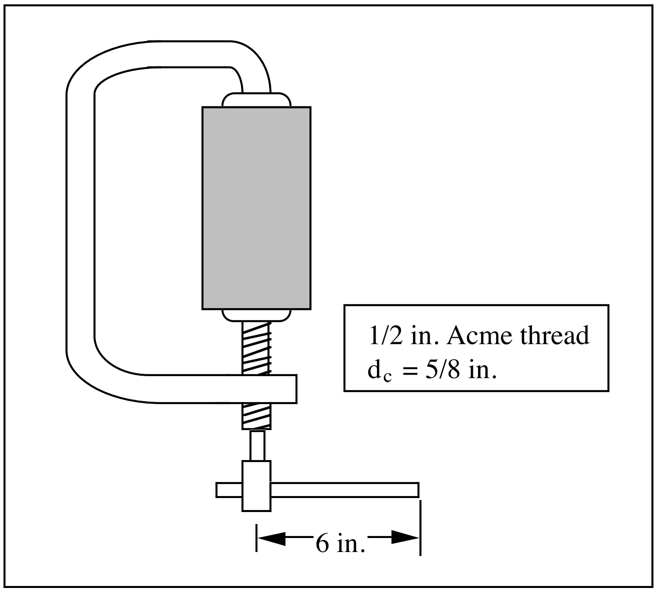
SOLUTION (10.1)

Known: A special C-clamp uses a 0.5-inch diameter Acme thread and a collar of 0.625-inch effective mean diameter.

Find: Estimate the force required at the end of a 5-in. handle to develop a 200 lb clamping force.

Schematic and Given Data:



Assumptions:

1. Coefficients of running friction are estimated as 0.15 for both the collar and the screw.
2. The screw has a single thread.

Analysis:

1. From section 10.3.1, and considering that service conditions may be conducive to relatively high friction, estimate $f = f_c \approx 0.15$ (for running friction).
2. From Table 10.3, p = 0.1 in., and with a single thread, L = 0.1 in.
3. From Fig. 10.4(a),

$$\alpha = 14.5^o \text{ and } d_m = d - \frac{p}{2} = 0.5 - 0.05 = 0.45 \text{ in.}$$

4. From Eq. (10.1),

$$\lambda = \tan^{-1} \frac{L}{\pi d_m} = \tan^{-1} \frac{0.1}{\pi(0.45)} = 4.05^o$$

5. From Eq. (10.6),

$$\alpha_n = \tan^{-1} (\tan \alpha \cos \lambda) = \tan^{-1} (\tan 14.5^o \cos 4.05^o)$$
$$= 14.47^o$$

(Note: with $\lambda \approx 4^o$, it is obvious that $\alpha_n \approx \alpha$ and well within the accuracy of assumed friction coefficients)

6. From Eq. (10.4),

$$T = \frac{Wd_m}{2}\left(\frac{f\,\pi d_m + L\cos\alpha_n}{\pi d_m \cos\alpha_n - f\,L}\right) + \frac{Wf_c\,d_c}{2}$$

$$T = \frac{(150)(0.45)}{2}\left(\frac{(0.15)\pi(0.45) + 0.1(\cos 14.47^\circ)}{\pi(0.45)(\cos 14.47^\circ) - (0.15)(0.1)}\right) + \frac{(150)(0.15)(0.625)}{2}$$

$T = 7.70 + 7.03 = 14.73$ lb in. Use $T \approx 15$ lb in.

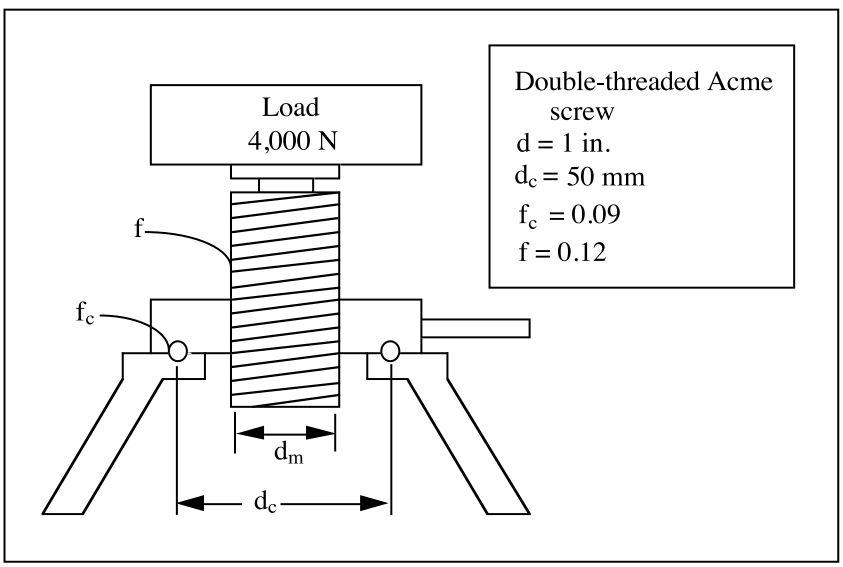
At the end of a 6-in. handle, the clamping force required ≈ 15/6 = 2.5 lb ■

SOLUTION (10.2)

Known: A double-threaded Acme screw of known major diameter is used in a jack having a plain thrust collar of known mean diameter. Coefficients of running friction are estimated as 0.09 for the collar and 0.12 for the screw.

Find:
(a) Determine the pitch, lead, thread depth, mean pitch diameter, and helix angle of the screw.
(b) Estimate the starting torque for raising and for lowering a 4000 N load.
(c) If the screw is lifting a 4000 N load, determine the efficiency of the jack.

Schematic and Given Data:



Assumptions:
1. The starting friction is about 1/3 higher than running friction.
2. The screw is not exposed to vibration.

Analysis:
1. From Table 10.3, there are 5 threads per inch.
   $p = 1/5 = 0.2$ in. $= 0.0051$ m ■
   Because of the double-threaded screw,
   $L = 2p = 0.4$ in. $= 0.0102$ m ■

2. From Fig. 10.4a,

   Threaded depth = 0.5p = 0.10 in. = 0.00254 m ■

   $d_m = d - 0.5p = 0.90$ in. = 0.02286 m ■

3. From Eq. (10.1),

$$\lambda = \tan^{-1}\left(\frac{L}{\pi d_m}\right) = \tan^{-1}\left(\frac{0.4}{0.90\pi}\right) = 8.05^o$$ ■

4. For starting, increase the coefficient of friction by 1/3:

   $f_c = 0.12, f = 0.16$

   From Eq. (10.6),

$$\alpha_n = \tan^{-1}(\tan\alpha\cos\lambda) = \tan^{-1}(\tan 14.5^o \cos 8.05^o)$$
$$= 14.36^o$$

5. From Eq. (10.4),

$$T = \frac{Wd_m}{2}\left(\frac{f\pi d_m + L\cos\alpha_n}{\pi d_m\cos\alpha_n - fL}\right) + \frac{Wf_c d_c}{2}$$

$$= \frac{4000(0.02286)}{2}\left[\frac{0.16\pi(0.02286) + 0.0102\cos 14.36^\circ}{\pi(0.02286)\cos 14.36^\circ - 0.16(0.0102)}\right]$$

$$+ \frac{4000(0.12)(0.05)}{2}$$

   T = 7.175 + 12 = 19.175 N•m. to raise the load ■

6. From Eq. (10.5),

$$T = \frac{Wd_m}{2}\left(\frac{f\pi d_m - L\cos\alpha_n}{\pi d_m\cos\alpha_n + fL}\right) + \frac{Wf_c d_c}{2}$$

$$T = \frac{4000(0.02286)}{2}\left[\frac{0.16\pi(0.02286) - 0.0102\cos 14.36^\circ}{\pi(0.02286)\cos 14.36^\circ + 0.16(0.0102)}\right]$$

$$+ \frac{4000(0.12)(0.05)}{2}$$

   T = -5.819 + 12 = 6.18 N•m. to lower the load ■

7. From Eq. (10.4) with $f_c = 0.09, f = 0.12$

$$T = \frac{4000(0.02286)}{2}\left[\frac{0.12\pi(0.02286) + (0.0102)(\cos 14.36^\circ)}{\pi(0.02286)\cos 14.36^\circ - 0.12(0.0102)}\right] + \frac{4000(0.09)(0.05)}{2}$$

$T = 7.00 + 9 = 16.00$ N•m

8. From Eq. (10.4), the friction free torque for raising the load is

$$T = \frac{4000(0.02286)}{2}\left[\frac{(0.0102)(\cos 14.36^\circ)}{\pi(0.02286)\cos 14.36^\circ}\right] = 6.49 \text{ N•m}$$

9. Efficiency = 6.49/16.00 = 40.6% ■
10. Work input to the screw during one revolution = $2\pi T = 2\pi(16.00) = 100.5$ N•m
11. Work output during one revolution = WL = (4000)(2)(0.0051) = 40.8 N•m
12. Efficiency = Work out/Work in = 40.8/100.5 = 40.6%

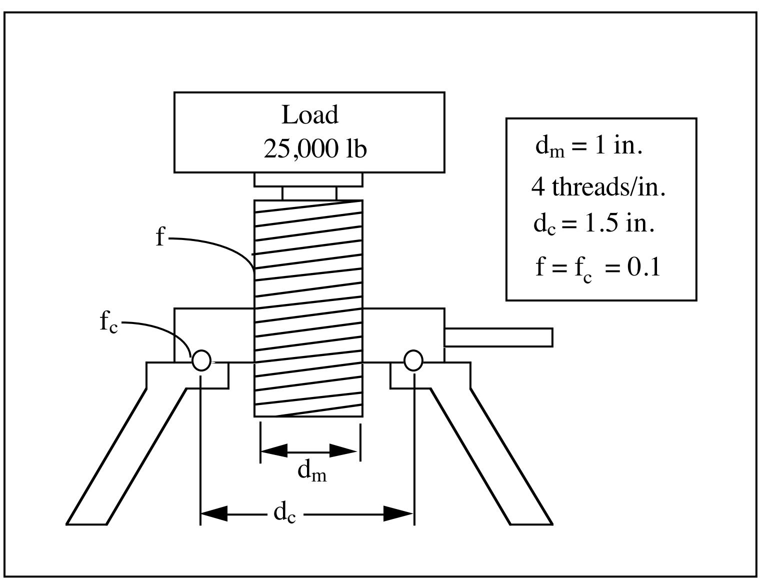
Comments:
1. For a double threaded screw the work output during one revolution is WL where L = 2p.
2. If a small thrust bearing were used so that the collar friction could be neglected, the efficiency would increase to 6.49/7.00 = 92.7%.

SOLUTION (10.3)

Known: A square-threaded, single thread power screw is used to raise a known load. The screw has a mean diameter of 1 in. and four threads per inch. The collar mean diameter is 1.5 in. The coefficient of friction is estimated as 0.1 for both the thread and the collar.

Find:
(a) Determine the major diameter of the screw.
(b) Estimate the screw torque required to raise the load.
(c) If collar friction is eliminated, determine the minimum value of thread coefficient of friction needed to prevent the screw from overhauling.

Schematic and Given Data:



Assumption: The screw is not exposed to vibration.

Analysis:

1. From Fig. 10.4(c),

$$d = d_m + \frac{p}{2} = 1 + \frac{0.25}{2} = 1.125 \text{ in.} \qquad \blacksquare$$

2. From Eq. (10.4a),

$$T = \frac{Wd_m}{2}\left(\frac{f\,\pi d_m + L}{\pi d_m - f\,L}\right) + \frac{Wf_c\, d_c}{2}$$

$$= \frac{(25000)(1)}{2}\left[\frac{(0.1)\pi(1) + 0.25}{\pi(1) - (0.1)(0.25)}\right] + \frac{(25000)(0.1)(1.5)}{2}$$

$$T = 2263 \text{ lb in.} + 1875 \text{ lb in.} = 4138 \text{ lb in.} \qquad \blacksquare$$

3. From Eq. (10.7a), the screw is self-locking if

$$f \geq \frac{L}{\pi d_m} = \frac{0.25}{\pi(1)} = 0.08$$

$$f \geq 0.08 \qquad \blacksquare$$

Therefore, the minimum value of thread coefficient of friction needed to prevent the screw from overhauling is 0.08.

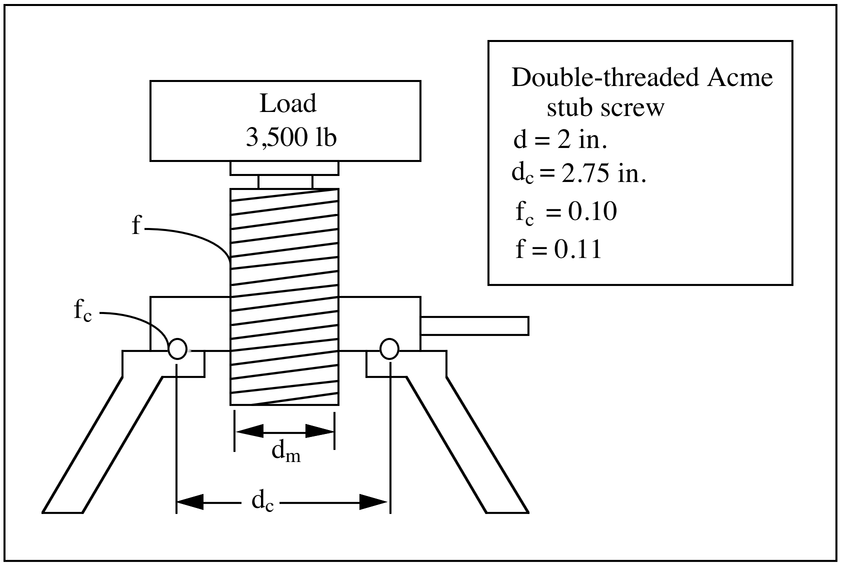
SOLUTION (10.4)

Known: A double-threaded Acme stub screw of known major diameter is used in a jack having a plain thrust collar of known mean diameter. Coefficients of running friction are estimated as 0.10 for the collar and 0.11 for the screw.

Find:

(a) Determine the pitch, lead, thread depth, mean pitch diameter, and helix angle of the screw.
(b) Estimate the starting torque for raising and for lowering a 5000 lb load.
(c) If the screw is lifting a 5000 lb load at the rate of 4 ft/min, determine the screw rpm. Also determine the efficiency of the jack under this steady-state condition.
(d) Determine if the screw will overhaul if a ball thrust bearing (of negligible friction) were used in place of the plain thrust collar.

Schematic and Given Data:



Assumptions:

1. The starting friction is about 1/3 higher than running friction.
2. The screw is not exposed to vibration.

Analysis:

1. From Table 10.3, there are 4 threads per inch.

   $p = 1/4 = 0.25$ in. ■

   Because of the double-threaded screw,

   $L = 2p = 0.50$ in. ■

   From Fig. 10.4 (b),

   Threaded depth = 0.3p = 0.075 in. ■

   $d_m = d - 0.3p = 1.925$ in. ■

   From Eq. (10.1),

$$\lambda = \tan^{-1}\frac{L}{\pi d_m} = \tan^{-1}\left(\frac{0.5}{1.925\pi}\right) = 4.73^\circ$$ ■

2. For starting, increase the coefficients of friction by 1/3:

   $f_c = 0.133, f = 0.147$

   From Eq. (10.6),

$$\alpha_n = \tan^{-1}(\tan\alpha\cos\lambda) = \tan^{-1}(\tan 14.5^\circ \cos 4.73^\circ) = 14.45^\circ$$

   From Eq. (10.4),

$$T = \frac{Wd_m}{2}\left(\frac{f\pi d_m - L\cos\alpha_n}{\pi d_m\cos\alpha_n + fL}\right) + \frac{Wf_c d_c}{2}$$

$$= \frac{3500(1.925)}{2}\left[\frac{0.147\pi(1.925) + 0.5\cos 14.45^\circ}{\pi(1.925)\cos 14.45^\circ - 0.147(0.5)}\right] + \frac{3500(0.133)(2.75)}{2}$$

$T = 799.9 + 640.1 = 1440$ lb in. to raise the load ■

From Eq. (10.5),

$$T = \frac{Wd_m}{2}\left(\frac{f\pi d_m - L\cos\alpha_n}{\pi d_m \cos\alpha_n + fL}\right) + \frac{Wf_c d_c}{2}$$

$$= \frac{3500(1.925)}{2}\left[\frac{0.147\pi(1.925) + 0.5\cos 14.45^\circ}{\pi(1.925)\cos 14.45^\circ - 0.147(0.5)}\right] + \frac{3500(0.133)(2.75)}{2}$$

$T = 230.0 + 640.1 = 870.1$ lb in. to lower the load ■

3. $\dfrac{4(12)\text{ in./min}}{0.5\text{ in./rev}} = 96$ rpm ■

4. From Eq. (10.4), with $f_c = 0.1, f = 0.11$

$$T = \frac{3500(1.925)}{2}\left[\frac{0.11\pi(1.925) + 0.5\cos 14.45^\circ}{\pi(1.925)\cos 14.45^\circ - 0.11(0.5)}\right] + \frac{3500(0.1)(2.75)}{2}$$

$T = 667.1 + 481.3 = 1148.4$ lb in.

5. From Eq. (1.3),

$$\dot{W}_{in} = \frac{Tn}{5252} = \frac{(1148.4/12)96}{5252} = 1.75 \text{ hp}$$

$$\dot{W}_{out} = \frac{(3500)4}{33000} = 0.424 \text{ hp}$$

Therefore, efficiency $= \dfrac{0.424}{1.75} = 0.24 = 24\%$ ■

6. From Eq. (10.7), the screw is self-locking if

$$f \geq \frac{L\cos\alpha_n}{\pi d_m} = \frac{0.5(\cos 14.45^\circ)}{\pi(1.925)} = 0.08$$

Thus, if $f = 0.11$, the screw is self-locking and not overhauling. ■

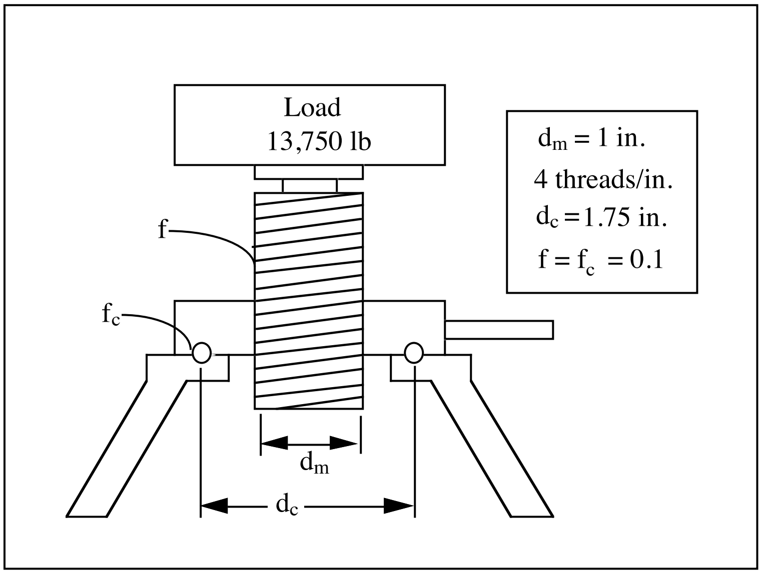
SOLUTION (10.7)

Known: A square-threaded, single thread power screw is used to raise a known load. The screw has a mean diameter of 1 in. and four threads per inch. The collar mean diameter is 1.75 in. The coefficient of friction is estimated as 0.1 for both the thread and the collar.

Find:

(a) Determine the major diameter of the screw.
(b) Estimate the screw torque required to raise the load.
(c) If collar friction is eliminated, determine the minimum value of thread coefficient of friction needed to prevent the screw from overhauling.

Schematic and Given Data:



Assumption: The screw is not exposed to vibration.

Analysis:

1. From Fig. 10.4(c),

$$d = d_m + \frac{p}{2} = 1 + \frac{0.25}{2} = 1.125 \text{ in.}$$ ■

2. From Eq. (10.4a),

$$T = \frac{Wd_m}{2}\left(\frac{f\,\pi d_m + L}{\pi d_m - f\,L}\right) + \frac{Wf_c\,d_c}{2}$$

$$= \frac{(13750)(1)}{2}\left[\frac{(0.1)\pi(1) + 0.25}{\pi(1) - (0.1)(0.25)}\right] + \frac{(13750)(0.1)(1.75)}{2}$$

$$T = 1245 \text{ lb in.} + 1203 \text{ lb in.} = 2448 \text{ lb in.}$$ ■

3. From Eq. (10.7a), the screw is self-locking if

$$f \geq \frac{L}{\pi d_m} = \frac{0.25}{\pi(1)} = 0.08$$

$f \geq 0.08$ ■

Therefore, the minimum value of thread coefficient of friction needed to prevent the screw from overhauling is 0.08.

SOLUTION (10.8)

Known: A double-threaded Acme stub screw of known major diameter is used in a jack having a plain thrust collar of known mean diameter. Coefficients of running friction are estimated as 0.10 for the collar and 0.11 for the screw.

Find:

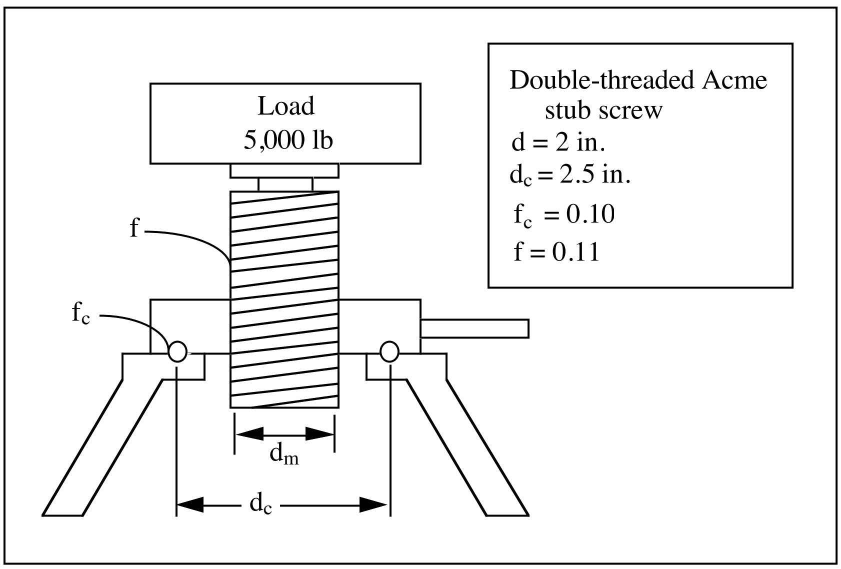
(a) Determine the pitch, lead, thread depth, mean pitch diameter, and helix angle of the screw.

(b) Estimate the starting torque for raising and for lowering a 5000 lb load.

(c) If the screw is lifting a 5000 lb load at the rate of 4 ft/min, determine the screw rpm. Also determine the efficiency of the jack under this steady-state condition.

(d) Determine if the screw will overhaul if a ball thrust bearing (of negligible friction) were used in place of the plain thrust collar.

Schematic and Given Data:



Assumptions:

1. The starting friction is about 1/3 higher than running friction.
2. The screw is not exposed to vibration.

Analysis:

1. From Table 10.3, there are 4 threads per inch.

   p = 1/4 = 0.25 in. ■

   Because of the double-threaded screw,

   L = 2p = 0.50 in. ■

2. From Fig. 10.4 (b),

   Threaded depth = 0.3p = 0.075 in. ■

   $d_m = d - 0.3p = 1.925$ in. ■

3. From Eq. (10.1),

$$\lambda = \tan^{-1} \frac{L}{\pi d_m} = \tan^{-1}\left(\frac{0.5}{1.925\pi}\right) = 4.73^\circ \qquad ■$$

4. For starting, increase the coefficients of friction by 1/3:
   $f_c = 0.133, f = 0.147$

5. From Eq. (10.6),
   $\alpha_n = \tan^{-1} (\tan \alpha \cos \lambda) = \tan^{-1} (\tan 14.5^\circ \cos 4.73^\circ)$
   $= 14.45^\circ$

6. From Eq. (10.4),

$$T = \frac{Wd_m}{2}\left(\frac{f \pi d_m + L\cos \alpha_n}{\pi d_m \cos \alpha_n - f L}\right) + \frac{W f_c d_c}{2}$$

$$= \frac{5000(1.925)}{2}\left[\frac{0.147\pi(1.925) + 0.5\cos 14.45^\circ}{\pi(1.925)\cos 14.45^\circ - 0.147(0.5)}\right] + \frac{5000(0.133)(2.5)}{2}$$

$T = 1142.7 + 831.3 = 1974$ lb in. to raise the load ■

7. From Eq. (10.5),

$$T = \frac{Wd_m}{2}\left(\frac{f \pi d_m - L\cos \alpha_n}{\pi d_m \cos \alpha_n + f L}\right) + \frac{W f_c d_c}{2}$$

$$= \frac{5000(1.925)}{2}\left[\frac{0.147\pi(1.925) - 0.5\cos 14.45^\circ}{\pi(1.925)\cos 14.45^\circ + 0.147(0.5)}\right] + \frac{5000(0.133)(2.5)}{2}$$

$T = 328.5 + 831.3 = 1160$ lb in. to lower the load ■

8. $\dfrac{4(12)\text{ in./min}}{0.5\text{ in./rev}} = 96$ rpm ■

9. From Eq. (10.4), with $f_c = 0.1, f = 0.11$

$$T = \frac{5000(1.925)}{2}\left[\frac{0.11\pi(1.925) + 0.5\cos 14.45^\circ}{\pi(1.925)\cos 14.45^\circ - 0.11(0.5)}\right] + \frac{5000(0.1)(2.5)}{2}$$

$T = 953 + 625 = 1578$ lb in.

10 From Eq. (1.3),

$$\dot{W}_{in} = \frac{Tn}{5252} = \frac{(1578/12)96}{5252} = 2.40 \text{ hp}$$

$$\dot{W}_{out} = \frac{(5000)4}{33000} = 0.606 \text{ hp}$$

11. Therefore, efficiency $= \dfrac{0.606}{2.40} = 0.25 = 25\%$ ■

12. From Eq. (10.7), the screw is self-locking if

$$f \geq \frac{L \cos \alpha_n}{\pi d_m} = \frac{0.5(\cos 14.45°)}{\pi(1.925)} = 0.08$$

Thus, if $f = 0.11$, the screw is self-locking and not overhauling. ■

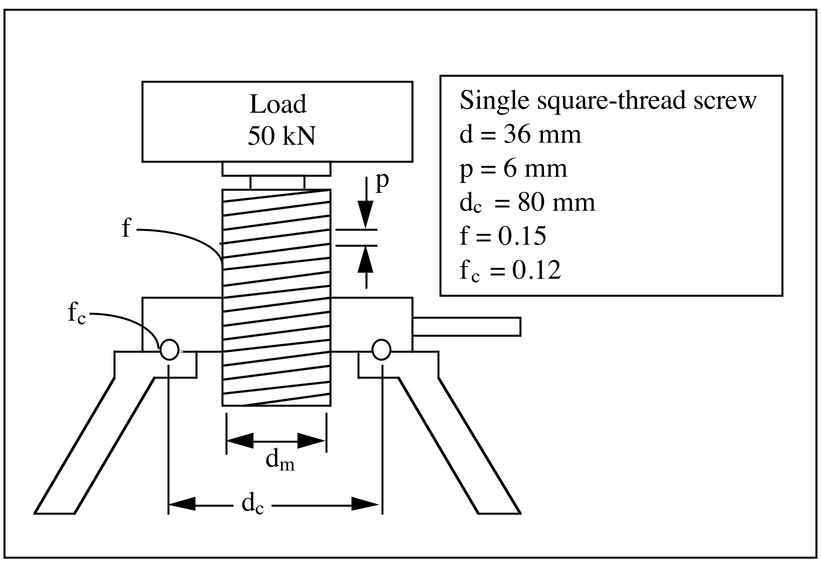
SOLUTION (10.9)

Known: A jack uses a single square-thread screw to raise a known load. The major diameter and pitch of the screw and the thrust collar mean diameter are known. Running friction coefficients are estimated.

Find:

(a) Determine the thread depth and helix angle.
(b) Estimate the starting torque for raising and lowering the load.
(c) Estimate the efficiency of the jack for raising the load.
(d) Estimate the power required to drive the screw at a constant 1 revolution per second.

Schematic and Given Data:



Assumption: The starting friction is about 1/3 higher than running friction.

Analysis:

1. From Fig. 10.4(c),
   Thread depth = p/2 = 6/2 = 3 mm ■

2. From Eq. (10.1),

$$\lambda = \tan^{-1} \frac{L}{\pi d_m} \quad \text{where } d_m = d - \frac{p}{2} = 33 \text{ mm}$$

$$\lambda = \tan^{-1} \frac{6}{\pi(33)} = 3.31^{\circ}$$ ■

3. For starting, increase the coefficients of friction by 1/3, then $f = 0.20, f_c = 0.16$

4. From Eq. (10.4a),

$$T = \frac{Wd_m}{2}\left(\frac{f\pi d_m + L}{\pi d_m - fL}\right) + \frac{Wf_c d_c}{2}$$

$$= \frac{(50{,}000)(0.033)}{2}\left(\frac{0.20\pi(0.033) + 0.006}{\pi(0.033) - (0.20)(0.006)}\right) + \frac{(50{,}000)(0.16)(0.080)}{2}$$

$T = 215 + 320$

$T = 535$ N•m to raise the load ■

5. From Eq. (10.5a),

$$T = \frac{Wd_m}{2}\left(\frac{f\pi d_m - L}{\pi d_m + fL}\right) + \frac{Wf_c d_c}{2}$$

$$= \frac{(50{,}000)(0.033)}{2}\left(\frac{0.20\pi(0.033) - 0.006}{\pi(0.033) + (0.20)(0.006)}\right) + \frac{(50{,}000)(0.16)(0.080)}{2}$$

$T = 116 + 320$

$T = 436$ N•m to lower the load ■

6. From Eq. (10.4a), with $f = 0.15, f_c = 0.12$,

$$T = \frac{(50{,}000)(0.033)}{2}\left(\frac{0.15\pi(0.033) + 0.006}{\pi(0.033) - (0.15)(0.006)}\right) + \frac{(50{,}000)(0.12)(0.080)}{2}$$

$T = 173 + 240 = 413$ N•m

7. Work input to the screw during one revolution $= 2\pi T = 2\pi(413) = 2595$ N•m

8. Work output during one revolution
$= W \bullet p = (50{,}000)(0.006) = 300\ N \bullet m$

9. $\text{Efficiency} = \frac{\text{Work}_{out}}{\text{Work}_{in}} = \frac{300}{2595} = 11.6\%$ ■

10. Check:
Torque during load raising with $f = f_c = 0$

$$T = \frac{(50{,}000)(0.033)}{2}\left(\frac{0 + 0.006}{\pi(0.033) - 0}\right) + 0$$

$T = 47.8\ N \bullet m$

$$\text{Efficiency} = \frac{T_{(\text{with zero friction})}}{T_{(\text{actual})}} = \frac{47.8}{413} = 11.6\%$$ ■

11. Check (partial):
Torque during load raising if collar friction is eliminated = 173 N•m

$$\text{Efficiency (screw only)} = \frac{47.8}{173} = 28\%$$

12. From Eq. (1.2),

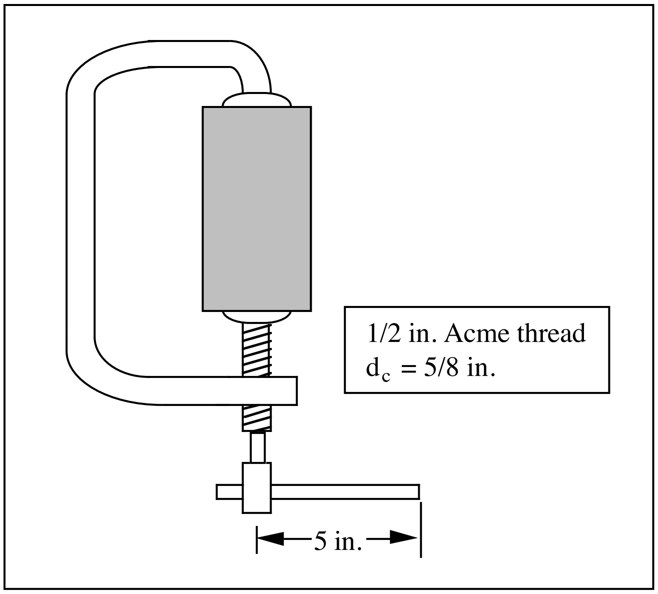
$$\dot{W} = \frac{nT}{9549} = \frac{(60)(413)}{9549} = 2.6\ kW$$ ■

SOLUTION (10.10)

Known: An ordinary C-clamp uses a 1/2 in. Acme thread and a collar of 5/8 in. mean diameter.

Find: Estimate the force required at the end of a 5-in. handle to develop a 200 lb clamping force.

Schematic and Given Data:



Assumptions:

1. Coefficients of running friction are estimated as 0.15 for both the collar and the screw.
2. The screw has a single thread.

Analysis:

1. From section 10.3.1, and considering that service conditions may be conducive to relatively high friction, estimate $f = f_c \approx 0.15$ (for running friction).
2. From Table 10.3, p = 0.1 in., and with a single thread, L = 0.1 in.
3. From Fig. 10.4(a),

$$d_m = d - \frac{p}{2} = 0.5 - 0.05 = 0.45 \text{ in.}$$

$$\alpha = 14.5^{\circ}$$

4. From Eq. (10.1),

$$\lambda = \tan^{-1}\frac{L}{\pi d_m} = \tan^{-1}\frac{0.1}{\pi(0.45)} = 4.05^{\circ}$$

5. From Eq. (10.6),

$$\alpha_n = \tan^{-1}(\tan\alpha\cos\lambda) = \tan^{-1}(\tan 14.5^{\circ}\cos 4.05^{\circ})$$
$$= 14.47^{\circ}$$

(Note: with $\lambda \approx 4^{\circ}$, it is obvious that $\alpha_n \approx \alpha$ and well within the accuracy of assumed friction coefficients)

6. From Eq. (10.4),

$$T = \frac{Wd_m}{2}\left(\frac{f\,\pi d_m + L\cos\alpha_n}{\pi d_m \cos\alpha_n - f\,L}\right) + \frac{Wf_c\,d_c}{2}$$

$$= \frac{(200)(0.45)}{2}\left(\frac{(0.15)\pi(0.45) + 0.1(\cos 14.47^\circ)}{\pi(0.45)(\cos 14.47^\circ) - (0.15)(0.1)}\right) + \frac{(200)(0.15)(0.625)}{2}$$

$T = 10.27 + 9.37 = 19.64$ lb in. Use $T \approx 20$ lb in.

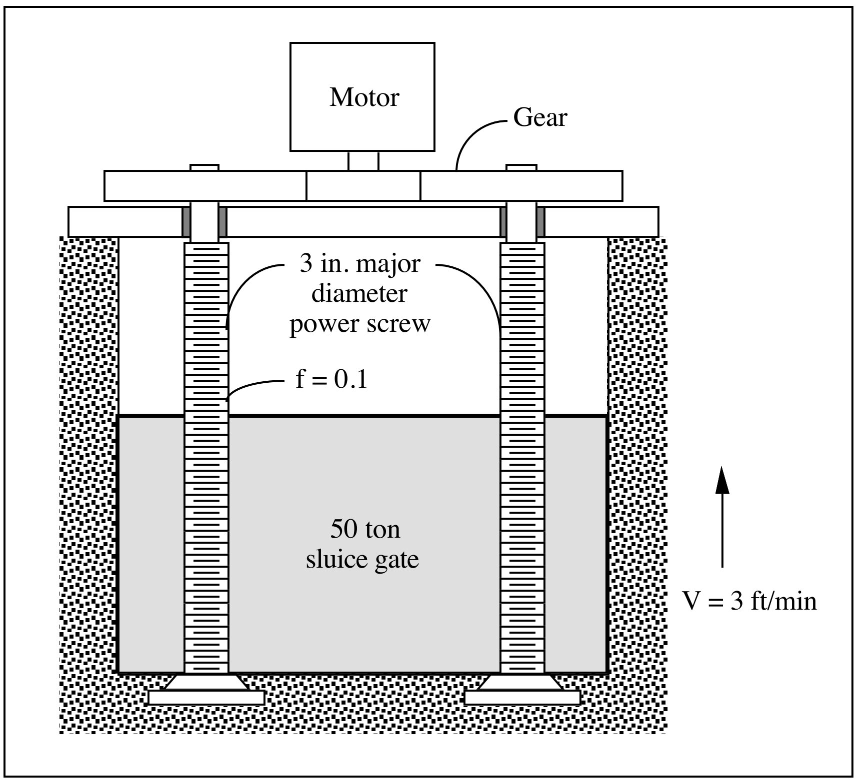
At the end of a 5-in. handle, the clamping force required $\approx \frac{20}{5} = 4$ lb ■

SOLUTION (10.11)

Known: Two identical 3 in. major diameter screws (single threaded) with modified square threads are used to raise and lower a 50-ton sluice gate of a dam. An estimated friction coefficient is only 0.1 for the screw. Because of gate friction, each screw must provide a lifting force of 26 tons.

Find: Determine the power required to drive each screw when the gate is being raised at the rate of 3 ft/min. Also calculate the corresponding rotating speed of the screws.

Schematic and Given Data:



Assumption: Collar friction can be neglected.

Analysis:

1. From Table 10.3,

   $p = L = 1/(1.75) = 0.571$ in.

2. From Fig. 10.4(d),

$$d_m = d - \frac{p}{2} = 3 - \frac{0.571}{2} = 2.71 \text{ in.}$$

   and $\alpha = 2.5^o$

3. Since $\cos \alpha = 0.999$, use Eq. (10.4a):

$$T = \frac{Wd_m}{2}\left(\frac{f\,\pi d_m + L}{\pi d_m - f\,L}\right) + \frac{Wf_c\,d_c}{2}$$

$$= \frac{(52{,}000)(2.71)}{2}\left(\frac{(0.1)\pi(2.71) + 0.571}{\pi(2.71) - (0.1)(0.571)}\right) + 0$$

   $T = 11{,}851$ lb in. $= 988$ lb ft (during load raising)

4. To raise the gate 36 in./min with $L = 0.571$ in.
   requires $36/0.571 = 63.05 \approx 63$ rpm ■

5. From Fig. (1.3),

$$\dot{W} = \frac{(63.05)(988)}{5252} = 11.9 \text{ hp say } 12 \text{ hp}$$

   Therefore, 12 hp are required to drive each screw. ■

6. Check:

   Work output per gate = 52,000 lb (3 ft/min)
   = 156,000 lb ft/min = 4.73 hp

$$\lambda = \tan^{-1}\frac{L}{\pi d_m} = \tan^{-1}\frac{0.571}{\pi(2.71)} = 3.84^o$$

   From Fig. 10.8, Efficiency ≈ 40 %

   Thus, $\dot{W}_{required} \approx \frac{4.73}{0.4} = 11.83$ hp ■

SOLUTION (10.23)

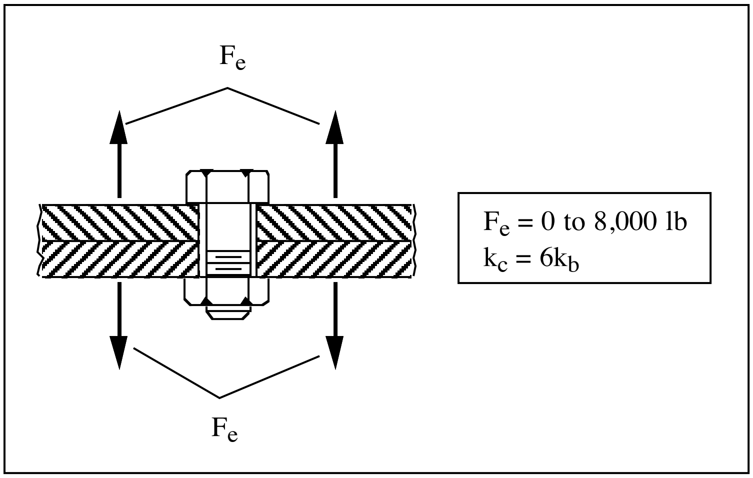
Known: The bolt shown is made from cold drawn steel. The load fluctuates continuously between 0 and 8000 lb.

Find:

(a) The minimum required value of initial load to prevent loss of compression of the plates.

(b) The minimum force in the plates for the fluctuating load when the preload is 8500 lb.

Schematic and Given Data:



Assumption: The bolt, nut, and plate materials do not yield.

Analysis:

1. Compression of the plates is lost when $F_c = 0$ when maximum load is applied. From Eq. (10.13)

$$F_i = F_c + \left(\frac{k_c}{k_b + k_c}\right) F_e$$

$$= 0 + \left(\frac{6k_b}{k_b + 6k_b}\right) 8{,}000 = \frac{6}{7}(8{,}000) = 6{,}857 \text{ lb} \quad \blacksquare$$

2. Minimum force in plates occurs when fluctuating load is maximum. From Eq. (10.13),

$$F_c = F_i - \left(\frac{k_c}{k_b + k_c}\right) F_e$$

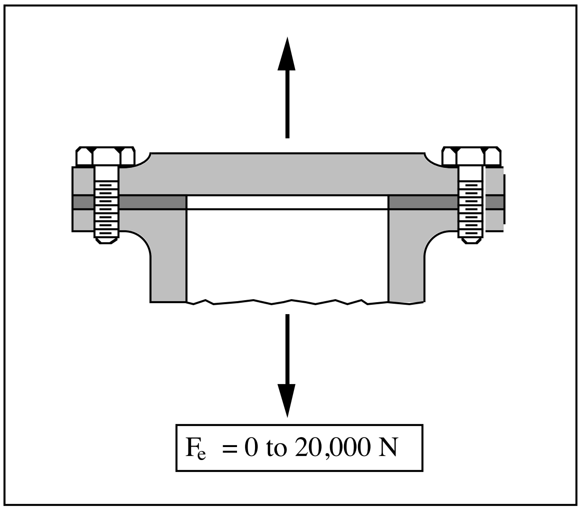
$$= 8{,}500 - \left(\frac{6k_b}{k_b + 6k_b}\right) 8{,}000 = 8{,}500 - \frac{6}{7}(8{,}000) = 1{,}643 \text{ lb} \quad \blacksquare$$

SOLUTION (10.25)

Known: The cylinder head of a piston-type air compressor is held in place by ten bolts. Total joint stiffness is four times total bolt stiffness. Each bolt is tightened to an initial tension of 5000 N. The total external force acting to separate the joint fluctuates between 0 and 20,000 N.

Find: Draw a graph (plotting force vs. time) showing three or four external load fluctuations, and corresponding curves showing the fluctuations in total bolt load and total joint clamping force.

Schematic and Given Data:



Assumption: The bolt size and material are such that the bolt load remains within the elastic range.

Analysis:

1. The total bolt load when an external load is applied is, from Eq. (10.13),

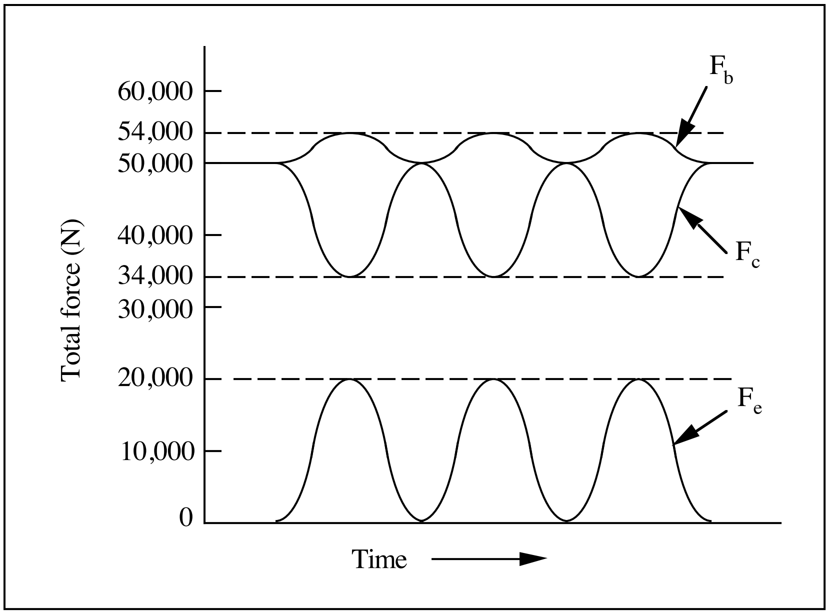
$$F_b = F_i + \left(\frac{k_b}{k_b + k_c}\right) F_e = [(5000)(10)] + \frac{1}{1+4}(20{,}000)$$

$$= 54{,}000 \text{ N}$$

$$F_c = F_i - \left(\frac{k_c}{k_c + k_b}\right) F_e = 50{,}000 - \frac{4}{5}(20{,}000)$$

$$= 34{,}000 \text{ N}$$

2.

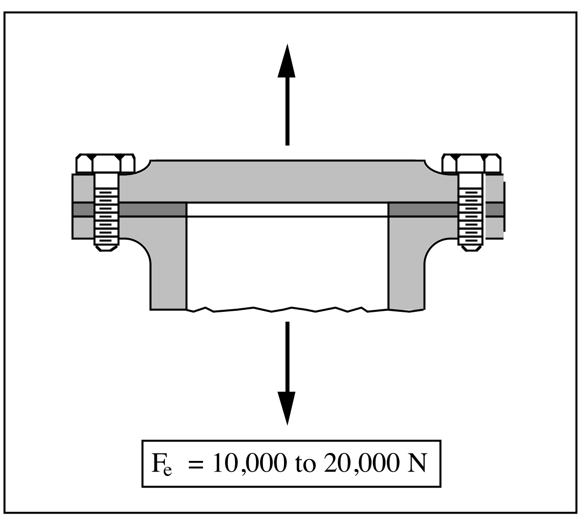


SOLUTION (10.26)

Known: The cylinder head of a piston-type air compressor is held in place by ten bolts. Total joint stiffness is four times total bolt stiffness. Each bolt is tightened to an initial tension of 5000 N. The total external force acting to separate the joint fluctuates between 10,000 and 20,000 N.

Find: Draw a graph (plotting force vs. time) showing three or four external load fluctuations, and draw corresponding curves showing the fluctuations in total bolt load and total joint clamping force.

Schematic and Given Data:



Assumption: The bolt size and material are such that the bolt load remains within the elastic range.

Analysis:

1. Using Eq. (10.13) for F_e = 20,000 N,

$$F_b = F_i + \left(\frac{k_b}{k_b + k_c}\right) F_e = [(5000)(10)] + \frac{1}{1+4}(20{,}000)$$
$$= 54{,}000 \text{ N}$$

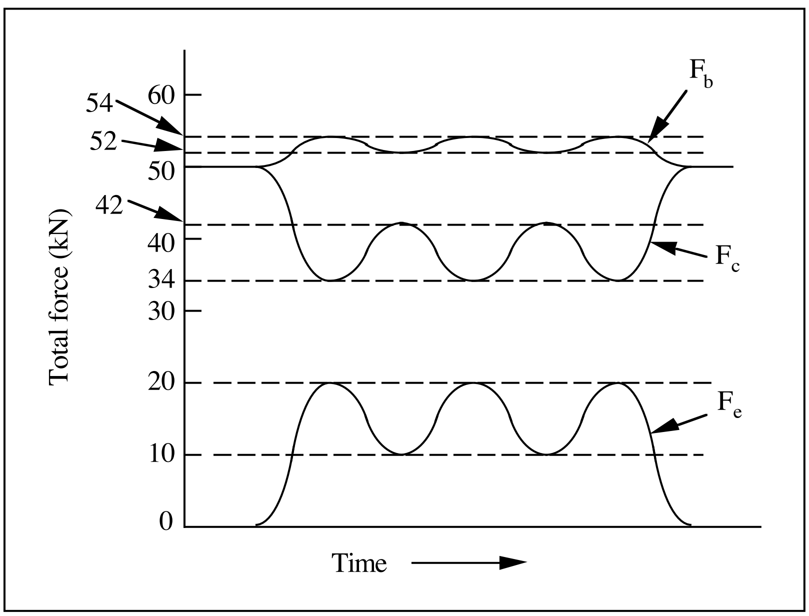
$$F_c = F_i - \left(\frac{k_c}{k_c + k_b}\right) F_e = 50{,}000 - \frac{4}{5}(20{,}000)$$
$$= 34{,}000 \text{ N}$$

2. For F_e = 10,000 N,

$$F_b = 50{,}000 + \frac{1}{1+4}(10{,}000) = 52{,}000 \text{ N}$$

$$F_c = 50{,}000 - \frac{4}{5}(10{,}000) = 42{,}000 \text{ N}$$

3.



SOLUTION (10.27)

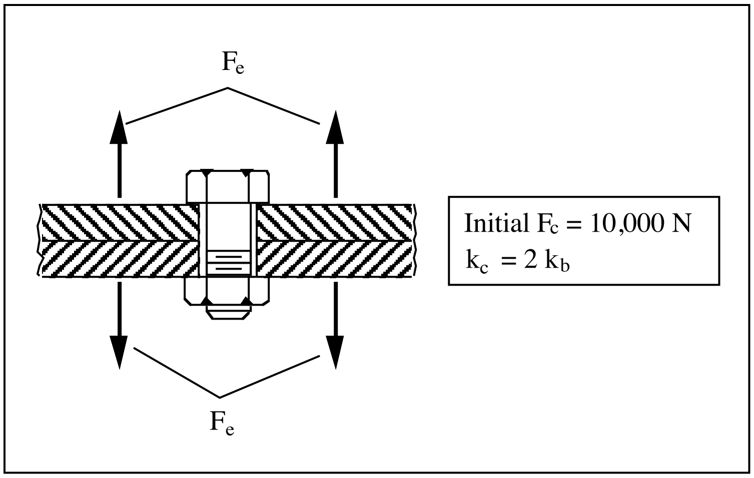
Known: Two parts of a machine are held together by bolts that are initially tightened to provide a total initial clamping force of 10,000 N. The elasticities are such that $k_c = 2k_b$.

Find:

(a) Determine the external separating force that would cause the clamping force to be reduced to 1000 N.

(b) If this separating force is repeatedly applied and removed, determine values of mean and alternating force acting on the bolts.

Schematic and Given Data:



Assumption: The stress on the bolt is within the elastic limit.

Analysis:
(a) From Eq. (10.13),

$$F_c = F_i - \left(\frac{k_c}{k_c + k_b}\right) F_e :$$

$$1000 = 10{,}000 - \left(\frac{2}{2+1}\right) F_e : \quad 9000 = \frac{2}{3} F_e$$

Hence, F_e = 13,500 N ■

(b) Load off; $F_b = F_i = 10{,}000$ N

Load on; $F_b = 10{,}000 + \frac{1}{3}(13{,}500) = 14{,}500$ N

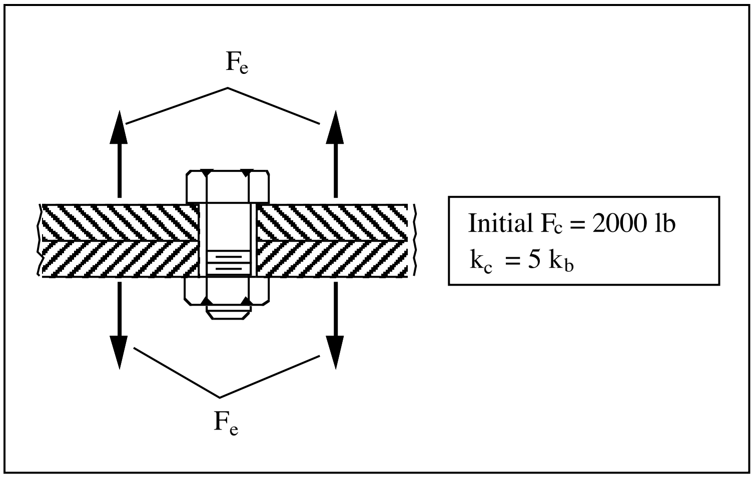
$$F_m = \frac{10{,}000 + 14{,}500}{2} = 12{,}250 \text{ N}$$ ■

$$F_a = \frac{14{,}500 - 10{,}000}{2} = 2250 \text{ N}$$ ■

SOLUTION (10.28)
Known: Two parts of a machine are held together by bolts that are initially tightened to provide a total initial clamping force of 2000 lb. The elasticities are such that $k_c = 5k_b$.

Find:
(a) Determine the external separating force that would cause the clamping force to be reduced to 500 lb.
(b) If this separating force is repeatedly applied and removed, determine values of mean and alternating force acting on the bolts.

Schematic and Given Data:



Assumption: The stress on the bolt is within the elastic limit.

Analysis:

(a) From Eq. (10.13),

$$F_c = F_i - \left(\frac{k_c}{k_c + k_b}\right) F_e :$$

$$500 = 2000 - \left(\frac{5}{5+1}\right) F_e \quad \text{(or)} \quad 1500 = \frac{5}{6} F_e$$

Hence, F_e = 1800 lb ■

(b) Load off; $F_b = F_i$ = 2000 lb

Load on; $F_b = 2000 + \frac{1}{6}(1800) = 2300$ lb

$$F_m = \frac{2000 + 2300}{2} = 2150 \text{ lb}$$ ■

$$F_a = \frac{2300 - 2000}{2} = 150 \text{ lb}$$ ■

SOLUTION (10.29)

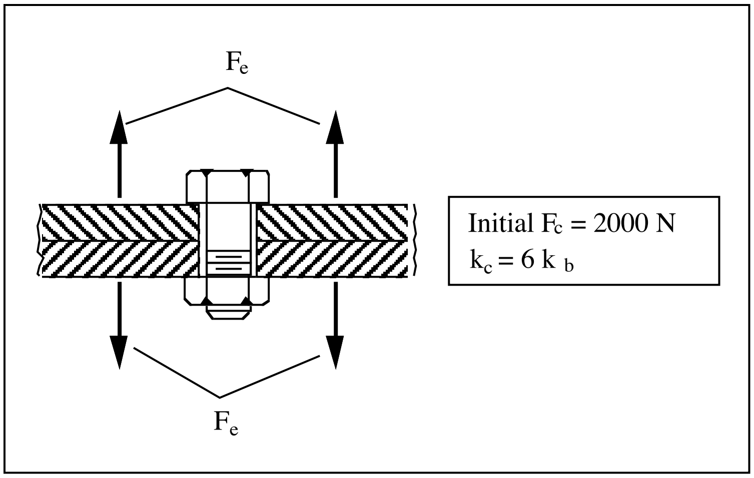
Known: Two parts of a machine are held together by bolts that are initially tightened to provide a total initial clamping force of 2000 lb. The elasticities are such that $k_c = 6k_b$.

Find:

(a) Determine the external separating force that would cause the clamping force to be reduced to 500 lb.

(b) If this separating force is repeatedly applied and removed, determine values of mean and alternating force acting on the bolts.

Schematic and Given Data:



Assumption: The bolt stress is less than the elastic limit of the bolt material.

Analysis:

(a) From Eq. (10.13),

$$F_c = F_i - \left(\frac{k_c}{k_c + k_b}\right) F_e :$$

$$500 = 2000 - \left(\frac{6}{6+1}\right) F_e \quad \text{(or)} \quad 1500 = \frac{6}{7} F_e$$

Hence, $F_e = 1750$ lb ■

(b) Load off; $F_b = F_i = 2000$ lb

Load on; $F_b = 2000 + \frac{1}{7}(1750) = 2250$ lb

$$F_m = \frac{2000 + 2250}{2} = 2125 \text{ lb}$$ ■

$$F_a = \frac{2250 - 2000}{2} = 125 \text{ lb}$$ ■

SOLUTION (10.30)

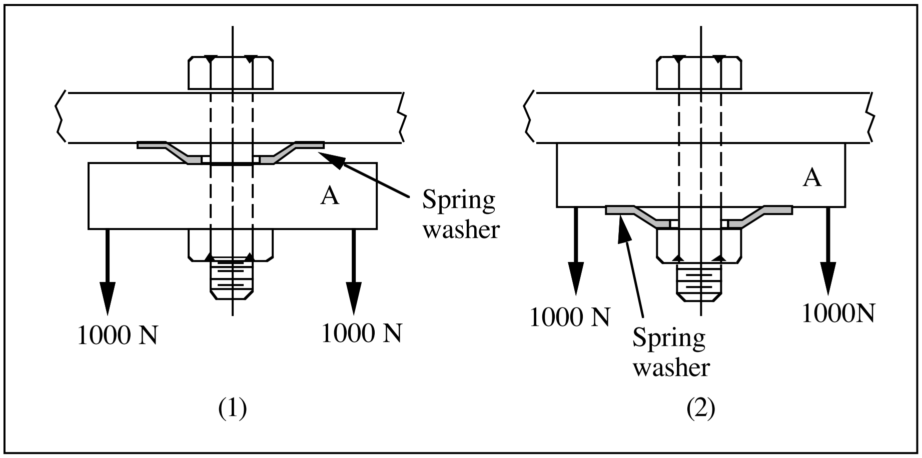
Known: Drawing 1 and 2 are identical except for placement of the spring washer. The bolt and the clamped members are "infinitely" rigid in comparison with the spring washer. In each case the bolt is initially tightened to a force of 10,000 N before two known external loads are applied.

Find:

(a) For both arrangements, draw block A as a free-body in equilibrium.

(b) For both arrangements, draw a bolt force-vs-time plot for the case involving repeated application and removal of the external loads.

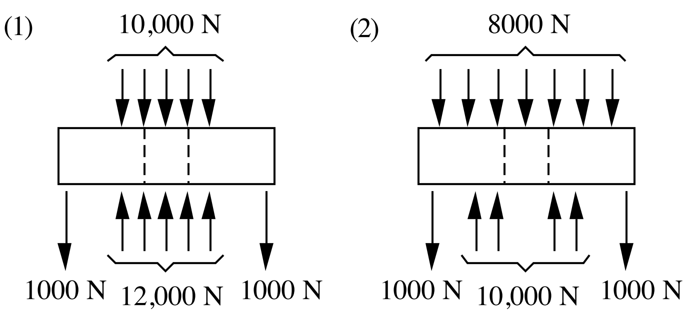
Schematic and Given Data:



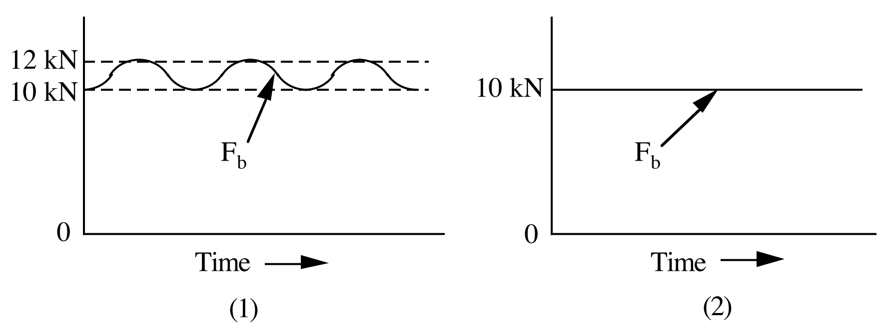
Assumption: The bolt stress is within the elastic limit of the bolt material.

Analysis:

(a)



(b)



Comment: Note that in neither case does the 10 kN force of the flexible spring washer change.

SOLUTION (10.33)

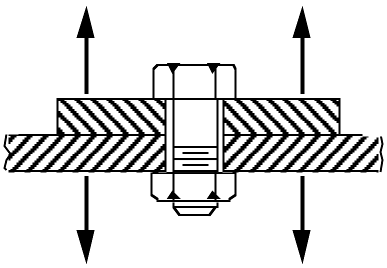
Known: Two parts of a machine, each carrying a static load, are held together by bolts. The factor of safety and the ratios of yield strength and proof strength of the nuts to the yield strength and proof strength of the bolts are known.

Find:

(a) Determine the size of class 5.8 coarse-thread metric bolts required.

(b) Determine the least number of threads that must be engaged for the thread shear strength to be equal to the bolt tensile strength.

Schematic and Given Data:



Assumptions:

1. For steel, $S_{ys} \approx 0.58 S_y$.
2. The loads are equally distributed among the threads.
3. $(S_y)_{nut} = 0.7(S_y)_{bolt}$

Analysis:

(a) From Table 10.5, $S_p = 380$ MPa

$$A_t = \frac{(\text{Force})(\text{SF})}{S_p} = \frac{3100(4)\text{ N}}{380\text{ MPa}} = 32.6\text{ mm}^2$$

From Table 10.2, select M8 × 1.25 with $A_t = 36.6\text{ mm}^2$ ■

(b) Bolt tensile strength $\approx A_t S_y = 36.6\text{ mm}^2 \bullet S_y$

Nut shear strength $\approx \pi d(0.75t)S_{ys}$

$= \pi(8\text{ mm})(0.75t)(0.58)(0.7S_y)$

where S_y pertains to the bolt material.

Equating the strengths gives $t = 4.78$ mm

For pitch = 1.25 mm, this corresponds to 3.83 ≈ 3.9 threads ■

SOLUTION (10.38)

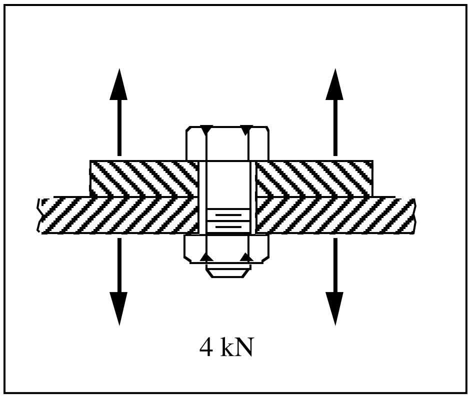
Known: The bolts that attach a bracket to an industrial machine must each carry a static tensile load of 4 kN. The safety factor is 5. The nuts are made of steel with 2/3 the yield strength and proof strength of the bolt steel.

Find:

(a) Determine the size of class 5.8 coarse-thread metric bolts required.

(b) Determine the least number of threads that must be engaged for the thread shear strength to be equal to the bolt tensile strength.

Schematic and Given Data:



Assumptions:

1. For steel, $S_{ys} \approx 0.58S_y$.
2. The loads are equally distributed among the threads.
3. $(S_y)_{nut} = 2/3\ (S_y)_{bolt}$

Analysis:

(a) From Table 10.5, $S_p = 380$ MPa

$$A_t = \frac{(\text{Force})(\text{SF})}{S_p} = \frac{4{,}000(5)\ \text{N}}{380\ \text{MPa}} = 52.6\ \text{mm}^2$$

From Table 10.2, select M10 $\times$ 1.5 ■

(b) Bolt tensile strength $\approx A_t\,(S_y)_{bolt} = 58\ \text{mm}^2 \bullet (S_y)_{bolt}$

Nut shear strength $\approx \pi d(0.75t)S_{ys}$

$= \pi(10\ \text{mm})(0.75t)(0.58)(2/3)(S_y)_{bolt}$

where S_{ys} pertains to the nut material and $(S_y)_{bolt}$ to the bolt material.

Equating the strengths gives t = 6.37 mm

For pitch = 1.50 mm, this corresponds to 4.25 ≈ 4.3 thread ■

SOLUTION (10.39)

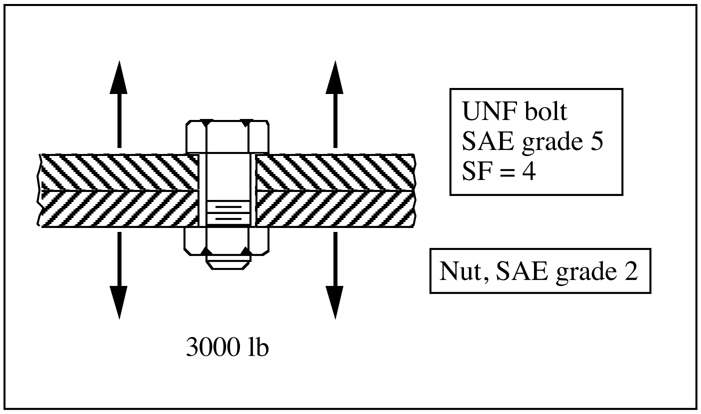
Known: A UNF bolt, made from SAE grade 5 steel, carries a static tensile load of 3000 lb. The bolt is used with a nut made of steel corresponding to SAE grade 2 specifications. The safety factor is 4 based on the proof strength.

Find:

(a) Determine the size of the UNF bolt.

(b) Determine the least number of threads that must be engaged for the thread shear yield strength to be equal to the bolt tensile yield strength.

Schematic and Given Data:



Assumptions:

1. For steel, $S_{ys} \approx 0.58S_y$.
2. The loads are equally distributed among the threads.

Analysis:

(a) For the 3,000 lb load, it is obvious that $d_{required} < 1$ in.
Hence, from Table 10.4, select $S_p = 85$ ksi

$$A_{t\ required} = \frac{(3{,}000)(4)}{85{,}000} = 0.14 \text{ in.}^2$$

From Table 10.1, select 1/2 in.-20 thread, with $A_t = 0.1599$ in.^{2} ■

(b) Tensile strength $\approx A_t S_y = (0.1599 \text{ in.}^2)(92{,}000 \text{ psi}) = 14{,}710$ lb
Nut shear strength $\approx \pi d(0.75t)S_{ys} = \pi(0.5)(0.75t)(0.58)(57{,}000)$
Equating the strengths gives $t = 0.38$ in.
For pitch = 1/20 in., this corresponds to 7.55, say 7.6 threads. ■

SOLUTION (10.40)

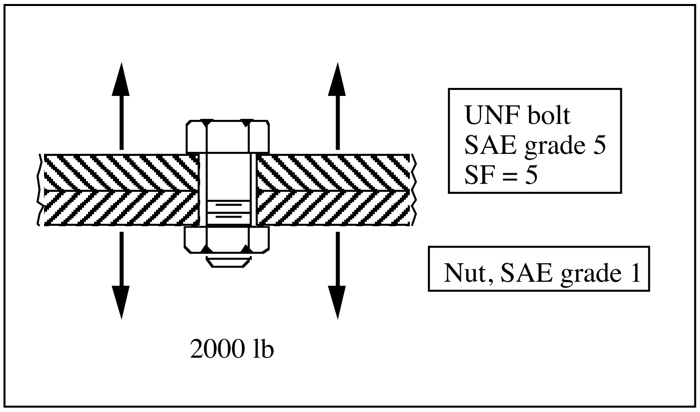
Known: A UNF bolt, made from SAE grade 5 steel, carries a static tensile load of 2000 lb. The bolt is used with a nut made of steel corresponding to SAE grade 1 specifications. The safety factor is 5 based on the proof strength.

Find:

(a) Determine the size of the UNF bolt.

(b) Determine the least number of threads that must be engaged for the thread shear strength to be equal to the bolt tensile strength.

Schematic and Given Data:



Assumptions:

1. For steel, $S_{ys} \approx 0.58S_y$.
2. The loads are equally distributed among the threads.

Analysis:

(a) For the 2000 lb load, it is obvious that $d_{required} < 1$ in.
Hence, from Table 10.4, select $S_p = 85$ ksi

$$A_{t\ required} = \frac{(2000)(5)}{85{,}000} = 0.118 \text{ in.}^2$$

From Table 10.1, select 0.500 in.-20 thread, with $A_t = 0.1599$ in.^{2} ■

(b) Tensile strength $\approx A_t S_y = (0.1599 \text{ in.}^2)(92{,}000 \text{ psi}) = 14711$ lb
Nut shear strength $\approx \pi d(0.75t)S_{ys} = \pi(0.500)(0.75t)(0.58)(36{,}000)$
where S_y is obtained from Table 10.4.
Equating the strengths gives t = 0.598 in.
For pitch = 1/20 in., this corresponds to 11.96, say 12 threads. ■

SOLUTION (10.41)

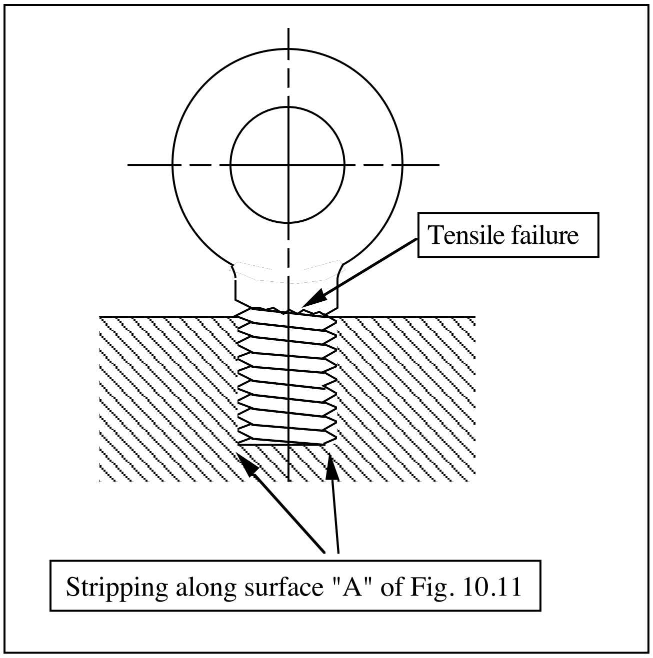
Known: A gear reducer of known weight is lifted using a steel eyebolt of SAE grade 5. The housing into which the bolt is threaded has only half the yield strength of the bolt steel.

Find:

(a) Select a suitable bolt size for a safety factor of 10.

(b) Determine the minimum number of threads that should be engaged.

Schematic and Given Data:



Assumption: The loads are equally distributed among the threads.

Analysis:

(a) From Table 10.4, S_p = 85 ksi

$$A_t = \frac{W(SF)}{S_p} = \frac{2000 \text{ lb } (10)}{85{,}000 \text{ psi}} = 0.235 \text{ in}^2$$

From Table 10.1, sizes $\frac{5}{8}$ in.-18 UNF or $\frac{3}{4}$ in.-10 UNC would be appropriate.

Arbitrarily choosing $\frac{3}{4}$ in.-10 UNC, a SF of $10\left(\frac{0.334}{0.235}\right) = 14$ is provided. ■

(b) For balanced tensile and "stripping" strength, Eq. (d) in Sec. 10.4.5 gives

$t = 0.47d = 0.47(0.75 \text{ in.}) = 0.353$ in.

But if threaded member strength is only half that of the bolt, use t = 0.706 in. With threads per in. = 10

Number of threads = (0.706)(10) = 7.06 threads engaged ■

SOLUTION (10.42)

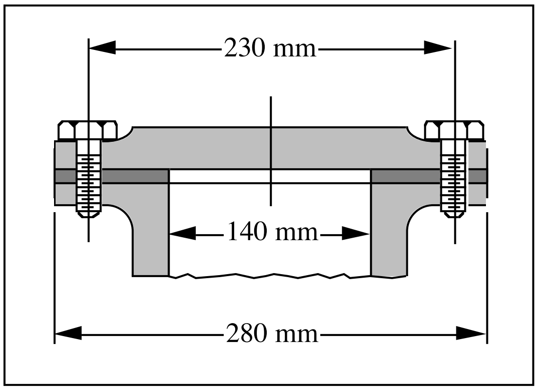
Known: The internal pressure of a pressure vessel with a gasketed end plate is sufficiently uniform that the bolt loading can be considered static. A gasket clamping pressure of at least 13 MPa is needed.

Find:

(a) For 12-, 16-, and 20-mm bolts with coarse threads and made of SAE class 8.8 or 9.8 steel, determine the number of bolts needed.

(b) If the ratio of bolt circle circumference to number of bolts should not exceed 10, nor be less than 5, state which of the bolt sizes considered gives a satisfactory bolt spacing.

Schematic and Given Data:



Assumption: When calculating gasket area, the bolt hole area is negligible.

Analysis:

(a) Clamping force required $= \frac{\pi}{4}\left(D_o^2 - D_i^2\right)$ (pressure)

$$= \frac{\pi}{4}\left(280^2 - 140^2\right) 13 = 600{,}358 \text{ N}$$

Bolt dia.	A_t (Tab. 10.2)	S_p (Tab. 10.5)	Clamping force/ bolt @ 90 % proof load $A_t(0.9S_p)$	600 kN force/bolt	Number of bolts required
12 mm	84.3 mm^2	650 MPa	49.3 kN	12.17	13
16	157	650	91.8	6.54	7
20	245	600	132.3	4.54	5

(b) For 12 mm bolts:

spacing = 230π/13 = 55.58 mm = 4.63d

For 16 mm bolts:

spacing = 230π/7 = 103.2 mm = 6.45d

For 20 mm bolts:

spacing = 230π/5 = 144.5 mm = 7.23d

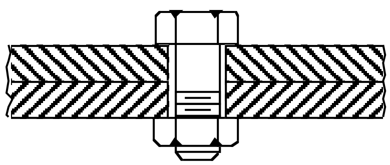
The 16 and 20 mm bolts satisfy the given guidelines.
The 12 mm bolts are a little too close together. ■

SOLUTION (10.47)

Known: A grade 7, 3/4-in., UNF bolt with rolled threads is used in a joint such that the clamped member stiffness is only half the bolt stiffness. The bolt initial tension corresponds to Eq. (e) in Section 10.7. During operation, there is an external separating force that fluctuates between 0 and P. The bending of the bolts is negligible.

Find:
(a) Estimate the maximum value of P that would not cause eventual bolt failure.
(b) Estimate the maximum value of P that would not cause joint separation.

Schematic and Given Data:



Assumption: The material has an idealized stress-strain curve, with the change from elastic to plastic occurring at the yield strength.

Analysis:

(a)

1. From Eq. (e),

$$F_i = 16{,}000d = 16{,}000\left(\frac{3}{4}\right) = 12{,}000 \text{ lb}$$

2. Using Eq. (10.13),

$$\text{Maximum Force/bolt} = F_i + \left(\frac{k_b}{k_b + k_c}\right)P$$

$$= 12{,}000 + \left(\frac{2}{1+2}\right)P = 12{,}000 + 2/3\,P \text{ lb}$$

Minimum Force/bolt = F_i = 12,000 lb

Thus, F_m = 12,000 + 1/3 P lb and F_a = 1/3 P lb

3. From Table 10.1, $A_t = 0.373$ in.^{2}
From Table 10.6, $K_f = 3$
From Table 10.4, $S_u = 133$ ksi, $S_y = 115$ ksi

4. $$\sigma_a = \frac{P}{A}K_f = \frac{1}{3}\,\frac{P}{0.373}(3) = \frac{P}{0.373}$$

5. $S_n = S_n' C_L C_G C_s C_T C_R$ [Eq. (8.1)]
$S_n' = 0.5 S_u$ (Fig. 8.5)
$C_L = C_T = C_R = 1$ (Table 8.1)
$C_G = 0.9$ (Table 8.1)

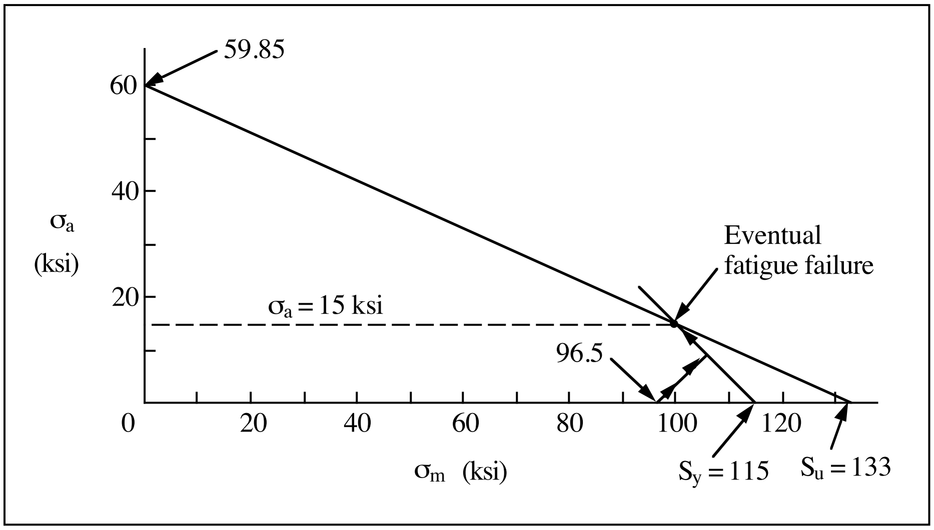
$C_s = 1$ (Table 10.6)

$S_n = 0.5(133)(1)(0.9)(1)(1)(1) = 59.85$ ksi

6. For $F_i = 12{,}000$ lb,

$$\sigma_i = \frac{12{,}000}{0.373}(3) = 96.5 \text{ ksi}$$

7.



8. $\sigma_a = \dfrac{P}{0.373} = 15{,}000$

Thus, P = 5595 ≈ 5600 lb for eventual fatigue failure ■

(b) ---

9. From Eq. (10.13),

$$F_c = 12{,}000 - \left(\frac{1}{1+2}\right)P$$

At separation, $F_c = 0$

$$0 = 12{,}000 - \frac{1}{3}P$$

Thus, P = 36,000 lb for separation ■

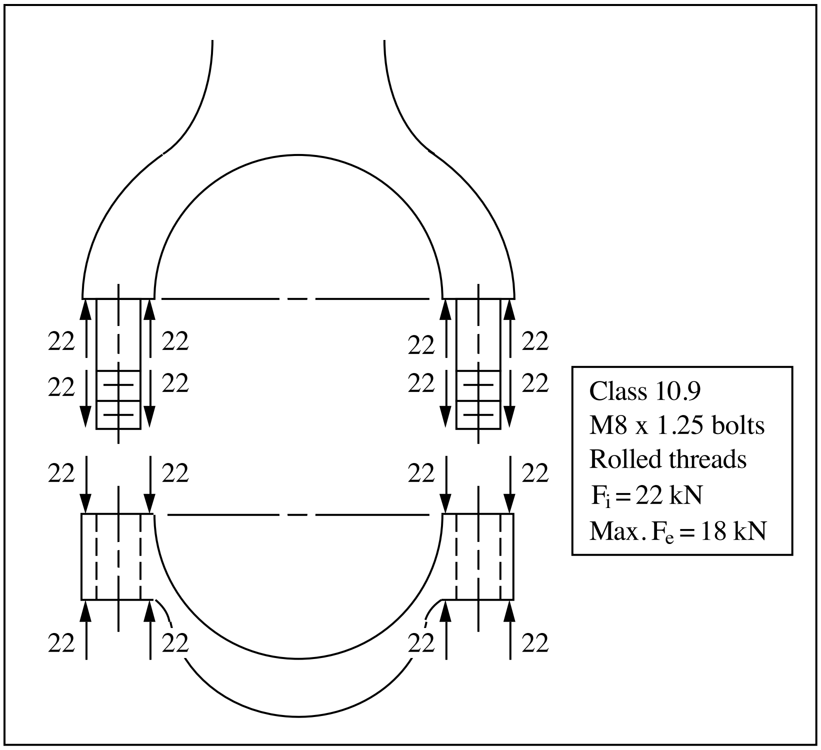
Comment: The value of P for separation would be somewhat less because of yielding in the thread root region, which reduces the value of k_b.

SOLUTION (10.48)

Known: The cap of an automotive connecting rod is secured by two class 10.9, M8×1.25 bolts with rolled threads. The grip and unthreaded length can both be taken as 16 mm. The connecting rod cap (the clamped member) has an effective cross-section area of 250 mm^2 per bolt. The initial tension and the maximum external load are known.

Find:
(a) Estimate the bolt tightening torque required.
(b) Determine the maximum total load per bolt during operation.
(c) Construct free-body diagrams when the maximum load of 18 kN is pushing downward on the center of the cap.
(d) Determine the safety factor for fatigue.

Schematic and Given Data:



Assumption: The material follows an idealized stress-strain-curve based on S_y.

Analysis:
(a) From Eq. (10.12), $T = 0.2F_i\,d$

$$T = 0.2(22{,}000)(0.008) = 35.2\ \text{N•m}$$ ■

(b) $A_b = \frac{\pi}{4}(8)^2 = 50.27\ \text{mm}^2$

(Note: use full 8 mm diameter to find k_b)

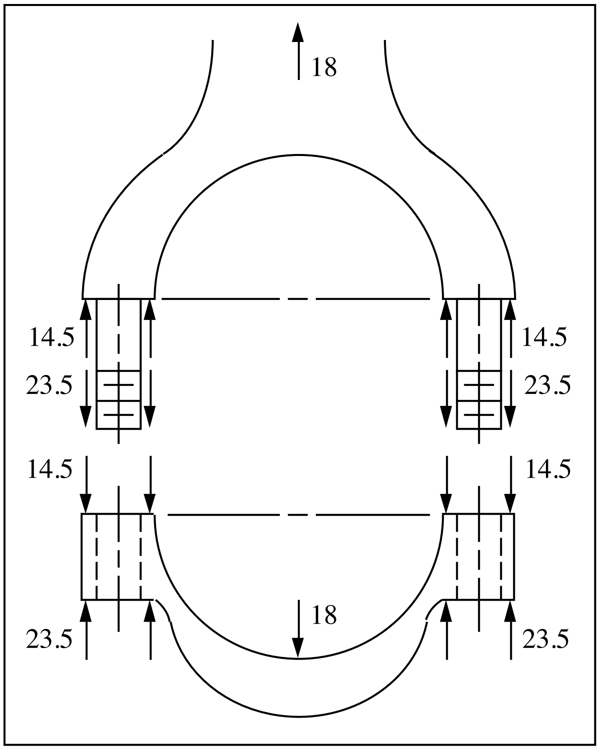
Since $E_b = E_c$ and $L_b = L_c$, then k's are directly proportional to A's

$$\text{Thus, } \frac{k_b}{k_b + k_c} = \frac{A_b}{A_b + A_c} = \frac{50.27}{50.27 + 250} = 0.167$$

From Eq. (10.13),

$$F_{b\,(max)} = 22\ \text{kN} + 0.167(9\ \text{kN}) = 23.5\ \text{kN}$$ ■

(c)



(d)1. From Table 10.5, $S_u = 1040$ MPa, $S_y = 940$ MPa
From Table 10.6, $K_f = 3$

(d)2. $S_n = S_n' C_L C_G C_s C_T C_R$ [Eq. (8.1)]
$S_n' = 0.5 S_u$ (Fig. 8.5)
$C_L = C_T = C_R = 1$ (Table 8.1)
$C_G = 0.7$ (Table 8.1)
$C_s = 1$ (Table 10.6)
$S_n = 0.5(1040)(1)(0.7)(1)(1)(1) = 364$ MPa

(d)3. $$F_m = \frac{22 + 23.5}{2} = 22.75 \text{ kN}$$

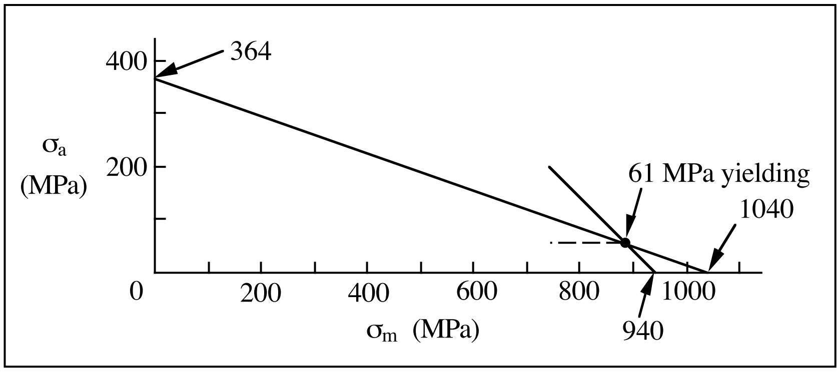
$$F_a = \frac{23.5 - 22}{2} = 0.75 \text{ kN}$$

(d)4. $$\sigma_m = \left(\frac{F_m}{A_t}\right) K_f = \left(\frac{22.75}{36.79}\right) 3 = 1.86 \text{ GPa}$$

(obviously relieved by yielding)

$$\sigma_a = \left(\frac{F_a}{A_t}\right) K_f = \left(\frac{0.75}{36.79}\right) 3 = 0.061 \text{ GPa} = 61 \text{ MPa}$$

(d)5.



(d)6. The drawing shows that σ_a = 60 MPa is as high as σ_a can be without eventual fatigue failure.
Hence, SF ≈ 1.0 ■

SOLUTION (10.49)

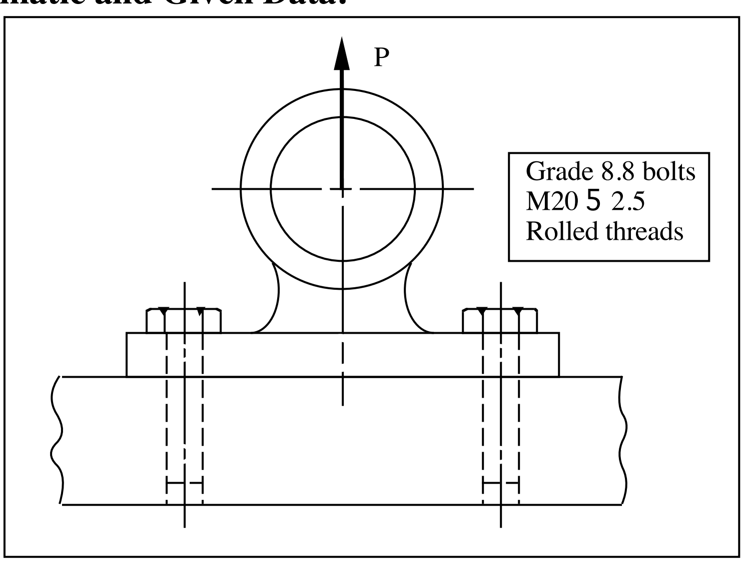
Known: Two grade 8.8 bolts with M20 × 2.5 rolled threads are used to attach a pillow block. The bolts are initially tightened in accordance with Eq. (10.11a). Joint stiffness is estimated to be three times bolt stiffness. The external load tending to separate the pillow block from its support varies rapidly between 0 and P.

Find:

(a) Estimate the maximum value of P that would not cause eventual fatigue failure of the bolts.

(b) Show on a mean stress-alternating stress diagram points representing thread-root stresses: (1) just after initial tightening, (2) during operation with the load fluctuating between 0 and P/2, and (3) with the machine shut down after operating with the 0 to P/2 load.

Schematic and Given Data:



Assumptions:
1. Bolt bending is negligible.
2. The material behaves as predicted by an idealized stress-strain curve based on S_y.
3. The safety factor is 2.

Analysis:
1. From Eq. (10.11a), $F_i = 0.9A_tS_p$

   where $A_t = 245\ mm^2$ (Table 10.2)

   $S_p = 600$ MPa (Table 10.5)

   $F_i = 0.9(245)(600) = 132.3$ kN
2. Since $K_f = 3.0$ (Table 10.6),

$$\sigma_i = \left(\frac{F_i}{A_t}\right)K_f = \left(\frac{132{,}300}{245}\right)(3) = 1620 \text{ MPa}$$

   Therefore, the bolt will yield.
3. Alternating bolt force,

$$F_a = \frac{1}{2}\left(\frac{k_b}{k_b + k_c}\right)\left(\frac{P}{2}\right) = \frac{1}{2}\left(\frac{1}{1+3}\right)\frac{P}{2} = \frac{P}{16}$$

   Alternating bolt stress,

$$\sigma_a = \left(\frac{F_a}{A_t}\right)K_f = \frac{P}{16(245)}(3)$$

4. $S_n = S_n'C_LC_GC_sC_TC_R$ [Eq. (8.1)]

   $S_n' = 0.5S_u$

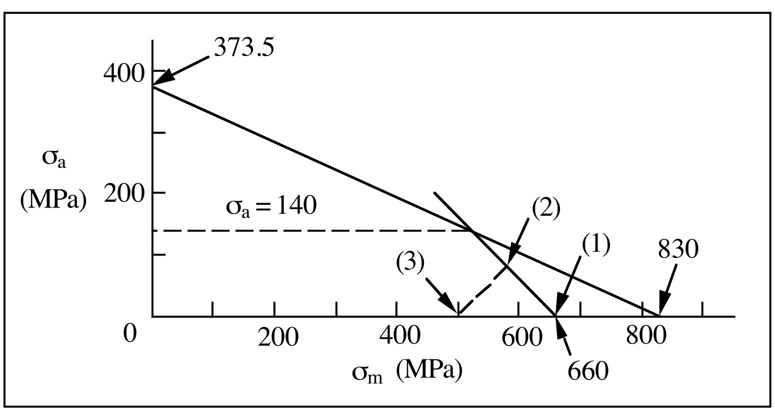
   $S_u = 830$ MPaR (Table 10.5)

   $C_L = C_T = C_R = 1$ (Table 8.1)

   $C_G = 0.9$ (Table 8.1)

   $C_s = 1$ (Table 10.6)

   $S_n = 0.5(830)(1)(0.9)(1)(1)(1) = 373.5$ MPa
5.



6. From the drawing, $\sigma_a = 140$ MPa

$$140 = \frac{P}{16(245)}(3)$$

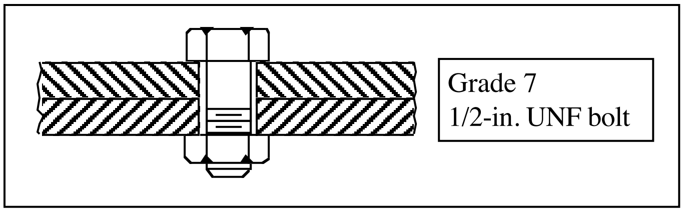
   Thus, P = 183 kN ■
7. The points (1), (2), and (3) are shown in the above figure. ■

SOLUTION (10.50)

Known: Two aluminum plates are held together by a grade 7, 1/2 in. UNF bolt. The effective area of the aluminum plates in compression is estimated to be 12 times the cross-sectional area of the steel bolt. The bolt is initially tightened to 90% of its proof strength. Gust loads, varying from zero to P, tend to pull the plates apart. The safety factor is 1.3.

Find:
(a) Determine the maximum value of P that will not cause eventual bolt fatigue failure.
(b) Determine the clamping force that will remain when this value of P acts.

Schematic and Given Data:



Assumptions:
1. Bolt bending is negligible.
2. Threads are rolled.

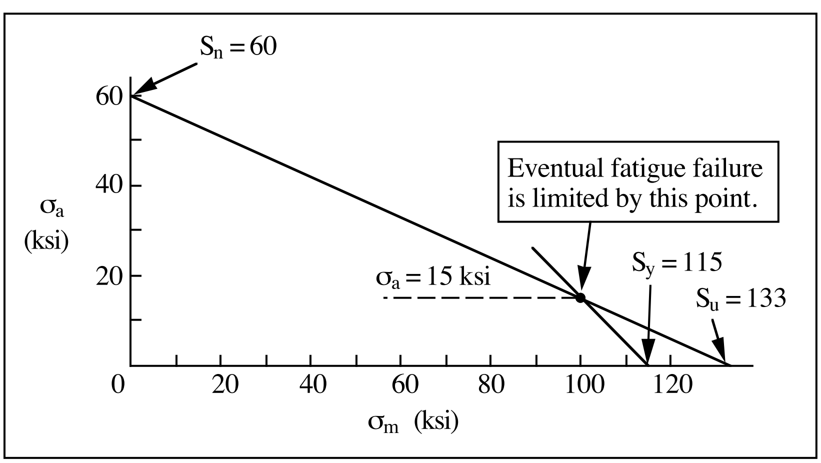
Analysis:
1. From Eq. (10.11a), $F_i = 0.9 A_t S_p$

   $A_t = 0.1599 \text{ in.}^2$ (Table 10.1)
   $S_p = 105$ ksi (Table 10.4)
   $F_i = 0.9(0.1599)(105{,}000) = 15{,}100$ lb

   With this initial tightening load, the threads roots are yielded.
2. $S_n = S_n' C_L C_G C_s C_T C_R$ [Eq. (8.1)]

   $S_n' = 0.5 S_u$
   $S_u = 133$ ksi (Table 10.4)
   $C_L = C_T = C_R = 1$ (Table 8.1)
   $C_G = 0.9$ (Table 8.1)
   $C_s = 1$ (Table 10.6)

   $S_n = 0.5(133)(1)(0.9)(1)(1)(1) = 60$ ksi
3.



4. With rolled threads as assumed, from Table 10.6

$K_f = 3.0$

5. $\sigma_a = \frac{F_a}{A_t} K_f$ (or) $15{,}000 = \frac{F_a}{0.1599}(3)$ (and) $F_a = 800$ lb

6. $\frac{k_b}{k_c} = \left(\frac{E_b}{E_c}\right)\left(\frac{A_b}{A_c}\right) = (3)\left(\frac{1}{12}\right) = 1/4$

Hence, $\frac{k_b}{k_b + k_c} = \frac{(1/4)}{(1/4) + 1} = 0.2$

Thus, $F_a = 0.1P$

7. $800 = 0.1P$

Hence, P = 8000 lb, but with SF = 1.3,

P = 8000/1.3 = 6150 lb ■

8. If the bolt did not yield at all when initially tightened, the clamping force remaining would be

$F_i - 0.8P = 15{,}100 - 4900 = 10{,}200$ lb

If the bolt were fully yielded when initially tightened, the clamping force remaining would be

$F_i - P = 15{,}100 - 6150 = 8950$ lb

The answer is between these values

8950 lb < F_c < 10,200 lb ■

SOLUTION (10.51)

Known: Solutions to problems (a) 10.46, (b) 10.47, (c) 10.48, (d) 10.49, and (e) 10.50 are given as the information in Section 10.12 and Table 10.7.

Find: Comment on the probable accuracy of the fatigue results. If previous designs had been made based on these earlier results, state whether or not it is important to specify that the bolt threads be rolled after heat treatment?

Analysis:

Base problem	S_u	Thread root σ_a	Nominal σ_a^*	Table 10.7 alt. strength	
				roll before	roll after
(a) 10.46	120 ksi	18 ksi	6 ksi	10 ksi	21 ksi
(b) 10.47	133 ksi	15 ksi	5 ksi	10 ksi	21 ksi
(c) 10.48	1040 MPa	61 MPa	20.3 MPa	69 MPa	145 MPa
(d) 10.49	830 MPa	140 MPa	46.7 MPa	69 MPa	145 MPa
(e) 10.50	133 ksi	15 ksi	5 ksi	10 ksi	21 ksi

* "dividing out" $K_f = 3$, in each case

Comment: In each case, the earlier results appear satisfactory with threads rolled before (as well as after) heat-treatment.

SOLUTION (10.52)

Known: A critical application requires the smallest possible bolt for resisting a dynamic separating force varying from 0 to 100 kN. It is estimated that by using an extra high strength bolt steel with S_p = 1200 MPa, and using special equipment to control initial tightening to the full A_tS_p, a stiffness ratio of k_c/k_b = 6 can be realized. Any of the bolt threads and finishes listed in Table 10.7 may be selected. The safety factor is 1.3.

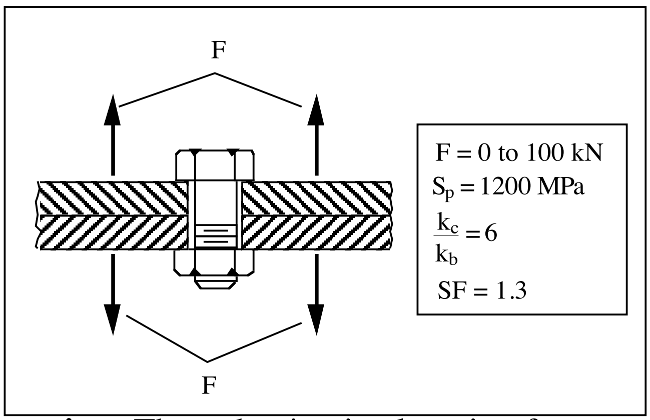
Find:

(a) With respect to eventual fatigue failure, determine the smallest size metric bolt that can be used.

(b) State the thread and finish selected.

(c) With this bolt tightened as specified, determine the clamping force that will remain (at least initially) when the 100-kN load is applied.

Schematic and Given Data:



Assumption: The reduction in clamping force approaches the full-applied load of 100 kN.

Analysis:

1. Alternating component of separating force = 50 kN.

Since, $\dfrac{k_b}{k_b + k_c} = \dfrac{1}{1+6} = \dfrac{1}{7}$,

$$F_a \text{ (felt by bolt)} = \frac{50}{7} = 7.14 \text{ kN}$$

2. From Table 10.7, find S_a = 179 MPa, with SF = 1.3.
The nominal value of σ_a can be 173/1.3 = 138 MPa

$$\sigma_{a,nom} = \frac{F_a}{A_t},$$

$$138 \text{ MPa} = \frac{7140 \text{ N}}{A_t}.$$

Hence, $A_t = 51.7 \text{ mm}^2$

3. Tentatively choose M10×1.5 thread, with $A_t = 58.0\ mm^2$. But this is unsatisfactory since because of separation when the bolt is tightened to full proof load, k_b becomes small. We have conservatively assumed that the reduction in clamping force approaches the full-applied load of 100 kN. This exceeds the initial clamping force of

$$A_t S_p = (58.0\ mm^2)(1200\ MPa) = 69{,}600\ N.$$

To provide SF = 1.3 against separation (and assuming $k_b \approx 0$), the required F_i is equal to (1.3)(100 kN).

$$130{,}000\ N = S_p \cdot A_t = 1200\ MPa \cdot A_t$$

$$A_t = 108\ mm^2$$

We select an M14×2 thread.

This gives $F_i = (1200\ MPa)(115\ mm^2) = 138{,}000\ N$. ■

Even with $k_b = 0$, this is a minimum clamping force of

$$138\ kN - 100\ kN = 38\ kN = F_{c,min}$$ ■
