**MECH 325**

**Homework Assignment #1**

**Due Oct. 8**

**Problem 1**

**13–24** A gearbox is to be designed with a compound reverted gear train that transmits 25 horsepower with an input speed of 2500 rev/min. The output should deliver the power at a rotational speed in the range of 280 to 300 rev/min. Spur gears with 20° pressure angle are to be used. Determine suitable numbers of teeth for each gear, to minimize the gearbox size while providing an output speed within the specified range. Be sure to avoid an interference problem in the teeth.

**13–42** Continue Problem 13–24 by finding the following information, assuming a diametral pitch of 6 teeth/in.

(*a*) Determine pitch diameters for each of the gears.

(*b*) Determine the pitch line velocities (in ft/min) for each set of gears.

(*c*) Determine the magnitudes of the tangential, radial, and total forces transmitted between each set of gears.

(*d*) Determine the input torque.

(*e*) Determine the output torque, neglecting frictional losses.

**13-24** $H$ = 25 hp, $\omega_i$ = 2500 rev/min

Let $\omega_o$ = 300 rev/min for minimal gear ratio to minimize gear size.

$$\frac{\omega_o}{\omega_i} = \frac{300}{2500} = \frac{1}{8.333} = \frac{N_2}{N_3}\frac{N_4}{N_5}$$

Let $$\frac{N_2}{N_3} = \frac{N_4}{N_5} = \sqrt{\frac{1}{8.333}} = \frac{1}{2.887}$$

From Eq. (13-11) with $k$ = 1, $\phi$ = 20°, and $m$ = 2.887, the minimum number of teeth on the pinions to avoid interference is 15.

Let $N_2 = N_4 = 15$ teeth

$N_3 = N_5 = 2.887(15) = 43.31$ teeth

Try $N_3 = N_5 = 43$ teeth.

$$\omega_o = \left(\frac{15}{43}\right)\left(\frac{15}{43}\right)(2500) = 304.2$$

Too big. Try $N_3 = N_5 = 44$.

$$\omega_o = \left(\frac{15}{44}\right)\left(\frac{15}{44}\right)(2500) = 290.55 \text{ rev/min}$$

$N_2 = N_4 = 15$ teeth, $N_3 = N_5 = 44$ teeth *Ans.*

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**(a)** $N_2 = N_4 = 15$ teeth, $N_3 = N_5 = 44$ teeth

$$P = \frac{N}{d} \quad \Rightarrow \quad d = \frac{N}{P}$$

$$d_2 = d_4 = \frac{15}{6} = 2.5 \text{ in} \qquad Ans.$$

$$d_3 = d_5 = \frac{44}{6} = 7.33 \text{ in} \qquad Ans.$$

**(b)** $$V_i = V_2 = V_3 = \frac{\pi d_2 n_2}{12} = \frac{\pi(2.5)(2500)}{12} = 1636 \text{ ft/min} \qquad Ans.$$

$$V_o = V_4 = V_5 = \frac{\pi d_4 n_4}{12} = \frac{\pi(2.5)\left[(2500)(15/44)\right]}{12} = 558 \text{ ft/min} \qquad Ans.$$

**(c)** Input gears:

$$W_{ti} = 33000\frac{H}{V_i} = \frac{33000(25)}{1636} = 504.3 \text{ lbf} = 504 \text{ lbf} \qquad Ans.$$

$$W_{ri} = W_{ti}\tan\phi = 504.3 \tan 20^\circ = 184 \text{ lbf} \qquad Ans.$$

$$W_i = \frac{W_{ti}}{\cos\phi} = \frac{504.3}{\cos 20^\circ} = 537 \text{ lbf} \qquad \textit{Ans.}$$

Output gears:

$$W_{to} = 33000\frac{H}{V_o} = \frac{33000(25)}{558} = 1478 \text{ lbf} \qquad \textit{Ans.}$$

$$W_{ro} = W_{to}\tan\phi = 1478\tan 20^\circ = 538 \text{ lbf} \qquad \textit{Ans.}$$

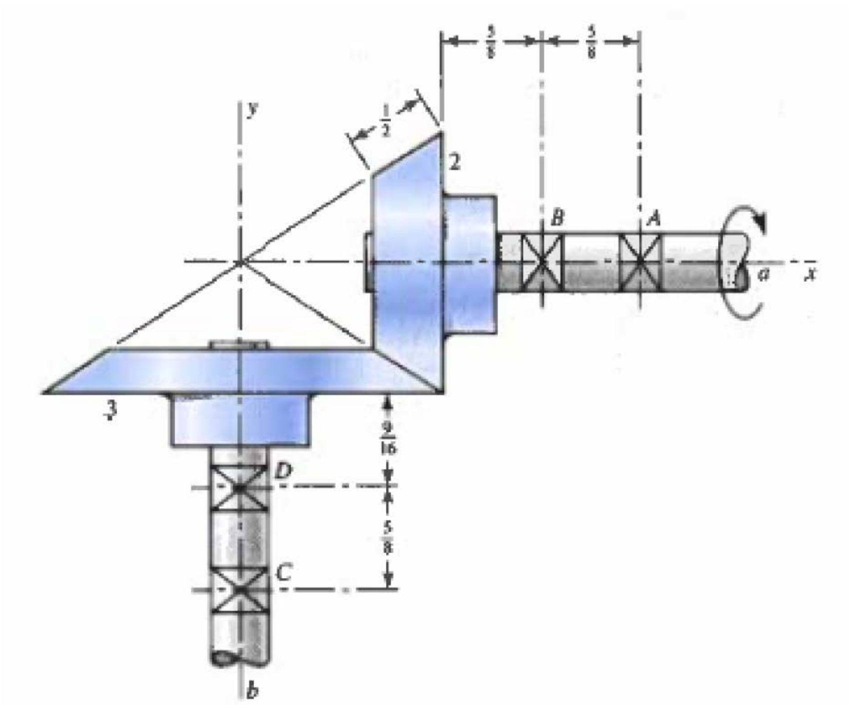
$$W_o = \frac{W_{to}}{\cos 20^\circ} = \frac{1478}{\cos 20^\circ} = 1573 \text{ lbf} \qquad \textit{Ans.}$$

**(d)** $$T_i = W_{ti}\left(\frac{d_2}{2}\right) = 504.3\left(\frac{2.5}{2}\right) = 630 \text{ lbf}\cdot\text{in} \qquad \textit{Ans.}$$

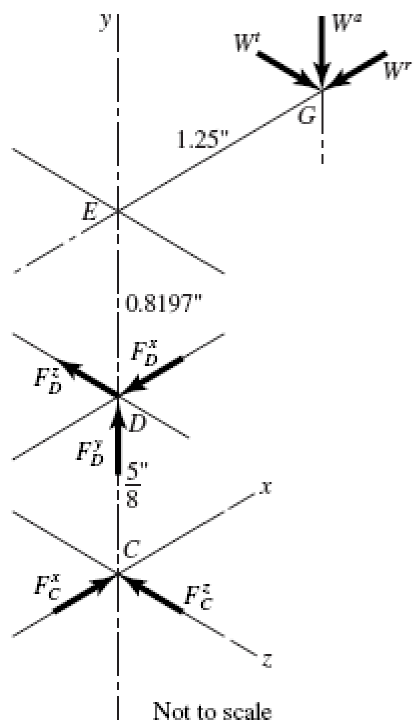
**(e)** $$T_o = T_i\left(\frac{44}{15}\right)^2 = 630\left(\frac{44}{15}\right)^2 = 5420 \text{ lbf}\cdot\text{in} \qquad \textit{Ans.}$$

**Problem 2**

**13–50** The figure shows a 10 diametral pitch 18-tooth 20° straight bevel pinion driving a 30-tooth gear. The transmitted load is 25 lbf. Find the bearing reactions at $C$ and $D$ on the output shaft if $D$ is to take both radial and thrust loads.




$$d_2 = 18/10 = 1.8 \text{ in}, \quad d_3 = 30/10 = 3.0 \text{ in}$$




$$\gamma = \tan^{-1}\left(\frac{d_2/2}{d_3/2}\right) = \tan^{-1}\left(\frac{0.9}{1.5}\right) = 30.96^\circ$$

$$\Gamma = 180^\circ - \gamma = 59.04^\circ$$

$$DE = \frac{9}{16} + 0.5\cos 59.04^\circ = 0.8197 \text{ in}$$

$$W^t = 25 \text{ lbf}$$

$$W^r = 25\tan 20^\circ \cos 59.04^\circ = 4.681 \text{ lbf}$$

$$W^a = 25\tan 20^\circ \sin 59.04^\circ = 7.803 \text{ lbf}$$

**W** = −4.681**i** – 7.803**j** +25**k**

**R**$_{DG}$ = 0.8197**j** + 1.25**i**

$\mathbf{R}_{DC} = -0.625\mathbf{j}$

$$\Sigma\mathbf{M}_D = \mathbf{R}_{DG} \times \mathbf{W} + \mathbf{R}_{DC} \times \mathbf{F}_C + \mathbf{T} = \mathbf{0}$$

$$\mathbf{R}_{DG} \times \mathbf{W} = 20.49\mathbf{i} - 31.25\mathbf{j} - 5.917\mathbf{k}$$

$$\mathbf{R}_{DC} \times \mathbf{F}_C = -0.625F_C^z\mathbf{i} + 0.625F_C^x\mathbf{k}$$

$$\left(20.49\mathbf{i} - 31.25\mathbf{j} - 5.917\mathbf{k}\right) + \left(-0.625F_C^z\mathbf{i} + 0.625F_C^x\mathbf{k}\right) + T\mathbf{j} = \mathbf{0}$$

$$T = 31.25 \text{ lbf} \cdot \text{in} \qquad Ans.$$

$$\mathbf{F}_C = 9.47\mathbf{i} + 32.8\mathbf{k} \text{ lbf} \qquad Ans.$$

$$F_C = \left(9.47^2 + 32.8^2\right)^{1/2} = 34.1 \text{ lbf} \qquad Ans.$$

$$\Sigma\mathbf{F} = 0 \qquad \mathbf{F}_D = -4.79\mathbf{i} + 7.80\mathbf{j} - 57.8\mathbf{k} \text{ lbf}$$

$$F_D(\text{radial}) = \left[\left(-4.79\right)^2 + \left(-57.8\right)^2\right]^{1/2} = 58.0 \text{ lbf} \qquad Ans.$$

$$F_D(\text{thrust}) = W^a = 7.80 \text{ lbf} \qquad Ans.$$

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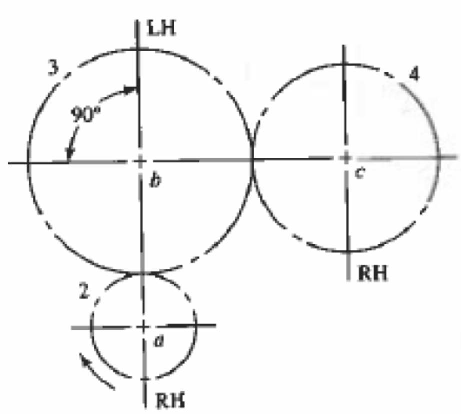
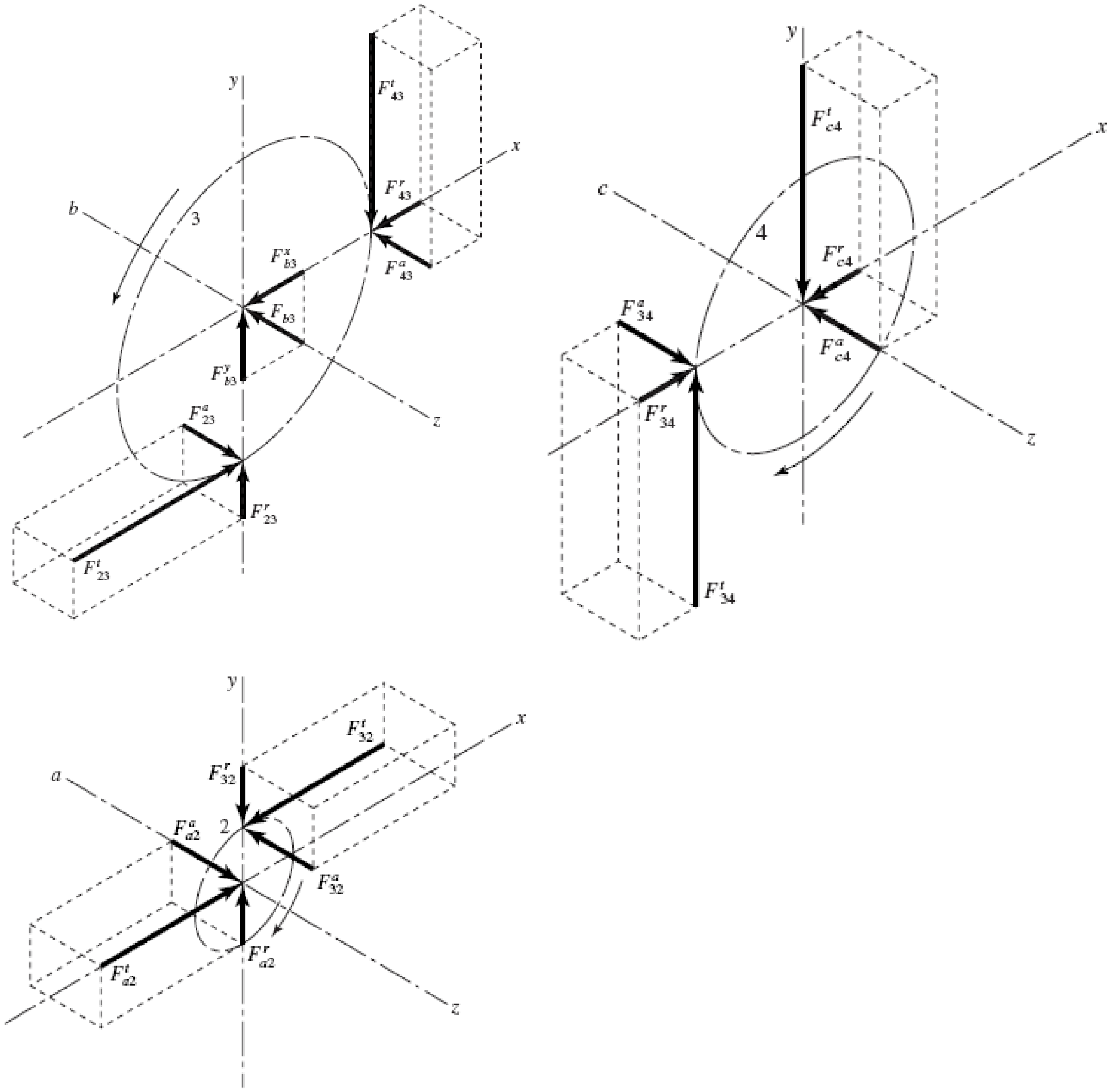
**Problem 3**

**13–55** Gear 2, in the figure, has 16 teeth, a 20° transverse pressure angle, a 15° helix angle, and a module of 4 mm. Gear 2 drives the idler on shaft *b*, which has 36 teeth. The driven gear on shaft *c* has 28 teeth. If the driver rotates at 1600 rev/min and transmits 6 kW, find the radial and thrust load on each shaft.




*Problem 13–55*




Since the transverse pressure angle is specified, we will assume the given module is also in terms of the transverse orientation.

$$d_2 = mN_2 = 4(16) = 64 \text{ mm}$$

$$d_3 = mN_3 = 4(36) = 144 \text{ mm}$$

$$d_4 = mN_4 = 4(28) = 112 \text{ mm}$$

$$T = \frac{H}{\omega} = \frac{6 \text{ kW}}{1600 \text{ rev/min}}\left(\frac{1000 \text{ W}}{\text{kW}}\right)\left(\frac{\text{rev}}{2\pi \text{ rad}}\right)\left(\frac{60 \text{ s}}{\text{min}}\right) = 35.81 \text{ N}\cdot\text{m}$$

$$W^t = \frac{T}{d_2/2} = \frac{35.81}{0.064/2} = 1119 \text{ N}$$

$$W^r = W^t \tan\phi_t = 1119 \tan 20^\circ = 407.3 \text{ N}$$

$$W^a = W^t \tan\psi = 1119 \tan 15^\circ = 299.8 \text{ N}$$

$$\mathbf{F}_{2a} = -1119\mathbf{i} - 407.3\mathbf{j} - 299.8\mathbf{k} \text{ N} \quad \textit{Ans.}$$

$$\begin{aligned}\mathbf{F}_{3b} &= (1119 - 407.3)\mathbf{i} - (1119 - 407.3)\mathbf{j} \\ &= 711.7\mathbf{i} - 711.7\mathbf{j} \text{ N} \quad \textit{Ans.}\end{aligned}$$

$$\mathbf{F}_{4c} = 407.3\mathbf{i} + 1119\mathbf{j} + 299.8\mathbf{k} \text{ N} \quad \textit{Ans.}$$

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**Problem 4**

**14–23** A spur gearset has 17 teeth on the pinion and 51 teeth on the gear. The pressure angle is 20° and the overload factor $K_o = 1$. The diametral pitch is 6 teeth/in and the face width is 2 in. The pinion speed is 1120 rev/min and its cycle life is to be $10^8$ revolutions at a reliability $R = 0.99$. The quality number is 5. The material is a through-hardened steel, grade 1, with Brinell hardnesses of 232 core and case of both gears. For a design factor of 2, rate the gearset for these conditions using the AGMA method.

Given: $R = 0.99$ at $10^8$ cycles, $H_B = 232$ through-hardening Grade 1, core and case, both gears. $N_P = 17T$, $N_G = 51T$,

Table 14-2: $Y_P = 0.303$, $Y_G = 0.4103$

Fig. 14-6: $J_P = 0.292$, $J_G = 0.396$

$d_P = N_P / P = 17 / 6 = 2.833$ in, $d_G = 51 / 6 = 8.500$ in.

*Pinion bending*

From Fig. 14-2:

$$\begin{aligned}{}_{0.99}(S_t)_{10^7} &= 77.3H_B + 12\ 800 \\ &= 77.3(232) + 12\ 800 = 30\ 734 \text{ psi}\end{aligned}$$

Fig. 14-14: $Y_N = 1.6831(10^8)^{-0.0323} = 0.928$

$$V = \pi d_P n / 12 = \pi(2.833)(1120 / 12) = 830.7 \text{ ft/min}$$

$$K_T = K_R = 1, \quad S_F = 2, \quad S_H = \sqrt{2}$$

$$\sigma_{\text{all}} = \frac{30\ 734(0.928)}{2(1)(1)} = 14\ 261 \text{ psi}$$

$$Q_v = 5, \quad B = 0.25(12 - 5)^{2/3} = 0.9148$$

$$A = 50 + 56(1 - 0.9148) = 54.77$$

$$K_v = \left( \frac{54.77 + \sqrt{830.7}}{54.77} \right)^{0.9148} = 1.472$$

$$K_s = 1.192 \left( \frac{2\sqrt{0.303}}{6} \right)^{0.0535} = 1.089 \Rightarrow \text{use } 1$$

$$K_m = C_{mf} = 1 + C_{mc}(C_{pf}C_{pm} + C_{ma}C_e)$$

$$C_{mc} = 1$$

$$C_{pf} = \frac{F}{10d} - 0.0375 + 0.0125F$$

$$= \frac{2}{10(2.833)} - 0.0375 + 0.0125(2) = 0.0581$$

$$C_{pm} = 1$$

$$C_{ma} = 0.127 + 0.0158(2) - 0.093(10^{-4})(2^2) = 0.1586$$

$$C_e = 1$$

$$K_m = 1 + 1[0.0581(1) + 0.1586(1)] = 1.217$$

$$K_B = 1$$

Eq. (14-15): $$W^t = \frac{FJ_P\sigma_{\text{all}}}{K_oK_vK_sP_dK_mK_B}$$

$$= \frac{2(0.292)(14\ 261)}{1(1.472)(1)(6)(1.217)(1)} = 775 \text{ lbf}$$

$$H = \frac{W^tV}{33\ 000} = \frac{775(830.7)}{33\ 000} = 19.5 \text{ hp}$$

*Pinion wear*

Fig. 14-15: $Z_N = 2.466N^{-0.056} = 2.466(10^8)^{-0.056} = 0.879$

$$m_G = 51 / 17 = 3$$

Eq. (14-23): $$I = \frac{\cos 20^\circ \sin 20^\circ}{2}\left(\frac{3}{3+1}\right) = 1.205, \quad C_H = 1$$

Fig. 14-5: $${}_{0.99}(S_c)_{10^7} = 322H_B + 29\,100$$

$$= 322(232) + 29\,100 = 103\,804 \text{ psi}$$

$$\sigma_{c,\text{all}} = \frac{103\,804(0.879)}{\sqrt{2}(1)(1)} = 64\,519 \text{ psi}$$

Eq. (14-16): $$W^t = \left(\frac{\sigma_{c,\text{all}}}{C_p}\right)^2 \frac{Fd_P I}{K_o K_v K_s K_m C_f}$$

$$= \left(\frac{64\,519}{2300}\right)^2 \left[\frac{2(2.833)(0.1205)}{1(1.472)(1)(1.2167)(1)}\right]$$

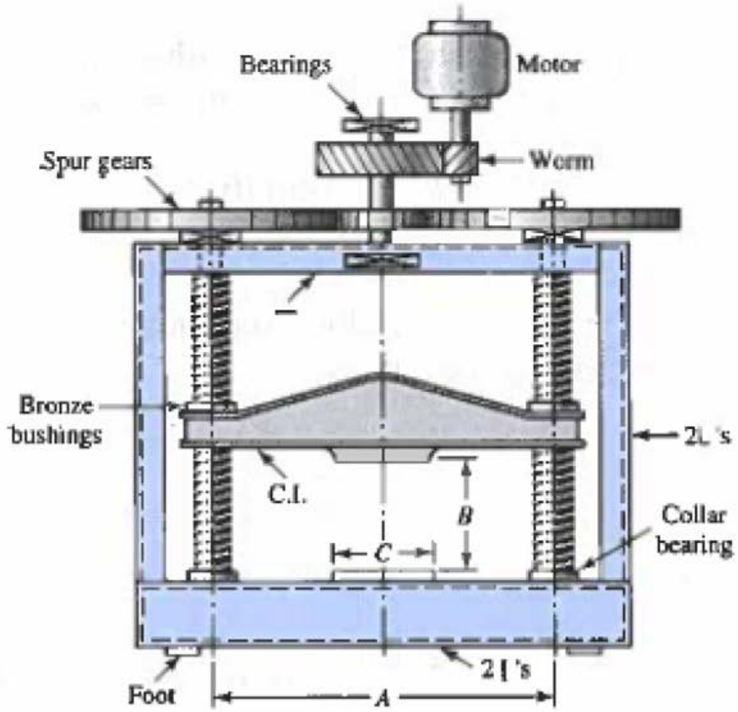
$$= 300 \text{ lbf}$$

$$H = \frac{W^t V}{33\,000} = \frac{300(830.7)}{33\,000} = 7.55 \text{ hp}$$

The pinion controls, therefore $H_{\text{rated}}$ = 7.55 hp *Ans.*

**Problem 5**

Problem 8–5




**8–5** The machine shown in the figure can be used for a tension test but not for a compression test. Why? Can both screws have the same hand?

**8–6** The press shown for Problem 8–5 has a rated load of 5000 lbf. The twin screws have Acme threads, a diameter of 2 in, and a pitch of $\frac{1}{4}$ in. Coefficients of friction are 0.05 for the threads and 0.08 for the collar bearings. Collar diameters are 3.5 in. The gears have an efficiency of 95 percent and a speed ratio of 60:1. A slip clutch, on the motor shaft, prevents overloading. The full-load motor speed is 1720 rev/min.
(*a*) When the motor is turned on, how fast will the press head move?
(*b*) What should be the horsepower rating of the motor?

**8-5** Collar (thrust) bearings, at the bottom of the screws, must bear on the collars. The bottom segment of the screws must be in compression. Whereas, tension specimens and their grips must be in tension. Both screws must be of the same-hand threads.

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**8-6** Screws rotate at an angular rate of

$$n = \frac{1720}{60} = 28.67 \text{ rev/min}$$

**(a)** The lead is 0.25 in, so the linear speed of the press head is

$$V = 28.67(0.25) = 7.17 \text{ in/min} \qquad \textit{Ans.}$$

**(b)** $F$ = 2500 lbf/screw

$$\begin{aligned} d_m &= 2 - 0.25/2 = 1.875 \text{ in} \\ \sec\alpha &= 1/\cos(29^\circ/2) = 1.033 \end{aligned}$$

Eq. (8-5):

$$T_R = \frac{2500(1.875)}{2}\left(\frac{0.25 + \pi(0.05)(1.875)(1.033)}{\pi(1.875) - 0.05(0.25)(1.033)}\right) = 221.0 \text{ lbf} \cdot \text{in}$$

Eq. (8-6):

$$\begin{aligned} T_c &= 2500(0.08)(3.5/2) = 350 \text{ lbf} \cdot \text{in} \\ T_{total} &= 350 + 221.0 = 571 \text{ lbf} \cdot \text{in/screw} \\ T_{motor} &= \frac{571(2)}{60(0.95)} = 20.04 \text{ lbf} \cdot \text{in} \\ H &= \frac{Tn}{63\,025} = \frac{20.04(1720)}{63\,025} = 0.547 \text{ hp} \qquad \textit{Ans.} \end{aligned}$$