**Chapter 10**

**10-1** From Eqs. (10-4) and (10-5)



Plot 100(*KW*−*KB*)/*KW* vs. *C* for 4 ≤*C*≤ 12 obtaining

We see the maximum and minimum occur at *C =* 4 and 12 respectively where

Maximum = 1.36 % *Ans*., and Minimum = 0.743 % *Ans*.

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**10-2** *A = Sdm*

dim(*A*uscu) = [dim (*S*) dim(*d*m)]uscu = kpsi⋅in*m*

dim(*A*SI) = [dim (*S*) dim(*dm*)]SI = MPa⋅mm*m*



For music wire, from Table 10-4:

*A*uscu = 201 kpsi⋅in*m*, *m* = 0.145; what is *A*SI?

*A*SI = 6.895(25.4)0.145(201) = 2215 MPa⋅mm*mAns*.

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**10-3** Given: Music wire, *d* = 2.5 mm, OD = 31 mm, plain ground ends, *Nt* = 14 coils.

(**a**) Table 10-1: *Na = Nt*− 1 = 14 − 1 = 13 coils

*D* = OD −*d* = 31− 2.5 = 28.5 mm

*C = D/d* = 28.5/2.5 = 11.4

Table 10-5: *d* = 2.5/25.4 = 0.098 in ⇒*G =* 81.0(103) MPa

Eq. (10-9): *Ans.*

**(b)** Table 10-1: *Ls* = *d Nt* = 2.5(14) = 35 mm

Table 10-4: *m* = 0.145, *A* = 2211 MPa⋅mm*m*

Eq. (10-14): 

Table 10-6: *Ssy* = 0.45(1936) = 871.2 MPa

Eq. (10-5): 

Eq. (10-7): *Ans.*

**(c)** 

(**d**) . Spring needs to be supported. *Ans*.

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**10-4** Given: Design load, *F*1 = 130 N.

Referring to Prob. 10-3 solution, *C* = 11.4, *Na*= 13 coils, *Ssy*= 871.2 MPa, *Fs*= 167.9 N,

*L*0 = 162.8 mm and (*L*0)cr = 149.9 mm*.*

Eq. (10-18): 4 ≤ *C* ≤ 12 *C* = 11.4 *O.K.*

Eq. (10-19): 3 ≤ *Na*≤ 15 *Na*= 13 *O.K.*

Eq. (10-17): 

Eq. (10-20): 

From Eq. (10-7) for static service



Eq. (10-21): *ns*≥ 1*.*2, *n* = 1*.*29*O.K.*



*Ssy/τs*≥ (*ns*)*d*: Not solid-safe (but was the basis of the design). *Not O.K.*

*L*0 ≤ (*L*0)cr: 162.8≥ 149.9*Not O.K.*

Design is unsatisfactory. Operate over a rod? *Ans.*

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**10-5** Given: Oil-tempered wire, *d* = 5.08 mm, *D* = 50.8 mm, *Nt* = 12 coils, *L*0 = , squared ends.

(**a**) Table 10-1: *Ls* = *d* (*Nt* + 1) = 5.08(12 + 1) = 66 mm *Ans*.

(**b**) Table 10-1: *Na = Nt*− 2 = 12 − 2 = 10 coils

Table 10-5: *G* = 77.2 GPa

Eq. (10-9): 

*Fs = k ys* = *k* (*L*0−*Ls* ) = 4.9(127 − 66) = 298.9 N *Ans*.

(**c**) Eq. (10-1): *C = D/d* = 50.8/5.08 = 10

Eq. (10-5): 

Eq. (10-7): 

Table 10-4: *m* = 0.187, *A* = 1855 MPa⋅mm*m*

Eq. (10-14): 

Table 10-6: *Ssy* = 0.50*Sut* = 0.50(1369.3) = 684.65 MPa



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**10-6**  Given: Oil-tempered wire, *d* = 4 mm, *C* = 10, plain ends, *L*0 = 80 mm, and at *F* = 50 N,

*y* = 15 mm.

(**a**) *k* =*F/y* = 50/15 = 3.333 N/mm *Ans*.

(**b**) *D = Cd =* 10(4) = 40 mm

OD = *D + d* = 40 + 4 = 44 mm *Ans*.

(**c**) From Table 10-5, *G* = 77.2 GPa

Eq. (10-9): 

Table 10-1: *Nt = Na =* 11.6 coils *Ans*.

(**d**) Table 10-1: *Ls* = *d* (*Nt* + 1) = 4(11.6 + 1) = 50.4 mm *Ans*.

(**e**) Table 10-4: *m* = 0.187, *A* = 1855 MPa⋅mm*m*

Eq. (10-14): 

Table 10-6: *Ssy* = 0.50 *Sut* = 0.50(1431) = 715.5 MPa

*ys* = *L*0−*Ls* = 80 − 50.4 = 29.6 mm

*Fs* = *kys* = 3.333(29.6) = 98.66 N

Eq. (10-5): 

Eq. (10-7): 



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**10-7**  Static service spring with: HD steel wire, *d* = 2.032 mm, OD = 22.352 mm, *Nt*= 8 coils, plainand ground ends.

*Preliminaries*

Table 10-4: *A* = 1783 MPa · mm*m*, *m* = 0*.*190

Eq. (10-14): 

Table 10-6: *Ssy*= 0*.*45(1558) = 702 MPa

Then,

*D* = OD −*d* = 22.352 − 2.032 = 20.32 mm

Eq. (10-1): *C = D/d* = 20.32/2.032 = 10

Eq. (10-5): 

Table 10-1: *Na* = *Nt*− 1 = 8 − 1 = 7 coils

*Ls =dNt* = 2.032(8) = 16.256 mm

Eq. (10-7) For solid-safe, *ns* = 1.2 : 

Eq. (10-9): 



**(a)** *L*0 = *ys*+ *Ls*= 28.96 + 16.256 = 45.21 mm  *Ans.*

**(b)** Table 10-1: 

**(c)** From above: *Fs*= 83.53 N  *Ans.*

**(d)** From above: *k* = 2.877 N/mm *Ans.*

**(e)** Table 10-2 and Eq. (10-13): 

Since *L*0< (*L*0)cr, buckling is unlikely *Ans.*

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**10-8**  Given: Design load, *F*1 = 73.4 N.

Referring to Prob. 10-7 solution, *C* = 10, *Na*= 7 coils, *Ssy*= 702 MPa, *Fs*= 83.53 N,

*ys* = 28.96 mm, *L*0 = 45.21 mm, and (*L*0)cr = 106.93 mm.

Eq. (10-18): 4 ≤ *C* ≤ 12 *C* = 10 *O.K.*

Eq. (10-19): 3 ≤ *Na*≤ 15 *Na*= 7 *O.K.*

Eq. (10-17): 

Eq. (10-20): , but probably acceptable.

From Eq. (10-7) for static service



Eq. (10-21): *ns*≥ 1*.*2, *n* = 1*.*37*O.K.*



Eq. (10-21): *ns*≥ 1.2, *ns*= 1.2 It is solid-safe (basis of design). *O.K.*

Eq. (10-13) and Table 10-2: *L*0 ≤ (*L*0)cr 45.21 mm ≤ 106.93 mm *O.K.*

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**10-9**  Given: A228 music wire, squared and ground ends, *d* = 0.178 mm, OD = 0.965 mm,

*L*0 = 14.732 mm,

*Nt* = 38 coils.

*D* = OD −*d* = 0.965 − 0.178 = 0.787 mm

Eq. (10-1): *C = D/d* = 0.787/0.178 = 4.429

Eq. (10-5): 

Table 10-1: *Na = Nt*− 2 = 38 − 2 = 36 coils (high)

Table 10-5: *G* = 82.7 MPa

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 0.178(38) = 6.756 mm

*ys = L*0−*Ls* = 14.732 − 6.756 = 7.975 mm

*Fs* = *kys* = .588(7.975) = 4.7 N

Eq. (10-7):  (1)

Table 10-4: *A* = 2211 MPa⋅mm*m*, *m* = 0.145

Eq. (10-14): 

Table 10-6: *Ssy* = 0.45 *Sut* = 0.45(2845.5) = 1280.36 MPa

*τs*>*Ssy*, that is, 2241.5 > 1280.36 MPa, the spring is not solid-safe. Return to Eq. (1) with

*Fs = kys* and*τs* = *Ssy /ns*, and solve for *ys*, giving



The free length should be wound to

*L*0 = *Ls + ys* = 6.756 + 3.785 = 10.541 mm *Ans*.

This only addresses the solid-safe criteria. There are additional problems.

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**10-10**  Given: B159 phosphor-bronze, squared and ground. ends, Use *d* = 0.3556 mm, OD = 3.251 mm,

*L*0 = 12.7 mm, *Nt* = 16 coils.

*D* = OD −*d* = 3.251 − 0.3556 = 2.895 mm

Eq. (10-1): *C = D/d* = 2.895/0.355 = 8.143

Eq. (10-5): 

Table 10-1: *Na = Nt*− 2 = 16 − 2 = 14 coils

Table 10-5: *G* = 41.4 GPa

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 0.355(16) = 5.69 mm

*ys = L*0−*Ls* = 12.7 − 5.69 = 7.01 mm

*Fs* = *kys* = 0.243(7.01) = 1.71 N

Eq. (10-7):  (1)

Table 10-4: *A* = 1000 MPa⋅mm*m*, *m* = 0

Eq. (10-14): 

Table 10-6: *Ssy* = 0.35 *Sut* = 0.35(1000) = 350 MPa

 Spring is not solid-safe (*ns*< 1.2) *Ans*.

Return to Eq. (1) with *Fs = kys* and*τs* = *Ssy /ns*, and solve for *ys*, giving



The free length should be wound to

*L*0 = *Ls + ys* = 5.69 + 6.22 = 11.91 mm *Ans*.

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**10-11**  Given: A313 stainless steel, squared and ground ends, *d* =1.27 mm, OD = 6.35 mm,

*L*0 = 17.27 mm, *Nt* = 11.2 coils.

*D* = OD −*d* = 6.35 − 1.27 = 5.08 mm

Eq. (10-1): *C = D/d* = 5.08/1.27 = 4

Eq. (10-5): 

Table 10-1: *Na = Nt*− 2 = 11.2 − 2 = 9.2 coils

Table 10-5: *G* = 69 GPa

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 1.27(11.2) = 14.22 mm

*ys = L*0−*Ls* = 17.27 − 14.22 = 3.05 mm

*Fs* = *kys* = 18.58(3.05) = 56.62 N

Eq. (10-7): 

Table 10-4: *A* = 1867 MPa⋅mm*m*, *m* = 0.146

Eq. (10-14): 

Table 10-6: *Ssy* = 0.35 *Sut* = 0.35(1804) = 631.56 MPa

 Spring is solid-safe (*ns*> 1.2)*Ans*.

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**10-12**  Given: A227 hard-drawn wire, squared and ground ends, *d* = 3.76 mm, OD = 53.84 mm,

*L*0 = 63.5 mm, *Nt* = 5.75 coils.

*D* = OD −*d* = 53.84 − 3.76 = 50.088 mm

Eq. (10-1): *C = D/d* = 50.088/3.76 = 13.32 (high)

Eq. (10-5): 

Table 10-1: *Na = Nt*− 2 = 5.75 − 2 = 3.75 coils

Table 10-5: *G* = 78.6 GPa

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 3.76(5.75) = 21.61 mm

*ys = L*0−*Ls* = 63.5− 21.61 = 41.88 mm

*Fs* = *kys* = 4.163(41.88) = 174.36 N

Eq. (10-7): 

Table 10-4: *A* = 1783 MPa⋅mm*m*, *m* = 0.190

Eq. (10-14): 

Table 10-6: *Ssy* = 0.35 *Sut* = 0.35(1388) = 485.8 MPa

 Spring is not solid-safe (*ns*<1.2 )*Ans*

Return to Eq. (1) with *Fs = kys* and*τs* = *Ssy /ns*, and solve for *ys*, giving



The free length should be wound to

*L*0 = *Ls + ys* = 21.61 + 36.87 = 58.48 mm *Ans*.

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**10-13**  Given: A229OQ&T steel, squared and ground ends, *d* = 3.50 mm, OD = 23.36 mm,

*L*0 = 72.64 mm, *Nt* = 12 coils.

*D* = OD −*d* = 23.36− 3.50 = 19.86 mm

Eq. (10-1): *C = D/d* = 19.86/3.50 = 5.667

Eq. (10-5): 

Table 10-1: *Na = Nt*− 2 = 12− 2 = 10 coils

A229 OQ&T steel is not given in Table 10-5. From Table A-5, for carbon steels,

*G* = 79.3 MPa.

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 3.50(12) = 42.06 mm

*ys = L*0−*Ls* = 72.64−42.06 = 30.58 mm

*Fs* = *kys* = 19.09(30.58) = 583.58 mm

Eq. (10-7):  (1)

Table 10-4: *A* = 1855 MPa⋅mm*m*, *m* = 0.187

Eq. (10-14): 

Table 10-6: *Ssy* = 0.50*Sut* = 0.50(1468) = 732 MPa

*τs*>*Ssy*, that is, 860 > 732 MPa, the spring is not solid-safe. Return to Eq. (1) with

*Fs = kys* and*τs* = *Ssy /ns*, and solve for *ys*, giving



The free length should be wound to

*L*0 = *Ls + ys* = 42.06 + 21.76 = 63.75 mm *Ans*.

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**10-14**  Given: A232 chrome-vanadium steel, squared and ground ends, *d* = 4.67 mm, OD = 69.85 mm, *L*0 = 190.5 mm, *Nt* = 8 coils.

*D* = OD −*d* = 69.85 − 4.67 = 65.15 mm

Eq. (10-1): *C = D/d* = 65.15/4.67 = 13.86 (high)

Eq. (10-5): 

Table 10-1: *Na = Nt*− 2 = 8 − 2 = 6 coils

Table 10-5: *G* = 77.2 GPa.

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 4.67(8) = 37.59 mm

*ys = L*0−*Ls* = 190.5− 37.59 = 152.91 mm

*Fs* = *kys* = 2.837(152.91) = 433.68 N

Eq. (10-7):  (1)

Table 10-4: *A* = 2005 MPa⋅mm*m*, *m* = 0.168

Eq. (10-14): 

Table 10-6: *Ssy* = 0.50 *Sut* = 0.50(1547.18) = 773.59 MPa

 Spring is not solid-safe (*ns*< 1.2)

Return to Eq. (1) with *Fs = kys* and*τs* = *Ssy /ns*, and solve for *ys*, giving



The free length should be wound to

*L*0 = *Ls + ys* = 37.59 + 152.91 = 167.38 mm *Ans*.

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**10-15**  Given: A313 stainless steel, squared and ground ends, *d* = 0.25 mm, OD = 0.95 mm,

*L*0 = 12.1 mm, *Nt* = 38 coils.

*D* = OD −*d* = 0.95 − 0.25 = 0.7 mm

Eq. (10-1): *C = D/d* = 0.7/0.25 = 2.8 (low)

Eq. (10-5): 

Table 10-1: *Na = Nt*− 2 = 38 − 2 = 36 coils (high)

Table 10-5: *G* = 69.0(103) MPa.

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 0.25(38) = 9.5 mm

*ys = L*0−*Ls* = 12.1 − 9.5 = 2.6 mm

*Fs* = *kys* = 2.728(2.6) = 7.093 N

Eq. (10-7):  (1)

Table 10-4 (dia. less than table): *A* = 1867 MPa⋅mm*m*, *m* = 0.146

Eq. (10-14): 

Table 10-6: *Ssy* = 0.35*Sut* = 0.35(2286) = 734 MPa

*τs*>*Ssy*, that is, 1303 > 734 MPa, the spring is not solid-safe. Return to Eq. (1) with

*Fs = kys* and*τs* = *Ssy /ns*, and solve for *ys*, giving



The free length should be wound to

*L*0 = *Ls + ys* = 9.5 + 1.22 = 10.72 mm *Ans*.

This only addresses the solid-safe criteria. There are additional problems.

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**10-16**  Given: A228 music wire, squared and ground ends, *d* = 1.2 mm, OD = 6.5 mm, *L*0 = 15.7 mm, *Nt* = 10.2 coils.

*D* = OD −*d* = 6.5 − 1.2 = 5.3 mm

Eq. (10-1): *C = D/d* = 5.3/1.2 = 4.417

Eq. (10-5): 

Table (10-1): *Na = Nt*− 2 = 10.2 − 2 = 8.2 coils

Table 10-5 (*d* = 1.2/25.4 = 0.0472 in): *G* = 81.7(103) MPa.

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 1.2(10.2) = 12.24 mm

*ys = L*0−*Ls* = 15.7−12.24 = 3.46 mm

*Fs* = *kys* = 17.35(3.46) = 60.03 N

Eq. (10-7):  (1)

Table 10-4: *A* = 2211 MPa⋅mm*m*, *m* = 0.145

Eq. (10-14): 

Table 10-6: *Ssy* = 0.45 *Sut* = 0.45(2153) = 969 MPa

 Spring is solid-safe (*ns*> 1.2)*Ans*.

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**10-17**  Given: A229 OQ&T steel, squared and ground ends, *d* = 3.5 mm, OD = 50.6 mm,

*L*0 = 75.5 mm, *Nt* = 5.5 coils.

*D* = OD −*d* = 50.6 − 3.5 = 47.1 mm

Eq. (10-1): *C = D/d* = 47.1/3.5 = 13.46 (high)

Eq. (10-5): 

Table 10-1: *Na = Nt*− 2 = 5.5 − 2 = 3.5 coils

A229 OQ&T steel is not given in Table 10-5. From Table A-5, for carbon steels,

*G* = 79.3(103)MPa.

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 3.5(5.5) = 19.25 mm

*ys = L*0−*Ls* = 75.5−19.25 = 56.25 mm

*Fs* = *kys* = 4.067(56.25) = 228.8 N

Eq. (10-7):  (1)

Table 10-4: *A* = 1855MPa⋅mm*m*, *m* = 0.187

Eq. (10-14): 

Table 10-6: *Ssy* = 0.50 *Sut* = 0.50(1468) = 734 MPa

 Spring is not solid-safe (*ns*< 1.2)

Return to Eq. (1) with *Fs = kys* and*τs* = *Ssy /ns*, and solve for *ys*, giving



The free length should be wound to

*L*0 = *Ls + ys* = 19.25 + 48.96 = 68.2 mm *Ans*.

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**10-18**  Given: B159 phosphor-bronze, squared and ground ends, *d* = 3.8 mm, OD = 31.4 mm,

*L*0 = 71.4 mm, *Nt* = 12.8 coils.

*D* = OD −*d* = 31.4 − 3.8 = 27.6 mm

Eq. (10-1): *C = D/d* = 27.6/3.8 = 7.263

Eq. (10-5): 

Table 10-1: *Na = Nt*− 2 = 12.8 − 2 = 10.8 coils

Table 10-5: *G* = 41.4(103) MPa.

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 3.8(12.8) = 48.64 mm

*ys = L*0−*Ls* = 71.4 − 48.64 = 22.76 mm

*Fs* = *kys* = 4.752(22.76) = 108.2 N

Eq. (10-7):  (1)

Table 10-4 (*d* = 3.8/25.4 = 0.150 in): *A* = 932 MPa⋅mm*m*, *m* = 0.064

Eq. (10-14): 

Table 10-6: *Ssy* = 0.35*Sut* = 0.35(855.7) = 299.5 MPa

 Spring is solid-safe (*ns*> 1.2)*Ans*.

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**10-19**  Given: A232 chrome-vanadium steel, squared and ground ends, *d* = 4.5 mm, OD = 69.2 mm, *L*0 = 215.6 mm, *Nt* = 8.2 coils.

*D* = OD −*d* = 69.2−4.5 = 64.7 mm

Eq. (10-1): *C = D/d* = 64.7/4.5 = 14.38 (high)

Eq. (10-5): 

Table 10-1: *Na = Nt*− 2 = 8.2− 2 = 6.2 coils

Table 10-5: *G* = 77.2(103) MPa.

Eq. (10-9): 

Table 10-1: *Ls = dNt* = 4.5(8.2) = 36.9 mm

*ys = L*0−*Ls* = 215.6−36.9 = 178.7 mm

*Fs* = *kys* = 2.357(178.7) = 421.2 N

Eq. (10-7):  (1)

Table 10-4: *A* = 2005 MPa⋅mm*m*, *m* = 0.168

Eq. (10-14): 

Table 10-6: *Ssy* = 0.50*Sut* = 0.50(1557) = 779 MPa

*τs*>*Ssy*, that is, 832 > 779 MPa, the spring is not solid-safe. Return to Eq. (1) with

*Fs = kys* and*τs* = *Ssy /ns*, and solve for *ys*, giving



The free length should be wound to

*L*0 = *Ls + ys* = 36.9 + 139.5 = 176.4 mm *Ans*.

This only addresses the solid-safe criteria. There are additional problems.

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**10-20**  Given: A227 HD steel.

From the figure: *L*0 = 120.65 mm, OD = 50.8 mm, and *d* = 3.429 mm. Thus

*D* = OD −*d* = 50.8−3.429 = 47.37 mm

**(a)** By counting, *Nt*= 12*.*5 coils. Since the ends are squared along 1*/*4 turn on each end,



The solid stack is 13 wire diameters

*Ls*= 13(3.429) = 44.57 mm *Ans.*

**(b)** From Table 10-5, *G* = 78.6 GPa



**(c)** *Fs*= *k*(*L*0 - *Ls*) = 1.065(120.65 − 44.57) = 80.95 N *Ans.*

**(d)** *C* = *D/d* = 47.37/3.429 = 13*.*81



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**10-21** Given: Plain end, hard drawn steel, 12 gauge W & M wire, OD = 19.05 mm, *Nt* = 20 coils,

*L*0 = 95.25 mm.

Table A-28: *d* = 2.68 mm

**(a)***D* = OD −*d* = 19.05 − 2.68 =16.37 mm. *C* = *D* / *d* =16.37/2.68 = 6.109 *Ans*.

**(b)** Table 10-1: *Na* = *Nt* = 20 coils,

*p* = (*L*0−*d*)/*Na* = (95.25 − 2.68)/20 = 4.62 mm/coil  *Ans*.

**(c)** Table 10-1: *Ls*= *d* (*Nt* + 1) = 2.68 (20 + 1) = 56.27 mm,

*ys* = *L*0−*Ls* = 95.25 − 56.27 = 38.97 mm *Ans*.

**(d)** Eq. (10-8): G = 79.3 GPa

****

**(e)** Eq. (10-5): 

Eq. (10-7):



**(f)** Table 10-4 and Eq. (10-14): 

Table 10-6:*Ssy* = 0.45 *Sut* = 0.45(1478.44) = 665.83 MPa.



**(g)** Exact, *k* = *Fs* / *ys* = 224/38.97 = 5.75 N/mm *Ans*.

Approximate using Eq. (10-9): 

Approximate is 1.34 percent higher than the exact. *Ans*.

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**10-22** Given: Squared and ground, oil tempered steel, *d* = 3 mm, OD = 30 mm, *Nt* = 32 coils,

*L*0 = 240 mm.

Table A-28: *d* = 2.68 mm

**(a)***D* = OD −*d* = 30 − 3 = 27 mm. *C* = *D* / *d* = 27/3 = 9 *Ans*.

**(b)** Table 10-1: *Na* = *Nt*− 2 = 32 − 2 = 30 coils,

*p* = (*L*0− 2*d*)/*Na* = [240 − 2(3)] / 30 = 7.8 mm/coil *Ans*.

**(c)** Table 10-1: *Ls*= *dNt* = 3 (32) = 96 mm,

*ys* = *L*0−*Ls* = 240 − 96 = 144 mm *Ans*.

**(d)** Eq. (10-8):

****

**(e)** Eq. (10-5): 

Eq. (10-7):



**(f)** Table 10-4 and Eq. (10-14): 

Table 10-5:*Ssy* = 0.45 *Sut* = 0.45(1510.5) = 679.7 MPa.



**(g)** Exact, *k* = *Fs* / *ys* = 189.45/144 = 1.316 N/mm *Ans*.

Approximate using Eq. (10-9): 

Approximate is 0.61 percent higher than the exact. *Ans*.

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**10-23** *y* = 50 mm, *F* = 90 N, *k* = *F* / *y* = 90/50 = 1.8 N/mm *Ans*.

*ys* = 60 mm, *Fs* =*kys* = 1.8(60) = 108 N.

Eq. (10-14), Table 10-4, assume 2.5 ≤*d*≤ 5 mm: 

Table 10-6 (includes *KB*): 

Eq. (10-7) (with *ns* = 1.2 but without *KB*): 

Equate Eqs. (1) and (2), 

Since this is less than 2.5 mm, return to Eq. (10-14), Table 10-4, for 0.3 ≤*d*≤ 2.5 mm: 

Again, equate Eqs. (1) and (2),



The final factor of safety is



OD =*Cd* + *d* = (*C* + 1)*d* = 11(2.40) = 26.4 mm *Ans*.

ID = (*C*− 1)*d* = 9(2.40) = 21.6 mm *Ans*.

*k* = 1.8 N/mm *Ans*. (found earlier)

Table 10-5, *G* = 69.0 GPa, Eq. (10-9):



Table 10-1: *Nt* =*Na* + 2 = 13.5 coils *Ans*.

*Ls* = *d* (*Nt* + 1) = 2.4(13.5 + 1) = 34.8 mm *Ans*.

*L*0 = *Ls* + *ys* = 34.8 + 60 = 94.8 mm *Ans*.

Eq. (10-13): 

Stable if supported between fixed-fixed ends. Otherwise would need to be supported by hole or rod.

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**10-24** Phosphor-bronze, closed ends, *C* = 10, at *y* = 50.8 mm, *F* = 66.72 N, *ys* = 76.2 mm, *ns* = 1.2.

*k*= *F* /*y* = 66.72/50.8 = 1.313 N/mm, *Fs* = *kys* = 1.313 (76.2) = 100 N.

Eq. (10-14) with Table 10-4 assuming 0.022 ≤*d*≤ 0.075 in, *A* = 913 MPa۰mmm and *m* = 0.028. Then, from Table 10-5, *Sys* = 0.45 *Sut*:



Eq. (10-5): 

Eq. (10-7) with *ns* = 1.2: 

Where *τ*max is in MPa. Equating (1) and (2) gives



Returning to Table 10-4, use *A* =932 Mpa۰mmm and *m* = 0.028,



Table A-17, select the preferred size of: *d* = 3.048 mm *Ans*.

Check *ns*, 



OD = *Cd* + *d* = (*C* + 1)*d* = (10 + 1)3.048 = 33.528 mm *Ans*.

ID = (*C*− 1)*d* = (10 − 1)3.048 = 27.432 mm

Found earlier, *k* = 1.313 N/mm *Ans*.

Table 10-5, *G* = 41.4 GPa. Eq. (10-9): 

Table 10-1: *Nt* = *Na* + 2 = 14 coils *Ans*.

*Ls* = *d* (*Nt* + 1) = 3.048(14 + 1) = 45.72 mm *Ans*.

*L*0 =*Ls* + *ys* = 45.72 + 76.2 = 121.92 mm *Ans*.

Eq. (10-13):*α* = 2.63 *D* / *L*0 = 2.63 (10)3.048/121.92 = 0.658

Table 10-2: Stable if supported between fixed-fixed ends. Otherwise would need to be supported by hole or rod.

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

**10-25** From Prob. 10-24, *d* = 3.048 mm and from Eq. (3),



OD = (*C* + 1)*d* = 11.46(3.048) = 34.925 mm  *Ans*.

ID = (*C*− 1)*d* = 9.46(3.048) = 28.829 mm  *Ans*.

Table 10-5, *G* = 41.4 GPa , Eq. (10-9): 

Table 10-1: *Nt* = *Na* + 2 = 12.5 coils *Ans*.

*Ls* = *d* (*Nt* + 1) = 3.048(12.5 + 1) = 41.148 mm *Ans*.

*L*0 =*Ls* + *ys* = 41.148 + 76.2 = 117.348 mm *Ans*.

Eq. (10-13):*α* = 2.63 *D* / *L*0 = 2.63 (10.46)3.048/117.348 = 0.715

Table 10-2: Stable if supported between fixed-fixed ends, or one end on flat surface and other end hinged. Otherwise would need to be supported by hole or rod.

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**10-26** For the wire diameter analyzed, *G* = 81 GPa per Table 10-5. Use squared and ground

ends. The following is a spread-sheet study using Fig. 10-3 for parts (*a*) and (*b*). For *Na*,

*k* =*F*max*/y* = 88.964*/*50.8 = 1.75 N/mm. For *τs*, *F* = *Fs* = 88.964(1 + *ξ*) = 88.96(1 + 0.15) = 102.3 N.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| (a) Spring over a Rod | | | | | (b) Spring in a Hole | | | | |
| Source |  | Parameter | Values |  | Source |  | Parameter | Values |  |
|  | *d* | 1.9 | 2.03 | 2.16 |  | *d* | 1.9 | 2.03 | 2.16 |
|  | ID | 20.32 | 20.32 | 20.32 |  | OD | 24.13 | 24.13 | 24.13 |
|  | *D* | 22.225 | 22.352 | 22.479 |  | *D* | 22.225 | 22.098 | 21.971 |
| Eq. (10-1) | *C* | 11.667 | 11.000 | 10.412 | Eq. (10-1) | *C* | 11.667 | 10.875 | 10.176 |
| Eq. (10-9) | *Na* | 6.937 | 8.828 | 11.061 | Eq. (10-9) | *Na* | 6.937 | 9.136 | 11.846 |
| Table 10-1 | *Nt* | 8.937 | 10.828 | 13.061 | Table 10-1 | *Nt* | 8.937 | 11.136 | 13.846 |
| Table 10-1 | *Ls* | 17.018 | 21.9964 | 28.194 | Table 10-1 | *Ls* | 17.018 | 22.631 | 29.896 |
| 1.15*y* + *Ls* | *L*0 | 75.438 | 80.416 | 86.614 | 1.15*y* + *Ls* | *L*0 | 75.438 | 81.051 | 88.316 |
| Eq. (10-13) | (*L*0)cr | 116.916 | 117.577 | 118.237 | Eq. (10-13) | (*L*0)cr | 116.916 | 116.230 | 115.570 |
| Table 10-4 | *A* | 2211 | 2211 | 2211 | Table 10-4 | *A* | 2211 | 2211 | 2211 |
| Table 10-4 | *m* | 0.145 | 0.145 | 0.145 | Table 10-4 | *m* | 0.145 | 0.145 | 0.145 |
| Eq. (10-14) | *Sut* | 2017.585 | 1998.790 | 1981.298 | Eq. (10-14) | *Sut* | 2017.585 | 1998.790 | 1981.298 |
| Table 10-6 | *Ssy* | 907.913 | 899.456 | 891.584 | Table 10-6 | *Ssy* | 907.913 | 899.456 | 891.584 |
| Eq. (10-5) | *KB* | 1.115 | 1.122 | 1.129 | Eq. (10-5) | *KB* | 1.115 | 1.123 | 1.133 |
| Eq. (10-7) | *τs* | 933.10 | 778.75 | 657.02 | Eq. (10-7) | *τs* | 933.102 | 770.744 | 644.205 |
| Eq. (10-3) | *ns* | 0.973 | 1.155 | **1.357** | Eq. (10-3) | *ns* | 0.973 | 1.167 | **1.384** |
| Eq. (10-22) | fom | −0.282 | −0.391 | −0.536 | Eq. (10-22) | fom | −0.282 | −0.398 | −0.555 |
| For *ns*≥ 1*.*2, the optimal size is *d* = 2.16 mm for both cases. | | | | | | | | | |

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**10-27** In Prob. 10-26, there is an advantage of first selecting *d* as one can select from the available sizes (Table A-28). Selecting *C* first requires a calculation of *d* where then a size must be selected from Table A-28.

Consider part (a) of the problem. It is required that

ID = *D*−*d* =20.32 mm. (1)

From Eq. (10-1), *D = Cd*. Substituting this into the first equation yields

 (2)

Starting with *C* = 10, from Eq. (2) we find that *d* = 2.26 mm. From Table A-28, the closest diameter is *d* = 2.28 mm. Substituting this back into Eq. (1) gives *D* = 22.6 mm, with *C* = 22.6/2.28 = 9.889, which are acceptable. From this point the solution is the same as Prob. 10-26. For part (b), use

OD = *D* + *d* = 24.13 mm. (3)

and,  (4)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| (a) Spring over a rod | | | | (b) Spring in a Hole | | |
| Source |  | Parameter | Values | Source | Parameter | Values |
|  | *C* | 10 | 10.5 |  | *C* | 10 |
| Eq. (2) | *d* | 2.261 | 2.134 | Eq. (4) | *d* | 2.184 |
| Table A-28 | *d* | 2.286 | 2.159 | Table A-28 | *d* | 2.159 |
| Eq. (1) | *D* | 22.606 | 22.479 | Eq. (3) | *D* | 21.971 |
| Eq. (10-1) | *C* | 9.889 | 10.412 | Eq. (10-1) | *C* | 10.176 |
| Eq. (10-9) | *Na* | 13.669 | 11.061 | Eq. (10-9) | *Na* | 11.846 |
| Table 10-1 | *Nt* | 15.669 | 13.061 | Table 10-1 | *Nt* | 13.846 |
| Table 10-1 | *Ls* | 35.814 | 28.194 | Table 10-1 | *Ls* | 29.896 |
| 1.15*y* + *Ls* | *L*0 | 94.234 | 86.614 | 1.15*y* + *Ls* | *L*0 | 88.316 |
| Eq. (10-13) | (*L*0)cr | 118.897 | 118.237 | Eq. (10-13) | (*L*0)cr | 115.570 |
| Table 10-4 | *A* | 2211 | 2211 | Table 10-4 | *A* | 2211 |
| Table 10-4 | *m* | 0.145 | 0.145 | Table 10-4 | *m* | 0.145 |
| Eq. (10-14) | *Sut* | 1964.94 | 1981.30 | Eq. (10-14) | *Sut* | 1981.30 |
| Table 10-6 | *Ssy* | 884.23 | 891.58 | Table 10-6 | *Ssy* | 891.58 |
| Eq. (10-5) | *KB* | 1.135 | 1.128 | Eq. (10-5) | *KB* | 1.135 |
| Eq. (10-7) | *s* | 559.63 | 656.54 | Eq. (10-7) | *s* | 645.65 |
| *ns = Ssy/s* | *ns* | 1.58 | **1.358** | *ns = Ssy/s* | *ns* | **1.381** |
| Eq. (10-22) | fom | -0.725 | -0.536 | Eq. (10-22) | fom | -0.555 |

Again, for *ns*≥ 1.2, the optimal size is = 2.16 mm.

Although this approach used less iterations than in Prob. 10-26, this was due to the initial values picked and not the approach.

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**10-28** One approach is to select A227HD steel for its low cost. Try *L*0 = 48 mm, then for

*y* = 48 − 37.5 = 10.5 mm when *F* = 45 N. The spring rate is *k = F/y* = 45/10.5 = 4.286 N/mm.

For a clearance of 1.25 mm with screw, ID = 10 + 1.25 = 11.25 mm. Starting with

*d* = 2mm,

*D* = ID + *d* = 11.25 + 2 = 13.25 mm

*C = D/d* = 13.25/2 = 6.625 (acceptable)

Table 10-5 (*d* = 2/25.4 = 0.0787 in): *G* = 79.3 GPa

Eq. (10-9): 

Assume squared and closed.

Table 10-1: *Nt* = *Na* + 2 = 15.9 + 2 = 17.9 coils

*Ls = dNt* = 2(17.9) =35.8 mm

*ys = L*0−*Ls* = 48 − 35.8 = 12.2 mm

*Fs = kys* = 4.286(12.2) = 52.29 N

Eq. (10-5): 

Eq. (10-7): 

Table 10-4: *A* = 1783MPa · mm*m*, *m* = 0*.*190

Eq. (10-14): 

Table 10-6: *Ssy* = 0.45*Sut* = 0.45(1563) = 703.3 MPa



No other diameters in the given range work. So specify

A227-47 HD steel,*d* = 2 mm,*D* = 13.25 mm, ID = 11.25 mm, OD = 15.25 mm, squared and closed, *Nt*= 17.9coils,*Na*= 15.9 coils,*k*= 4.286N/mm, *Ls*= 35.8 mm, and*L*0 = 48 mm. *Ans*.

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**10-29** Select A227HD steel for its low cost. Try *L*0 = 48 mm, then for *y* = 48 − 37.5 = 10.5 mm when *F* = 45 N. The spring rate is *k = F/y* = 45/10.5 = 4.286 N/mm.

For a clearance of 1.25 mm with screw, ID = 10 + 1.25 = 11.25 mm.

*D*−*d* = 11.25 (1)

and, *D =Cd* (2)

Starting with *C* = 8, gives *D* = 8*d*. Substitute into Eq. (1) resulting in *d* = 1.607 mm. Selecting the nearest diameter in the given range, *d* = 1.6 mm. From this point, the calculations are shown in the third column of the spreadsheet output shown. We see that for *d* = 1.6 mm, the spring is not solid safe. Iterating on *C* we find that *C* = 6.5 provides acceptable results with the specifications

A227-47 HD steel,*d* = 2 mm,*D* = 13.25 mm, ID = 11.25 mm, OD = 15.25 mm, squared and closed, *Nt*= 17.9coils,*Na*= 15.9 coils,*k*= 4.286N/mm, *Ls*= 35.8 mm, and*L*0 = 48 mm. *Ans*.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source |  | Parameter Values | | |
|  | *C* | 8.000 | 7 | 6.500 |
| Eq. (2) | *d* | 1.607 | 1.875 | 2.045 |
| Table A-28 | *d* | 1.600 | 1.800 | 2.000 |
| Eq. (1) | *D* | 12.850 | 13.050 | 13.250 |
| Eq. (10-1) | *C* | 8.031 | 7.250 | 6.625 |
| Eq. (10-9) | *Na* | 7.206 | 10.924 | 15.908 |
| Table 10-1 | *Nt* | 9.206 | 12.924 | 17.908 |
| Table 10-1 | *Ls* | 14.730 | 23.264 | 35.815 |
| *L*0*Ls* | *ys* | 33.270 | 24.736 | 12.185 |
| *Fs = kys* | *Fs* | 142.594 | 106.020 | 52.224 |
| Table 10-4 | *A* | 1783.000 | 1783.000 | 1783.000 |
| Table 10-4 | *m* | 0.190 | 0.190 | 0.190 |
| Eq. (10-14) | *Sut* | 1630.679 | 1594.592 | 1562.988 |
| Table 10-6 | *Ssy* | 733.806 | 717.566 | 703.345 |
| Eq. (10-5) | *KB* | 1.172 | 1.200 | 1.217 |
| Eq. (10-7) | *s* | 1335.568 | 724.943 | 268.145 |
| *ns = Ssy/s* | *ns* | 0.549 | 0.990 | 2.623 |

The only difference between selecting *C* first rather than *d* as was done in Prob. 10-28, is that once *d* is calculated, the closest wire size must be selected. Iterating on *d* uses available wire sizes from the beginning.

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**10-30** A stock spring catalog may have over two hundred pages of compression springs with up to 80 springs per page listed.

• Students should be made aware that such catalogs exist.

• Many springs are selected from catalogs rather than designed.

• The wire size you want may not be listed.

• Catalogs may also be available on disk or the web through search routines.

• It is better to familiarize yourself with vendor resources rather than invent them yourself.

• Sample catalog pages can be given to students for study.

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**10-31** Given: ID = 15.24 mm, *C* = 10, *L*0 = 127 mm, *Ls* = 127 − 76.2 = 50.8 mm, sq. &grd ends, unpeened, HD A227 wire.

(**a**) With ID = *D*−*d* = 15.24 mm and *C = D/d* = 10 ⇒10 *d* −*d* = 15.24 ⇒*d* = 1.69 mm *Ans*.,

and *D* = 16.94 mm.

(**b**) Table 10-1: *Ls* = *dNt* = 50.8 mm ⇒*Nt* = 50.8/1.69 = 30 coils *Ans*.

(**c**) Table 10-1: *Na* = *Nt*− 2 = 30 − 2 = 28 coils

Table 10-5: *G* = 79.3 GPa

Eq. (10-9): 

(**d**) Table 10-4: *A* = 1783 MPa⋅mm*m*, *m* = 0.190

Eq. (10-14): 

Table 10-6: *Ssy* = 0.45 *Sut* = 0.45 (1615) = 726.7 MPa

*Fs = kys* = 0.6(76.2) = 45.68 N

Eq. (10-5): 

Eq. (10-7): 



(**e**) *τa* = *τm* = 0.5*τs* = 0.5(460) = 230 MPa, *r* = *τa* / *τm* = 1. Using the Gerber fatigue failure criterion with Zimmerli data,

Eq. (10-30): *Ssu* = 0.67 *Sut* = 0.67(1615) = 1082 MPa

The Gerber ordinate intercept for the Zimmerli data is obtained using Eqs. (10-28) and (10-29b).



The Gerber fatigue criterion from Eq. (6-48), adapted for shear,



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**10-32** Given: OD ≤ 22.86 mm, *C* = 8, *L*0 = 76.2 mm, *Ls* = 25.4 mm, *ys* = 76.2 − 25.4 = 50.8 mm, sq. ends, unpeened, music wire.

(**a**) Try OD = *D + d* = 22.86 mm, *C = D/d* = 8 ⇒*D* = 8*d*⇒ 9*d* = 22.86 ⇒*d* = 2.54 mm *Ans*.

*D* = 8(2.54) = 20.32 mm

(**b**) Table 10-1: *Ls = d* (*Nt* + 1) ⇒*Nt*= *Ls* /*d*− 1 = 25.4/2.54− 1 = 9 coils *Ans*.

Table 10-1: *Na* =*Nt*− 2 = 9 − 2 = 7 coils

(**c**) Table 10-5: *G* = 81 GPa

Eq. (10-9): 

(**d**) *Fs = kys* = 7.177(50.8) = 364.56 N

Eq. (10-5): 

Eq. (10-7): 

Table 10-4: *A* = 2211 MPa⋅mm*m*, *m* = 0.145

Eq. (10-14): 

Table 10-6: *Ssy* = 0.45 *Sut* = 0.45(1935) = 870.81 MPa



(**e**) *τa* = *τm* = *τs* /2 = 1350/2 = 675 MPa.Using the Gerber fatigue failure criterion with Zimmerli data,

Eq. (10-30): *Ssu* = 0.67 *Sut* = 0.67(1935) = 1297 MPa

The Gerber ordinate intercept for the Zimmerli data isobtained using Eqs. (10-28) and (10-29b).



The Gerber fatigue criterion from Eq. (6-48), adapted for shear,



Obviously, the spring is severely under designed and will fail statically and in fatigue. Increasing *C* would improve matters. Try *C* = 12. This yields *ns* = 1.83 and *nf* = 1.00.

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

**10-33** Given: *F*max = 1334.4 N, *F*min = 667.2 N, Δ*y* = 25.4 mm, OD = 53.34 − 5.08 = 48.26 mm, *C* = 7, unpeened, squared & ground, oil-tempered wire.

(**a**) *D* = OD −*d* = 48.26−*d* (1)

*C = D/d* = 7 ⇒*D* = 7*d* (2)

Substitute Eq. (2) into (1)

7*d* = 48.26 −*d*⇒*d* = 48.26/8 = 6.03 mm *Ans*.

(**b**) From Eq. (2): *D* = 7*d* = 7(6.03) = 42.24 mm *Ans*.

(**c**) 

(**d**) Table 10-5: *G* = 80 MPa

Eq. (10-9): 

Table 10-1: *Nt* = *Na* + 2 = 8.69 coils *Ans*.

(**e**) Table 10-4: *A* = 1855 MPa⋅mm*m*, *m* = 0.187

Eq. (10-14): 

Table 10-6: *Ssy* = 0.5*Sut* = 0.5(1326) = 663 MPa

Eq. (10-5): 

Eq. (10-7): 



*ys = Fs* / *k* = 1127.6/26.27 = 42.92 mm

Table 10-1: *Ls* = *Nt d* = 8.69(6.03) = 51.05 mm

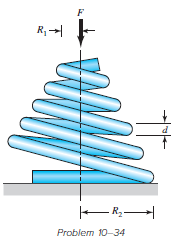
*L*0 = *Ls + ys* = 51.05 + 42.92 = 93.97 mm *Ans*.

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**10-34** For a coil radius given by:



The torsion of a section is *T* = *PR* where *dL*= *R dθ*





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**10-35**  Given: *F*min = 18 N, *F*max = 80 N, *k* = 1.664 N/mm, OD ≤ 63.5 mm, *nf* = 1.5.

For a food service machinery application select A313 Stainless wire.

Table 10-5: *G* = 69 GPa

Note that for 0*.*33 ≤ *d* ≤ 2.54 mm *A* = 1867, *m* = 0*.*146

2.54 *< d* ≤ 5.08 mm *A* = 2065, *m* = 0*.*263



Try, 

*Ssu*= 0*.*67*Sut*= 1129 MPa, *Ssy*= 0*.*35*Sut*= 590 MPa

The Gerber ordinate intercept for the Zimmerli data isobtained using Eqs. (10-28) and (10-29b).



Let *r* = *τa /τm* = 31/49. The Gerber fatigue criterion from Eq. (6-48), adapted for shear,



Solving for *τm* gives,



But,



Let *α = τm*= 253 MPa, and From Eq. (10-23),



*D = Cd* = 6.98(2.03) = 14.17 mm



The Gerber fatigue criterion from Eq. (6-48), adapted for shear,





*Nt* = 31.02 + 2 = 33 coils

*Ls* = *dNt* = 2.03(33) = 67 mm

*y*max = *F*max / *k* = 80/ 1.664 = 48.13 mm

*ys* = (1 + *ξ*)*y*max = (1 + 0.15)(48.13) = 55.34 mm

*L*0 = *Ls* + *y*max = 67+ 55.34 = 122.34 mm

(*L*0)cr = 2.63 *D / α* = 2.63(14.17) / 0.5 = 74.5 mm

*τs* = (1 + *ξ*)(*F*max /*Fa*)*τa* = 1.15(80/31.14)160.65 = 474.36 MPa

*ns* = *Ssy / τs* = 590/474.36 = 1.24



These steps are easily implemented on a spreadsheet, as shown below, for differentdiameters.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | *d*1 | *d*2 | *d*3 | *d*4 |
| *d* | 2.0 | 2.3 | 2.7 | 3.1 |
| *m* | 0.146 | 0.146 | 0.263 | 0.263 |
| *A* | 1867 | 1867 | 2065 | 2065 |
| *Sut* | 1684.82 | 1652.11 | 1594.46 | 674.65 |
| *Ssu* | 1128.83 | 1106.91 | 1068.29 | 674.65 |
| *Ssy* | 589.69 | 578.24 | 558.06 | 674.65 |
| *Ssa* | 240 | 240 | 240 | 240 |
| *Sse* | 272.0 | 273.4 | 276.1 | 279.0 |
| *m* | 253 | 253 | 253 | 253 |
| ** | 253 | 253 | 253 | 253 |
| ** | 30 | 23 | 17 | 13 |
| *C* | 6.977 | 9.603 | 13.244 | 17.702 |
| *D* | 14.17 | 22.33 | 35.48 | 54.18 |
| *KB* | 1.201 | 1.141 | 1.100 | 1.074 |
| *a* | 161 | 161 | 161 | 161 |
| *nf* | 1.5 | 1.5 | 1.5 | 1.5 |
| *Na* | 30.99 | 13.59 | 5.98 | 2.86 |
| *Nt* | 32.99 | 15.59 | 7.98 | 4.86 |
| *Ls* | 67.03 | 36.25 | 21.36 | 14.86 |
| *ys* | 55.35 | 55.35 | 55.35 | 55.35 |
| *L*0 | 122.38 | 91.59 | 76.71 | 70.21 |
| (*L*0)cr | 74.57 | 117.40 | 186.69 | 284.99 |
| *s* | 476 | 476 | 476 | 476 |
| *ns* | 1.24 | 1.215 | 1.173 | 1.133 |
| *f*, (Hz) | 108.895 | 114.578 | 118.863 | 121.775 |

The shaded areas depict conditions outside the recommended design conditions. Thus, one spring is satisfactory. The specifications are: A313 stainless wire, unpeened, squared and ground,*d* = 23.24 mm, OD = 22.32 + 2.33 = 24.66 mm, *L*0 = 91.60 mm, and *Nt*= 15*.*59 turns *Ans.*

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**10-36**  The steps are the same as in Prob. 10-35 except that the Gerber-Zimmerli criterion isreplaced with the Goodman-Zimmerli relationship of Eq. (10-29*a*) :



The problem then proceeds as in Prob. 10-30. The results for the wire sizes are shownbelow (see solution to Prob. 10-35 for additional details).

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | Iteration of *d* for the first trial | | | |  |  |  |
|  | *d*1 | *d*2 | *d*3 | *d*4 |  |  | *d*1 | *d*2 | *d*3 | *d*4 |
| *d* | 2.0 | 2.3 | 2.7 | 3.1 |  | *d* | 2.0 | 2.3 | 2.7 | 3.1 |
| *m* | 0.146 | 0.146 | 0.263 | 0.263 |  | *KB* | 1.151 | 1.108 | 1.078 | 1.058 |
| *A* | 1867 | 1867 | 2065 | 2065 |  | *a* | 200.0 | 200.2 | 200.6 | 200.8 |
| *Sut* | 1684.82 | 1652.11 | 1594.46 | 1539.68 |  | *nf* | 1.500 | 1.500 | 1.500 | 1.500 |
| *Ssu* | 1128.83 | 1106.91 | 1068.29 | 1031.58 |  | *Na* | 14.191 | 6.456 | 2.899 | 1.404 |
| *Ssy* | 589.69 | 578.24 | 558.06 | 538.89 |  | *Nt* | 16.191 | 8.456 | 4.899 | 3.404 |
| *Ssa* | 241.32 | 241.32 | 241.32 | 241.32 |  | *Ls* | 32.89 | 19.66 | 13.13 | 10.41 |
| *Sse* | 363.40 | 367.07 | 374.12 | 381.59 |  | *ys* | 55.35 | 55.35 | 55.35 | 55.35 |
| *m* | 314.30 | 314.64 | 315.17 | 315.58 |  | *L*0 | 88.24 | 75.01 | 68.48 | 65.76 |
| ** | 314.30 | 314.64 | 315.17 | 315.58 |  | (*L*0)cr | 96.75 | 150.47 | 237.59 | 361.16 |
| ** | 30.18 | 23.07 | 17.35 | 13.30 |  | *s* | 591.4 | 592.1 | 593.1 | 593.9 |
| *C* | 9.052 | 12.309 | 16.856 | 22.433 |  | *ns* | 0.997 | 0.977 | 0.941 | 0.907 |
| *D* | 18.4 | 28.6 | 45.2 | 68.7 |  | *f*, (Hz) | 141.284 | 146.853 | 151.271 | 154.326 |

Without checking all of the design conditions, it is obvious that none of the wire sizessatisfy *ns*≥ 1*.*2. Also, the Gerber line is closer to the yield line than the Goodman. Setting*nf*= 1*.*5 for Goodman makes it impossible to reach the yield line (*ns<*1) . The tablebelow uses *nf*= 2.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | Iteration of *d* for the second trial | | | | |  |  |
|  | *d*1 | *d*2 | *d*3 | *d*4 |  |  | *d*1 | *d*2 | *d*3 | *d*4 |
| *d* | 2.0 | 2.3 | 2.7 | 3.1 |  | *d* | 2.0 | 2.3 | 2.7 | 3.1 |
| *m* | 0.146 | 0.146 | 0.263 | 0.263 |  | *KB* | 1.221 | 1.154 | 1.108 | 1.079 |
| *A* | 1867 | 1867 | 2065 | 2065 |  | *a* | 150.00 | 150.17 | 150.42 | 150.62 |
| *Sut* | 1684.82 | 1652.11 | 1594.46 | 1539.68 |  | *nf* | 2.000 | 2.000 | 2.000 | 2.000 |
| *Ssu* | 1128.83 | 1106.91 | 1068.29 | 1031.58 |  | *Na* | 40.243 | 17.286 | 7.475 | 3.539 |
| *Ssy* | 589.69 | 578.24 | 558.06 | 538.89 |  | *Nt* | 42.243 | 19.286 | 9.475 | 5.539 |
| *Ssa* | 241.32 | 241.32 | 241.32 | 241.32 |  | *Ls* | 85.83 | 44.83 | 25.40 | 16.94 |
| *Sse* | 363.40 | 367.07 | 374.12 | 381.59 |  | *ys* | 55.35 | 55.35 | 55.35 | 55.35 |
| *m* | 314.30 | 314.64 | 315.17 | 315.58 |  | *L*0 | 141.17 | 100.18 | 80.75 | 72.29 |
| ** | 314.30 | 314.64 | 315.17 | 315.58 |  | (*L*0)cr | 68.35 | 108.36 | 173.25 | 265.40 |
| ** | 30.18 | 23.07 | 17.35 | 13.30 |  | *s* | 443.6 | 444.1 | 444.8 | 445.4 |
| *C* | 6.395 | 8.864 | 12.292 | 16.485 |  | *ns* | 1.329 | 1.302 | 1.255 | 1.210 |
| *D* | 13.0 | 20.6 | 32.9 | 50.4 |  | *f*, (Hz) | 99.816 | 105.759 | 110.312 | 113.408 |

The satisfactory spring has design specifications of: A313 stainless wire, unpeened, squaredand ground, *d* = 2.32 mm, OD = 20.59 + 2.33 = 22.92 mm, *L*0 = 100.17 mm, and

.*Nt*= 19*.*3 turns. *Ans*.

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**10-37** This is the same as Prob. 10-35 since *Ssa*= 241 MPa. Therefore, the specifications are: A313 stainless wire, unpeened, squared and ground,*d* = 2.32 mm, OD = 22.32 + 2.33 = 24.65 mm, *L*0 = 91.6 mm, and*Nt*= 15*.*59 turns*Ans*.

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**10-38** For the Gerber-Zimmerlifatigue-failure criterion, *Ssu*= 0*.*67*Sut*,



See the process used in Prob. 10-36. The last 2 columns of diameters of Ex. 10-5are presented below with additional calculations.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *d* | 2.67 | 2.84 | *d* | 2.67 | 2.84 |
| *Sut* | 1921.51 | 1903.61 | *Nt* | 10.915 | 8.190 |
| *Ssu* | 1287.41 | 1275.42 | *Ls* | 29.11 | 23.29 |
| *Sse* | 264.24 | 264.72 | L0 | 87.53 | 81.71 |
| *m* | 265.50 | 265.46 | (*L*0)cr | 168.40 | 207.26 |
| ** | 265.50 | 265.46 | *KB* | 1.111 | 1.095 |
| ** | 19.91 | 17.50 | *a* | 159.30 | 159.28 |
| *C* | 12.004 | 13.851 | *nf* | 1.500 | 1.500 |
| *D* | 32.00 | 39.40 | *s* | 488.53 | 488.45 |
| ID | 29.34 | 36.55 | *ns* | 1.770 | 1.754 |
| OD | 34.67 | 42.24 | *fn* | 105.433 | 106.922 |
| *Na* | 8.915 | 6.190 | fom | -0.973 | -1.022 |

There are only slight changes in the results.

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

**10-39** As in Prob. 10-38, the basic change is *Ssa.*

For Goodman, using Eq. (10-29*a*): 

Recalculate *τm*using Eq. (6-41) for shear. That is,



Where *r = τa / τm*. Thus,



See the process used in Prob. 10-36. Calculations for the last 2 diameters of Ex. 10-5 are given below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *d* | 2.67 | 2.84 | *d* | 2.67 | 2.84 |
| *Sut* | 1921.51 | 1903.61 | *Nt* | 11.153 | 8.353 |
| *Ssu* | 1287.41 | 1275.42 | *Ls* | 29.74 | 23.77 |
| *Sse* | 342.08 | 343.43 | L0 | 88.16 | 82.19 |
| *m* | 263.43 | 263.39 | (*L*0)cr | 166.93 | 205.49 |
| ** | 263.43 | 263.39 | *KB* | 1.112 | 1.096 |
| ** | 19.91 | 17.50 | *a* | 158.06 | 158.03 |
| *C* | 11.899 | 13.732 | *nf* | 1.500 | 1.500 |
| *D* | 31.72 | 39.07 | *s* | 484.7 | 484.6 |
| ID | 29.06 | 36.22 | *ns* | 1.784 | 1.768 |
| OD | 34.39 | 41.91 | *fn* | 104.509 | 106.000 |
| *Na* | 9.153 | 6.353 | fom | -0.986 | -1.034 |

There are only slight differences in the results.

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

**10-40** Use: *E* = 197.2 GPa, *G* = 79.3 GPa, *A* = 1783 MPa· mm*m*,*m* = 0*.*190, rel cost = 1*.*

Try 

Table 10-6: *Ssy*= 0*.*45*Sut*= 726 MPa

Table 10-7: *Sy*= 0*.*75*Sut*= 1210 MPa

Eq. (10-34) with *D/d* = *C* and *C*1 = *C*









Use the lowest *Fi*in the preferred range. This results in the best fom.



For simplicity, we will round up to the next integer or half integer.Therefore, use *Fi*= 31 N



Body: 















Several diameters, evaluated using a spreadsheet, are shown below.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *d* | 1.7 | 1.8 | 1.9 | 2.1 | 2.2 | 2.3 | 2.4 | 2.6 |
| *Sut* | 1613 | 1591 | 1575 | 1556 | 1542 | 1525 | 1510 | 1484 |
| *Ssy* | 726 | 716 | 709 | 700 | 694 | 686 | 679 | 668 |
| *Sy* | 1210 | 1193 | 1181 | 1167 | 1156 | 1144 | 1132 | 1113 |
| *C* | 4.589 | 5.412 | 6.099 | 6.993 | 7.738 | 8.708 | 9.721 | 11.650 |
| *D* | 7.8 | 9.9 | 11.8 | 14.4 | 16.7 | 19.9 | 23.4 | 30.8 |
| *Fi*(calc) | 28.9 | 25.7 | 23.4 | 20.8 | 18.9 | 16.7 | 14.8 | 11.7 |
| *Fi*(rd) | 31.1 | 26.7 | 24.5 | 22.2 | 20.0 | 17.8 | 15.6 | 13.3 |
| *k* | 3.85 | 4.20 | 4.38 | 4.55 | 4.73 | 4.90 | 5.08 | 5.25 |
| *Na* | 45.29 | 27.20 | 19.27 | 13.10 | 9.77 | 7.00 | 5.13 | 3.15 |
| *Nb* | 44.89 | 26.80 | 18.86 | 12.69 | 9.36 | 6.59 | 4.72 | 2.75 |
| *L*0 | 90.32 | 66.98 | 58.04 | 52.83 | 51.46 | 52.60 | 55.91 | 66.17 |
| *L*90N | 103.02 | 79.68 | 70.74 | 65.53 | 64.16 | 65.30 | 68.61 | 78.87 |
| *KB* | 1.326 | 1.268 | 1.234 | 1.200 | 1.179 | 1.157 | 1.139 | 1.115 |
| *τ*max | 428.29 | 418.42 | 411.67 | 404.28 | 399.03 | 393.13 | 387.82 | 379.43 |
| (*ny*)body | 1.695 | 1.711 | 1.722 | 1.732 | 1.739 | 1.746 | 1.752 | 1.760 |
| *τB* | 403.87 | 412.44 | 417.10 | 421.04 | 423.11 | 424.70 | 425.49 | 425.49 |
| (*ny*)*B* | 1.797 | 1.736 | 1.699 | 1.663 | 1.640 | 1.616 | 1.597 | 1.569 |
| (*ny*)*A* | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 | 1.500 |
| fom | −0.160 | −0.144 | -0.138 | −0.135 | −0.133 | −0.135 | −0.138 | −0.154 |

Except for the 1.7 mm wire, all springs satisfy the requirements of length and number ofcoils. The 2.16 mm wire has the highest fom.

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**10-41** Given: *Nb*= 84 coils, *Fi*= 71.2 N, OQ&T steel, OD = 38.1 mm, *d* = 4.11 mm.

*D* = OD −*d* = 38.1−4.11 =33.98 mm

**(a)** Eq. (10-39):

*L*0 = 2(*D* −*d*) + (*Nb*+ 1)*d*

= 2(33.98 − 4.11) + (84 + 1)(4.11) = 409.4 mm *Ans.*

or 2*d* + *L*0 = 2(4.11) + 409.4 = 417.8 mm overall

**(b) **

**

**(c)** From Table 10-5 use: *G* = 78.6 GPa and *E* = 196.5 GPa



**(d)** Table 10-4: *A* = 1855 MPa · mm*m*,  *m* = 0*.*187



*Body*



*Torsional stress on hook point B*



*Normal stress on hook point A*









**(e)** Eq. (10-48):



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

**10-42**  *F*min = 40 N, *F*max = 80 N



A313 stainless: 0*.*3 ≤ *d* ≤ 2.5 *A* = 1867 MPa · mm*m*, *m* = 0*.*146

2.5 ≤ *d* ≤ 5 *A* = 2065 MPa · mm*m*, *m* = 0*.*263

*E* = 193 GPa, *G* = 69 GPa

Try *d* = 2 mm and refer to the discussion following Ex. 10-7 

Table 10-8: *Sr*= 0*.*45*Sut*= 757 MPa



For Gerber, Eq. (6-48), solving for (*σm*)*A* gives



Hook bending



Let 

Equation (1) reduces to



The useable root for *C* is







*D = Cd* = 10.1 mm

Using Eq. (10-4) for *τi*



Use the lowest *Fi*in the preferred range.



For simplicity we will round *Fi* up to next 1*/*4 integer. Let *Fi* = 38.92 N.













Body: 



The repeating allowable stress from Table 10-8 is

*Ssr*= 0*.*30*Sut*= 0*.*30(1682) = 504.5 MPa

The Gerber intercept is given by Eq. (10-42) as



From Eq. (6-48),



Let *r*2 = 2*d* = 2(2) = 4



Table 10-8: (*Ssr*)*B*= 0*.*28*Sut*= 0*.*28(1682) = 471 MPa



*Yield*

Bending:



Body:



Hook shear:



A tabulation of several wire sizes follow

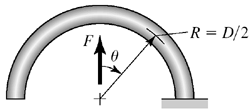
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *d* | 2.06 | 2.16 | 2.34 | 2.49 | 2.67 | 3.05 |
| *Sut* | 1681.77 | 1669.98 | 1650.79 | 1635.64 | 1619.24 | 1587.98 |
| *Ssu* | 1126.79 | 1118.89 | 1106.03 | 1095.87 | 1084.89 | 1063.94 |
| *Ssy* | 588.62 | 584.49 | 577.78 | 572.47 | 566.74 | 555.79 |
| *Sr* | 756.80 | 751.49 | 742.85 | 736.04 | 728.66 | 714.59 |
| *Se* | 398.58 | 395.78 | 391.24 | 387.64 | 383.76 | 376.35 |
| (*m*)*A* | 436.65 | 433.59 | 428.61 | 424.68 | 420.41 | 412.30 |
| ** | 96.70 | 105.73 | 122.44 | 137.66 | 156.44 | 200.39 |
| *C* | 4.92 | 5.50 | 6.56 | 7.53 | 8.71 | 11.48 |
| (*a*)*A* | 145.55 | 144.53 | 142.87 | 141.56 | 140.14 | 137.43 |
| (*nf*)*A* | 2 | 2 | 2 | 2 | 2 | 2 |
| *D* | 10.11 | 11.86 | 15.34 | 18.75 | 23.24 | 34.98 |
| OD | 12.17 | 14.02 | 17.68 | 21.23 | 25.91 | 38.02 |
| *Fi* (calc) | 37.97 | 34.88 | 30.11 | 26.51 | 22.76 | 16.09 |
| *Fi* (rd) | 38.92 | 38.92 | 38.92 | 38.92 | 38.92 | 38.92 |
| *k* | 36 | 36 | 36 | 36 | 36 | 36 |
| *Na* | 23.68 | 17.77 | 11.30 | 7.98 | 5.51 | 2.76 |
| *Nb* | 23.32 | 17.41 | 10.94 | 7.62 | 5.16 | 2.40 |
| *L*0 | 66.14 | 59.16 | 53.90 | 53.95 | 57.56 | 74.22 |
| *L*max | 72.67 | 65.68 | 60.43 | 60.48 | 64.08 | 80.75 |
| *KB* | 1.3 | 1.263 | 1.215 | 1.184 | 1.157 | 1.117 |
| (*a*)body | 76.96 | 75.95 | 74.44 | 73.35 | 72.24 | 70.31 |
| (*m*)body | 230.88 | 227.83 | 223.31 | 220.03 | 216.72 | 210.92 |
| *Ssr* | 504.53 | 500.99 | 495.24 | 490.69 | 485.77 | 476.39 |
| *Sse* | 265.58 | 263.72 | 260.68 | 258.29 | 255.71 | 250.77 |
| (*nf*)body | 2.53 | 2.54 | 2.56 | 2.58 | 2.59 | 2.61 |
| (*KB*)*B* | 4 | 4 | 4 | 4 | 4 | 4 |
| (*a*)*B* | 73.99 | 75.14 | 76.57 | 77.40 | 78.05 | 78.71 |
| (*m*)*B* | 221.98 | 225.42 | 229.73 | 232.21 | 234.15 | 236.13 |
| (*Ssr*)*B* | 470.90 | 467.60 | 462.22 | 457.98 | 453.39 | 444.64 |
| (*Sse*)*B* | 246.20 | 244.47 | 241.66 | 239.44 | 237.04 | 232.47 |
| (*nf*)*B* | 2.51 | 2.46 | 2.38 | 2.34 | 2.29 | 2.23 |
| *Sy* | 924.97 | 918.49 | 907.94 | 899.60 | 890.58 | 873.39 |
| (*A*)max | 582.20 | 578.12 | 571.48 | 566.23 | 560.56 | 549.73 |
| (*ny*)*A* | 1.59 | 1.59 | 1.59 | 1.59 | 1.59 | 1.59 |
| *i* | 149.64 | 147.67 | 144.73 | 142.61 | 140.47 | 136.71 |
| *r* | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| (*Ssa*)*y* | 213.56 | 212.51 | 210.67 | 209.12 | 207.37 | 203.88 |
| (*ny*)body | 2.78 | 2.80 | 2.83 | 2.85 | 2.87 | 2.90 |
| (*Ssy*)*B* | 504.53 | 500.99 | 495.24 | 490.69 | 485.77 | 476.39 |
| (*B*)max | 295.98 | 300.57 | 306.31 | 309.61 | 312.19 | 314.84 |
| (*ny*)*B* | 1.705 | 1.667 | 1.617 | 1.585 | 1.556 | 1.513 |
| fom | -1.24 | -1.229 | -1.24 | -1.278 | -1.353 | -1.636 |

optimalfom

The shaded areas show the conditions not satisfied.

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**10-43** For the hook,



*M* = *FR* sin*θ*, *∂M/∂F* = *R* sin*θ*

**

The total deflection of the body and the two hooks



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**10-44** Table 10-5 (*d* = 4 mm = 0.1575 in): *E* = 196.5 GPa

Table 10-4 for A227:

*A* = 1783MPa · mm*m*, *m* = 0*.*190

Eq. (10-14): 

Eq. (10-57): *Sy* = *σ*all = 0.78 *Sut* = 0.78(1370) = 1069 MPa

*D* = OD −*d* = 32 − 4 = 28 mm

*C = D/d* = 28/4 = 7

Eq. (10-43): 

Eq. (10-44): 

At yield, *Fr = My,σ = Sy*. Thus,



Count the turns when *M* = 0



where from Eq. (10-51): 

Thus,



Solving for *N* gives



This means (2*.*5 − 2*.*413)(360°) or 31.3° from closed. *Ans*.

Treating the hand force as in themiddle of the grip,



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**10-45** The spring material and condition are unknown. Given *d* = 2.05 mm and OD = 12.7 mm,

**(a)** *D* = 12.7 − 2.05 = 10.64 mm

Using *E* = 197.2 GPa for an estimate



for each spring. The moment corresponding to a force of 36 N

*Fr* = (36*/*2)(84.15) = 1497 N· mm/spring

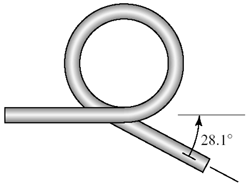
The fraction windup turn is



The arm swings through an arc of slightly less than 180°, say 165°. This uses up

165*/*360 or 0.458 turns. So *n* = 0*.*536 − 0*.*458 = 0*.*078 turns are left (or

0*.*078(360°) = 28*.*1° ). The original configuration of the spring was



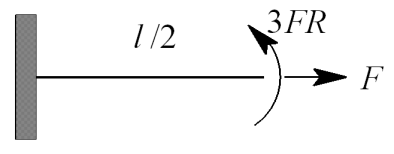
**(b)**

**

To achieve this stress level, the spring had to have set removed.

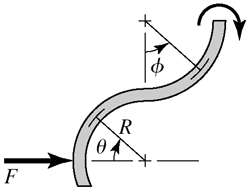
\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**10-46** (**a**) Consider half and double results



Straight section: *M* = 3*FR*,

Upper 180° section:





Lower section: *M* = *FR* sin *θ*, 

Considering bending only:



The spring rate is



(**b**) Given: A227 HD wire, *d* = 2 mm, *R* = 6 mm, and *l* = 25 mm.

Table 10-5 (*d* = 2 mm = 0.0787 in): *E* = 197.2 GPa



(**c**) The maximum stress will occur at the bottom of the top hook where the bending- moment is 3*FR* and the axial fore is *F*. Using curved beam theory for bending,

Eq. (3-65): 

Axial: 

Combining, 



For the clip in part (b),

Eq. (10-14) and Table 10-4: *Sut* = *A/dm* = 1783/20.190 = 1563 MPa

Eq. (10-57): *Sy* = 0.78 *Sut* = 0.78(1563) = 1219 MPa

Table 3-4:



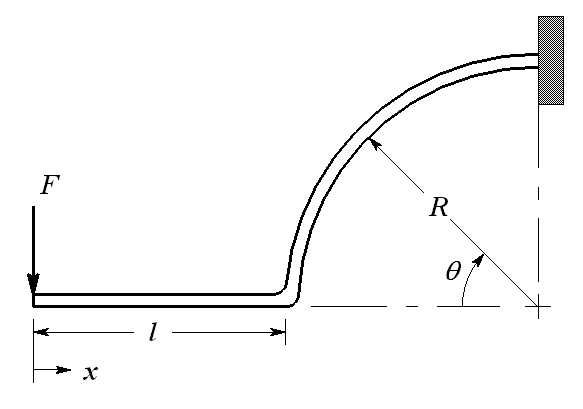
*e = rc−rn* = 6 − 5.95804 = 0.04196 mm

*ci = rn−* (*R − d* /2) = 5.95804 − (6 − 2/2) = 0.95804 mm

Eq. (1):



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**10-47** (**a**)

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The spring rate is



(**b**) Given: A313 stainless wire, *d* = 1.6 mm, *R* = 15.87 mm, and *l* = 12.7 mm.

Table 10-5: *E* = 193 GPa





(**c**) Table 10-4: *A* = 1867 MPa⋅mm*m*, *m* = 0.146

Eq. (10-14): *Sut* = *A/ d m* = 1867/1.60.146 = 1744.37 MPa

Eq. (10-57): *Sy* = 0.61 *Sut* = 0.61(1744.37) = 1064.55 MPa

One can use curved beam theory as in the solution for Prob. 10-41. However, the equations developed in Sec. 10-12 are equally valid.

*C = D/d* = 2(15.87 + 1.6/2)/1.6 = 20.8

Eq. (10-43): 

Eq. (10-44), setting *σ = Sy*:



Solving for *F* yields *F* = 14.46 N *Ans*.

Try solving part (c) of this problem using curved beam theory. You should obtain the same answer.

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**10-48** (**a**) *M = −Fx*



Constant stress,



At *x = l*,



(**b**) *M = −Fx*, *∂ M /∂ F =− x*





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**10-49** Computer programs will vary.

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**10-50** Computer programs will vary.