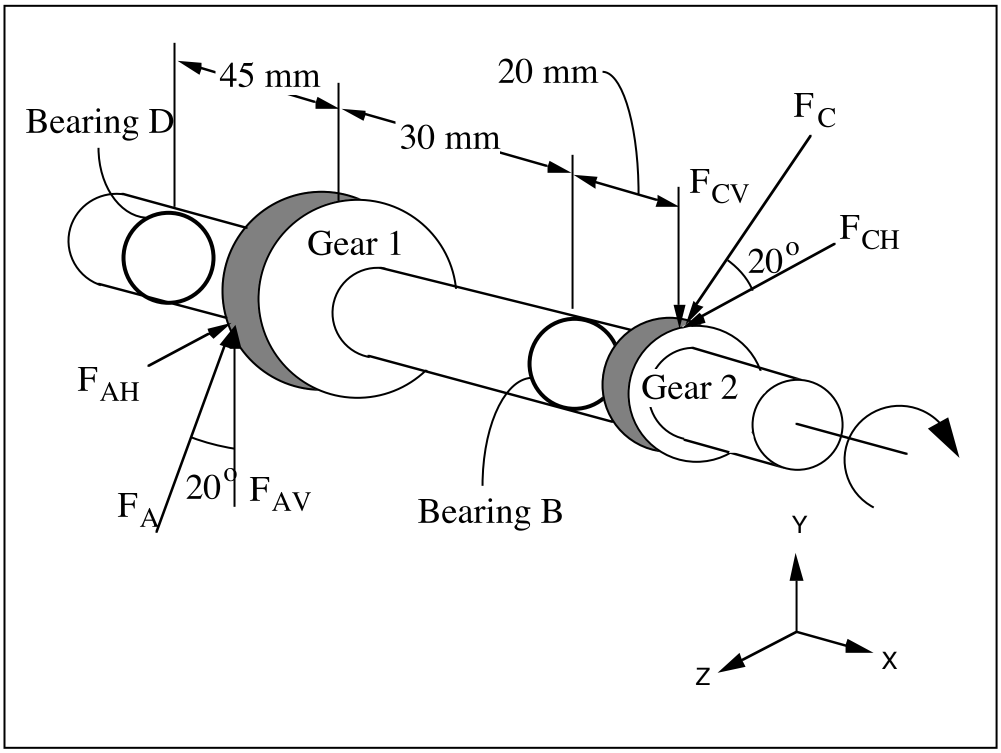
SOLUTION (2.49)

Known: The geometry and dimensions of the gear and shaft assembly are shown in Figure P2.48. The force F_A applied to gear 1 is 550 N.

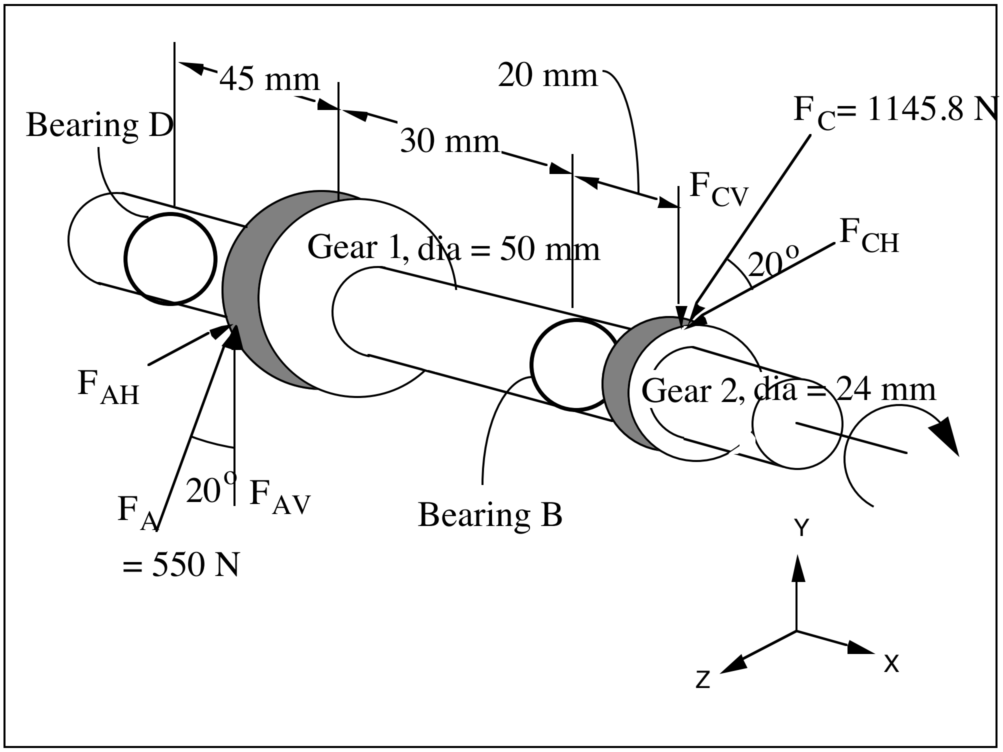
Find: Determine the magnitude of force F_C and list the assumptions.

Assumptions:
1. Frictional losses in the bearings can be neglected.
2. The gears are rigidly connected to the shafts.
3. The shaft is in static equilibrium or operating in a steady state condition.

Schematic and Given Data:



Analysis:



1. Since $\sum T = 0$ about the axis of the shaft, we have $\sum T = F_A \cos 20^o (25 \text{ mm}) - F_C \cdot \cos 20^o (12 \text{ mm}) = 0$.

2. Solving the above equation, gives $F_C = F_A \cdot (25/12) = 1145.8$ N ■

Comment: Recall that gear 1 has a diameter of 50 mm and gear 2 has a diameter of 24 mm; i.e., gear 1 has a radius of 25 mm and gear 2 has a radius of 12 mm.

SOLUTION (2.50)

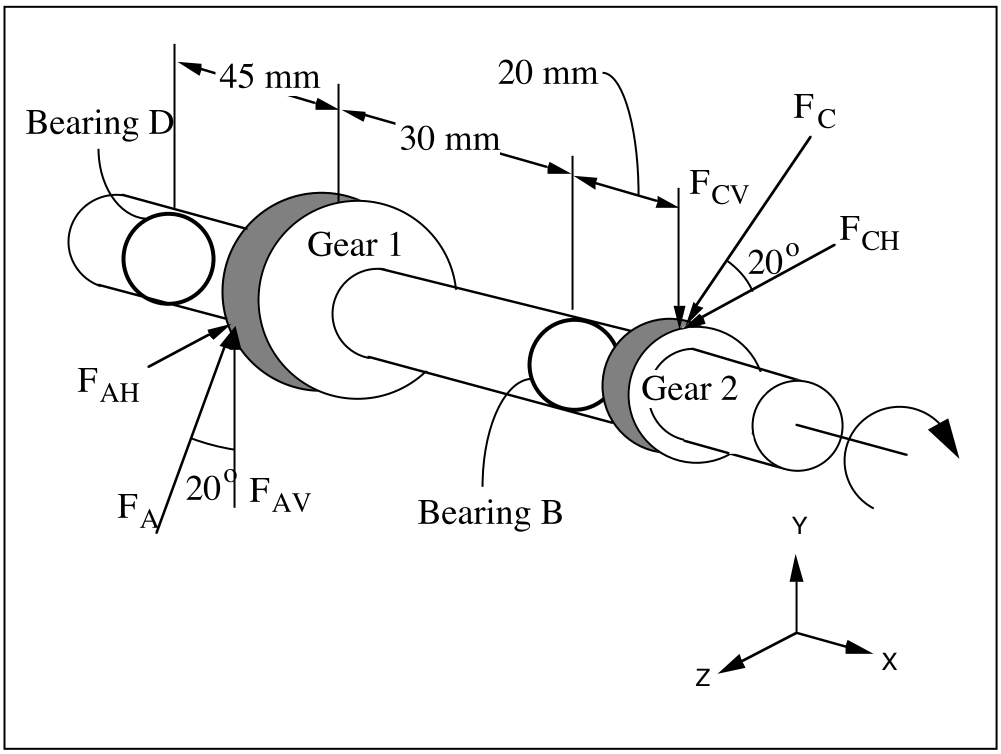
Known: The geometry and dimensions of a gear shaft are shown in Figure P2.48. The force F_A applied to gear 1 is 1000 N.

Find: Determine the forces at bearing D and list the assumptions.

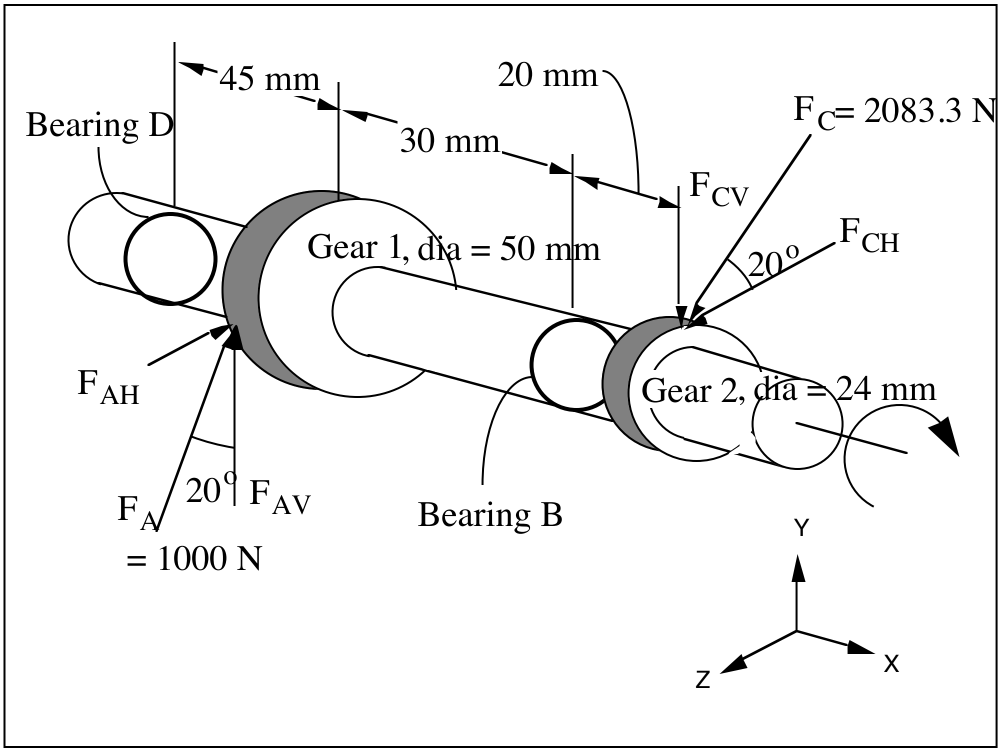
Assumptions:

1. There is no thrust load on the shaft.
2. The free body diagram determined in problem 2.48 is accurate.
3. Frictional losses in the bearings can be neglected.
4. Gravity forces and shaft deflection are negligible.
5. The location of the bearing loads can be idealized as points.
6. The gears are rigidly connected to the shafts.
7. The shaft is in static equilibrium or operating in a steady state condition.

Schematic and Given Data:



Analysis:



1. Summing moments about the X axis gives $F_C = F_A\,(25/12) = 1000(25/12) = 2083.3$ N.

2. Using the free body diagram created, we can directly write the equations of equilibrium for the moments about the bearing B.

3. The sum of the moments about the Z-axis at B is given by

   $\Sigma M_{ZB} = 0 = F_{DV}(45+30) + (F_A \cos 20^{\circ})(30) + (F_C \sin 20^{\circ})(20)$

   Solving for $F_{DV} = -565.9$ N ■

4. Similarly for the Y axis

   $\Sigma M_{YB} = 0 = F_{DH}(45+30) - (F_A \sin 20^{\circ})(30) - (F_C \cos 20^{\circ})(20)$

   Solving for $F_{DH} = 658.9$ N ■

Comments: Summing moments about the Y axis, $\Sigma M_{YD} = 0$ and then the Z axis, $\Sigma M_{ZD} = 0$ at bearing D yields bearing forces at B of $F_{BV} = 338.7$ N and $F_{BH} = -2275$ N. We can check the answers by verifying that the sum of the forces in the Y direction and then the Z direction are both equal to zero.

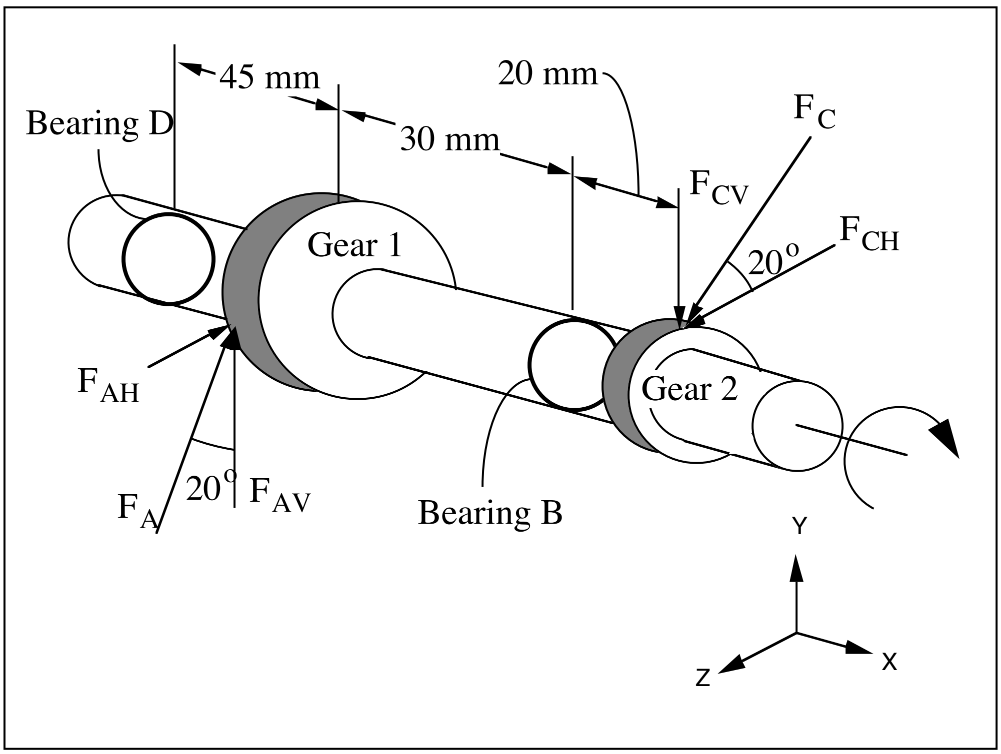
SOLUTION (2.51)

Known: The geometry and dimensions of a gear shaft are shown in Figure P2.48. The force F_C applied to gear 2 is 750 N.

Find: Determine the forces at bearing B and list the assumptions.

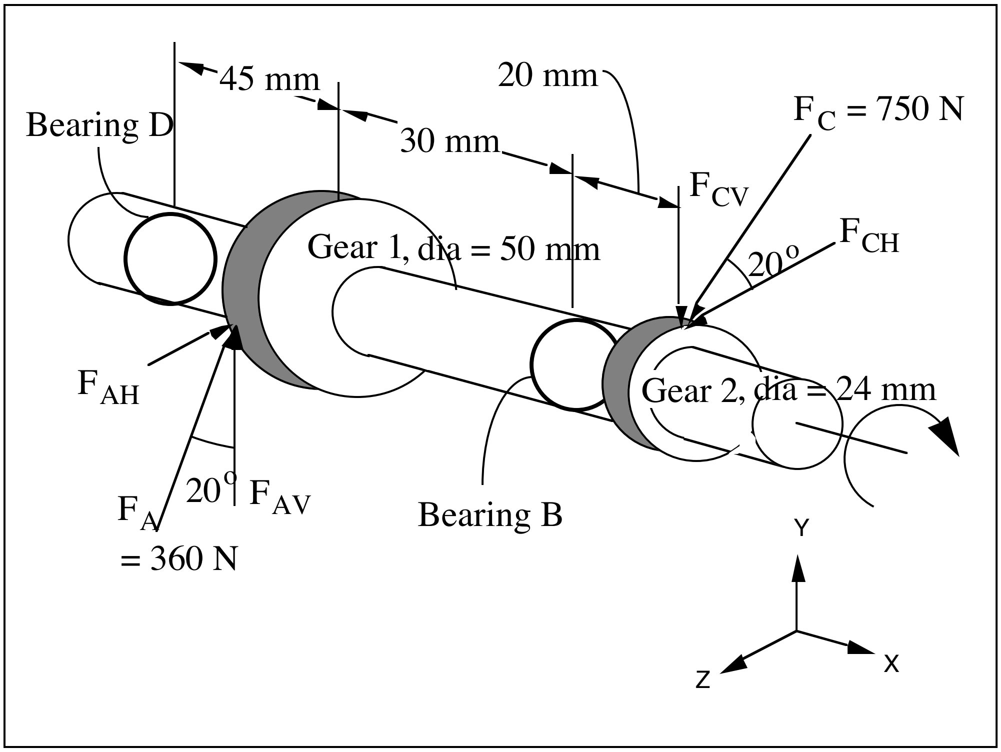
Assumptions:
1. There is no thrust load on the shaft.
2. The free body diagram determined in problem 2.48 is accurate.
3. Frictional losses in the bearings can be neglected.
4. Gravity forces and shaft deflection are negligible.
5. The location of the bearing loads can be idealized as points.
6. The gears are rigidly connected to the shafts.
7. The shaft is in static equilibrium or operating in a steady state condition.

Schematic and Given Data:



Assumption: Gravity forces are negligible.

Analysis:



1. Summing moments about the X axis gives $F_A = F_C\,(12/25) = 750(12/25) = 360N$

2. Using the free body diagram created, we can directly write the equations of equilibrium for the moments about the bearing D.

3. The sum of the moments about the Z-axis at D is given by

$$\Sigma M_{ZB} = 0 = F_{BV}(45+30) + F_A \cos 20^{\circ}\,(45) - F_C \sin 20^{\circ}\,(45 + 30 + 20)$$

Solving for $F_{BV} = 121.9$ N ■

4. Similarly for the Y-axis

$$\Sigma M_{YB} = 0 = -F_{BH}(45+30) + F_A \sin 20^{\circ}\,(45) - F_C \cos 20^{\circ}\,(45 + 30 + 20)$$

Solving for $F_{BH} = -818.8$ N ■

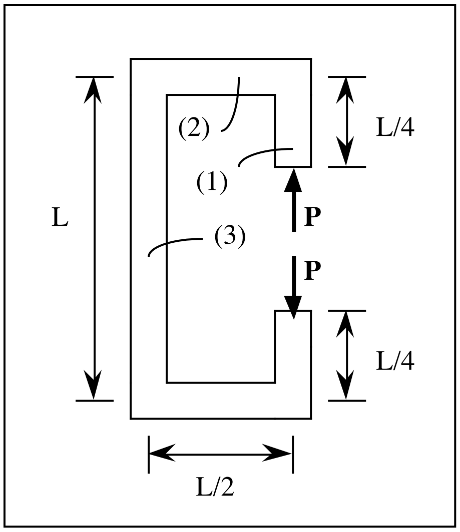
Comments: Summing moments about the Z axis and then the Y axis at bearing D yields bearing forces at D of $F_{DV} = -203.7$ N and $F_{DH} = 237.2$ N. We can check the answers by verifying that the sum of the forces in the Y direction and then the Z direction are both equal to zero.

SOLUTION (2.52)

Known: The solid continuous member shown in textbook Figure P2.52 can be viewed as comprised of several straight segments. The member is loaded as shown. We are to neglect the weight of the member.

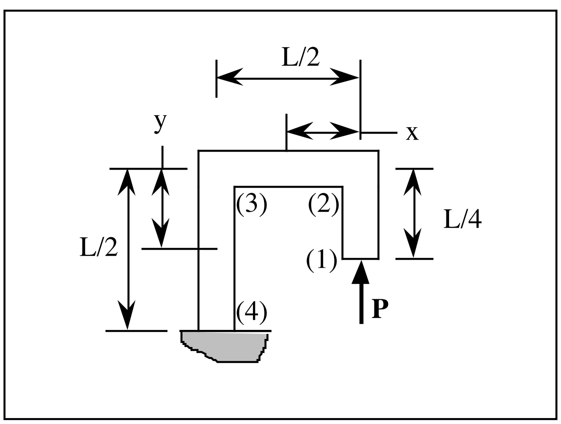
Find: Draw free-body diagrams for the straight segments 1, 2, and 3. Also, determine the magnitudes (symbolically) of the force and moments acting on the straight segments.

Schematic and Given Data:



Analysis:

1. Because of symmetry, we need to look only at one half of the member.



2. In Section 1 to 2, the axial compressive force, F = P.

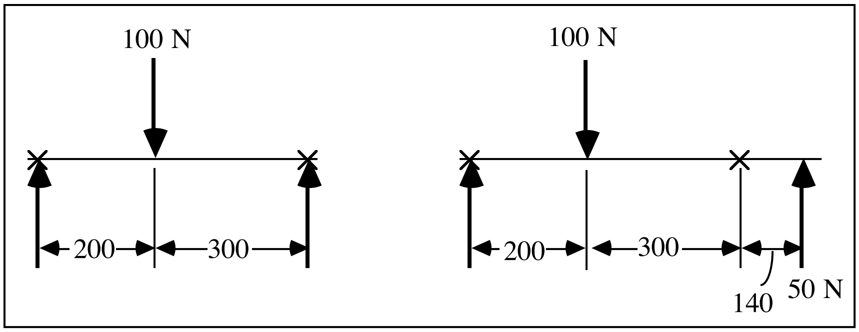
3. In Section 2 to 3, the moment, M = Px, and the shear force,V = P.

4. In Section 3 to 4, the moment, M = PL/2, and the axial tensile force, F = P.

SOLUTION (2.53)
Known: A gear exerts the same known force on each of two geometrically different steel shafts supported by self-aligning bearings at A and B.

Find: Draw shear and bending moment diagrams for each shaft.

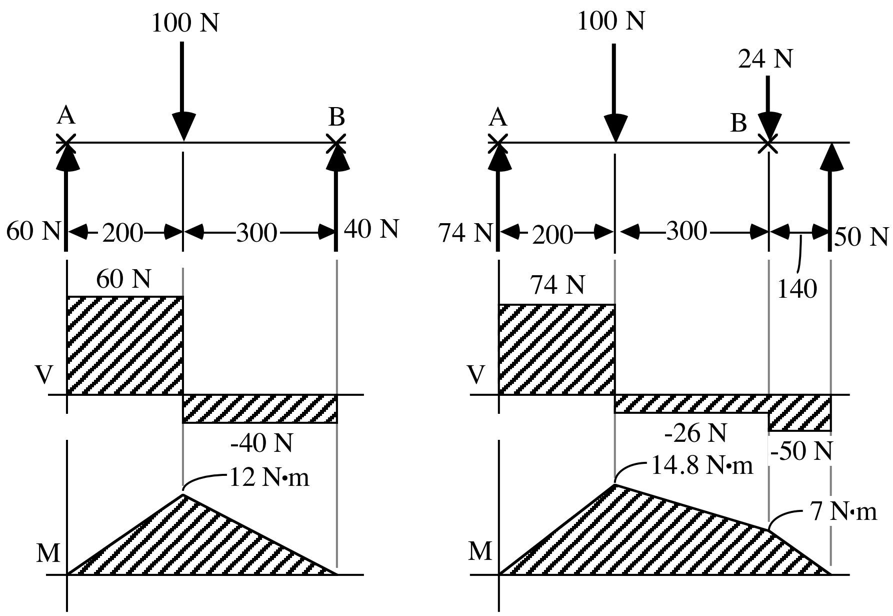
Schematic and Given Data:



Analysis:

$$F_B = 100\left(\frac{200}{500}\right) = 40\text{ N}$$

$$F_B = \frac{-100(200) + 50(640)}{500} = 24\text{ N}$$

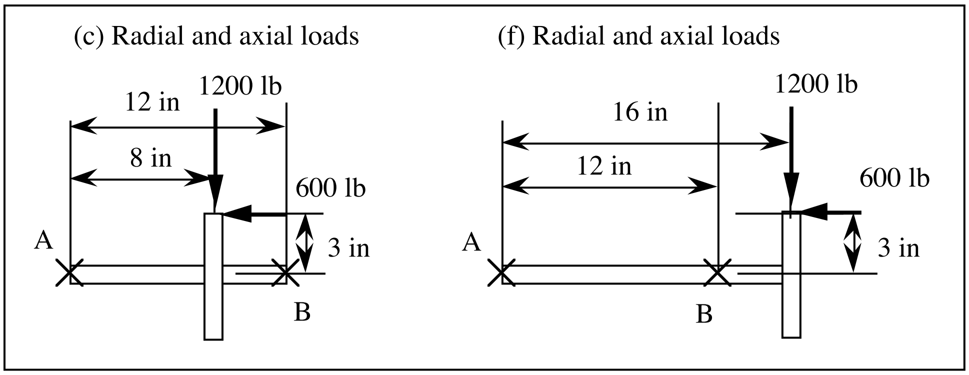


SOLUTION (2.54)

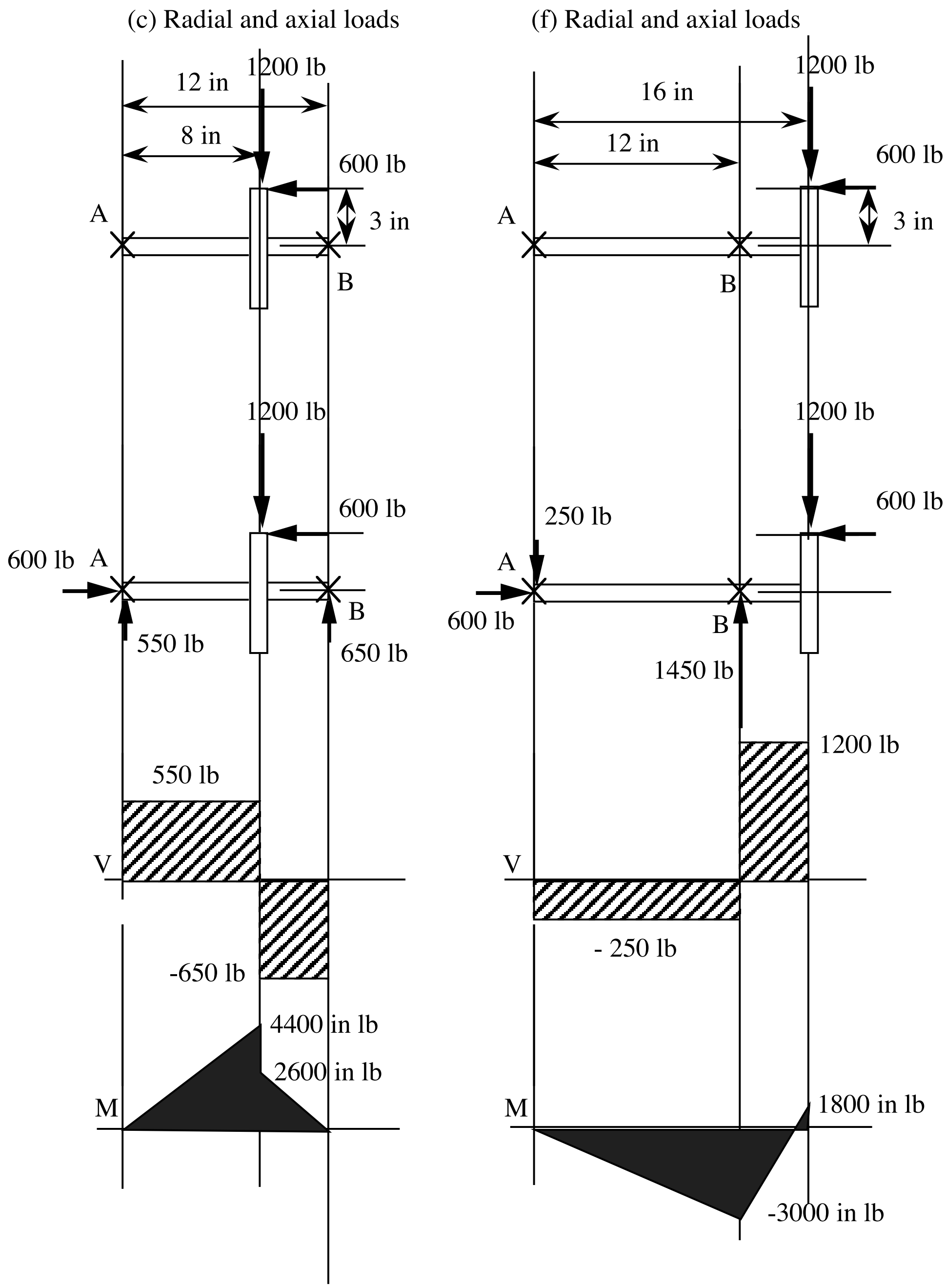
Known: Six shaft loading configurations are shown in Fig. P2.54. For each configuration, the 2-in. diameter steel shaft is supported by self-aligning ball bearings at A and B; and a special 6-in. diameter gear mounted on the shaft caused the forces to be applied as shown.

Find: Determine bearing reactions, and draw appropriate shear and bending moment diagrams for each shaft and gear loading configuration.

Schematic and Given Data:



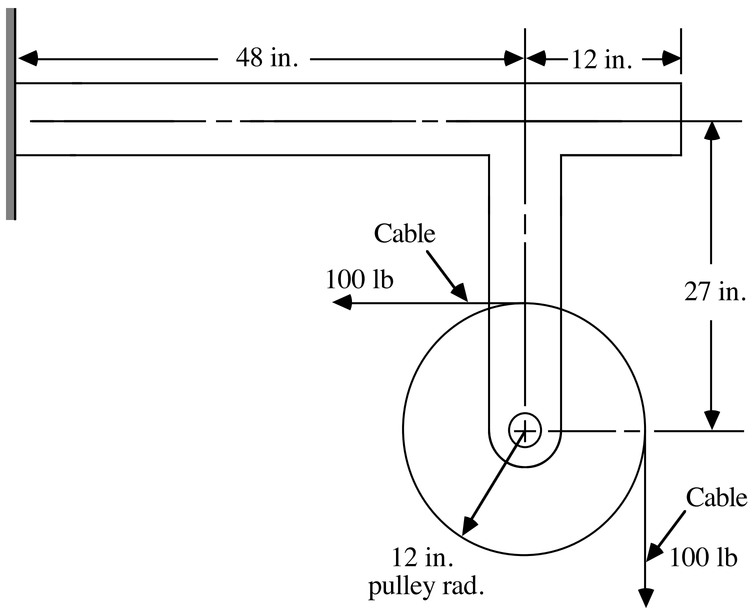
Analysis:


(c) Radial and axial loads
12 in
1200 lb
8 in
600 lb
3 in
A
B
1200 lb
600 lb
600 lb
A
B
550 lb
650 lb
550 lb
V
-650 lb
4400 in lb
2600 in lb
M
(f) Radial and axial loads
1200 lb
16 in
12 in
600 lb
A
3 in
B
1200 lb
600 lb
250 lb
A
600 lb
B
1450 lb
1200 lb
V
- 250 lb
M
1800 in lb
-3000 in lb

SOLUTION (2.55)
Known: A pulley of known radius is attached at its center to a structural member. A cable wrapped 90° around the pulley carries a known tension.

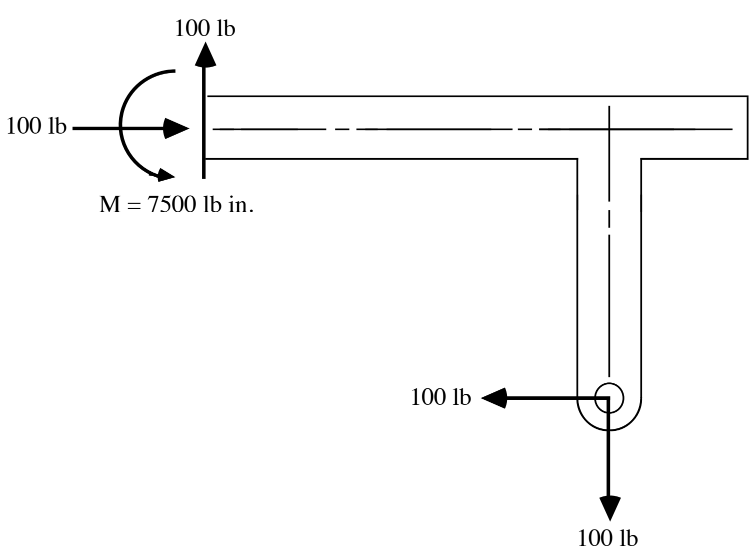
Find:
(a) Draw a free-body diagram of the structure supporting the pulley.
(b) Draw shear and bending moment diagrams for both the vertical and horizontal portions of the structure.

Schematic and Given Data:



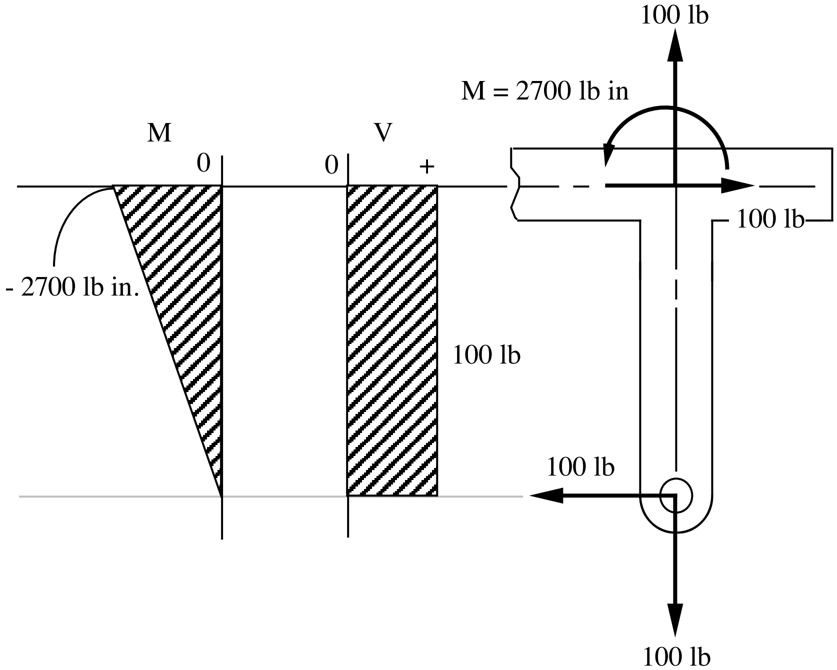
Assumption: The weight of the pulley and the supporting structure is negligible.

Analysis:
1. Free-body diagram of the structural member:

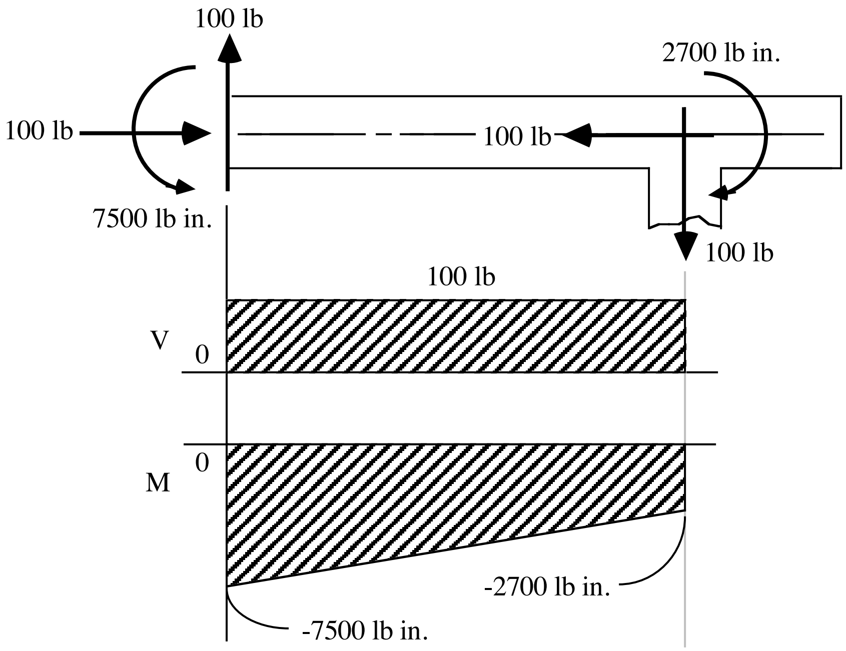


$M = 100\,(27+48) = 7500$ lb in.

2. Vertical portion of member:



3. Horizontal portion of member:



SOLUTION (2.56)

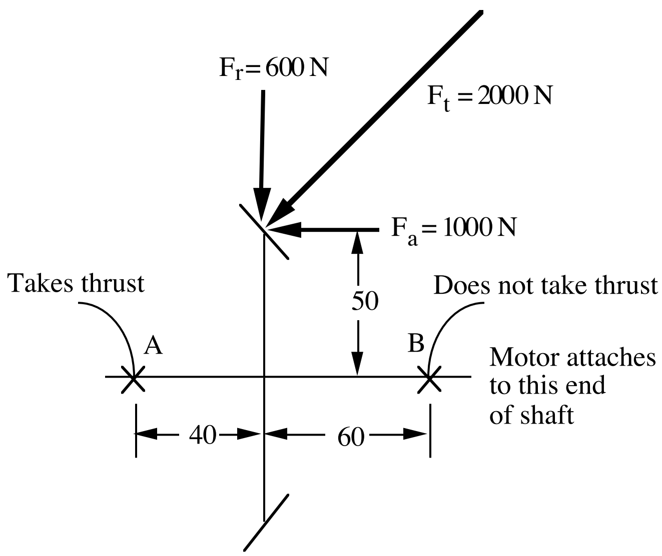
Known: A bevel gear is attached to a shaft supported by self-aligning bearings at A and B, and is driven by a motor. The axial force, radial force, and tangential force are known.

Find:

(a) Draw (to scale) axial load, shaft torque, shear force, and bending moment diagrams for the shaft.

(b) Determine the values of axial load and torque along the shaft.

Schematic and Given Data:

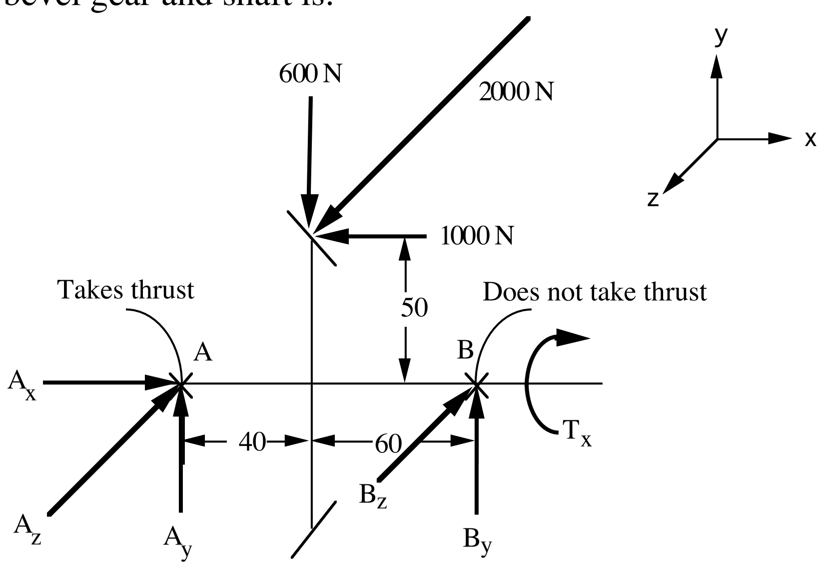


Assumptions:

1. The weight of the gear and shaft is negligible.
2. The bearing at A takes all the thrust load.

Analysis:

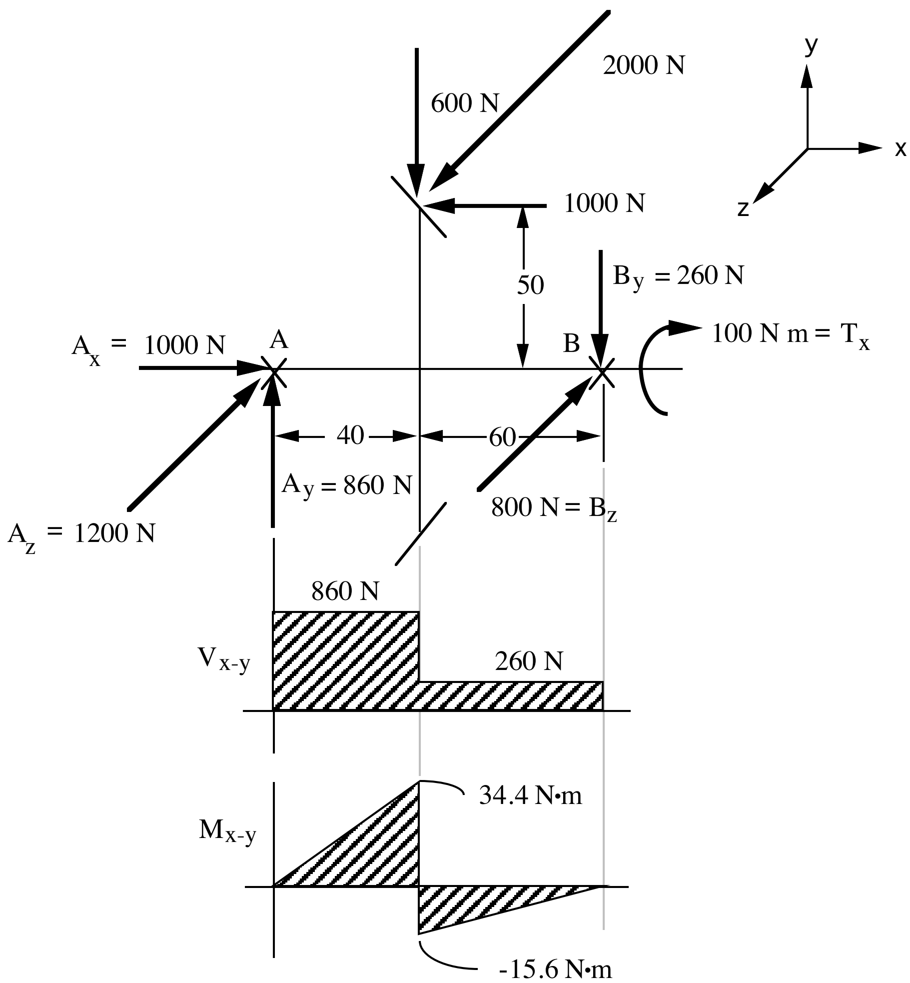
(a) Since bearing B carries no axial thrust load, $B_x = 0$. A free body diagram of the bevel gear and shaft is:

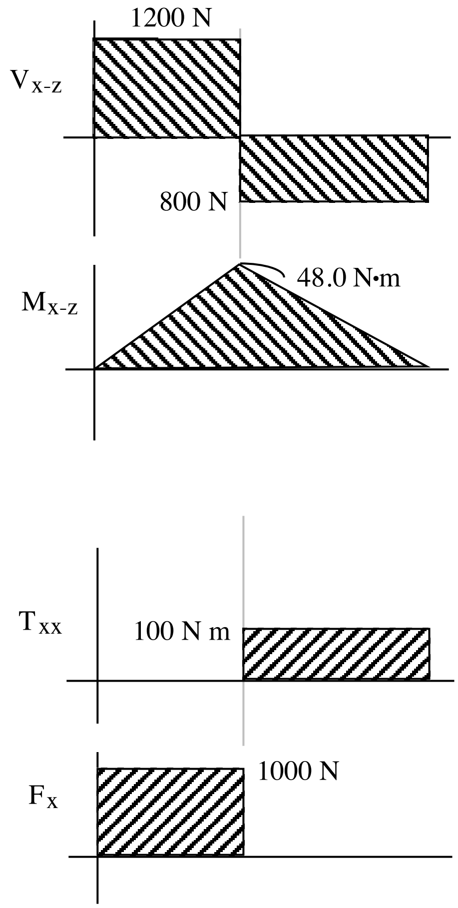


From force equilibrium:

1. $\sum M_{zA} = 0 : B_y = \dfrac{600(40) - 1000(50)}{100} = -260 \text{ N}$
2. $\sum F_y = 0 : \; A_y - 600 + B_y = 0; \; A_y = 860 \text{ N}$
3. $\sum M_{yA} = 0 : (2000)(40) - (B_Z)(100) = 0; \;\; B_Z = 800 \text{ N}$
4. $\sum M_{xx} = 0 : \; T_x - (2000)(50) = 0; \; T_x = 100{,}000 \text{ N mm}$
5. $\sum F_x = 0 : \; A_x - 1000 \text{ N} = 0; \; A_x = 1000 \text{ N}$
6. $\sum F_z = 0 : \; A_z + B_z - 2000 = 0; \; A_z = 1200 \text{ N}$

The answers are:



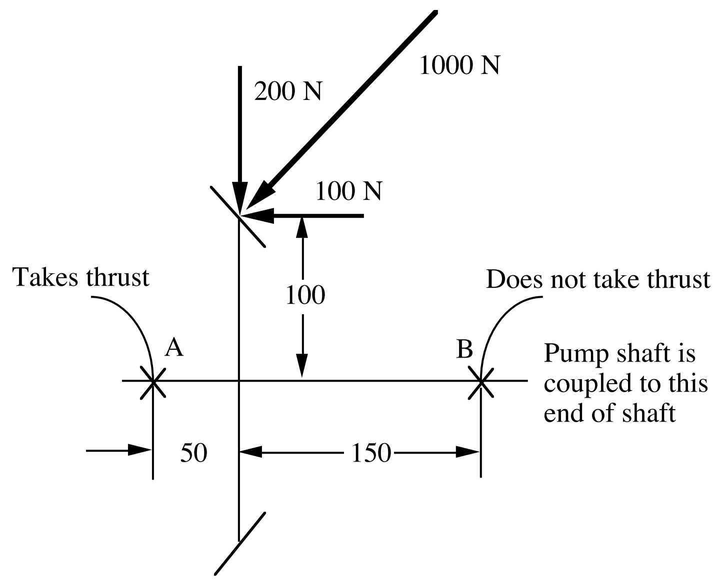


(b) The compressive force between the gear and the bearing A is 1000 N. The torque between the gear and the bearing B is 50 mm times the tangential gear force, F_t. For F_t = 2000 N, this torque is (2 kN)(50 mm) = 100 N·m.

SOLUTION (2.57)
Known: The shaft with bevel gear is supported by self-aligning bearings A and B. Gear loads are known.

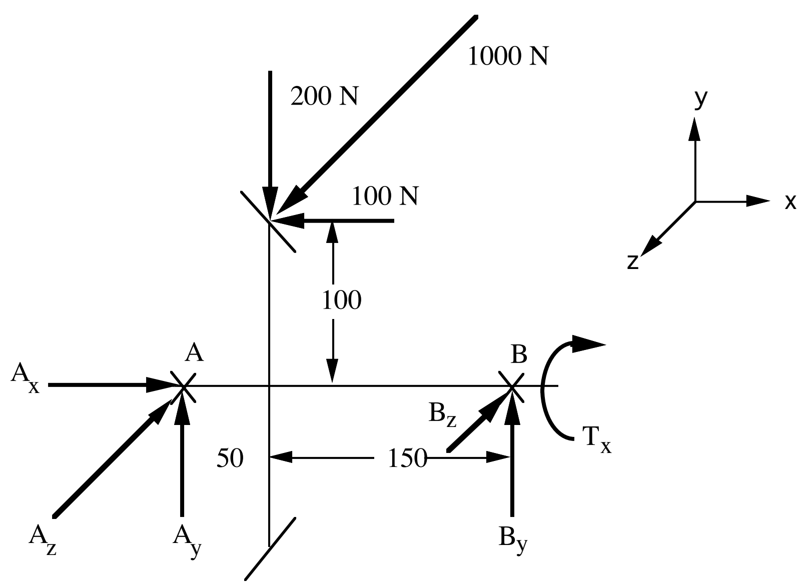
Find: Draw axial load, shaft torque, shear force, and bending moment diagrams for the shaft.

Schematic and Given Data:



Assumptions:
1. The weight of the gear and shaft is negligible.
2. The bearing at A takes all the thrust load.

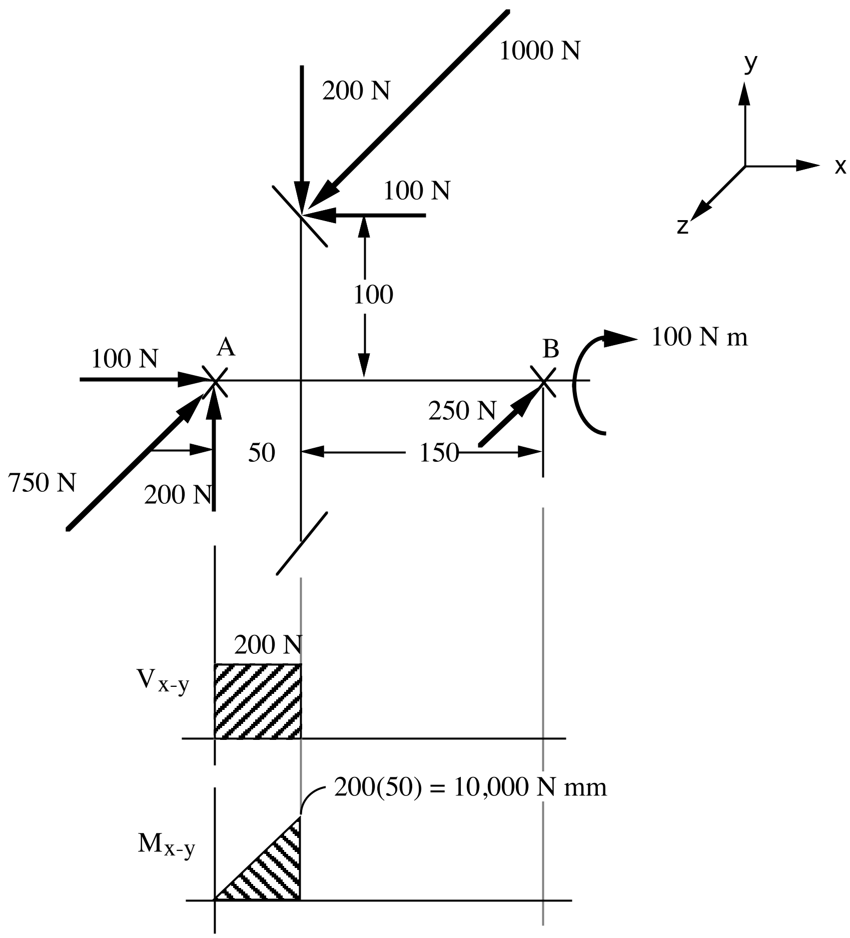
Analysis: A free body diagram of the shaft with bevel gear is:

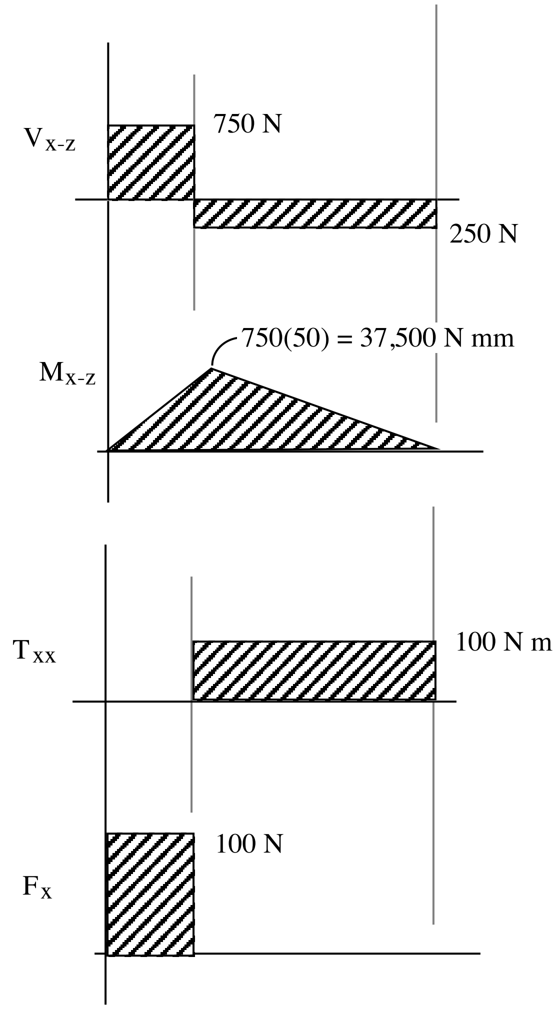


Force equilibrium requires:

1. $\sum M_{zA} = 0 : B_y = \dfrac{100(100) - 200(50)}{200} = 0 \text{ N}$
2. $\sum F_y = 0 : \; A_y - 200 + B_y = 0; A_y = 200 \text{ N}$
3. $\sum M_{yA} = 0 : (1000)(50) - (B_Z)(200) = 0; \quad B_Z = 250 \text{ N}$
4. $\sum M_{xx} = 0 : \; T_x - (1000)(100) = 0; \; T_x = 100 \text{ N m}$
5. $\sum F_x = 0 : \; A_x - 100 = 0; \; A_x = 100 \text{ N}$
6. $\sum F_z = 0 : \; A_z + B_z \; - 1000 = 0; \; A_z = 750 \text{ N}$

The answers are:

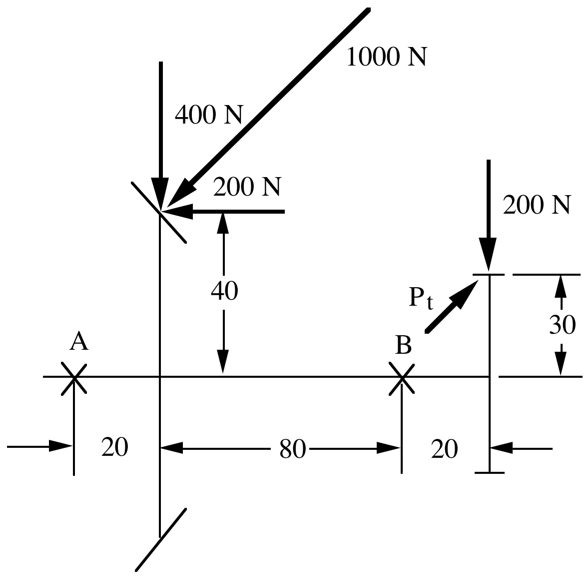



V x-z
750 N
250 N
750(50) = 37,500 N mm
M x-z
T xx
100 N m
100 N
F x

SOLUTION (2.58)
Known: The shaft with a bevel gear and a spur gear is supported by self-aligning bearings A and B. Neither end of the shaft is connected to another component. The gear loads are known except for the transmitted force on the spur gear.

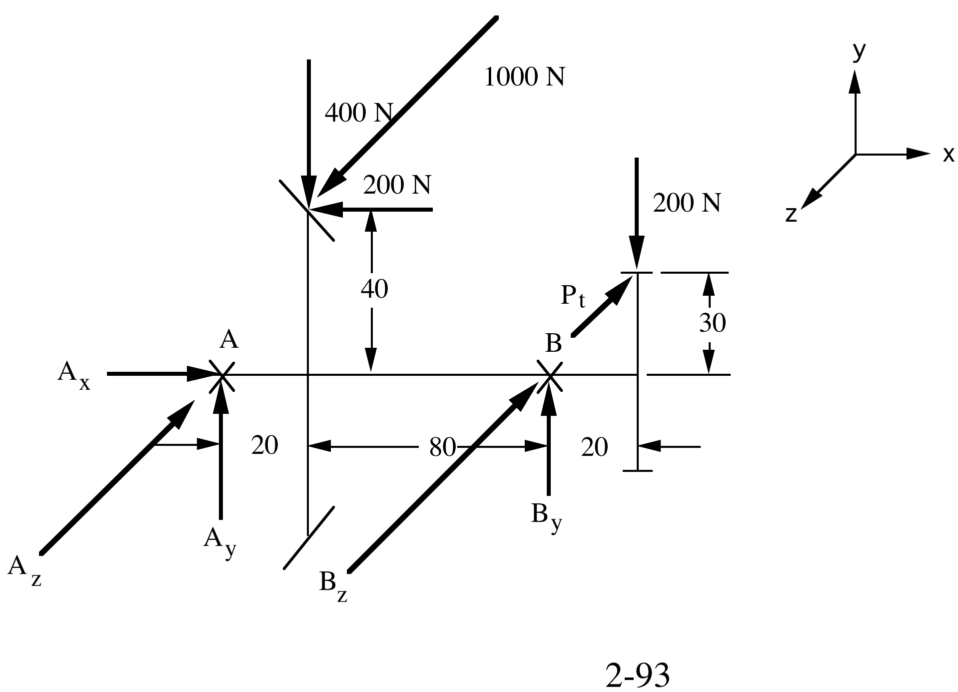
Find: Draw axial load, shaft torque, shear force, and bending moment diagrams for the shaft.

Schematic and Given Data:



Assumptions:
1. The weight of the components is negligible.
2. The bearing at A carries all the thrust load.

Analysis: A free body diagram of the shaft with bevel gear is:



Force equilibruim requires:

1. $\sum F_x = 0$: $A_x - 200 = 0$; $A_x = 200$ N

2. $\sum M_{xx} = 0$: $-(30)P_t + (1000)(40) = 0$; $P_t = 1333.33$ N

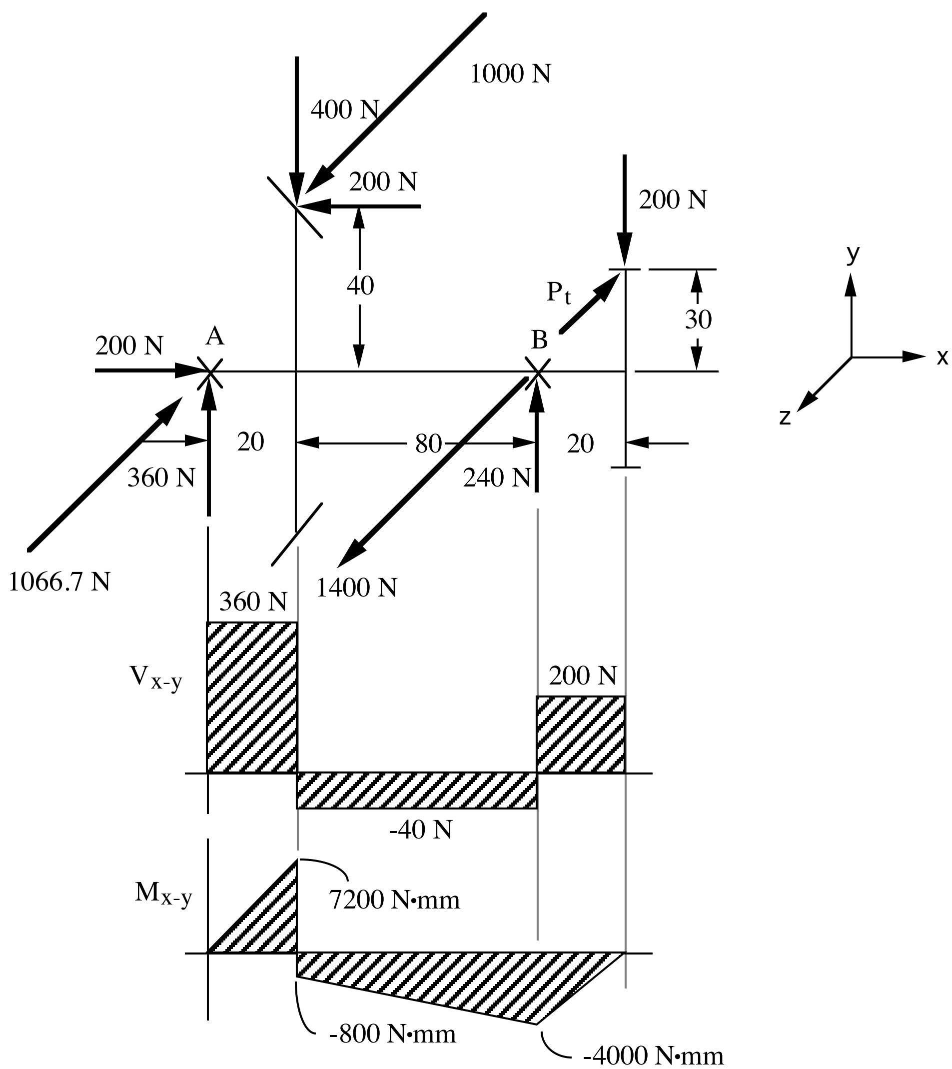
3. $\sum M_{yA} = 0$: $(1000)(20) - (B_Z)(100) - (120)P_t = 0$; $B_Z = -1400$ N

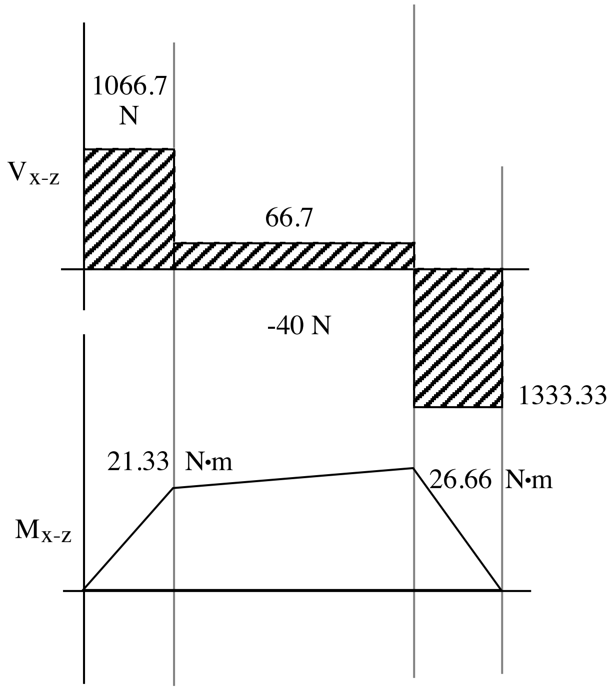
4. $\sum F_z = 0$: $A_z - 1000 - 1400 + 1333.33 = 0$; $A_z = 1066.7$ N

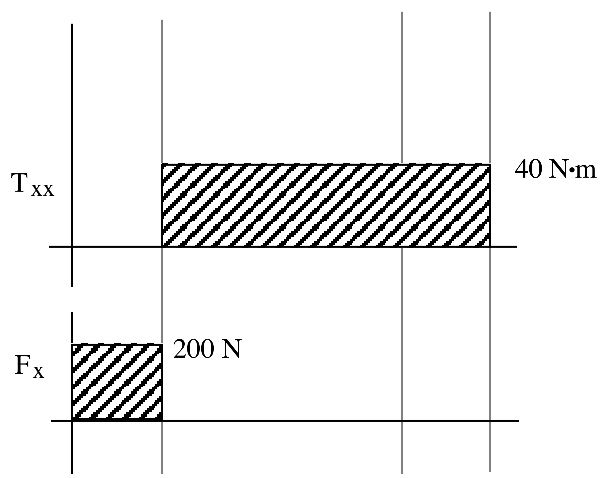
5. $\sum M_{zA} = 0$: $400(20) - 200(40) - B_y(100) + 200(120) = 0$; $B_y = 240$ N

6. $\sum F_y = 0$: $A_y - 400 + B_y - 200 = 0$; $A_y = 360$ N

The answers are:




1066.7
N
Vx-z
66.7
-40 N
1333.33
21.33 N•m
26.66 N•m
Mx-z

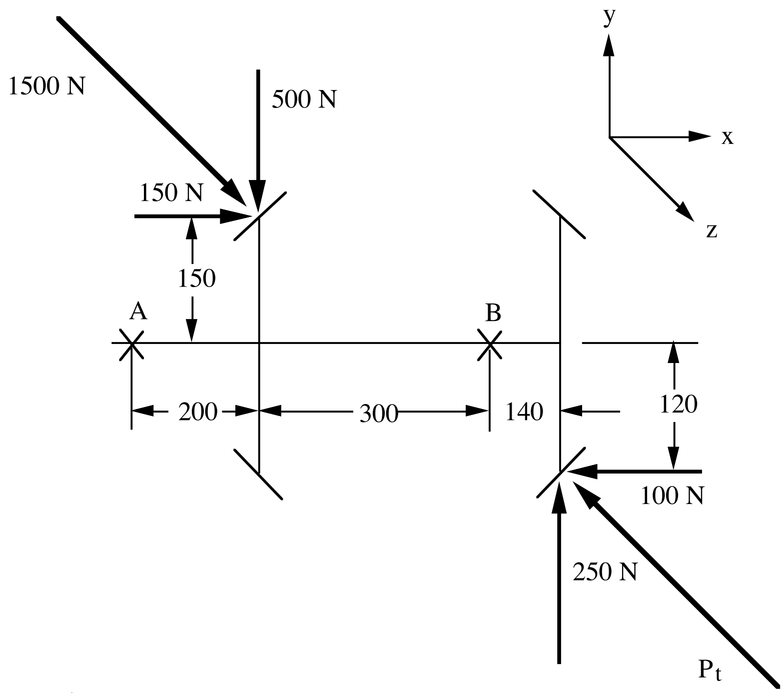

Txx
40 N•m
Fx
200 N

SOLUTION (2.59)

Known: A shaft has two bevel gears, and neither end of the shaft is connected to another component. The gear loads are known except for the transmitted force on one bevel gear.

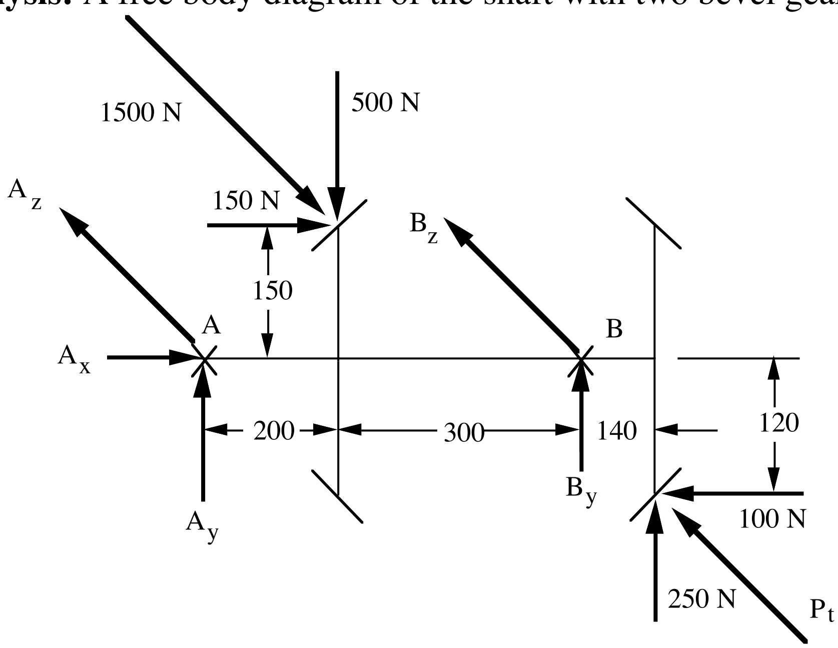
Find: Draw axial load, shaft torque, shear force, and bending moment diagrams for the shaft.

Schematic and Given Data:



Assumptions:
1. The weight of the components is negligible.
2. The bearing at A carries all the thrust load.

Analysis: A free body diagram of the shaft with two bevel gears is:



From force equilibrium:

1. $\sum M_{xx} = 0$: $-(120)P_t + (1500)(150) = 0$; $P_t = 1875$ N

2. $\sum F_x = 0$: $A_x + 150 - 100 = 0$; $A_x = -50$ N

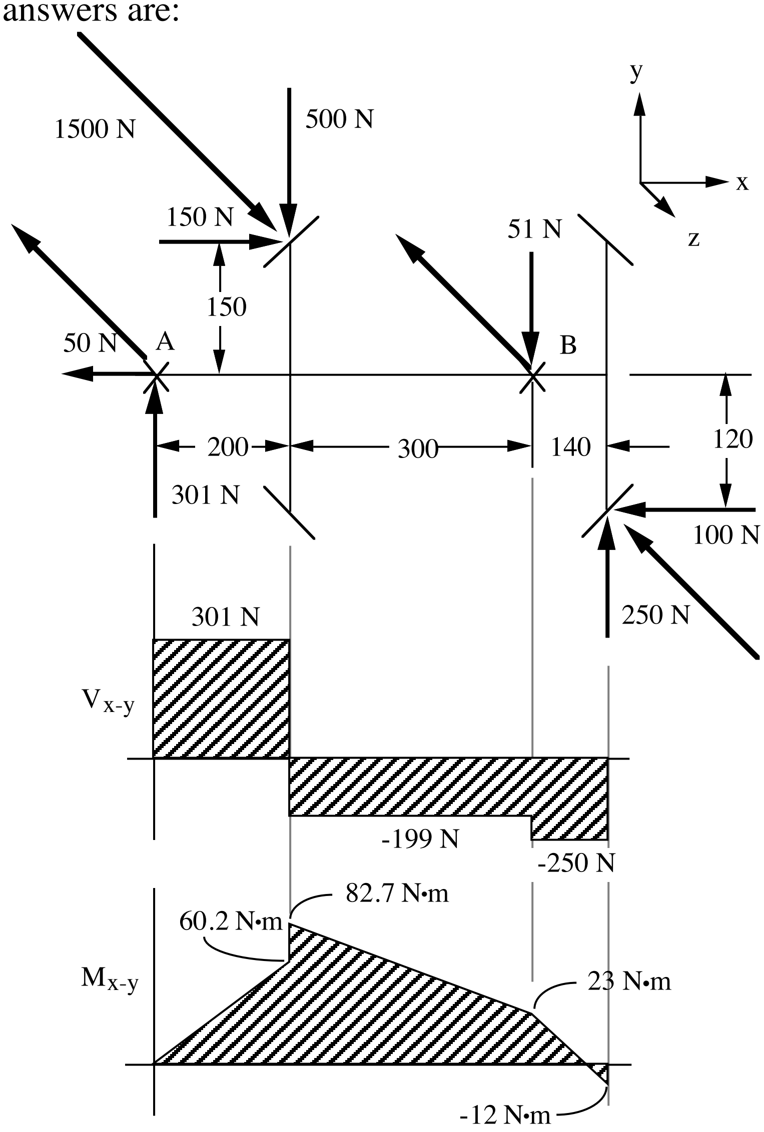
3. $\sum M_{yA} = 0$: $(1500)(200) - (B_Z)(500) - (640)P_t = 0$; $B_Z = -1800$ N

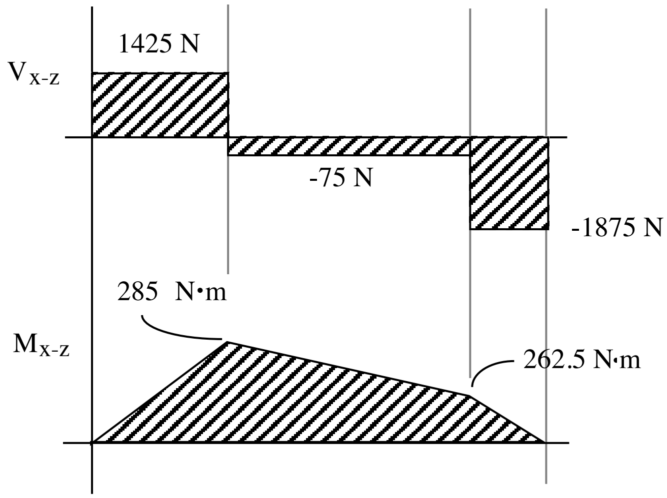
4. $\sum F_z = 0$: $A_z - 1500 - 1800 + 1875 = 0$; $A_z = 1425$ N

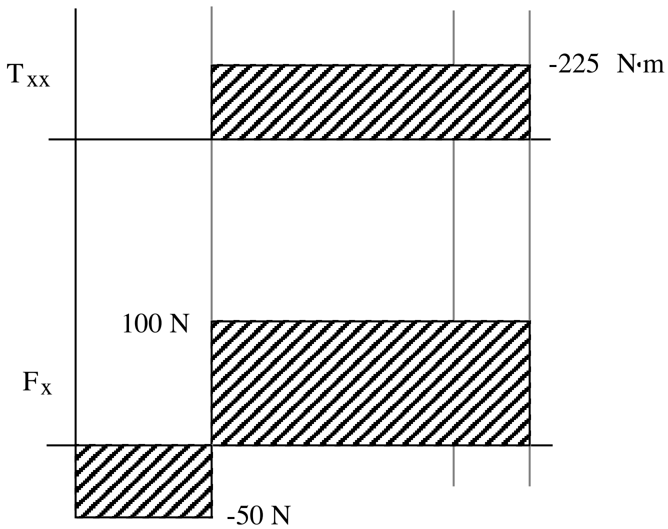
5. $\sum M_{zA} = 0$: $150(150) + 500(200) - B_y(500) - 250(640) + 100(120) = 0$;
   $B_y = -51$ N

6. $\sum F_y = 0$: $A_y - 500 + B_y + 250 = 0$; $A_y = 301$ N

The answers are:





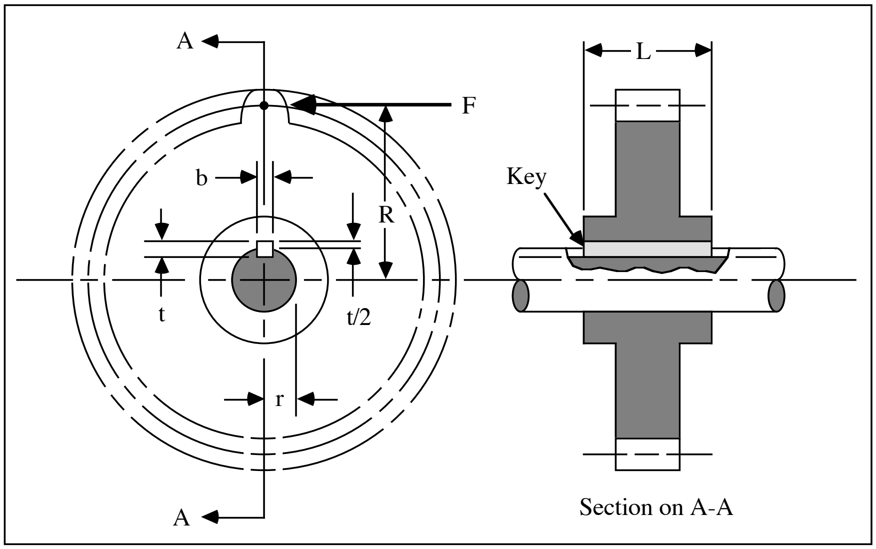


SOLUTION (2.60)

Known: A static force, F, is applied to the tooth of a gear that is keyed to a shaft.

Find: Identify the stresses in the key, and write an equation for each. State the assumptions, and discuss briefly their effects.

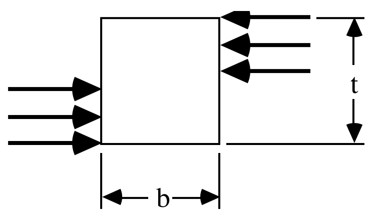
Schematic and Given Data:



Assumption: The compressive forces on each side of the key are uniform.

Analysis:

1. Compression on key sides



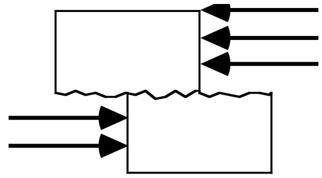
$(\sigma_c \cdot L \cdot \frac{t}{2})r \approx FR$;

Hence, $\sigma_c \approx \frac{2FR}{(L)\ (t)\ \ (r)}$ or more precisely,

$\sigma_c L \bullet \frac{t}{2}\ (r - \frac{t}{4}) = FR$

so, $\sigma_c = \frac{2FR}{Lt\ (r - t/4)}$

2. Key shear



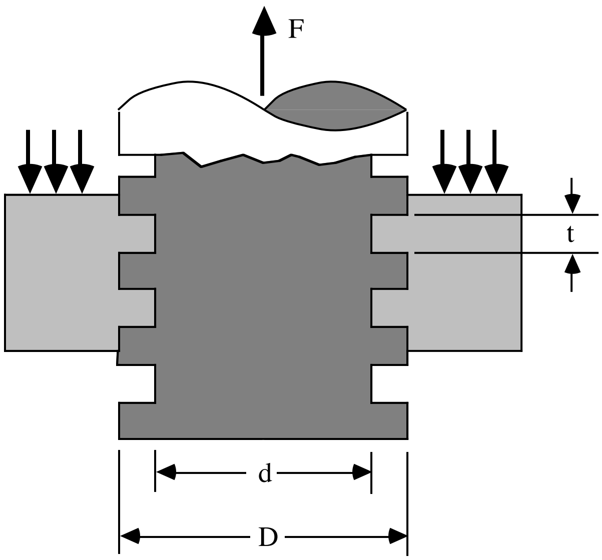
$\tau\ (bL)r = FR$; hence, $\tau = \frac{FR}{bLr}$

Comment: The compressive forces on each side of the key will most probably not be uniform because of key cocking.

SOLUTION(2.61)
Known: A screw with a square thread is transmitting axial force F through a nut with n threads engaged.

Find: Identify the types of stresses in the threaded portion of the screw and write an equation for each. State the assumptions made, and discuss briefly their effect.

Schematic and Given Data:



Assumption: The assumptions will be stated in the analysis section.

Analysis:
1. Compression at interface. Assuming uniform stress distribution, we have

$$\sigma = \frac{F}{\pi(D - d)n}$$ ■

(The bending of the thread would tend to concentrate the stress toward the inside diameter and also produce a tensile stress at the thread root. Geometric inaccuracy may concentrate the load at one portion of a thread.)

2. Shear at the base of threads. Assuming uniform distribution of τ across the cylindrical failure surface, we have

$$\tau = \frac{F}{\pi dnt}$$ ■

(The stress concentration would create a higher stress in the thread root. The effect of thread helix angle is neglected.)
