

Chapter 14

14-1

$$d = \frac{N}{P} = \frac{22}{6} = 3.667 \text{ in}$$

Table 14-2: $Y = 0.331$

$$V = \frac{\pi d n}{12} = \frac{\pi(3.667)(1200)}{12} = 1152 \text{ ft/min}$$

Eq. (14-4b): $K_v = \frac{1200 + 1152}{1200} = 1.96$

$$W^t = \frac{T}{d/2} = \frac{63\,025 H}{n d/2} = \frac{63\,025(15)}{1200(3.667/2)} = 429.7 \text{ lbf}$$

Eq. (14-7):

$$\sigma = \frac{K_v W^t P}{F Y} = \frac{1.96(429.7)(6)}{2(0.331)} = 7633 \text{ psi} = 7.63 \text{ kpsi} \quad \text{Ans.}$$

14-2

$$d = \frac{16}{12} = 1.333 \text{ in}, \quad Y = 0.296$$

$$V = \frac{\pi(1.333)(700)}{12} = 244.3 \text{ ft/min}$$

Eq. (14-4b): $K_v = \frac{1200 + 244.3}{1200} = 1.204$

$$W^t = \frac{63\,025 H}{n d/2} = \frac{63\,025(1.5)}{700(1.333/2)} = 202.6 \text{ lbf}$$

Eq. (14-7):

$$\sigma = \frac{K_v W^t P}{F Y} = \frac{1.204(202.6)(12)}{0.75(0.296)} = 13\,185 \text{ psi} = 13.2 \text{ kpsi} \quad \text{Ans.}$$

14-3

$$d = m N = 1.25(18) = 22.5 \text{ mm}, \quad Y = 0.309$$

$$V = \frac{\pi(22.5)(10^{-3})(1800)}{60} = 2.121 \text{ m/s}$$

Eq. (14-6b): $K_v = \frac{6.1 + 2.121}{6.1} = 1.348$

$$W^t = \frac{60 H}{\pi d n} = \frac{60(0.5)(10^3)}{\pi(22.5)(10^{-3})(1800)} = 235.8 \text{ N}$$

Eq. (14-8): $\sigma = \frac{K_v W^t}{F m Y} = \frac{1.348(235.8)}{12(1.25)(0.309)} = 68.6 \text{ MPa} \quad \text{Ans.}$

14-4

$$d = 5(15) = 75 \text{ mm}, \quad Y = 0.290$$

$$V = \frac{\pi(75)(10^{-3})(200)}{60} = 0.7854 \text{ m/s}$$

Assume steel and apply Eq. (14-6b):

$$K_v = \frac{6.1 + 0.7854}{6.1} = 1.129$$

$$W^t = \frac{60H}{\pi dn} = \frac{60(5)(10^3)}{\pi(75)(10^{-3})(200)} = 6366 \text{ N}$$

Eq. (14-8):
$$\sigma = \frac{K_v W^t}{FmY} = \frac{1.129(6366)}{60(5)(0.290)} = 82.6 \text{ MPa} \quad \text{Ans.}$$

14-5

$$d = 1(16) = 16 \text{ mm}, \quad Y = 0.296$$

$$V = \frac{\pi(16)(10^{-3})(400)}{60} = 0.335 \text{ m/s}$$

Assume steel and apply Eq. (14-6b):

$$K_v = \frac{6.1 + 0.335}{6.1} = 1.055$$

$$W^t = \frac{60H}{\pi dn} = \frac{60(0.15)(10^3)}{\pi(16)(10^{-3})(400)} = 447.6 \text{ N}$$

Eq. (14-8):
$$F = \frac{K_v W^t}{\sigma m Y} = \frac{1.055(447.6)}{150(1)(0.296)} = 10.6 \text{ mm}$$

From Table A-17, use $F = 11 \text{ mm}$ Ans.

14-6

$$d = 1.5(17) = 25.5 \text{ mm}, \quad Y = 0.303$$

$$V = \frac{\pi(25.5)(10^{-3})(400)}{60} = 0.534 \text{ m/s}$$

Eq. (14-6b):
$$K_v = \frac{6.1 + 0.534}{6.1} = 1.088$$

$$W^t = \frac{60H}{\pi dn} = \frac{60(0.25)(10^3)}{\pi(25.5)(10^{-3})(400)} = 468 \text{ N}$$

Eq. (14-8):
$$F = \frac{K_v W^t}{\sigma m Y} = \frac{1.088(468)}{75(1.5)(0.303)} = 14.9 \text{ mm}$$

Use $F = 15 \text{ mm}$ Ans.

14-7

$$d = \frac{24}{5} = 4.8 \text{ in}, \quad Y = 0.337$$

$$V = \frac{\pi(4.8)(50)}{12} = 62.83 \text{ ft/min}$$

$$\text{Eq. (14-4b):} \quad K_v = \frac{1200 + 62.83}{1200} = 1.052$$

$$W^t = \frac{63\,025H}{nd/2} = \frac{63\,025(6)}{50(4.8/2)} = 3151 \text{ lbf}$$

$$\text{Eq. (14-7):} \quad F = \frac{K_v W^t P}{\sigma Y} = \frac{1.052(3151)(5)}{20(10^3)(0.337)} = 2.46 \text{ in}$$

Use $F = 2.5 \text{ in}$ *Ans.*

14-8

$$d = \frac{16}{5} = 3.2 \text{ in}, \quad Y = 0.296$$

$$V = \frac{\pi(3.2)(600)}{12} = 502.7 \text{ ft/min}$$

$$\text{Eq. (14-4b):} \quad K_v = \frac{1200 + 502.7}{1200} = 1.419$$

$$W^t = \frac{63\,025(15)}{600(3.2/2)} = 984.8 \text{ lbf}$$

$$\text{Eq. (14-7):} \quad F = \frac{K_v W^t P}{\sigma Y} = \frac{1.419(984.8)(5)}{10(10^3)(0.296)} = 2.38 \text{ in}$$

Use $F = 2.5 \text{ in}$ *Ans.*

14-9 Try $P = 8$ which gives $d = 18/8 = 2.25 \text{ in}$ and $Y = 0.309$.

$$V = \frac{\pi(2.25)(600)}{12} = 353.4 \text{ ft/min}$$

$$\text{Eq. (14-4b):} \quad K_v = \frac{1200 + 353.4}{1200} = 1.295$$

$$W^t = \frac{63\,025(2.5)}{600(2.25/2)} = 233.4 \text{ lbf}$$

$$\text{Eq. (14-7):} \quad F = \frac{K_v W^t P}{\sigma Y} = \frac{1.295(233.4)(8)}{10(10^3)(0.309)} = 0.783 \text{ in}$$

Using coarse integer pitches from Table 13-2, the following table is formed.

P	d	V	K_v	W^t	F
2	9.000	1413.717	2.178	58.356	0.082
3	6.000	942.478	1.785	87.535	0.152
4	4.500	706.858	1.589	116.713	0.240
6	3.000	471.239	1.393	175.069	0.473
8	2.250	353.429	1.295	233.426	0.782
10	1.800	282.743	1.236	291.782	1.167
12	1.500	235.619	1.196	350.139	1.627
16	1.125	176.715	1.147	466.852	2.773

Other considerations may dictate the selection. Good candidates are $P = 8$ ($F = 7/8$ in) and $P = 10$ ($F = 1.25$ in). *Ans.*

14-10 Try $m = 2$ mm which gives $d = 2(18) = 36$ mm and $Y = 0.309$.

$$V = \frac{\pi(36)(10^{-3})(900)}{60} = 1.696 \text{ m/s}$$

Eq. (14-6b): $K_v = \frac{6.1 + 1.696}{6.1} = 1.278$

$$W^t = \frac{60(1.5)(10^3)}{\pi(36)(10^{-3})(900)} = 884 \text{ N}$$

Eq. (14-8): $F = \frac{1.278(884)}{75(2)(0.309)} = 24.4 \text{ mm}$

Using the preferred module sizes from Table 13-2:

m	d	V	K_v	W^t	F
1.00	18.0	0.848	1.139	1768.388	86.917
1.25	22.5	1.060	1.174	1414.711	57.324
1.50	27.0	1.272	1.209	1178.926	40.987
2.00	36.0	1.696	1.278	884.194	24.382
3.00	54.0	2.545	1.417	589.463	12.015
4.00	72.0	3.393	1.556	442.097	7.422
5.00	90.0	4.241	1.695	353.678	5.174
6.00	108.0	5.089	1.834	294.731	3.888
8.00	144.0	6.786	2.112	221.049	2.519
10.00	180.0	8.482	2.391	176.839	1.824
12.00	216.0	10.179	2.669	147.366	1.414
16.00	288.0	13.572	3.225	110.524	0.961
20.00	360.0	16.965	3.781	88.419	0.721
25.00	450.0	21.206	4.476	70.736	0.547
32.00	576.0	27.143	5.450	55.262	0.406
40.00	720.0	33.929	6.562	44.210	0.313
50.00	900.0	42.412	7.953	35.368	0.243

Other design considerations may dictate the size selection. For the present design, $m = 2$ mm ($F = 25$ mm) is a good selection. *Ans.*

14-11

$$d_P = \frac{22}{6} = 3.667 \text{ in}, \quad d_G = \frac{60}{6} = 10 \text{ in}$$

$$V = \frac{\pi(3.667)(1200)}{12} = 1152 \text{ ft/min}$$

$$\text{Eq. (14-4b):} \quad K_v = \frac{1200 + 1152}{1200} = 1.96$$

$$W^t = \frac{63\,025(15)}{1200(3.667/2)} = 429.7 \text{ lbf}$$

Table 14-8: $C_p = 2100\sqrt{\text{psi}}$ [Note: using Eq. (14-13) can result in wide variation in C_p due to wide variation in cast iron properties]

$$\text{Eq. (14-12):} \quad r_1 = \frac{3.667 \sin 20^\circ}{2} = 0.627 \text{ in}, \quad r_2 = \frac{10 \sin 20^\circ}{2} = 1.710 \text{ in}$$

$$\begin{aligned} \text{Eq. (14-14):} \quad \sigma_C &= -C_p \left[\frac{K_v W^t}{F \cos \phi} \left(\frac{1}{r_1} + \frac{1}{r_2} \right) \right]^{1/2} \\ &= -2100 \left[\frac{1.96(429.7)}{2 \cos 20^\circ} \left(\frac{1}{0.627} + \frac{1}{1.710} \right) \right]^{1/2} \\ &= -65.6(10^3) \text{ psi} = -65.6 \text{ kpsi} \quad \text{Ans.} \end{aligned}$$

14-12

$$d_P = \frac{16}{12} = 1.333 \text{ in}, \quad d_G = \frac{48}{12} = 4 \text{ in}$$

$$V = \frac{\pi(1.333)(700)}{12} = 244.3 \text{ ft/min}$$

$$\text{Eq. (14-4b):} \quad K_v = \frac{1200 + 244.3}{1200} = 1.204$$

$$W^t = \frac{63\,025(1.5)}{700(1.333/2)} = 202.6 \text{ lbf}$$

Table 14-8: $C_p = 2100\sqrt{\text{psi}}$ (see note in Prob. 14-11 solution)

$$\text{Eq. (14-12):} \quad r_1 = \frac{1.333 \sin 20^\circ}{2} = 0.228 \text{ in}, \quad r_2 = \frac{4 \sin 20^\circ}{2} = 0.684 \text{ in}$$

Eq. (14-14):

$$\sigma_C = -2100 \left[\frac{1.202(202.6)}{F \cos 20^\circ} \left(\frac{1}{0.228} + \frac{1}{0.684} \right) \right]^{1/2} = -100(10^3)$$

$$F = \left(\frac{2100}{100(10^3)} \right)^2 \left[\frac{1.202(202.6)}{\cos 20^\circ} \right] \left(\frac{1}{0.228} + \frac{1}{0.684} \right) = 0.668 \text{ in}$$

Use $F = 0.75 \text{ in}$ Ans.

14-13

$$d_P = \frac{24}{5} = 4.8 \text{ in}, \quad d_G = \frac{48}{5} = 9.6 \text{ in}$$

$$V = \frac{\pi(4.8)(50)}{12} = 62.83 \text{ ft/min}$$

$$\text{Eq. (14-4a):} \quad K_v = \frac{600 + 62.83}{600} = 1.105$$

$$W^t = \frac{63\,025H}{50(4.8/2)} = 525.2H$$

$$\text{Table 14-8:} \quad C_p = 1960\sqrt{\text{psi}} \quad (\text{see note in Prob. 14-11 solution})$$

$$\text{Eq. (14-12):} \quad r_1 = \frac{4.8 \sin 20^\circ}{2} = 0.821 \text{ in}, \quad r_2 = 2r_1 = 1.642 \text{ in}$$

$$\text{Eq. (14-14):} \quad -100(10^3) = -1960 \left[\frac{1.105(525.2H)}{2.5 \cos 20^\circ} \left(\frac{1}{0.821} + \frac{1}{1.642} \right) \right]^{1/2}$$

$$H = 5.77 \text{ hp} \quad \text{Ans.}$$

14-14

$$d_P = 4(20) = 80 \text{ mm}, \quad d_G = 4(32) = 128 \text{ mm}$$

$$V = \frac{\pi(80)(10^{-3})(1000)}{60} = 4.189 \text{ m/s}$$

$$\text{Eq. (14-6a):} \quad K_v = \frac{3.05 + 4.189}{3.05} = 2.373$$

$$W^t = \frac{60(10)(10^3)}{\pi(80)(10^{-3})(1000)} = 2387 \text{ N}$$

$$\text{Table 14-8:} \quad C_p = 163\sqrt{\text{MPa}} \quad (\text{see note in Prob. 14-11 solution})$$

$$\text{Eq. (14-12):} \quad r_1 = \frac{80 \sin 20^\circ}{2} = 13.68 \text{ mm}, \quad r_2 = \frac{128 \sin 20^\circ}{2} = 21.89 \text{ mm}$$

$$\text{Eq. (14-14):} \quad \sigma_C = -163 \left[\frac{2.373(2387)}{50 \cos 20^\circ} \left(\frac{1}{13.68} + \frac{1}{21.89} \right) \right]^{1/2} = -617 \text{ MPa} \quad \text{Ans.}$$

14-15 The pinion controls the design.

$$\text{Bending} \quad Y_P = 0.303, \quad Y_G = 0.359$$

$$d_P = \frac{17}{12} = 1.417 \text{ in}, \quad d_G = \frac{30}{12} = 2.500 \text{ in}$$

$$V = \frac{\pi d_P n}{12} = \frac{\pi(1.417)(525)}{12} = 194.8 \text{ ft/min}$$

$$\text{Eq. (14-4b):} \quad K_v = \frac{1200 + 194.8}{1200} = 1.162$$

$$\text{Eq. (6-8):} \quad S'_e = 0.5(76) = 38 \text{ kpsi}$$

$$\text{Eq. (6-19):} \quad k_a = 2.70(76)^{-0.265} = 0.857$$

$$l = \frac{2.25}{P_d} = \frac{2.25}{12} = 0.1875 \text{ in}$$

$$\text{Eq. (14-3):} \quad x = \frac{3Y_P}{2P} = \frac{3(0.303)}{2(12)} = 0.0379 \text{ in}$$

$$\text{Eq. (b), p. 717:} \quad t = \sqrt{4(0.1875)(0.0379)} = 0.1686 \text{ in}$$

$$\text{Eq. (6-25):} \quad d_e = 0.808\sqrt{0.875(0.1686)} = 0.310 \text{ in}$$

$$\text{Eq. (6-20):} \quad k_b = \left(\frac{0.310}{0.30}\right)^{-0.107} = 0.996$$

$$k_c = k_d = k_e = 1, \quad k_{f_1} = 1.66 \quad (\text{see Ex. 14-2})$$

$$r_f = \frac{0.300}{12} = 0.025 \text{ in} \quad (\text{see Ex. 14-2})$$

$$\frac{r}{d} = \frac{r_f}{t} = \frac{0.025}{0.1686} = 0.148$$

Approximate $D/d = \infty$ with $D/d = 3$; from Fig. A-15-6, $K_t = 1.68$.

From Fig. 6-20, with $S_{ut} = 76$ kpsi and $r = 0.025$ in, $q = 0.62$. From Eq. (6-32)

$$K_f = 1 + 0.62(1.68 - 1) = 1.42$$

Miscellaneous-Effects Factor:

$$k_f = k_{f_1}k_{f_2} = 1.65 \left(\frac{1}{1.323}\right) = 1.247$$

$$\text{Eq. (7-17):} \quad S_e = 0.857(0.996)(1)(1)(1)(1.247)(38\,000) \\ = 40\,450 \text{ psi}$$

$$\sigma_{\text{all}} = \frac{40\,770}{2.25} = 18\,120 \text{ psi}$$

$$W^t = \frac{FY_P\sigma_{\text{all}}}{K_v P_d} = \frac{0.875(0.303)(18\,120)}{1.162(12)} \\ = 345 \text{ lbf}$$

$$\text{Wear} \quad H = \frac{345(194.8)}{33\,000} = 2.04 \text{ hp} \quad \text{Ans.}$$

$$v_1 = v_2 = 0.292, \quad E_1 = E_2 = 30(10^6) \text{ psi}$$

$$\text{Eq. (14-13):} \quad C_p = \left[\frac{1}{2\pi \left(\frac{1 - 0.292^2}{30(10^6)} \right)} \right] = 2285\sqrt{\text{psi}}$$

$$\text{Eq. (14-12):} \quad r_1 = \frac{d_P}{2} \sin \phi = \frac{1.417}{2} \sin 20^\circ = 0.242 \text{ in}$$

$$r_2 = \frac{d_G}{2} \sin \phi = \frac{2.500}{2} \sin 20^\circ = 0.428$$

$$\frac{1}{r_1} + \frac{1}{r_2} = \frac{1}{0.242} + \frac{1}{0.428} = 6.469 \text{ in}^{-1}$$

From Eq. (6-68),

$$(S_C)_{10^8} = 0.4H_B - 10 \text{ kpsi}$$

$$= [0.4(149) - 10](10^3) = 49\,600 \text{ psi}$$

$$\sigma_{C,\text{all}} = -\frac{(S_C)_{10^8}}{\sqrt{n}} = \frac{-49\,600}{\sqrt{2.25}} = -33\,067 \text{ psi}$$

Eq. (14-14):
$$W^t = \left(\frac{-33\,067}{2285} \right)^2 \left[\frac{0.875 \cos 20^\circ}{1.162(6.469)} \right] = 22.6 \text{ lbf}$$

$$H = \frac{22.6(194.8)}{33\,000} = 0.133 \text{ hp} \quad \text{Ans.}$$

Rating power (pinion controls):

$$H_1 = 2.04 \text{ hp}$$

$$H_2 = 0.133 \text{ hp}$$

$$H_{\text{all}} = (\min 2.04, 0.133) = 0.133 \text{ hp} \quad \text{Ans.}$$

14-16 See Prob. 14-15 solution for equation numbers.

Pinion controls: $Y_P = 0.322$, $Y_G = 0.447$

Bending $d_P = 20/3 = 6.667 \text{ in}$, $d_G = 33.333 \text{ in}$

$$V = \pi d_P n / 12 = \pi(6.667)(870) / 12 = 1519 \text{ ft/min}$$

$$K_v = (1200 + 1519) / 1200 = 2.266$$

$$S'_e = 0.5(113) = 56.5 \text{ kpsi}$$

$$k_a = 2.70(113)^{-0.265} = 0.771$$

$$l = 2.25 / P_d = 2.25 / 3 = 0.75 \text{ in}$$

$$x = 3(0.322) / [2(3)] = 0.161 \text{ in}$$

$$t = \sqrt{4(0.75)(0.161)} = 0.695 \text{ in}$$

$$d_e = 0.808 \sqrt{2.5(0.695)} = 1.065 \text{ in}$$

$$k_b = (1.065 / 0.30)^{-0.107} = 0.873$$

$$k_c = k_d = k_e = 1$$

$$r_f = 0.300 / 3 = 0.100 \text{ in}$$

$$\frac{r}{d} = \frac{r_f}{t} = \frac{0.100}{0.695} = 0.144$$

From Table A-15-6, $K_t = 1.75$; Fig. 6-20, $q = 0.85$; Eq. (6-32), $K_f = 1.64$

$$k_{f2} = 1 / 1.597, \quad k_f = k_{f1} k_{f2} = 1.66 / 1.597 = 1.039$$

$$S_e = 0.771(0.873)(1)(1)(1)(1.039)(56\,500) = 39\,500 \text{ psi}$$

$$\sigma_{\text{all}} = S_e / n = 39\,500 / 1.5 = 26\,330 \text{ psi}$$

$$W^t = \frac{F Y_P \sigma_{\text{all}}}{K_v P_d} = \frac{2.5(0.322)(26\,330)}{2.266(3)} = 3118 \text{ lbf}$$

$$H = W^t V / 33\,000 = 3118(1519) / 33\,000 = 144 \text{ hp} \quad \text{Ans.}$$

Wear

Eq. (14-13): $C_p = 2285\sqrt{\text{psi}}$

Eq. (14-12): $r_1 = (6.667/2) \sin 20^\circ = 1.140 \text{ in}$
 $r_2 = (33.333/2) \sin 20^\circ = 5.700 \text{ in}$

Eq. (6-68): $S_C = [0.4(262) - 10](10^3) = 94\,800 \text{ psi}$

$$\sigma_{C,\text{all}} = -S_C/\sqrt{n_d} = -94\,800/\sqrt{1.5} = -77\,404 \text{ psi}$$

$$W^t = \left(\frac{\sigma_{C,\text{all}}}{C_p} \right)^2 \frac{F \cos \phi}{K_v} \frac{1}{1/r_1 + 1/r_2}$$

$$= \left(\frac{-77\,404}{2300} \right)^2 \left(\frac{2.5 \cos 20^\circ}{2.266} \right) \left(\frac{1}{1/1.140 + 1/5.700} \right)$$

$$= 1115 \text{ lbf}$$

$$H = \frac{W^t V}{33\,000} = \frac{1115(1519)}{33\,000} = 51.3 \text{ hp} \quad \text{Ans.}$$

For 10^8 cycles (revolutions of the pinion), the power based on wear is 51.3 hp.

Rating power–pinion controls

$$H_1 = 144 \text{ hp}$$

$$H_2 = 51.3 \text{ hp}$$

$$H_{\text{rated}} = \min(144, 51.3) = 51.3 \text{ hp} \quad \text{Ans.}$$

14-17 Given: $\phi = 20^\circ$, $n = 1145 \text{ rev/min}$, $m = 6 \text{ mm}$, $F = 75 \text{ mm}$, $N_P = 16$ milled teeth, $N_G = 30$, $S_{ut} = 900 \text{ MPa}$, $H_B = 260$, $n_d = 3$, $Y_P = 0.296$, and $Y_G = 0.359$.

Pinion bending

$$d_P = mN_P = 6(16) = 96 \text{ mm}$$

$$d_G = 6(30) = 180 \text{ mm}$$

$$V = \frac{\pi d_P n}{12} = \frac{\pi(96)(1145)(10^{-3})(12)}{(12)(60)} = 5.76 \text{ m/s}$$

Eq. (14-6b): $K_v = \frac{6.1 + 5.76}{6.1} = 1.944$

$$S'_e = 0.5(900) = 450 \text{ MPa}$$

$$a = 4.45, \quad b = -0.265$$

$$k_a = 4.51(900)^{-0.265} = 0.744$$

$$l = 2.25m = 2.25(6) = 13.5 \text{ mm}$$

$$x = 3Y_P m/2 = 3(0.296)6/2 = 2.664 \text{ mm}$$

$$t = \sqrt{4lx} = \sqrt{4(13.5)(2.664)} = 12.0 \text{ mm}$$

$$d_e = 0.808\sqrt{75(12.0)} = 24.23 \text{ mm}$$

$$k_b = \left(\frac{24.23}{7.62} \right)^{-0.107} = 0.884$$

$$k_c = k_d = k_e = 1$$

$$r_f = 0.300m = 0.300(6) = 1.8 \text{ mm}$$

From Fig. A-15-6 for $r/d = r_f/t = 1.8/12 = 0.15$, $K_t = 1.68$.

Figure 6-20, $q = 0.86$; Eq. (6-32),

$$K_f = 1 + 0.86(1.68 - 1) = 1.58$$

$$k_{f1} = 1.66 \quad (\text{Gerber failure criterion})$$

$$k_{f2} = 1/K_f = 1/1.537 = 0.651$$

$$k_f = k_{f1}k_{f2} = 1.66(0.651) = 1.08$$

$$S_e = 0.744(0.884)(1)(1)(1)(1.08)(450) = 319.6 \text{ MPa}$$

$$\sigma_{\text{all}} = \frac{S_e}{n_d} = \frac{319.6}{1.3} = 245.8 \text{ MPa}$$

$$\text{Eq. (14-8): } W^t = \frac{F Y m \sigma_{\text{all}}}{K_v} = \frac{75(0.296)(6)(245.8)}{1.944} = 16\,840 \text{ N}$$

$$H = \frac{T n}{9.55} = \frac{16\,840(96/2)(1145)}{9.55(10^6)} = 96.9 \text{ kW} \quad \text{Ans.}$$

Wear: Pinion and gear

$$\text{Eq. (14-12): } r_1 = (96/2) \sin 20^\circ = 16.42 \text{ mm}$$

$$r_2 = (180/2) \sin 20^\circ = 30.78 \text{ mm}$$

Eq. (14-13), with $E = 207(10^3) \text{ MPa}$ and $\nu = 0.292$, gives

$$C_p = \left[\frac{1}{2\pi(1 - 0.292^2)/(207 \times 10^3)} \right] = 190\sqrt{\text{MPa}}$$

$$\text{Eq. (6-68): } S_C = 6.89[0.4(260) - 10] = 647.7 \text{ MPa}$$

$$\sigma_{C,\text{all}} = -\frac{S_C}{\sqrt{n}} = -\frac{647.7}{\sqrt{1.3}} = -568 \text{ MPa}$$

$$\begin{aligned} \text{Eq. (14-14): } W^t &= \left(\frac{\sigma_{C,\text{all}}}{C_p} \right)^2 \frac{F \cos \phi}{K_v} \frac{1}{1/r_1 + 1/r_2} \\ &= \left(\frac{-568}{191} \right)^2 \left(\frac{75 \cos 20^\circ}{1.944} \right) \left(\frac{1}{1/16.42 + 1/30.78} \right) \\ &= 3433 \text{ N} \end{aligned}$$

$$T = \frac{W^t d_P}{2} = \frac{3433(96)}{2} = 164\,784 \text{ N} \cdot \text{mm} = 164.8 \text{ N} \cdot \text{m}$$

$$H = \frac{T n}{9.55} = \frac{164.8(1145)}{9.55} = 19\,758.7 \text{ W} = 19.8 \text{ kW} \quad \text{Ans.}$$

Thus, wear controls the gearset power rating; $H = 19.8 \text{ kW}$. *Ans.*

14-18 Preliminaries: $N_P = 17$, $N_G = 51$

$$d_P = \frac{N}{P_d} = \frac{17}{6} = 2.833 \text{ in}$$

$$d_G = \frac{51}{6} = 8.500 \text{ in}$$

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

Eq. (14-4b):

$$K_v = (1200 + 830.7) / 1200 = 1.692$$

$$\sigma_{\text{all}} = \frac{S_y}{n_d} = \frac{90\,000}{2} = 45\,000 \text{ psi}$$

Table 14-2:

$$Y_P = 0.303, \quad Y_G = 0.410$$

Eq. (14-7):

$$W^t = \frac{F Y_P \sigma_{\text{all}}}{K_v P_d} = \frac{2(0.303)(45\,000)}{1.692(6)} = 2686 \text{ lbf}$$

$$H = \frac{W^t V}{33\,000} = \frac{2686(830.7)}{33\,000} = 67.6 \text{ hp}$$

Based on yielding in bending, the power is 67.6 hp.

(a) Pinion fatigue

Bending

Eq. (2-17): $S_{ut} \doteq 0.5H_B = 0.5(232) = 116 \text{ kpsi}$

Eq. (6-8): $S'_e = 0.5S_{ut} = 0.5(116) = 58 \text{ kpsi}$

Eq. (6-19): $a = 2.70, \quad b = -0.265, \quad k_a = 2.70(116)^{-0.265} = 0.766$

Table 13-1: $l = \frac{1}{P_d} + \frac{1.25}{P_d} = \frac{2.25}{P_d} = \frac{2.25}{6} = 0.375 \text{ in}$

Eq. (14-3): $x = \frac{3Y_P}{2P_d} = \frac{3(0.303)}{2(6)} = 0.0758$

Eq. (b), p. 717: $t = \sqrt{4lx} = \sqrt{4(0.375)(0.0758)} = 0.337 \text{ in}$

Eq. (6-25): $d_e = 0.808\sqrt{Ft} = 0.808\sqrt{2(0.337)} = 0.663 \text{ in}$

Eq. (6-20): $k_b = \left(\frac{0.663}{0.30}\right)^{-0.107} = 0.919$

$k_c = k_d = k_e = 1$. Assess two components contributing to k_f . First, based upon one-way bending and the Gerber failure criterion, $k_{f1} = 1.66$ (see Ex. 14-2). Second, due to stress-concentration,

$$r_f = \frac{0.300}{P_d} = \frac{0.300}{6} = 0.050 \text{ in} \quad (\text{see Ex. 14-2})$$

Fig. A-15-6: $\frac{r}{d} = \frac{r_f}{t} = \frac{0.05}{0.338} = 0.148$

Estimate $D/d = \infty$ by setting $D/d = 3$, $K_t = 1.68$. From Fig. 6-20, $q = 0.86$, and Eq. (6-32)

$$K_f = 1 + 0.86(1.68 - 1) = 1.58$$

$$k_{f2} = \frac{1}{K_f} = \frac{1}{1.58} = 0.633$$

$$k_f = k_{f1}k_{f2} = 1.66(0.633) = 1.051$$

$$S_e = 0.766(0.919)(1)(1)(1)(1.051)(58) = 42.9 \text{ kpsi}$$

$$\sigma_{\text{all}} = \frac{S_e}{n_d} = \frac{42.9}{2} = 21.5 \text{ kpsi}$$

$$W^t = \frac{F Y_P \sigma_{\text{all}}}{K_v P_d} = \frac{2(0.303)(21\,500)}{1.692(6)} = 1283 \text{ lbf}$$

$$H = \frac{W^t V}{33\,000} = \frac{1283(830.7)}{33\,000} = 32.3 \text{ hp} \quad \text{Ans.}$$

(b) Pinion fatigue

Wear

From Table A-5 for steel: $\nu = 0.292$, $E = 30(10^6) \text{ psi}$

Eq. (14-13) or Table 14-8:

$$C_P = \left\{ \frac{1}{2\pi[(1 - 0.292^2)/30(10^6)]} \right\}^{1/2} = 2285\sqrt{\text{psi}}$$

In preparation for Eq. (14-14):

$$\text{Eq. (14-12):} \quad r_1 = \frac{d_P}{2} \sin \phi = \frac{2.833}{2} \sin 20^\circ = 0.485 \text{ in}$$

$$r_2 = \frac{d_G}{2} \sin \phi = \frac{8.500}{2} \sin 20^\circ = 1.454 \text{ in}$$

$$\left(\frac{1}{r_1} + \frac{1}{r_2} \right) = \frac{1}{0.485} + \frac{1}{1.454} = 2.750 \text{ in}$$

$$\text{Eq. (6-68):} \quad (S_C)_{10^8} = 0.4H_B - 10 \text{ kpsi}$$

In terms of gear notation

$$\sigma_C = [0.4(232) - 10]10^3 = 82\,800 \text{ psi}$$

We will introduce the design factor of $n_d = 2$ and because it is a contact stress apply it to the load W^t by dividing by $\sqrt{2}$.

$$\sigma_{C,\text{all}} = -\frac{\sigma_c}{\sqrt{2}} = -\frac{82\,800}{\sqrt{2}} = -58\,548 \text{ psi}$$

Solve Eq. (14-14) for W^t :

$$W^t = \left(\frac{-58\,548}{2285} \right)^2 \left[\frac{2 \cos 20^\circ}{1.692(2.750)} \right] = 265 \text{ lbf}$$

$$H_{\text{all}} = \frac{265(830.7)}{33\,000} = 6.67 \text{ hp} \quad \text{Ans.}$$

For 10^8 cycles (turns of pinion), the allowable power is 6.67 hp.

(c) Gear fatigue due to bending and wear

Bending

$$\text{Eq. (14-3):} \quad x = \frac{3Y_G}{2P_d} = \frac{3(0.4103)}{2(6)} = 0.1026 \text{ in}$$

$$\text{Eq. (b), p. 717:} \quad t = \sqrt{4(0.375)(0.1026)} = 0.392 \text{ in}$$

$$\text{Eq. (6-25):} \quad d_e = 0.808\sqrt{2(0.392)} = 0.715 \text{ in}$$

$$\text{Eq. (6-20):} \quad k_b = \left(\frac{0.715}{0.30} \right)^{-0.107} = 0.911$$

$$k_c = k_d = k_e = 1$$

$$\frac{r}{d} = \frac{r_f}{t} = \frac{0.050}{0.392} = 0.128$$

Approximate $D/d = \infty$ by setting $D/d = 3$ for Fig. A-15-6; $K_t = 1.80$. Use $K_f = 1.80$.

$$k_{f2} = \frac{1}{1.80} = 0.556, \quad k_f = 1.66(0.556) = 0.923$$

$$S_e = 0.766(0.911)(1)(1)(1)(0.923)(58) = 37.36 \text{ kpsi}$$

$$\sigma_{\text{all}} = \frac{S_e}{n_d} = \frac{37.36}{2} = 18.68 \text{ kpsi}$$

$$W^t = \frac{FY_G\sigma_{\text{all}}}{K_v - P_d} = \frac{2(0.4103)(18\,680)}{1.692(6)} = 1510 \text{ lbf}$$

$$H_{\text{all}} = \frac{1510(830.7)}{33\,000} = 38.0 \text{ hp} \quad \text{Ans.}$$

The gear is thus stronger than the pinion in bending.

Wear Since the material of the pinion and the gear are the same, and the contact stresses are the same, the allowable power transmission of both is the same. Thus, $H_{\text{all}} = 6.67 \text{ hp}$ for 10^8 revolutions of each. As yet, we have no way to establish S_C for $10^8/3$ revolutions.

(d) Pinion bending: $H_1 = 32.3$ hp

Pinion wear: $H_2 = 6.67$ hp

Gear bending: $H_3 = 38.0$ hp

Gear wear: $H_4 = 6.67$ hp

Power rating of the gear set is thus

$$H_{\text{rated}} = \min(32.3, 6.67, 38.0, 6.67) = 6.67 \text{ hp} \quad \text{Ans.}$$

14-19 $d_P = 16/6 = 2.667$ in, $d_G = 48/6 = 8$ in

$$V = \frac{\pi(2.667)(300)}{12} = 209.4 \text{ ft/min}$$

$$W^t = \frac{33\,000(5)}{209.4} = 787.8 \text{ lbf}$$

Assuming uniform loading, $K_o = 1$. From Eq. (14-28),

$$Q_v = 6, \quad B = 0.25(12 - 6)^{2/3} = 0.8255$$

$$A = 50 + 56(1 - 0.8255) = 59.77$$

Eq. (14-27):

$$K_v = \left(\frac{59.77 + \sqrt{209.4}}{59.77} \right)^{0.8255} = 1.196$$

From Table 14-2,

$$N_P = 16T, \quad Y_P = 0.296$$

$$N_G = 48T, \quad Y_G = 0.4056$$

From Eq. (a), Sec. 14-10 with $F = 2$ in

$$(K_s)_P = 1.192 \left(\frac{2\sqrt{0.296}}{6} \right)^{0.0535} = 1.088$$

$$(K_s)_G = 1.192 \left(\frac{2\sqrt{0.4056}}{6} \right)^{0.0535} = 1.097$$

From Eq. (14-30) with $C_{mc} = 1$

$$C_{pf} = \frac{2}{10(2.667)} - 0.0375 + 0.0125(2) = 0.0625$$

$$C_{pm} = 1, \quad C_{ma} = 0.093 \quad (\text{Fig. 14-11}), \quad C_e = 1$$

$$K_m = 1 + 1[0.0625(1) + 0.093(1)] = 1.156$$

Assuming constant thickness of the gears $\rightarrow K_B = 1$

$$m_G = N_G/N_P = 48/16 = 3$$

With N (pinion) = 10^8 cycles and N (gear) = $10^8/3$, Fig. 14-14 provides the relations:

$$(Y_N)_P = 1.3558(10^8)^{-0.0178} = 0.977$$

$$(Y_N)_G = 1.3558(10^8/3)^{-0.0178} = 0.996$$

Fig. 14-6: $J_P = 0.27, \quad J_G = 0.38$

From Table 14-10 for $R = 0.9, K_R = 0.85$

$$K_T = C_f = 1$$

Eq. (14-23) with $m_N = 1 \quad I = \frac{\cos 20^\circ \sin 20^\circ}{2} \left(\frac{3}{3+1} \right) = 0.1205$

Table 14-8: $C_p = 2300\sqrt{\text{psi}}$

Strength: Grade 1 steel with $H_{BP} = H_{BG} = 200$

Fig. 14-2: $(S_t)_P = (S_t)_G = 77.3(200) + 12\,800 = 28\,260 \text{ psi}$

Fig. 14-5: $(S_c)_P = (S_c)_G = 322(200) + 29\,100 = 93\,500 \text{ psi}$

Fig. 14-15: $(Z_N)_P = 1.4488(10^8)^{-0.023} = 0.948$

$$(Z_N)_G = 1.4488(10^8/3)^{-0.023} = 0.973$$

Fig. 14-12: $H_{BP}/H_{BG} = 1 \quad \therefore C_H = 1$

Pinion tooth bending

Eq. (14-15):

$$\begin{aligned} (\sigma)_P &= W^t K_o K_v K_s \frac{P_d}{F} \frac{K_m K_B}{J} = 787.8(1)(1.196)(1.088) \left(\frac{6}{2} \right) \left[\frac{(1.156)(1)}{0.27} \right] \\ &= 13\,167 \text{ psi} \quad \text{Ans.} \end{aligned}$$

Factor of safety from Eq. (14-41)

$$(S_F)_P = \left[\frac{S_t Y_N / (K_T K_R)}{\sigma} \right] = \frac{28\,260(0.977) / [(1)(0.85)]}{13\,167} = 2.47 \quad \text{Ans.}$$

Gear tooth bending

$$(\sigma)_G = 787.8(1)(1.196)(1.097) \left(\frac{6}{2} \right) \left[\frac{(1.156)(1)}{0.38} \right] = 9433 \text{ psi} \quad \text{Ans.}$$

$$(S_F)_G = \frac{28\,260(0.996) / [(1)(0.85)]}{9433} = 3.51 \quad \text{Ans.}$$

Pinion tooth wear

Eq. (14-16): $(\sigma_c)_P = C_p \left(W^t K_o K_v K_s \frac{K_m C_f}{d_P F I} \right)_P^{1/2}$

$$\begin{aligned} &= 2300 \left[787.8(1)(1.196)(1.088) \left(\frac{1.156}{2.667(2)} \right) \left(\frac{1}{0.1205} \right) \right]^{1/2} \\ &= 98\,760 \text{ psi} \quad \text{Ans.} \end{aligned}$$

Eq. (14-42):

$$(S_H)_P = \left[\frac{S_c Z_N / (K_T K_R)}{\sigma_c} \right]_P = \left\{ \frac{93\,500(0.948) / [(1)(0.85)]}{98\,760} \right\} = 1.06 \quad \text{Ans.}$$

Gear tooth wear

$$(\sigma_c)_G = \left[\frac{(K_s)_G}{(K_s)_P} \right]^{1/2} (\sigma_c)_P = \left(\frac{1.097}{1.088} \right)^{1/2} (98\,760) = 99\,170 \text{ psi} \quad \text{Ans.}$$

$$(S_H)_G = \frac{93\,500(0.973)(1)/[(1)(0.85)]}{99\,170} = 1.08 \quad \text{Ans.}$$

The hardness of the pinion and the gear should be increased.

14-20 $d_P = 2.5(20) = 50 \text{ mm}$, $d_G = 2.5(36) = 90 \text{ mm}$

$$V = \frac{\pi d_P n_P}{60} = \frac{\pi(50)(10^{-3})(100)}{60} = 0.2618 \text{ m/s}$$

$$W^t = \frac{60(120)}{\pi(50)(10^{-3})(100)} = 458.4 \text{ N}$$

Eq. (14-28): $K_o = 1$, $Q_v = 6$, $B = 0.25(12 - 6)^{2/3} = 0.8255$

$$A = 50 + 56(1 - 0.8255) = 59.77$$

Eq. (14-27): $K_v = \left[\frac{59.77 + \sqrt{200(0.2618)}}{59.77} \right]^{0.8255} = 1.099$

Table 14-2: $Y_P = 0.322$, $Y_G = 0.3775$

Similar to Eq. (a) of Sec. 14-10 but for SI units:

$$K_s = \frac{1}{k_b} = 0.8433(mF\sqrt{Y})^{0.0535}$$

$$(K_s)_P = 0.8433[2.5(18)\sqrt{0.322}]^{0.0535} = 1.003 \quad \text{use 1}$$

$$(K_s)_G = 0.8433[2.5(18)\sqrt{0.3775}]^{0.0535} > 1 \quad \text{use 1}$$

$$C_{mc} = 1, \quad F = 18/25.4 = 0.709 \text{ in}, \quad C_{pf} = \frac{18}{10(50)} - 0.025 = 0.011$$

$$C_{pm} = 1, \quad C_{ma} = 0.247 + 0.0167(0.709) - 0.765(10^{-4})(0.709^2) = 0.259$$

$$C_e = 1$$

$$K_H = 1 + 1[0.011(1) + 0.259(1)] = 1.27$$

Eq. (14-40): $K_B = 1$, $m_G = N_G/N_P = 36/20 = 1.8$

Fig. 14-14: $(Y_N)_P = 1.3558(10^8)^{-0.0178} = 0.977$

$$(Y_N)_G = 1.3558(10^8/1.8)^{-0.0178} = 0.987$$

Fig. 14-6: $(Y_J)_P = 0.33$, $(Y_J)_G = 0.38$

Eq. (14-38): $Y_Z = 0.658 - 0.0759 \ln(1 - 0.95) = 0.885$

Sec. 14-15: $Y_\theta = Z_R = 1$

Eq. (14-23) with $m_N = 1$:

$$Z_I = \frac{\cos 20^\circ \sin 20^\circ}{2} \left(\frac{1.8}{1.8 + 1} \right) = 0.103$$

Table 14-8: $Z_E = 191\sqrt{\text{MPa}}$

Strength Grade 1 steel, given $H_{BP} = H_{BG} = 200$

Fig. 14-2: $(\sigma_{FP})_P = (\sigma_{FP})_G = 0.533(200) + 88.3 = 194.9 \text{ MPa}$

Fig. 14-5: $(\sigma_{HP})_P = (\sigma_{HP})_G = 2.22(200) + 200 = 644 \text{ MPa}$

Fig. 14-15: $(Z_N)_P = 1.4488(10^8)^{-0.023} = 0.948$

$$(Z_N)_G = 1.4488(10^8/1.8)^{-0.023} = 0.961$$

Fig. 14-12: $H_{BP}/H_{BG} = 1 \quad \therefore Z_W = 1$

Pinion tooth bending

$$\begin{aligned} (\sigma)_P &= \left(W^t K_o K_v K_s \frac{1}{b m_t} \frac{K_H K_B}{Y_J} \right)_P \\ &= 458.4(1)(1.099)(1) \left[\frac{1}{18(2.5)} \right] \left[\frac{1.27(1)}{0.33} \right] = 43.08 \text{ MPa} \quad \text{Ans.} \end{aligned}$$

$$\text{Eq. (14-41): } (S_F)_P = \left(\frac{\sigma_{FP}}{\sigma} \frac{Y_N}{Y_\theta Y_Z} \right)_P = \frac{194.9}{43.08} \left[\frac{0.977}{1(0.885)} \right] = 4.99 \quad \text{Ans.}$$

Gear tooth bending

$$\text{Eq. (14-15): } (\sigma)_G = 458.4(1)(1.099)(1) \left[\frac{1}{18(2.5)} \right] \left[\frac{1.27(1)}{0.38} \right] = 37.42 \text{ MPa} \quad \text{Ans.}$$

$$(S_F)_G = \frac{194.9}{37.42} \left[\frac{0.987}{1(0.885)} \right] = 5.81 \quad \text{Ans.}$$

Pinion tooth wear

$$\begin{aligned} \text{Eq. (14-16): } (\sigma_c)_P &= \left(Z_E \sqrt{W^t K_o K_v K_s \frac{K_H}{d_{w1} b} \frac{Z_R}{Z_I}} \right)_P \\ &= 191 \sqrt{458.4(1)(1.099)(1) \left[\frac{1.27}{50(18)} \right] \left[\frac{1}{0.103} \right]} = 501.8 \text{ MPa} \quad \text{Ans.} \end{aligned}$$

$$\text{Eq. (14-42): } (S_H)_P = \left(\frac{\sigma_{HP}}{\sigma_c} \frac{Z_N Z_W}{Y_\theta Y_Z} \right)_P = \frac{644}{501.8} \left[\frac{0.948(1)}{1(0.885)} \right] = 1.37 \quad \text{Ans.}$$

Gear tooth wear

$$(\sigma_c)_G = \left[\frac{(K_s)_G}{(K_s)_P} \right]^{1/2} (\sigma_c)_P = \left(\frac{1}{1} \right)^{1/2} (501.8) = 501.8 \text{ MPa} \quad \text{Ans.}$$

$$(S_H)_G = \frac{644}{501.8} \left[\frac{0.961(1)}{1(0.885)} \right] = 1.39 \quad \text{Ans.}$$

14-21

$$P_t = P_n \cos \psi = 6 \cos 30^\circ = 5.196 \text{ teeth/in}$$

$$d_P = \frac{16}{5.196} = 3.079 \text{ in}, \quad d_G = \frac{48}{16}(3.079) = 9.238 \text{ in}$$

$$V = \frac{\pi(3.079)(300)}{12} = 241.8 \text{ ft/min}$$

$$W^t = \frac{33\,000(5)}{241.8} = 682.3 \text{ lbf}, \quad K_v = \left(\frac{59.77 + \sqrt{241.8}}{59.77} \right)^{0.8255} = 1.210$$

From Prob. 14-19:

$$Y_P = 0.296, \quad Y_G = 0.4056$$

$$(K_s)_P = 1.088, \quad (K_s)_G = 1.097, \quad K_B = 1$$

$$m_G = 3, \quad (Y_N)_P = 0.977, \quad (Y_N)_G = 0.996, \quad K_R = 0.85$$

$$(S_t)_P = (S_t)_G = 28\,260 \text{ psi}, \quad C_H = 1, \quad (S_c)_P = (S_c)_G = 93\,500 \text{ psi}$$

$$(Z_N)_P = 0.948, \quad (Z_N)_G = 0.973, \quad C_p = 2300\sqrt{\text{psi}}$$

The pressure angle is:

$$\text{Eq. (13-19):} \quad \phi_t = \tan^{-1} \left(\frac{\tan 20^\circ}{\cos 30^\circ} \right) = 22.80^\circ$$

$$(r_b)_P = \frac{3.079}{2} \cos 22.8^\circ = 1.419 \text{ in}, \quad (r_b)_G = 3(r_b)_P = 4.258 \text{ in}$$

$$a = 1/P_n = 1/6 = 0.167 \text{ in}$$

Eq. (14-25):

$$\begin{aligned} Z &= \left[\left(\frac{3.079}{2} + 0.167 \right)^2 - 1.419^2 \right]^{1/2} + \left[\left(\frac{9.238}{2} + 0.167 \right)^2 - 4.258^2 \right]^{1/2} \\ &\quad - \left(\frac{3.079}{2} + \frac{9.238}{2} \right) \sin 22.8^\circ \\ &= 0.9479 + 2.1852 - 2.3865 = 0.7466 \quad \text{Conditions O.K. for use} \end{aligned}$$

$$p_N = p_n \cos \phi_n = \frac{\pi}{6} \cos 20^\circ = 0.4920 \text{ in}$$

$$\text{Eq. (14-21):} \quad m_N = \frac{p_N}{0.95Z} = \frac{0.492}{0.95(0.7466)} = 0.6937$$

$$\text{Eq. (14-23):} \quad I = \left[\frac{\sin 22.8^\circ \cos 22.8^\circ}{2(0.6937)} \right] \left(\frac{3}{3+1} \right) = 0.193$$

Fig. 14-7:

$$J'_P \doteq 0.45, \quad J'_G \doteq 0.54$$

Fig. 14-8: Corrections are 0.94 and 0.98

$$J_P = 0.45(0.94) = 0.423, \quad J_G = 0.54(0.98) = 0.529$$

$$C_{mc} = 1, \quad C_{pf} = \frac{2}{10(3.079)} - 0.0375 + 0.0125(2) = 0.0525$$

$$C_{pm} = 1, \quad C_{ma} = 0.093, \quad C_e = 1$$

$$K_m = 1 + (1)[0.0525(1) + 0.093(1)] = 1.146$$

Pinion tooth bending

$$(\sigma)_P = 682.3(1)(1.21)(1.088) \left(\frac{5.196}{2} \right) \left[\frac{1.146(1)}{0.423} \right] = 6323 \text{ psi} \quad \text{Ans.}$$

$$(S_F)_P = \frac{28\,260(0.977)/[1(0.85)]}{6323} = 5.14 \quad \text{Ans.}$$

Gear tooth bending

$$(\sigma)_G = 682.3(1)(1.21)(1.097) \left(\frac{5.196}{2} \right) \left[\frac{1.146(1)}{0.529} \right] = 5097 \text{ psi} \quad \text{Ans.}$$

$$(S_F)_G = \frac{28\,260(0.996)/[1(0.85)]}{5097} = 6.50 \quad \text{Ans.}$$

Pinion tooth wear

$$(\sigma_c)_P = 2300 \left\{ 682.3(1)(1.21)(1.088) \left[\frac{1.146}{3.078(2)} \right] \left(\frac{1}{0.193} \right) \right\}^{1/2} = 67\,700 \text{ psi} \quad \text{Ans.}$$

$$(S_H)_P = \frac{93\,500(0.948)/[(1)(0.85)]}{67\,700} = 1.54 \quad \text{Ans.}$$

Gear tooth wear

$$(\sigma_c)_G = \left[\frac{1.097}{1.088} \right]^{1/2} (67\,700) = 67\,980 \text{ psi} \quad \text{Ans.}$$

$$(S_H)_G = \frac{93\,500(0.973)/[(1)(0.85)]}{67\,980} = 1.57 \quad \text{Ans.}$$

14-22 Given: $N_P = 17T$, $N_G = 51T$, $R = 0.99$ at 10^8 cycles, $H_B = 232$ through-hardening Grade 1, core and case, both gears.

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

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

$$d_P = N_P/P = 17/6 = 2.833 \text{ in}, \quad d_G = 51/6 = 8.5 \text{ in}$$

Pinion bending

From Fig. 14-2:

$$_{0.99}(S_t)_{10^7} = 77.3H_B + 12\,800$$

$$= 77.3(232) + 12\,800 = 30\,734 \text{ psi}$$

Fig. 14-14:

$$Y_N = 1.6831(10^8)^{-0.0323} = 0.928$$

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

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

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

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

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

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

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

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

$$C_{mc} = 1$$

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

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

$$= 0.0581$$

$$C_{pm} = 1$$

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

$$C_e = 1$$

$$K_m = 1 + 1[0.0581(1) + 0.1586(1)] = 1.2167$$

$$K_\beta = 1$$

Eq. (14-15):

$$W^t = \frac{F J_P \sigma_{\text{all}}}{K_o K_v K_s P_d K_m K_B}$$

$$= \frac{2(0.292)(14\,261)}{1(1.472)(1)(6)(1.2167)(1)} = 775 \text{ lbf}$$

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

Pinion wear

Fig. 14-15:

$$Z_N = 2.466N^{-0.056} = 2.466(10^8)^{-0.056} = 0.879$$

$$M_G = 51/17 = 3$$

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

Fig. 14-5: $0.99(S_c)_{10^7} = 322H_B + 29\,100$
 $= 322(232) + 29\,100 = 103\,804 \text{ psi}$
 $\sigma_{c,all} = \frac{103\,804(0.879)}{\sqrt{2}(1)(1)} = 64\,519 \text{ psi}$

Eq. (14-16): $W^t = \left(\frac{\sigma_{c,all}}{C_p} \right)^2 \frac{F d_P I}{K_o K_v K_s K_m C_f}$
 $= \left(\frac{64\,519}{2300} \right)^2 \left[\frac{2(2.833)(0.1205)}{1(1.472)(1)(1.2167)(1)} \right]$
 $= 300 \text{ lbf}$
 $H = \frac{W^t V}{33\,000} = \frac{300(830.7)}{33\,000} = 7.55 \text{ hp}$

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

14-23

$$l = 2.25/P_d, \quad x = \frac{3Y}{2P_d}$$

$$t = \sqrt{4lx} = \sqrt{4 \left(\frac{2.25}{P_d} \right) \left(\frac{3Y}{2P_d} \right)} = \frac{3.674}{P_d} \sqrt{Y}$$

$$d_e = 0.808 \sqrt{Ft} = 0.808 \sqrt{F \left(\frac{3.674}{P_d} \right) \sqrt{Y}} = 1.5487 \sqrt{\frac{F \sqrt{Y}}{P_d}}$$

$$k_b = \left(\frac{1.5487 \sqrt{F \sqrt{Y}/P_d}}{0.30} \right)^{-0.107} = 0.8389 \left(\frac{F \sqrt{Y}}{P_d} \right)^{-0.0535}$$

$$K_s = \frac{1}{k_b} = 1.192 \left(\frac{F \sqrt{Y}}{P_d} \right)^{0.0535} \quad \text{Ans.}$$

14-24 $Y_P = 0.331$, $Y_G = 0.422$, $J_P = 0.345$, $J_G = 0.410$, $K_o = 1.25$. The service conditions are adequately described by K_o . Set $S_F = S_H = 1$.

$$d_P = 22/4 = 5.500 \text{ in}$$

$$d_G = 60/4 = 15.000 \text{ in}$$

$$V = \frac{\pi(5.5)(1145)}{12} = 1649 \text{ ft/min}$$

Pinion bending

$$0.99(S_t)_{10^7} = 77.3H_B + 12\,800 = 77.3(250) + 12\,800 = 32\,125 \text{ psi}$$

$$Y_N = 1.6831[3(10^9)]^{-0.0323} = 0.832$$

$$\text{Eq. (14-17):} \quad (\sigma_{\text{all}})_P = \frac{32\,125(0.832)}{1(1)(1)} = 26\,728 \text{ psi}$$

$$B = 0.25(12 - 6)^{2/3} = 0.8255$$

$$A = 50 + 56(1 - 0.8255) = 59.77$$

$$K_v = \left(\frac{59.77 + \sqrt{1649}}{59.77} \right)^{0.8255} = 1.534$$

$$K_s = 1, \quad C_m = 1$$

$$\begin{aligned} C_{mc} &= \frac{F}{10d} - 0.0375 + 0.0125F \\ &= \frac{3.25}{10(5.5)} - 0.0375 + 0.0125(3.25) = 0.0622 \end{aligned}$$

$$C_{ma} = 0.127 + 0.0158(3.25) - 0.093(10^{-4})(3.25^2) = 0.178$$

$$C_e = 1$$

$$K_m = C_{mf} = 1 + (1)[0.0622(1) + 0.178(1)] = 1.240$$

$$K_B = 1, \quad K_T = 1$$

$$\text{Eq. (14-15):} \quad W_1^t = \frac{26\,728(3.25)(0.345)}{1.25(1.534)(1)(4)(1.240)} = 3151 \text{ lbf}$$

$$H_1 = \frac{3151(1649)}{33\,000} = 157.5 \text{ hp}$$

Gear bending By similar reasoning, $W_2^t = 3861 \text{ lbf}$ and $H_2 = 192.9 \text{ hp}$

Pinion wear

$$m_G = 60/22 = 2.727$$

$$I = \frac{\cos 20^\circ \sin 20^\circ}{2} \left(\frac{2.727}{1 + 2.727} \right) = 0.1176$$

$$0.99(S_c)_{10^7} = 322(250) + 29\,100 = 109\,600 \text{ psi}$$

$$(Z_N)_P = 2.466[3(10^9)]^{-0.056} = 0.727$$

$$(Z_N)_G = 2.466[3(10^9)/2.727]^{-0.056} = 0.769$$

$$(\sigma_{c,\text{all}})_P = \frac{109\,600(0.727)}{1(1)(1)} = 79\,679 \text{ psi}$$

$$\begin{aligned} W_3^t &= \left(\frac{\sigma_{c,\text{all}}}{C_p} \right)^2 \frac{F d_p I}{K_o K_v K_s K_m C_f} \\ &= \left(\frac{79\,679}{2300} \right)^2 \left[\frac{3.25(5.5)(0.1176)}{1.25(1.534)(1)(1.24)(1)} \right] = 1061 \text{ lbf} \end{aligned}$$

$$H_3 = \frac{1061(1649)}{33\,000} = 53.0 \text{ hp}$$

Gear wear

Similarly, $W_4^t = 1182 \text{ lbf}$, $H_4 = 59.0 \text{ hp}$

Rating

$$H_{\text{rated}} = \min(H_1, H_2, H_3, H_4) \\ = \min(157.5, 192.9, 53, 59) = 53 \text{ hp} \quad \text{Ans.}$$

Note differing capacities. Can these be equalized?

14-25 From Prob. 14-24:

$$W_1^t = 3151 \text{ lbf}, \quad W_2^t = 3861 \text{ lbf},$$

$$W_3^t = 1061 \text{ lbf}, \quad W_4^t = 1182 \text{ lbf}$$

$$W^t = \frac{33\,000 K_o H}{V} = \frac{33\,000(1.25)(40)}{1649} = 1000 \text{ lbf}$$

Pinion bending: The factor of safety, based on load and stress, is

$$(S_F)_P = \frac{W_1^t}{1000} = \frac{3151}{1000} = 3.15$$

Gear bending based on load and stress

$$(S_F)_G = \frac{W_2^t}{1000} = \frac{3861}{1000} = 3.86$$

Pinion wear

$$\text{based on load:} \quad n_3 = \frac{W_3^t}{1000} = \frac{1061}{1000} = 1.06$$

$$\text{based on stress:} \quad (S_H)_P = \sqrt{1.06} = 1.03$$

Gear wear

$$\text{based on load:} \quad n_4 = \frac{W_4^t}{1000} = \frac{1182}{1000} = 1.18$$

$$\text{based on stress:} \quad (S_H)_G = \sqrt{1.18} = 1.09$$

Factors of safety are used to assess the relative threat of loss of function 3.15, 3.86, 1.06, 1.18 where the threat is from pinion wear. By comparison, the AGMA safety factors

$$(S_F)_P, (S_F)_G, (S_H)_P, (S_H)_G$$

are

$$3.15, 3.86, 1.03, 1.09 \quad \text{or} \quad 3.15, 3.86, 1.06^{1/2}, 1.18^{1/2}$$

and the threat is again from pinion wear. Depending on the magnitude of the numbers, using S_F and S_H as defined by AGMA, does not *necessarily* lead to the same conclusion concerning threat. Therefore be cautious.

14-26 Solution summary from Prob. 14-24: $n = 1145$ rev/min, $K_o = 1.25$, Grade 1 materials, $N_P = 22T$, $N_G = 60T$, $m_G = 2.727$, $Y_P = 0.331$, $Y_G = 0.422$, $J_P = 0.345$, $J_G = 0.410$, $P_d = 4T/\text{in}$, $F = 3.25$ in, $Q_v = 6$, $(N_c)_P = 3(10^9)$, $R = 0.99$

Pinion H_B : 250 core, 390 case

Gear H_B : 250 core, 390 case

$K_m = 1.240$, $K_T = 1$, $K_B = 1$, $d_P = 5.500$ in, $d_G = 15.000$ in,
 $V = 1649$ ft/min, $K_v = 1.534$, $(K_s)_P = (K_s)_G = 1$, $(Y_N)_P = 0.832$,
 $(Y_N)_G = 0.859$, $K_R = 1$

Bending

$$(\sigma_{\text{all}})_P = 26\,728 \text{ psi} \quad (S_t)_P = 32\,125 \text{ psi}$$

$$(\sigma_{\text{all}})_G = 27\,546 \text{ psi} \quad (S_t)_G = 32\,125 \text{ psi}$$

$$W_1^t = 3151 \text{ lbf}, \quad H_1 = 157.5 \text{ hp}$$

$$W_2^t = 3861 \text{ lbf}, \quad H_2 = 192.9 \text{ hp}$$

Wear

$$\phi = 20^\circ, \quad I = 0.1176, \quad (Z_N)_P = 0.727,$$

$$(Z_N)_G = 0.769, \quad C_P = 2300\sqrt{\text{psi}}$$

$$(S_c)_P = S_c = 322(390) + 29\,100 = 154\,680 \text{ psi}$$

$$(\sigma_{c,\text{all}})_P = \frac{154\,680(0.727)}{1(1)(1)} = 112\,450 \text{ psi}$$

$$(\sigma_{c,\text{all}})_G = \frac{154\,680(0.769)}{1(1)(1)} = 118\,950 \text{ psi}$$

$$W_3^t = \left(\frac{112\,450}{79\,679} \right)^2 (1061) = 2113 \text{ lbf}, \quad H_3 = \frac{2113(1649)}{33\,000} = 105.6 \text{ hp}$$

$$W_4^t = \left(\frac{118\,950}{109\,600(0.769)} \right)^2 (1182) = 2354 \text{ lbf}, \quad H_4 = \frac{2354(1649)}{33\,000} = 117.6 \text{ hp}$$

Rated power

$$H_{\text{rated}} = \min(157.5, 192.9, 105.6, 117.6) = 105.6 \text{ hp} \quad \text{Ans.}$$

Prob. 14-24

$$H_{\text{rated}} = \min(157.5, 192.9, 53.0, 59.0) = 53 \text{ hp}$$

The rated power approximately doubled.

14-27 The gear and the pinion are 9310 grade 1, carburized and case-hardened to obtain Brinell 285 core and Brinell 580–600 case.

Table 14-3:

$$0.99(S_t)_{10^7} = 55\,000 \text{ psi}$$

Modification of S_t by $(Y_N)_P = 0.832$ produces

$$(\sigma_{\text{all}})_P = 45\,657 \text{ psi},$$

Similarly for $(Y_N)_G = 0.859$

$$(\sigma_{\text{all}})_G = 47\,161 \text{ psi}, \quad \text{and}$$

$$W_1^t = 4569 \text{ lbf}, \quad H_1 = 228 \text{ hp}$$

$$W_2^t = 5668 \text{ lbf}, \quad H_2 = 283 \text{ hp}$$

From Table 14-8, $C_p = 2300\sqrt{\text{psi}}$. Also, from Table 14-6:

$$0.99(S_c)_{10^7} = 180\,000 \text{ psi}$$

Modification of S_c by (Y_N) produces

$$(\sigma_{c,\text{all}})_P = 130\,525 \text{ psi}$$

$$(\sigma_{c,\text{all}})_G = 138\,069 \text{ psi}$$

and

$$W_3^t = 2489 \text{ lbf}, \quad H_3 = 124.3 \text{ hp}$$

$$W_4^t = 2767 \text{ lbf}, \quad H_4 = 138.2 \text{ hp}$$

Rating

$$H_{\text{rated}} = \min(228, 283, 124, 138) = 124 \text{ hp} \quad \text{Ans.}$$

14-28 Grade 2 9310 carburized and case-hardened to 285 core and 580 case in Prob. 14-27.

Summary:

Table 14-3:

$$0.99(S_t)_{10^7} = 65\,000 \text{ psi}$$

$$(\sigma_{\text{all}})_P = 53\,959 \text{ psi}$$

$$(\sigma_{\text{all}})_G = 55\,736 \text{ psi}$$

and it follows that

$$W_1^t = 5399.5 \text{ lbf}, \quad H_1 = 270 \text{ hp}$$

$$W_2^t = 6699 \text{ lbf}, \quad H_2 = 335 \text{ hp}$$

From Table 14-8, $C_p = 2300\sqrt{\text{psi}}$. Also, from Table 14-6:

$$S_c = 225\,000 \text{ psi}$$

$$(\sigma_{c,\text{all}})_P = 181\,285 \text{ psi}$$

$$(\sigma_{c,\text{all}})_G = 191\,762 \text{ psi}$$

Consequently,

$$W_3^t = 4801 \text{ lbf}, \quad H_3 = 240 \text{ hp}$$

$$W_4^t = 5337 \text{ lbf}, \quad H_4 = 267 \text{ hp}$$

Rating

$$H_{\text{rated}} = \min(270, 335, 240, 267) = 240 \text{ hp.} \quad \text{Ans.}$$

14-29 $n = 1145 \text{ rev/min}$, $K_o = 1.25$, $N_P = 22T$, $N_G = 60T$, $m_G = 2.727$, $d_P = 2.75 \text{ in}$, $d_G = 7.5 \text{ in}$, $Y_P = 0.331$, $Y_G = 0.422$, $J_P = 0.335$, $J_G = 0.405$, $P = 8T/\text{in}$, $F = 1.625 \text{ in}$, $H_B = 250$, case and core, both gears. $C_m = 1$, $F/d_P = 0.0591$, $C_f = 0.0419$, $C_{pm} = 1$, $C_{ma} = 0.152$, $C_e = 1$, $K_m = 1.1942$, $K_T = 1$, $K_\beta = 1$, $K_s = 1$, $V = 824 \text{ ft/min}$, $(Y_N)_P = 0.8318$, $(Y_N)_G = 0.859$, $K_R = 1$, $I = 0.11758$

$$0.99(S_t)_{10^7} = 32\,125 \text{ psi}$$

$$(\sigma_{\text{all}})_P = 26\,668 \text{ psi}$$

$$(\sigma_{\text{all}})_G = 27\,546 \text{ psi}$$

and it follows that

$$W_1^t = 879.3 \text{ lbf}, \quad H_1 = 21.97 \text{ hp}$$

$$W_2^t = 1098 \text{ lbf}, \quad H_2 = 27.4 \text{ hp}$$

For wear

$$W_3^t = 304 \text{ lbf}, \quad H_3 = 7.59 \text{ hp}$$

$$W_4^t = 340 \text{ lbf}, \quad H_4 = 8.50 \text{ hp}$$

Rating

$$H_{\text{rated}} = \min(21.97, 27.4, 7.59, 8.50) = 7.59 \text{ hp}$$

In Prob. 14-24, $H_{\text{rated}} = 53 \text{ hp}$

Thus

$$\frac{7.59}{53.0} = 0.1432 = \frac{1}{6.98}, \quad \text{not } \frac{1}{8} \quad \text{Ans.}$$

The transmitted load rating is

$$W_{\text{rated}}^t = \min(879.3, 1098, 304, 340) = 304 \text{ lbf}$$

In Prob. 14-24

$$W_{\text{rated}}^t = 1061 \text{ lbf}$$

Thus

$$\frac{304}{1061} = 0.2865 = \frac{1}{3.49}, \quad \text{not } \frac{1}{4}, \quad \text{Ans.}$$

14-30 $S_P = S_H = 1$, $P_d = 4$, $J_P = 0.345$, $J_G = 0.410$, $K_o = 1.25$

Bending

Table 14-4: $0.99(S_t)_{10^7} = 13\,000 \text{ psi}$

$$(\sigma_{\text{all}})_P = (\sigma_{\text{all}})_G = \frac{13\,000(1)}{1(1)(1)} = 13\,000 \text{ psi}$$

$$W_1^t = \frac{\sigma_{\text{all}} F J_P}{K_o K_v K_s P_d K_m K_B} = \frac{13\,000(3.25)(0.345)}{1.25(1.534)(1)(4)(1.24)(1)} = 1533 \text{ lbf}$$

$$H_1 = \frac{1533(1649)}{33\,000} = 76.6 \text{ hp}$$

$$W_2^t = W_1^t J_G / J_P = 1533(0.410) / 0.345 = 1822 \text{ lbf}$$

$$H_2 = H_1 J_G / J_P = 76.6(0.410) / 0.345 = 91.0 \text{ hp}$$

Wear

Table 14-8:

$$C_p = 1960\sqrt{\text{psi}}$$

Table 14-7: $0.99(S_c)_{10^7} = 75\,000 \text{ psi} = (\sigma_{c,\text{all}})_P = (\sigma_{c,\text{all}})_G$

$$W_3^t = \left(\frac{(\sigma_{c,\text{all}})_P}{C_p} \right)^2 \frac{F d p I}{K_o K_v K_s K_m C_f}$$

$$W_3^t = \left(\frac{75\,000}{1960} \right)^2 \frac{3.25(5.5)(0.1176)}{1.25(1.534)(1)(1.24)(1)} = 1295 \text{ lbf}$$

$$W_4^t = W_3^t = 1295 \text{ lbf}$$

$$H_4 = H_3 = \frac{1295(1649)}{33\,000} = 64.7 \text{ hp}$$

Rating

$$H_{\text{rated}} = \min(76.7, 94.4, 64.7, 64.7) = 64.7 \text{ hp} \quad \text{Ans.}$$

Notice that the balance between bending and wear power is improved due to CI's more favorable S_c/S_t ratio. Also note that the life is 10^7 pinion revolutions which is $(1/300)$ of $3(10^9)$. Longer life goals require power derating.

14-31 From Table A-24a, $E_{av} = 11.8(10^6)$

For $\phi = 14.5^\circ$ and $H_B = 156$

$$S_C = \sqrt{\frac{1.4(81)}{2 \sin 14.5^\circ / [11.8(10^6)]}} = 51\,693 \text{ psi}$$

For $\phi = 20^\circ$

$$S_C = \sqrt{\frac{1.4(112)}{2 \sin 20^\circ / [11.8(10^6)]}} = 52\,008 \text{ psi}$$

$$S_C = 0.32(156) = 49.9 \text{ kpsi}$$

14-32 Programs will vary.

14-33

$$(Y_N)_P = 0.977, \quad (Y_N)_G = 0.996$$

$$(S_t)_P = (S_t)_G = 82.3(250) + 12\,150 = 32\,725 \text{ psi}$$

$$(\sigma_{\text{all}})_P = \frac{32\,725(0.977)}{1(0.85)} = 37\,615 \text{ psi}$$

$$W_1^t = \frac{37\,615(1.5)(0.423)}{1(1.404)(1.043)(8.66)(1.208)(1)} = 1558 \text{ lbf}$$

$$H_1 = \frac{1558(925)}{33\,000} = 43.7 \text{ hp}$$

$$(\sigma_{\text{all}})_G = \frac{32\,725(0.996)}{1(0.85)} = 38\,346 \text{ psi}$$

$$W_2^t = \frac{38\,346(1.5)(0.5346)}{1(1.404)(1.043)(8.66)(1.208)(1)} = 2007 \text{ lbf}$$

$$H_2 = \frac{2007(925)}{33\,000} = 56.3 \text{ hp}$$

$$(Z_N)_P = 0.948, \quad (Z_N)_G = 0.973$$

Table 14-6: $0.99(S_c)_{10^7} = 150\,000 \text{ psi}$

$$(\sigma_{c,\text{allow}})_P = 150\,000 \left[\frac{0.948(1)}{1(0.85)} \right] = 167\,294 \text{ psi}$$

$$W_3^t = \left(\frac{167\,294}{2300} \right)^2 \left[\frac{1.963(1.5)(0.195)}{1(1.404)(1.043)} \right] = 2074 \text{ lbf}$$

$$H_3 = \frac{2074(925)}{33\,000} = 58.1 \text{ hp}$$

$$(\sigma_{c,\text{allow}})_G = \frac{0.973}{0.948}(167\,294) = 171\,706 \text{ psi}$$

$$W_4^t = \left(\frac{171\,706}{2300} \right)^2 \left[\frac{1.963(1.5)(0.195)}{1(1.404)(1.052)} \right] = 2167 \text{ lbf}$$

$$H_4 = \frac{2167(925)}{33\,000} = 60.7 \text{ hp}$$

$$H_{\text{rated}} = \min(43.7, 56.3, 58.1, 60.7) = 43.7 \text{ hp} \quad \text{Ans.}$$

Pinion bending controlling

14-34

$$(Y_N)_P = 1.6831(10^8)^{-0.0323} = 0.928$$

$$(Y_N)_G = 1.6831(10^8/3.059)^{-0.0323} = 0.962$$

Table 14-3: $S_t = 55\,000 \text{ psi}$

$$(\sigma_{\text{all}})_P = \frac{55\,000(0.928)}{1(0.85)} = 60\,047 \text{ psi}$$

$$W_1^t = \frac{60\,047(1.5)(0.423)}{1(1.404)(1.043)(8.66)(1.208)(1)} = 2487 \text{ lbf}$$

$$H_1 = \frac{2487(925)}{33\,000} = 69.7 \text{ hp}$$

$$(\sigma_{\text{all}})_G = \frac{0.962}{0.928}(60\,047) = 62\,247 \text{ psi}$$

$$W_2^t = \frac{62\,247}{60\,047} \left(\frac{0.5346}{0.423} \right) (2487) = 3258 \text{ lbf}$$

$$H_2 = \frac{3258}{2487}(69.7) = 91.3 \text{ hp}$$

Table 14-6:

$$S_c = 180\,000 \text{ psi}$$

$$(Z_N)_P = 2.466(10^8)^{-0.056} = 0.8790$$

$$(Z_N)_G = 2.466(10^8/3.059)^{-0.056} = 0.9358$$

$$(\sigma_{c,all})_P = \frac{180\,000(0.8790)}{1(0.85)} = 186\,141 \text{ psi}$$

$$W_3^t = \left(\frac{186\,141}{2300} \right)^2 \left[\frac{1.963(1.5)(0.195)}{1(1.404)(1.043)} \right] = 2568 \text{ lbf}$$

$$H_3 = \frac{2568(925)}{33\,000} = 72.0 \text{ hp}$$

$$(\sigma_{c,all})_G = \frac{0.9358}{0.8790}(186\,141) = 198\,169 \text{ psi}$$

$$W_4^t = \left(\frac{198\,169}{186\,141} \right)^2 \left(\frac{1.043}{1.052} \right) (2568) = 2886 \text{ lbf}$$

$$H_4 = \frac{2886(925)}{33\,000} = 80.9 \text{ hp}$$

$$H_{\text{rated}} = \min(69.7, 91.3, 72, 80.9) = 69.7 \text{ hp} \quad \text{Ans.}$$

Pinion bending controlling

14-35 $(Y_N)_P = 0.928$, $(Y_N)_G = 0.962$ (See Prob. 14-34)

Table 14-3:

$$S_t = 65\,000 \text{ psi}$$

$$(\sigma_{all})_P = \frac{65\,000(0.928)}{1(0.85)} = 70\,965 \text{ psi}$$

$$W_1^t = \frac{70\,965(1.5)(0.423)}{1(1.404)(1.043)(8.66)(1.208)} = 2939 \text{ lbf}$$

$$H_1 = \frac{2939(925)}{33\,000} = 82.4 \text{ hp}$$

$$(\sigma_{all})_G = \frac{65\,000(0.962)}{1(0.85)} = 73\,565 \text{ psi}$$

$$W_2^t = \frac{73\,565}{70\,965} \left(\frac{0.5346}{0.423} \right) (2939) = 3850 \text{ lbf}$$

$$H_2 = \frac{3850}{2939}(82.4) = 108 \text{ hp}$$

Table 14-6: $S_c = 225\,000$ psi

$$(Z_N)_P = 0.8790, \quad (Z_N)_G = 0.9358$$

$$(\sigma_{c,all})_P = \frac{225\,000(0.879)}{1(0.85)} = 232\,676 \text{ psi}$$

$$W_3^t = \left(\frac{232\,676}{2300} \right)^2 \left[\frac{1.963(1.5)(0.195)}{1(1.404)(1.043)} \right] = 4013 \text{ lbf}$$

$$H_3 = \frac{4013(925)}{33\,000} = 112.5 \text{ hp}$$

$$(\sigma_{c,all})_G = \frac{0.9358}{0.8790}(232\,676) = 247\,711 \text{ psi}$$

$$W_4^t = \left(\frac{247\,711}{232\,676} \right)^2 \left(\frac{1.043}{1.052} \right) (4013) = 4509 \text{ lbf}$$

$$H_4 = \frac{4509(925)}{33\,000} = 126 \text{ hp}$$

$$H_{\text{rated}} = \min(82.4, 108, 112.5, 126) = 82.4 \text{ hp} \quad \text{Ans.}$$

The bending of the pinion is the controlling factor.