**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 ± 0.0127 mm is 270%. Cost of turning to ± 0.0762 mm is 60%.

Relative cost of grinding vs. turning = 270/60 = 4.5 times *Ans.*

­­­­­­­­­­­­­­­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-8** *CA* = *CB*,

10 + 0.8 *P* = 60 + 0.8 *P* − 0.005 *P* 2

*P* 2 = 50/0.005 ⇒ *P* = 100 parts *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



\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-10** (**a**) *X*1 + *X*2:

****

(**b**) *X*1 − *X*2:



(**c**) *X*1 *X*2:



(**d**) *X*1/*X*2:



\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-11** (**a**) *x*1 =  = 2.645 751 311 1

*X*1 = 2.64 (3 correct digits)

*x*2 =  = 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

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

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** 

Table A-17: *d* = 31.75 mm *Ans.*

Factor of safety: 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-13** (**a**)

|  |  |  |  |
| --- | --- | --- | --- |
| *x* | *f* | *f x* | *f x*2 |
| 60 | 2 | 120 | 7200 |
| 70 | 1 | 70 | 4900 |
| 80 | 3 | 240 | 19200 |
| 90 | 5 | 450 | 40500 |
| 100 | 8 | 800 | 80000 |
| 110 | 12 | 1320 | 145200 |
| 120 | 6 | 720 | 86400 |
| 130 | 10 | 1300 | 169000 |
| 140 | 8 | 1120 | 156800 |
| 150 | 5 | 750 | 112500 |
| 160 | 2 | 320 | 51200 |
| 170 | 3 | 510 | 86700 |
| 180 | 2 | 360 | 64800 |
| 190 | 1 | 190 | 36100 |
| 200 | 0 | 0 | 0 |
| 210 | 1 | 210 | 44100 |
|  | 69 | 8480 | 1 104 600 |

Eq**.** (1-6) 

Eq. (1-7) 

(**b**) Eq. (1-5) 

Interpolating from Table (A-10)

0.2600 0.3974

0.2607 *x*  *x* = 0.3971

0.2700 0.3936

*N*Φ(−0.2607) = 69 (0.3971) = 27.4 ≈ 27 *Ans.*

From the data, the number of instances less than 115 kcycles is

2 + 1 + 3 + 5 + 8 + 12 = 31 (the data is not perfectly normal)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-14**

|  |  |  |  |
| --- | --- | --- | --- |
| *x* | *f* | *f x* | *f x*2 |
| 1.2 | 6 | 7.2 | 8.64 |
| 1.25 | 9 | 11.29 | 14.17 |
| 1.31 | 44 | 57.64 | 75.51 |
| 1.37 | 67 | 91.47 | 124.87 |
| 1.42 | 53 | 75.28 | 106.92 |
| 1.48 | 12 | 17.71 | 26.12 |
| 1.53 | 6 | 9.18 | 14.0 |
|  | 197 | 269.76 | 370.28 |

Eq**.** (1-6) 

Eq. (1-7) 

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-15** 

Eq. (1-5) 

Thus, *x*10 = 122.9 + 30.3 *z*10 = *L*10

From Table A-10, for 10 percent failure, *z*10 = −1.282. Thus,

*L*10 = 122.9 + 30.3(−1.282) = 84.1 kcycles *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-16**

|  |  |  |  |
| --- | --- | --- | --- |
| *x* | *f* | *fx* | *fx*2 |
| 0.64 | 19 | 12.18 | 7.81 |
| 0.66 | 25 | 16.38 | 10.73 |
| 0.67 | 38 | 25.41 | 17.00 |
| 0.68 | 17 | 11.60 | 7.92 |
| 0.70 | 12 | 8.36 | 5.82 |
| 0.71 | 10 | 7.10 | 5.04 |
| 0.72 | 5 | 3.62 | 2.62 |
| 0.74 | 4 | 2.95 | 2.18 |
| 0.75 | 4 | 3.01 | 2.26 |
| 0.77 | 2 | 1.53 | 1.17 |
|  | 136 | 92.14 | 62.55 |

Eq. (1-6)  MPa

Eq. (1-7) 

**Note**, for accuracy in the calculation given above,needs to be of more significant figures than the rounded value.

For a normal distribution, from Eq. (1-5), and a yield strength exceeded by 99 percent

(*R* = 0.99, *pf* = 0.01),

  
Solving for the yield strength gives

*x*0.01 = 0.68 + 0.030 *z*0.01

From Table A-10, *z*0.01 = − 2.326. Thus

*x*0.01 = 0.68 + 0.030(− 2.326) = 0.61 MPa *Ans*.

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**1-17** Eq. (1-9): *R* == 0.98(0.96)0.94 = 0.88

Overall reliability = 88 percent *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-18** Obtain the coefficients of variance for strength and stress

****

****

For *R* = 0.99, from Table A-10, *z* = − 2.326.

Eq. (1-12):



From the given equation for stress,



Solving for *d* gives



\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-19** Obtain the coefficients of variance for stress and strength

****

****

(**a**) 

Eq. (1-11): 

Interpolating Table A-10,

1.76 0.0392

1.7695 Φ  Φ = 0.03844

1.77 0.0384

*R* = 1 − 0.03844 = 0.96156 *Ans*.



(**b**) 



3.8 0.000072

3.8770 Φ  Φ = 0.00005367

3.9 0.000048

*R* = 1 − 0.00005367 = 0.99994633 *Ans*.



\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-20** 

From footnote 9 of text,



****

****

****

Eq. (1-11): 

From Table A-10, Φ(− 1.635) = 0.05105

*R* = 1 − 0.05105 = 0.94895 = 94.9 percent *Ans*.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-21** *a* = 38.1 ± 0.0254 mm

*b* = 50.8 ± 0.0762 mm

*c* = 76.2 ± 0.1016 mm

*d* = 165.608 ± 0.254 mm

(**a**) = 165.608 − 38.1 − 50.8 − 76.2 = 0.508 mm

= 0.0254 + 0.0762 + 0.1016 + 0.254 = 0.457 mm

*w* = 0.508 ± 0.457 mm *Ans.*

(**b**) From part (a), *w*min = 0.05 mm. Thus, must add 0.2 mm to . Therefore,

= 165.608 + 0.2 = 165.808 mm *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-22** *V = xyz*, and *x = a* ± Δ *a*, *y = b* ± Δ *b*, *z = c* ± Δ *c*,





The higher order terms in Δ are negligible. Thus,



and, 

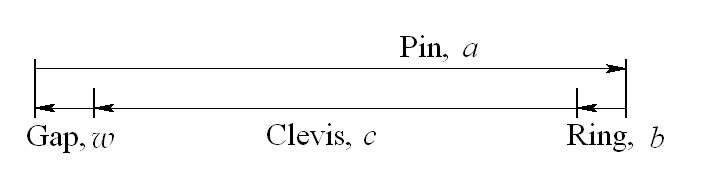
For the numerical values given, 



*V* = 138265.85 ± 590.66 mm3 *Ans.*

This answer yields  mm3, whereas, exact is  mm3

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-23**

*w*max = 1.27 mm, *w*min = 0.102 mm



Thus, Δ *w* = 1.27 − 0.686 = 0.584 mm, and then, *w* = 0.686 ± 0.584 mm.



*tw* =  ⇒ 0.584 = *ta* + 1.27 + 0.127 ⇒ *ta* = 0.4 mm

Thus, *a* = 39.85 ± 0.4 mm *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-24** 



*Do* = 101.90 ± 0.91 mm *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-25** From O-Rings, Inc. (oringsusa.com), *Di* = 9.19 ± 0.13 mm, *d* = 2.62 ± 0.08 mm





*Do* = 14.43 ± 0.29 mm *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-26** From O-Rings, Inc. (oringsusa.com), *Di* = 34.52 ± 0.30 mm, *d* = 3.53 ± 0.10 mm





*Do* = 41.58 ± 0.50 mm *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-27** From O-Rings, Inc. (oringsusa.com), *Di* = 133.02 ± 0.89 mm, *d* = 2.62 ± 0.076 mm





*Do* = 138.25 ± 1.04 mm *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-28** From O-Rings, Inc. (oringsusa.com), *Di* = 27.94 ± 0.30 mm, *d* = 5.33 ± 0.13 mm





*Do* = 38.61 ± 0.56 mm *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-29** From Table A-2,

(**a**) *σ* = 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/ 25.42 = 2.33 in2 *Ans.*

(**e**) *I* = 750/2.544 = 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.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-30** From Table A-2,

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

(**b**) *σ* = 90(6.89) = 620 MPa *Ans.*

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

(**d**) *Z* =12(16.4) = 197 cm3 *Ans.*

(**e**) *w* = 0.208(175) = 36.4 N/m *Ans.*

(**f**) *δ* = 0.001 89(25.4) = 0.048 0 mm *Ans.*

(**g**) *v* = 1 200(0.0051) = 6.12 m/s *Ans.*

(**h**)  = 0.002 15(1) = 0.002 15 mm/mm *Ans.*

(**i**) *V* = 1830(25.43) = 30.0 (106) mm3 *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-31**

(**a**) *σ* = *M /Z* = 200/23.7(10)-9 = 8.43 GPa *Ans.*

(**b**) *σ* = *F /A* = 41991.212/(604.52(10)-6 ) = 69.46 MPa *Ans.*

(**c**) *y =Fl*3*/*3*EI* = 1201(0.8)3/[3(206.843)109(3.912) 10-12] = 253.4 m *Ans.*

(**d**) *θ = Tl /GJ* = 110047(0.2502)/[77.911(109)(*π* /32)0.02544] = 8.65(10−2) rad = 4.96° *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-32**

(**a**) *σ =F /* *wt* = 1000/[25(5)] = 8 MPa *Ans.*

(**b**) *I = bh*3 /12 = 10(25)3/12 = 13.0(103) mm4 *Ans.*

(**c**) *I =π d*4/64 = *π* (25.4)4/64 = 20.4(103) mm4 *Ans.*

(**d**) *τ =*16*T /π d* 3 = 16(25)103/[*π* (12.7)3] = 62.2 MPa *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**1-33**

(**a**) *τ =F /A* = 12010.198/[*π* (0.01905)2/4] = 42.15 MPa *Ans.*

(**b**) *σ =* 32*Fa/π d* 3 = 32(800.68)0.8001/[*π* (.03175)3] = 203.92 MPa *Ans.*

(**c**) *Z =π* (*do*4 − *di*4)/(32 *do*) = *π* (38.14 − 25.44)/[32(38.1)] = 4356.33 mm3 *Ans.*

(**d**) *k* = (*d* 4*G*)/(8*D* 3 *N*) = 0.0015884(77.911)109/[8(0.019304)3 32] = 269.04 N/m *Ans.*

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_