

Chapter 1

Problems 1-1 through 1-6 are for student research. No standard solutions are provided.

- 1-7 From Fig. 1-2, cost of grinding to ± 0.0005 in is 270%. Cost of turning to ± 0.003 in is 60%.

$$\text{Relative cost of grinding vs. turning} = 270/60 = 4.5 \text{ times} \quad \text{Ans.}$$

- 1-8 $C_A = C_B$,

$$10 + 0.8 P = 60 + 0.8 P - 0.005 P^2$$

$$P^2 = 50/0.005 \quad \Rightarrow \quad P = 100 \text{ parts} \quad \text{Ans.}$$

- 1-9 Max. load = $1.10 P$
Min. area = $(0.95)^2 A$
Min. strength = $0.85 S$

To offset the absolute uncertainties, the design factor, from Eq. (1-1) should be

$$n_d = \frac{1.10}{0.85(0.95)^2} = 1.43 \quad \text{Ans.}$$

- 1-10 (a) $X_1 + X_2$:

$$x_1 + x_2 = X_1 + e_1 + X_2 + e_2$$

$$\begin{aligned} \text{error} = e &= (x_1 + x_2) - (X_1 + X_2) \\ &= e_1 + e_2 \quad \text{Ans.} \end{aligned}$$

- (b) $X_1 - X_2$:

$$x_1 - x_2 = X_1 + e_1 - (X_2 + e_2)$$

$$e = (x_1 - x_2) - (X_1 - X_2) = e_1 - e_2 \quad \text{Ans.}$$

- (c) $X_1 X_2$:

$$x_1 x_2 = (X_1 + e_1)(X_2 + e_2)$$

$$e = x_1 x_2 - X_1 X_2 = X_1 e_2 + X_2 e_1 + e_1 e_2$$

$$\doteq X_1 e_2 + X_2 e_1 = X_1 X_2 \left(\frac{e_1}{X_1} + \frac{e_2}{X_2} \right) \quad \text{Ans.}$$

(d) X_1/X_2 :

$$\frac{x_1}{x_2} = \frac{X_1 + e_1}{X_2 + e_2} = \frac{X_1}{X_2} \left(\frac{1 + e_1/X_1}{1 + e_2/X_2} \right)$$

$$\left(1 + \frac{e_2}{X_2} \right)^{-1} \doteq 1 - \frac{e_2}{X_2} \quad \text{then} \quad \left(\frac{1 + e_1/X_1}{1 + e_2/X_2} \right) \doteq \left(1 + \frac{e_1}{X_1} \right) \left(1 - \frac{e_2}{X_2} \right) \doteq 1 + \frac{e_1}{X_1} - \frac{e_2}{X_2}$$

Thus, $e = \frac{x_1}{x_2} - \frac{X_1}{X_2} \doteq \frac{X_1}{X_2} \left(\frac{e_1}{X_1} - \frac{e_2}{X_2} \right)$ Ans.

1-11 (a) $x_1 = \sqrt{7} = 2.645\,751\,311\,1$
 $X_1 = 2.64$ (3 correct digits)
 $x_2 = \sqrt{8} = 2.828\,427\,124\,7$
 $X_2 = 2.82$ (3 correct digits)
 $x_1 + x_2 = 5.474\,178\,435\,8$
 $e_1 = x_1 - X_1 = 0.005\,751\,311\,1$
 $e_2 = x_2 - X_2 = 0.008\,427\,124\,7$
 $e = e_1 + e_2 = 0.014\,178\,435\,8$
 $\text{Sum} = x_1 + x_2 = X_1 + X_2 + e$
 $= 2.64 + 2.82 + 0.014\,178\,435\,8 = 5.474\,178\,435\,8$ Checks

(b) $X_1 = 2.65$, $X_2 = 2.83$ (3 digit significant numbers)
 $e_1 = x_1 - X_1 = -0.004\,248\,688\,9$
 $e_2 = x_2 - X_2 = -0.001\,572\,875\,3$
 $e = e_1 + e_2 = -0.005\,821\,564\,2$
 $\text{Sum} = x_1 + x_2 = X_1 + X_2 + e$
 $= 2.65 + 2.83 - 0.001\,572\,875\,3 = 5.474\,178\,435\,8$ Checks

1-12 $\sigma = \frac{S}{n_d} \Rightarrow \frac{16(1000)}{\pi d^3} = \frac{25(10^3)}{2.5} \Rightarrow d = 0.799$ in Ans.

Table A-17: $d = \frac{7}{8}$ in Ans.

Factor of safety: $n = \frac{S}{\sigma} = \frac{25(10^3)}{\frac{16(1000)}{\pi \left(\frac{7}{8}\right)^3}} = 3.29$ Ans.

1-13 Eq. (1-5): $R = \sum_{i=1}^n R_i = 0.98(0.96)0.94 = 0.88$

Overall reliability = 88 percent Ans.

1-14

$$a = 1.500 \pm 0.001 \text{ in}$$

$$b = 2.000 \pm 0.003 \text{ in}$$

$$c = 3.000 \pm 0.004 \text{ in}$$

$$d = 6.520 \pm 0.010 \text{ in}$$

(a) $\bar{w} = \bar{d} - \bar{a} - \bar{b} - \bar{c} = 6.520 - 1.5 - 2 - 3 = 0.020 \text{ in}$

$$t_w = \sum t_{\text{all}} = 0.001 + 0.003 + 0.004 + 0.010 = 0.018$$

$$w = 0.020 \pm 0.018 \text{ in} \quad \text{Ans.}$$

(b) From part (a), $w_{\min} = 0.002 \text{ in}$. Thus, must add 0.008 in to $\bar{d}$. Therefore,

$$\bar{d} = 6.520 + 0.008 = 6.528 \text{ in} \quad \text{Ans.}$$

1-15 $V = xyz$, and $x = a \pm \Delta a$, $y = b \pm \Delta b$, $z = c \pm \Delta c$,

$$\bar{V} = abc$$

$$V = (a \pm \Delta a)(b \pm \Delta b)(c \pm \Delta c)$$

$$= abc \pm bc\Delta a \pm ac\Delta b \pm ab\Delta c \pm a\Delta b\Delta c \pm b\Delta c\Delta a \pm c\Delta a\Delta b \pm \Delta a\Delta b\Delta c$$

The higher order terms in Δ are negligible. Thus,

$$\Delta V \doteq bc\Delta a + ac\Delta b + ab\Delta c$$

and,
$$\frac{\Delta V}{\bar{V}} \doteq \frac{bc\Delta a + ac\Delta b + ab\Delta c}{abc} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c} = \frac{\Delta a}{\bar{a}} + \frac{\Delta b}{\bar{b}} + \frac{\Delta c}{\bar{c}} \quad \text{Ans.}$$

For the numerical values given, $\bar{V} = 1.500(1.875)3.000 = 8.4375 \text{ in}^3$

$$\frac{\Delta V}{\bar{V}} = \frac{0.002}{1.500} + \frac{0.003}{1.875} + \frac{0.004}{3.000} = 0.00427 \Rightarrow \Delta V = 0.00427(8.4375) = 0.036 \text{ in}^3$$

$$V = 8.438 \pm 0.036 \text{ in}^3 \quad \text{Ans.}$$

1-16

$$w_{\max} = 0.05 \text{ in}, \quad w_{\min} = 0.004 \text{ in}$$

$$\bar{w} = \frac{0.05 + 0.004}{2} = 0.027 \text{ in}$$

Thus, $\Delta w = 0.05 - 0.027 = 0.023 \text{ in}$, and then, $w = 0.027 \pm 0.023 \text{ in}$.

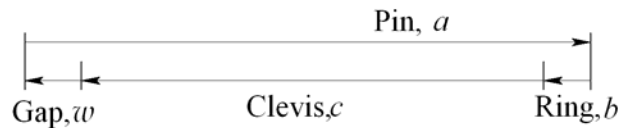
$$\bar{w} = \bar{a} - \bar{b} - \bar{c}$$

$$0.027 = \bar{a} - 0.042 - 1.5$$

$$\bar{a} = 1.569 \text{ in}$$

$$t_w = \sum t_{\text{all}} \Rightarrow 0.023 = t_a + 0.002 + 0.005 \Rightarrow t_a = 0.016 \text{ in}$$

Thus, $a = 1.569 \pm 0.016 \text{ in}$ *Ans.*



1-17

$$\bar{D}_o = \bar{D}_i + 2\bar{d} = 3.734 + 2(0.139) = 4.012 \text{ in}$$

$$t_{D_o} = \sum t_{\text{all}} = 0.028 + 2(0.004) = 0.036 \text{ in}$$

$D_o = 4.012 \pm 0.036 \text{ in}$ *Ans.*

1-18 From O-Rings, Inc. (oringsusa.com), $D_i = 9.19 \pm 0.13 \text{ mm}$, $d = 2.62 \pm 0.08 \text{ mm}$

$$\bar{D}_o = \bar{D}_i + 2\bar{d} = 9.19 + 2(2.62) = 14.43 \text{ mm}$$

$$t_{D_o} = \sum t_{\text{all}} = 0.13 + 2(0.08) = 0.29 \text{ mm}$$

$D_o = 14.43 \pm 0.29 \text{ mm}$ *Ans.*

1-19 From O-Rings, Inc. (oringsusa.com), $D_i = 34.52 \pm 0.30 \text{ mm}$, $d = 3.53 \pm 0.10 \text{ mm}$

$$\bar{D}_o = \bar{D}_i + 2\bar{d} = 34.52 + 2(3.53) = 41.58 \text{ mm}$$

$$t_{D_o} = \sum t_{\text{all}} = 0.30 + 2(0.10) = 0.50 \text{ mm}$$

$D_o = 41.58 \pm 0.50 \text{ mm}$ *Ans.*

1-20 From O-Rings, Inc. (oringsusa.com), $D_i = 5.237 \pm 0.035$ in, $d = 0.103 \pm 0.003$ in

$$\bar{D}_o = \bar{D}_i + 2\bar{d} = 5.237 + 2(0.103) = 5.443 \text{ in}$$

$$t_{D_o} = \sum t_{\text{all}} = 0.035 + 2(0.003) = 0.041 \text{ in}$$

$$D_o = 5.443 \pm 0.041 \text{ in} \quad \text{Ans.}$$

1-21 From O-Rings, Inc. (oringsusa.com), $D_i = 1.100 \pm 0.012$ in, $d = 0.210 \pm 0.005$ in

$$\bar{D}_o = \bar{D}_i + 2\bar{d} = 1.100 + 2(0.210) = 1.520 \text{ in}$$

$$t_{D_o} = \sum t_{\text{all}} = 0.012 + 2(0.005) = 0.022 \text{ in}$$

$$D_o = 1.520 \pm 0.022 \text{ in} \quad \text{Ans.}$$

1-22 From Table A-2,

(a) $\sigma = 150/6.89 = 21.8$ kpsi *Ans.*

(b) $F = 2/4.45 = 0.449$ kip = 449 lbf *Ans.*

(c) $M = 150/0.113 = 1330$ lbf · in = 1.33 kip · in *Ans.*

(d) $A = 1500/25.4^2 = 2.33$ in² *Ans.*

(e) $I = 750/2.54^4 = 18.0$ in⁴ *Ans.*

(f) $E = 145/6.89 = 21.0$ Mpsi *Ans.*

(g) $v = 75/1.61 = 46.6$ mi/h *Ans.*

(h) $V = 1000/946 = 1.06$ qt *Ans.*

1-23 From Table A-2,

(a) $l = 5(0.305) = 1.53$ m *Ans.*

(b) $\sigma = 90(6.89) = 620$ MPa *Ans.*

(c) $p = 25(6.89) = 172$ kPa *Ans.*

- (d) $Z = 12(16.4) = 197 \text{ cm}^3$ *Ans.*
- (e) $w = 0.208(175) = 36.4 \text{ N/m}$ *Ans.*
- (f) $\delta = 0.00189(25.4) = 0.0480 \text{ mm}$ *Ans.*
- (g) $v = 1200(0.0051) = 6.12 \text{ m/s}$ *Ans.*
- (h) $\epsilon = 0.00215(1) = 0.00215 \text{ mm/mm}$ *Ans.*
- (i) $V = 1830(25.4^3) = 30.0(10^6) \text{ mm}^3$ *Ans.*
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1-24

- (a) $\sigma = M/Z = 1770/0.934 = 1895 \text{ psi} = 1.90 \text{ kpsi}$ *Ans.*
- (b) $\sigma = F/A = 9440/23.8 = 397 \text{ psi}$ *Ans.*
- (c) $y = Fl^3/3EI = 270(31.5)^3/[3(30)10^6(0.154)] = 0.609 \text{ in}$ *Ans.*
- (d) $\theta = Tl/GJ = 9740(9.85)/[11.3(10^6)(\pi/32)1.00^4] = 8.648(10^{-2}) \text{ rad} = 4.95^\circ$ *Ans.*
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1-25

- (a) $\sigma = F/wt = 1000/[25(5)] = 8 \text{ MPa}$ *Ans.*
- (b) $I = bh^3/12 = 10(25)^3/12 = 13.0(10^3) \text{ mm}^4$ *Ans.*
- (c) $I = \pi d^4/64 = \pi(25.4)^4/64 = 20.4(10^3) \text{ mm}^4$ *Ans.*
- (d) $\tau = 16T/\pi d^3 = 16(25)10^3/[\pi(12.7)^3] = 62.2 \text{ MPa}$ *Ans.*
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1-26

- (a) $\tau = F/A = 2700/[\pi(0.750)^2/4] = 6110 \text{ psi} = 6.11 \text{ kpsi}$ *Ans.*
- (b) $\sigma = 32Fa/\pi d^3 = 32(180)31.5/[\pi(1.25)^3] = 29570 \text{ psi} = 29.6 \text{ kpsi}$ *Ans.*
- (c) $Z = \pi(d_o^4 - d_i^4)/(32d_o) = \pi(1.50^4 - 1.00^4)/[32(1.50)] = 0.266 \text{ in}^3$ *Ans.*
- (d) $k = (d^4G)/(8D^3N) = 0.0625^4(11.3)10^6/[8(0.760)^332] = 1.53 \text{ lbf/in}$ *Ans.*
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