**Chapter 12**

**12-1** Given: *d*max = 25 mm, *b*min = 25.03 mm, *l/d* = 1/2, *W* = 1.2 kN, *μ* = 55 mPa⋅s, and *N* = 1100 rev/min.



*r* 25/2 = 12.5 mm

*r/c* = 12.5/0.015 = 833.3

*N* = 1100/60 = 18.33 rev/s

*P* = *W/* (*ld*) = 1200/ [12.5(25)] = 3.84 N/mm2 = 3.84 MPa

Eq. (12-10): 

Fig. 12-15: *h*0 /*c* = 0.3 ⇒ *h*0  = 0.3(0.015) = 0.0045 mm *Ans*.

Fig. 12-17: *f r/c* = 5.4 ⇒ *f* = 5.4/833.3 = 0.006 48

*T =f Wr* = 0.006 48(1200)12.5(10−3) = 0.0972 N⋅m

*H*loss = 2*π TN* = 2*π* (0.0972)18.33 = 11.2 W *Ans*.

Fig. 12-18: *Q*/(*rcNl*) = 5.1 ⇒ *Q* = 5.1(12.5)0.015(18.33)12.5 = 219 mm3/s

Fig. 12-19: *Qs /Q* = 0.81 ⇒ *Qs*  = 0.81(219) = 177 mm3/s *Ans*.

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**12-2** Given: *d*max = 32 mm, *b*min = 32.05 mm, *l* = 64 mm, *W* = 1.75 kN, *μ* = 55 mPa⋅s, and *N* = 900 rev/min.



*r*≈ 32/2 = 16 mm

*r/c* = 16/0.025 = 640

*N* = 900/60 = 15 rev/s

*P* = *W/* (*ld*) = 1750/ [32(64)] = 0.854 MPa

*l/d* = 64/32 = 2

Eq. (12-10): 

Eq. (12-20), Figs. 12-15, 12-18, and 12-20

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *l/d* | *y* | *y*1 | *y*1/2 | *y*1/4 | *yl/d* |
| *h*0*/c* | 2 | 0.98 | 0.83 | 0.61 | 0.36 | 0.92 |
| *P/p*max | 2 | 0.84 | 0.54 | 0.45 | 0.31 | 0.65 |
| *Q/rcNl* | 2 | 3.1 | 3.45 | 4.2 | 5.08 | 3.20 |

*h*0= 0.92*c* = 0.92(0.025) = 0.023 mm *Ans*.

*p*max = *P* / 0.65 = 0.854/0.65 = 1.31 MPa *Ans*.

*Q* = 3.20 *rcNl* = 3.20(16)0.025(15)64 = 1.23 (103) mm3/s *Ans*.

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**12-3** Given: *d*max = 76.2 mm, *b*min = 76.327 mm, *l* = 38.1 mm, *W* = 3558.40, *N* = 600 rev/min,and SAE 10 and SAE 40 at 4.43°C.



Fig. 12-3: SAE 10 at 4.43°C, 



Figs. 12-15 and 12-20: *h*0*/c* = 0*.6* and*P/p*max = 0*.*45

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Fig. 12-3: SAE 40at 4.43°C, 



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**12-4** Given: *d*max = 82.55 mm, *b*min = 82.702 mm, *l* = 76.2 mm, *W* = 3558.4 N, and *N* = 1000 rev/min.



Fig. 12-4: SAE 20W at 150°F (65.6 °C) ,*μ′* = 2.40 *μ*reyn =0.0196 Pa.s

**Note to instructors:** Some students may obtain a higher value of viscosity (2.85) from Fig. 12-4. The value from Fig. 12-3 is used here as the preferred value since this figure is specifically for single-viscosity oils.



From Eq. (12-20), and Figs. 12-15 and 12-20:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *l/d* | *y* | *y*1 | *y*1/2 | *y*1/4 | *yl/d* |
| *h*0*/c* | 0.923 | 0.82 | 0.44 | 0.26 | 0.14 | 0.42 |
| *P/p*max | 0.923 | 0.83 | 0.44 | 0.31 | 0.21 | 0.42 |

**

Fig. 12-4: SAE 20W-40at 150°F(65.6 °C), *μ′* = 4.4 *μ*reyn=0.03032 Pa.s



From Eq. (12-20), and Figs. 12-15 and 12-20:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *l/d* | *y* | *y*1 | *y*1/2 | *y*1/4 | *yl/d* |
| *h*0*/c* | 0.923 | 0.91 | 0.6 | 0.38 | 0.2 | 0.58 |
| *P/p*max | 0.923 | 0.83 | 0.48 | 0.35 | 0.24 | 0.46 |



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**12-5** Given: *d*max = 50.8 mm, *b*min = 50.861 mm, *l* = 25.4 mm, *W* = 2668.8 N, *N* = 800 rev/min, and SAE 20 at 3.84 °C.



Fig. 12-2: SAE 20at 3.84°C, 



From Figs. 12-15, 12-17 and 12-18:



The power loss due to friction is



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**12-6** Given: *d*max = 25 mm, *b*min = 25.04 mm, *l/d* = 1, *W* = 1.25 kN, *μ* = 50 mPa⋅s, and *N* = 1200 rev/min.



For *µ* = 50 mPa · s, 

From Figs. 12-15, 12-17 and 12-19:



The power loss due to friction is

*H* = 2*πT N* = 2*π*(0*.*1125)(20) = 14*.*14 W *Ans.*

*Qs*= 0*.*57*Q* The side flow is 57% of *QAns.*

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**12-7** Given: *d*max = 31.75 mm, *b*min = 31.8008 mm, *l*  = 50.8 mm, *W* = 2757.76 mm, *μ′* = 30 mPa.s, and *N* = 1120 rev/min.



|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *l/d* | *y* | *y*1 | *y*1/2 | *y*1/4 | *yl/d* |
| *h*0*/c* | 1.6 | 0.8 | 0.4 | 0.25 | 0.12 | 0.5 |
| *fr/c* | 1.6 | 2.5 | 3.2 | 4.0 | 5 | 2.6 |
| *Q/rcNl* | 1.6 | 2.8 | 4.3 | 5.3 | 5.8 | 3.5 |

From Eq. (12-20), and Figs. 12-15, 12-17, and 12-1 *h*0 = 0.5 *c* = 0.5(0.0254) =0.0127 mm. *Ans*.

*f* = 2.6/(*r/c*) = 2.6/625 = 0.00416 *Ans*.

*Q* = 3.5 *rcNl* = 3.5(15.785) 0.0254(18.57) 50.8 = 699.13 mm3/s *Ans*.

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**12-8** Given: *d*max = 75.00 mm, *b*min = 75.10 mm, *l* = 36 mm, *W* = 2 kN, *N* = 720 rev/min,and SAE 20 and SAE 40 at 60°C.



Fig. 12-3: SAE 20 at 60°C, *µ* = 18*.*5 mPa · s



From Figures 12-15, 12-17 and 12-20:



The heat loss rate equals the rate of work on the film

*H*loss = 2*πT N* = 2*π*(0*.*51)(12) = 38*.*5W *Ans.*

*p*max = 0*.*741*/*0*.*315 = 2*.*35 MPa *Ans.*

Fig. 12-3: SAE 40at 60°C, *µ* = 37 mPa · s

*S* = 0*.*169(37)*/*18*.*5 = 0*.*338

From Figures 12-15, 12-17 and 12-20:



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**12-9** Given: *d*max = 56.00 mm, *b*min = 56.05 mm, *l* = 28 mm, *W* = 2.4 kN, *N* = 900 rev/min,and SAE 40 at 65°C.



Fig. 12-3: SAE 40 at 65°C, *µ* = 30 mPa · s



From Figures 12-15, 12-17, 12-18 and 12-19:

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**12-10** Given: SAE 40, *N* = 10 rev/s, *Ts*= 140°F(60°C), *l/d* = 1, *d* = 76.2 mm, *b* = 76.2762 mm,

*W* = 3002.4 N.



*Trial* #1: From Figure 12-3 for *T* = 80°C, *µ* = 16 mPa.s,



From Fig. 12-23,



Discrepancy = 40 −9.5 = 30.5°C

*Trial* #2: *T* = 65°C,*µ* = 29.5 mPa.s,



From Fig. 12-23,



Discrepancy = 10 − 16.34 = -6.34 °C

*Trial* #3: *T* = 68°C, *µ* = 27.5 mPa.s



From Fig. 12-23,



Discrepancy = 16 − 15.33 = − 0.677°C (OK)

*T*av= 60 +16/2 = 68 °C *Ans.*



From Figures 12-15, 12-17to 12-19:



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**12-11** Given: *d* = 63.5 mm,*b* = 63.6016 mm, *c*min = 0*.*0508 mm, *W*= 5376 N, SAE = 20, Using *Ts*= 110°F , *N*= 1120 rev/min, and *l* = 63.5 mm.

*P* = *W/*(*ld*) = 5376/(63.5)2 = 1.33 MPa, *N* = 1120/60 = 18.67 rev/s

Table 12-1: *μ* (*μ*reyn) = *μ*0 (106) exp [*b* / (*T* + 95)] *b* and *T* in °F

The conversion from *μ*reyn to mPa⋅s is given in Sec. 12-2. For a temperature of *C* degrees Celsius, *T* = 1.8 *C* + 32. Substituting into the above equation gives

*μ* (mPa⋅s) = 6.89 *μ*0 (106) exp [*b* / (1.8 *C* + 32+ 95)]

= 6.89 *μ*0 (106) exp [*b* / (1.8 *C* + 127)]

For a trial film temperature, let *Tf*= 65°C

*μ′* = (6.89)0.0136 exp[1271.6/(1.8(65) + 127)] = 17.18(10-3) Pa.s

Eq. (12-10): 

Fig. 12-23:





*which is not 0.1 or less*, therefore try averaging for the new trial film temperature, let



Proceed with additional trialsusing a spreadsheet (table also shows the first trial)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Trial *Tf* | *'* | *S* | *T* | *T*av | *Tf**T*av | New *Tf* |
| 65.00 | 0.01718 | 0.0942 | 10.06 | 48.33 | 16.67 | 56.67 |
| 56.67 | 0.02417 | 0.1326 | 12.62 | 49.61 | 7.06 | 53.14 |
| 53.14 | 0.02832 | 0.1553 | 14.14 | 50.37 | 2.77 | 51.75 |
| 51.75 | 0.03021 | 0.1657 | 14.83 | 50.71 | 1.04 | 51.23 |
| 51.23 | 0.03097 | 0.1698 | 15.11 | 50.85 | 0.38 | 51.04 |
| 51.04 | 0.03125 | 0.1714 | 15.21 | 50.90 | 0.14 | 50.97 |
| 50.97 | 0.03135 | 0.1719 | 15.25 | 50.92 | **0.05** | 50.95 |

Note that the convergence begins rapidly. There are ways to speed this, but at this point

they would only add complexity.

**(a) **

From Fig. 12-15: 

From Fig. 12-16: *φ*= 56° *Ans.*

**(b)** *e* = *c* −*h*0= 0*.*0508 − 0*.*0245 = 0*.*0263 mm  *Ans.*

**(c)** From Fig. 12-17:

**(d)** *T* = *f Wr*= 0*.*006 56(5376)(31.75/1000) = 1.119 N· m



**(e)** From Fig. 12-18:



From Fig. 12-19:

**(f)** From Fig. 12-20:

From Fig. 12-21: **

**(g)** From Fig. 12-21: ****

**(h)**From the trial table,*Tf*= 50.95°C *Ans.*

**(i)** WithΔ*T* = 15.25°C from thetrial table,*Ts*+ Δ*T* = 43.3 + 15.25 = 48.55°C *Ans.*

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**12-12** Given: *d* = 31.750 mm, *td*= 0*.*025 mm, *b* = 31.801 mm, *tb*= 0*.*076 mm, *l* = 31.75 mm, *W* = 1120 N, *N* = 1750 rev/min, SAE 10 lubricant, sump temperature *Ts*= 49°C*.*

*P = W/*(*ld*) = 1120/31.752 = 1.11 MPa, *N* = 1750/60 = 29.17 rev/s

For the clearance, *c* = 0.051 ± 0.025 mm. Thus, *c*min = 0.025 mm, *c*median = 0.051 mm, and

*c*max = 0.076 mm.

For *c*min = 0.025 mm, start with a trial film temperature of *Tf*= 60°C

Table 12-1: *μ′* = (6.89)0.0136 exp[1271.6/(1.8(60) + 127)] = 20.98(10-3) Pa.s

Eq. (12-10): 

Fig. 12-23:





which is not 0.1 or less, therefore try averaging for the new trial film temperature, let



Proceed with additional trials using a spreadsheet (table also shows the first trial)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Trial *Tf* | *'* | *S* | *T* | *T*av | *Tf**T*av | New *Tf* |
| 60.00 | 0.02098 | 0.2153 | 15.15 | 56.57 | 3.43 | 58.29 |
| 58.29 | 0.02254 | 0.2314 | 16.04 | 57.02 | 1.27 | 57.65 |
| 57.65 | 0.02316 | 0.2378 | 16.40 | 57.20 | 0.46 | 57.43 |
| 57.43 | 0.02339 | 0.2401 | 16.53 | 57.26 | 0.16 | 57.34 |
| 57.34 | **0.02347** | **0.2409** | 16.57 | 57.29 | **0.06** | 57.32 |

With *Tf* = 57.32°C, Δ*T* = 16.57°C, *μ′* = 23.47(10-3) Pa.s,  *S* = 0.2409,

*T*max = *Ts +* Δ*T* = 49 + 16.57 = 65.57°C

Fig. 12-15: *h*0/*c* = 0.55, *h*0 = 0.55(0.025) = 0.0140 mm

**= 1 −*h*0/*c* = 1 − 0.55 = 0.45 mm

Fig. 12-17: *r f /c* = 5, *f* = 5/(1/625) = 0.008

Fig. 12-18: *Q*/(*rcNl*) = 4, *Q* = 4(15.875)0.0254(29.17)31.75 = 1493.6 mm3/s

Fig. 12-19: *Qs/Q* = 0.54, *Qs* = 0.54(1493.6) = 806.55 mm3/s

The above can be repeated for *c*median = 0.051 mm, and *c*max = 0.076 mm. The results are shown below.

|  |  |  |  |
| --- | --- | --- | --- |
|  | *c*min  0.025 mm | *c*median0.05 mm | *c*max  0.075 mm |
| *Tf* | 57.32 | 52.68 | 51.57 |
| ** | 0.0235 | 0.0289 | 0.0305 |
| *S* | 0.2409 | 0.0744 | 0.0346 |
| Δ*Τ* | 16.57 | 7.29 | 5.08 |
| *T*max | 65.57 | 56.29 | 54.08 |
| *h*0/*c* | 0.55 | 0.27 | 0.15 |
| *h*0 | 0.01397 | 0.013716 | 0.01143 |
| ** | 0.45 | 0.73 | 0.85 |
| *fr/c* | 5 | 2 | 1.4 |
| *f* | 0.008 | 0.0064 | 0.00672 |
| *Q/*(*rcNl*) | 4 | 4.6 | 4.7 |
| *Q* | 1493.61 | 3435.31 | 5264.98 |
| *Qs /Q* | 0.54 | 0.79 | 0.88 |
| *Qs* | 806.55 | 2713.89 | 4633.19 |

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**12-13** Computer programs will vary.

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**12-14** In a step-by-step fashion, we are building a skill for natural circulation bearings.

• Given the average film temperature, establish the bearing properties.

• Given a sump temperature, find the average film temperature, then, establish the

bearingproperties.

• Now we acknowledge the environmental temperature’s role in establishing the sump

temperature. Sec. 12-9 and Ex. 12-5 address this problem.

Given: *d*max = 63.5 mm, *b*min = 63.605,mm *l/d* = 1, *N* = 1120 rev/min, SAE 20 lubricant, *W* = 1344 N, *A* = 38700 mm2, Using *T*∞ = 21°C, and *α* = 1.

2688 N *load with minimal clearance:* We will start by using *W* = 2688 N (*nd* = 2).The task is to iteratively find the average film temperature, *Tf*, which makes *H*gen and *H*loss equal.



*N* = 1120/60 = 18.67 rev/s





Table 12-1: *μ′* = (6.89)0.0136 exp[1271.6/(1.8 + 127)]





Start with trial values of *Tf* of 105 and 115°C.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trial *Tf* | *μ′* | *S* | *f r/c* | *H*gen | *H*loss |
| 105 | 0.00524 | 0.0553 | 1.8 | 28.51 | 24.87 |
| 115 | 0.00422 | 0.0445 | 1.6 | 25.34 | 27.83 |

As a linear approximation, let *H*gen = *mTf* +*b*. Substituting the two sets of values of *Tf* and *H*gen we find that *H*gen = − 0.317 *Tf* +61.8. Setting this equal to *H*loss and solving for *Tf* gives*Tf* = 111°C.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trial *Tf* | *μ′* | *S* | *f r/c* | *H*gen | *H*loss |
| 111 | 0.00459 | 0.0484 | 1.7 | 26.9 | 26.6 |

which is satisfactory.

Fig. 12-15: *h*0/*c* = 0.21, *h*0 = 0.21 (0.05) = 0.0105 mm

Fig. 12-23:



*T*1 = *Ts* = *Tf*−Δ*T* = 111 − 3.69/2 = 109.2°C

*T*max = *T*1 + Δ*T* = 109.2 + 3.69 = 112.9°C

*Trumpler’s design criteria:*

0.00508 + 0.000 04*d* = 0.002 + 0.000 04(63.5) = 0.0076 mm <*h*0*O.K.*

*T*max = 112.9°FC< 121°C *O.K.*



*nd* = 2 (assessed at *W* = 2688 N) *O.K.*

We see that the design passes Trumpler’s criteria and is deemed acceptable.

For an operating load of *W* = 1344 N, it can be shown that *Tf* = 104.7°C, *μ′* = 0.00528, *S* = 0.111, *f r/c* = 3.09, *H*gen = *H*loss = 23.75 W, *h*0 =0.019 , Δ*T* = 2.9°C, *T*1 = 103.2°C, and*T*max = 106.1°C.

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**12-15** Given: , SAE 30, *Using Ts* = 49°C, *ps* = 0.345 MPa, *N* = 2000/60 = 33.33 rev/s, *W* = 20.7 kN, bearing length = 50.8 mm, groove width = 6.35 mm, and *H*loss≤ 1.46 kW.



*r=d*/ 2 = 88.9/2 = 44.45 mm

*r / c* = 44.45/0.06 = 700

*l′* = (50.8− 6.35)/2 = 22.25 mm

*l′* / *d* = 22.25/88.9 = 0.25



*Trial* #1: Choose (*Tf*)1 = 65°C*.* From Table 12-1,

*μ′* = (6.89)0.0136 exp[1271.6/(1.8(65) + 127)] = 0.0256 Pa.s



From Figs. 12-15 and 12-17: **= 0.9, *f r/ c =*3.6

From Eq. (12-31),



*T*av = *Ts* +Δ*T* / 2 = 49 + 41.7/2 = 69.9°C

*Trial* #2: Choose (*Tf*)2 = 71°C. From Table 12-1

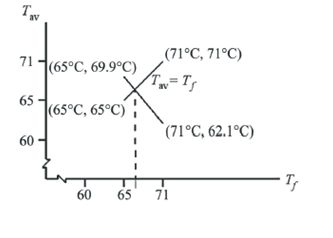
*μ′* = (6.89)0.0136 exp[1271.6/(1.8(71) + 127)] = 0.0202 Pa.s



From Figs. 12-15 and12-17: **= 0.91, *f r/ c =*3



*T*av =49 + 26.2/2 = 62.1°C



*Trial* #3: Thus, the plot gives (*Tf*)3 = 66.9°C*.* From Table 12-1

*μ′* = (6.89)0.0136 exp[1271.6/(1.8(66.9) + 127)] = 0.0237 Pa.s



From Figs. 12-15 and12-17:**= 0.91, *f r/ c =*3.2



*T*av =69 + 33.88/2 = 65.9°C

Result is close. Choose 

*μ′* = (6.89)0.0136 exp[1271.6/(1.8(66.4) + 127)] = 0.0242 Pa.s 

*h*0 = 0.095(0.0635) = 0.0059 mm

*T*max = *Ts* + Δ*T* = 49 + 34.38 =83.4°C

Eq. (12-28): 

*H*loss = *ρCpQs*Δ*T* = 861(1758)16245(10-9)(34.8) = 855 W *O.K.*

= 0.877(602) = 3160 Btu/h *O.K.*

*Trumpler’s design criteria:*

0.00508 + 0.000 04(87.5) = 0.00858 mm > 0.00594 *Not O.K.*

*T*max= 83.8°C < 121°C *O.K.*

*Pst* = 5.24 MPa > 2.068 MPa *Not O.K.*

*n* = 1, as done *Not O.K.*

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**12-16** Given: , SAE 30, *Ts* = 55°C, *ps* = 200 kPa,

*N* = 2880/60 =48 rev/s, *W* = 10 kN, bearing length = 55 mm, groove width = 5 mm, and *H*loss≤ 300 W.



*r =d*/ 2 = 50/2 = 25 mm

*r/c* = 25/0.042 = 595

*l′* = (55 − 5)/2 = 25 mm

*l′* / *d* = 25/50 = 0.5



*Trial* #1: Choose (*Tf*)1 = 79°C*.* From Fig. 12-3, *µ* = 13 mPa · s*.*



From Figs. 12-15 and 12-17:**= 0.85, *f r/ c =* 2.3

From Eq. (12-32),



*T*av = *Ts* +Δ*T* / 2 = 55 + 76.3/2 = 93.2°C

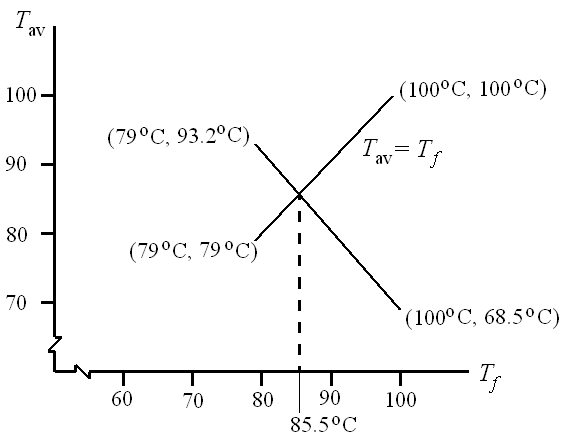
*Trial* #2: Choose (*Tf*)2 = 100°C. From Fig. 12-3, *µ* = 7 mPa · s*.*



From Figs. 12-15 and12-17:**= 0.90, *f r/ c =*1.6



*T*av = 55 + 26.9/2 = 68.5°C



*Trial* #3: Thus, the plot gives (*Tf*)3 = 85.5°C*.* From Fig. 12-3, *µ* = 10*.*5 mPa · s*.*



From Figs. 12-15 and12-17:**= 0.87, *f r/ c =*2.2



*T*av = 55 + 58.9/2 = 84.5°C

Result is close. Choose 

Fig. 12-3: *µ* = 10*.*5 mPa · s



From Eq. (12-28)

*h*0 = 0.13(0.042) = 0.005 46 mm or 0.000 215 in

*T*max = *Ts* + Δ*T* = 55 + 58.9 = 113.9°C or 237°F



*H*loss = *ρCpQs*Δ*T* = 0.0311(0.42)0.193(138) = 0.348 Btu/s

= 1.05(0.348) = 0.365 kW = 365 W *not O.K.*

*Trumpler’s design criteria:*

0.0002 + 0.000 04(50/25.4) = 0.000 279 in>*h*0*Not O.K.*

*T*max= 113.9 °C or 237°F *O.K.*

*Pst* = 4000 kPa or 581 psi> 300 psi *Not O.K.*

*n* = 1, as done *Not O.K.*

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**12-17** So far, we have performed elements of the design task. Now let’s do it more completely.

The values of the unilateral tolerances, *tb*and *td*, reflect the routine capabilities of thebushing vendor and the in-house capabilities. While the designer has to live with these,his approach should not depend on them. They can be incorporated later.

First we shall find the minimum size of the journal which satisfies Trumpler’s constraintof *Pst*≤ 2.07 MPa.



In this problem we will take journal diameter as the nominal value and the bushing boreas a variable. In the next problem, we will take the bushing bore as nominal and the journaldiameter as free.

To determine where the constraints are, we will set *tb*= *td* = 0, and thereby shrinkthe design window to a point.

We set *d* = 50.0 mm

*b* = *d* + 2*c*min = *d* + 2*c*

*nd*= 2 (This makes Trumpler’s*nd*≤ 2 tight)

and construct a table.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *c* | *b* | *d* |  | *T*max | *h*0 | *Pst* | *T*max | *n* | fom |
| 0.025 | 50.05 | 50 | 101 | 153 | × |  | × |  | −5.74 |
| 0.0275 | 50.055 | 50 | 96.9 | 144 | × |  |  |  | −6.06 |
| 0.03 | 50.06 | 50 | 93 | 136 | × |  |  |  | −6.37 |
| 0.0325 | 50.065 | 50 | 89.7 | 128.8 | × |  |  |  | −6.66 |
| 0.035 | 50.07 | 50 | 86.6 | 122.8 | × |  |  |  | −6.94 |
| 0.0375 | 50.075 | 50 | 84.3 | 117.5 | × |  |  |  | −7.20 |
| 0.04 | 50.08 | 50 | 82 | 112.8 | × |  |  |  | −7.45 |
| 0.0425 | 50.085 | 50 | 80.2 | 108 | × |  |  |  | −7.65 |
| 0.045 | 50.09 | 50 | 78.2 | 104.9 |  |  |  |  | −7.91 |
| 0.0475 | 50.095 | 50 | 76.6 | 101.5 |  |  |  |  | −8.12 |
| 0.05 | 50.1 | 50 | 75.2 | 98.4 |  |  |  |  | −8.32 |

\*Sample calculation for the first entry of this column.

Iteration yields: 

With , from Table 12-1



From Figs. 12-15 and 12-17: **= 0*.*7, *f r/c* = 5*.*5

Eq. (12–31):



For the nominal 50 mm bearing, the various clearances show that we have been in contactwith the recurving of (*h*0)min*.*The figure of merit (the parasitic friction torque plus thepumping torque negated) is best at *c* = 0*.*045 mm. For the nominal 50 mm bearing, we will place the top of the design window at *c*min = 0*.*05 mm, and *b* = *d* + 2(0*.*05) = 50.1 mm. At this point, add the *b* and *d* unilateral tolerances:



Now we can check the performance at *c*min ,, and *c*max . Of immediate interest is the fomof the median clearance assembly, −9*.*82, as compared to any other satisfactory bearingensemble.

If a nominal 47.62 mm bearing is possible, construct another table with *tb*= 0 and*td*= 0*.*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *c* | *b* | *d* |  | *T*max | *h*0 | *Pst* | *T*max | *n* | fom |
| 0.05 | 46.9 | 46.8 | 73.7 | 91.1 | × |  |  |  | −7.36 |
| 0.075 | 46.95 | 46.8 | 65 | 73.7 |  |  |  |  | −8.64 |
| 0.0875 | 46.975 | 46.8 | 62.6 | 69 |  |  |  |  | −9.05 |
| 0.1 | 47 | 46.8 | 60.9 | 65.7 |  |  |  |  | −9.32 |
| 0.125 | 47.05 | 46.8 | 58.9 | 61.6 |  |  |  |  | −9.59 |
| 0.1375 | 47.075 | 46.8 | 58.3 | 60.4 |  |  |  |  | −9.63 |
| 0.15 | 47.1 | 46.8 | 57.8 | 59.5 | × |  |  |  | −9.64 |

The range of clearance is 0*.*075 *< c <*0*.*1375 mm*.* That is enough room to fit in our design window.



The ensemble median assembly has a fom = −9*.*31*.*

We just had room to fit in a design window based upon the (*h*0)min constraint. Further reduction in nominal diameter will preclude any smaller bearings .A table constructed for a *d* = 44 mm journal will prove this.

We choose the nominal 46.8 mm bearing ensemble because it has the largest figure of merit. *Ans.*

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**12-18** This is the same as Prob. 12-17 but uses design variables of nominal bushing bore *b* andradial clearance *c*.

The approach is similar to that of Prob. 12-17 and the tables will change slightly. In the table for a nominal *b* = 47.6 mm, note that at *c* = 0*.*075 mm the constraints are “loose.” Set

*b* = 47.6 mm

*d* = 47.6 − 2(0.075) = 47.47 mm

For the ensemble



Analyze at *c*min = 0*.*075 mm, = 0*.*1 mm and *c*max = 0*.*125 mm

At and theTrumpler conditions are met.

At *μ′* = 0.02668 Pa.s, *S* = 0.0205, *H*loss = 320 W, fom = −9.246 and the Trumpler conditions are *O.K.*

At *μ′* = 0.0298 Pa., *S* = 0.014 66, *H*loss = 326 W and the Trumpler conditions are *O.K.*

The ensemble figure of merit is slightly better; this bearing is *slightly* smaller. The lubricantcooler has sufficient capacity.

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**12-19** Table 12-1: *μ* (*μ*reyn) = *μ*0 (106) exp [*b* / (*T* + 95)] *b* and *T* in °F

The conversion from *μ*reyn to mPa⋅s is given in Sec. 12-2. For a temperature of *C* degrees Celsius, *T* = 1.8 *C* + 32. Substituting into the above equation gives

*μ* (mPa⋅s) = 6.89 *μ*0 (106) exp [*b* / (1.8 *C* + 32+ 95)]

= 6.89 *μ*0 (106) exp [*b* / (1.8 *C* + 127)] *Ans*.

For SAE 50 oil at 70°C, from Table 12-1, *μ*0 = 0.0170 (10−6) reyn, and *b* = 1509.6°F. From the equation,

*μ*= 6.89(0.0170)10−6(106) exp {1509.6/[1.8(70) + 127]}

= 45.7 mPa⋅s *Ans*.

From Fig. 12-3, *μ* = 39 mPa⋅s *Ans*.

The figure gives a value of about 15 % lower than the equation.

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**12-20** Originally



Doubled,



The radial load quadrupled to 16 kN when the analyses for parts (a) and (b) were carriedout. Some of the results are:

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Part |  | *μ′* | *S* |  | *f r/c* | *Qs* | *h*0 */c* | ** | *H*loss | *h*0 | Trumpler  *h*0 | *f* |
| (a) | 0.177 | 0.0235 | 0.0310 | 75.1 | 0.1612 | 6.56 | 0.1032 | 0.157 | 10393 | 0.01806 | 0.009 | 0.005 67 |
| (b) | 0.089 | 0.0235 | 0.0310 | 75.1 | 0.1612 | 0.870 | 0.1032 | 0.157 | 1299 | 0.00903 | 0.007 | 0.005 67 |

The side flow *Qs*differs because there is a *c*3 term and consequently an 8-fold increase.

*H*loss is related by a 9898*/*1237 or an 8-fold increase. The existing *h*0is related by a 2-foldincrease. Trumpler’s (*h*0)min is related by a 1.286-fold increase.

**See spreadsheets for Problems 12-21, 12-22, and 12-23**

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**12-21** (*a*) Δt = (0.5 deg)(1 s / 200 rad)(π rad / 180 deg) = 43.633(10-6) s

*c* = 25(10-6) m

*l* = 0.025 m

*d* = 0.050 m

*μ* = 7(10-3) N-s/m2

Using the procedure outlined in Example 12-7, the results after two Euler time steps are

*t* = 0 s *t* = 43.633(10-6) s *t* = 87.266(10-6) s

(0 deg) (0.5 deg) (1.0 deg)

*Fx* (N)3000 3000 3000

*Fy* (N)0 0 0

*F* (N) 3000 3000 3000

cos*α* 1 1 1

sin *α* 0 0 0

*εξ*−0.8 −0.713100 −0.636471

*εη*−0.3 −0.285328 −0.272453

*M*0 1.430331 1.259763 1.120271

*Mξ* 5.721322 5.039051 4.481084

*Mη* 1.214102 1.068612 0.949896

*Mx* 5.721322 5.039051 4.481084

*My*1.214102 1.068612 0.949896

**** 100 100 100

*F(c/r)2/*

*(μld/c)* 8.571429(10-3) 8.571429(10-3) 8.571429(10-3)

*vx* (m/s) 4.978990(10-2) 4.390518(10-2) 3.909042(10-2)

*vy* (m/s) 8.406591(10-3) 7.376781(10-3) 6.550789(10-3)

*εx* −0.8 −0.713100 −0.636471

*εy*−0.3 −0.285328 −0.272453

Plotting eccentricity ratio components at 720 successive Euler time steps from *t* = 0 s

(0 deg) to *t* = 3.1416(10-2) s (360 deg) gives the following journal orbit:



*Ans.*

Values of journal eccentricity ratio at selected times:

time (deg) *εxεy* *ε*

0.0 −0.8000 −0.3000 0.8544

90.0 0.6498 0.2020 0.6805

180.0 0.6293 0.4211 0.7572 *Ans.*

270.0 0.5983 0.4453 0.7458

360.0 0.5964 0.4362 0.7389

(*b*) N = (200 rad/s) (1 rev/2π rad) = 100/π rev/s



Eq. (12-10): S = (r/c)2 (μN/P) = 0.0928

Fig. 12-15: *h*0 / *c* = 0.2 ⇒*h*0 = 0.2(25)(10−6) = 5(10−6) = 5 μm *Ans.*

Fig. 12-16:*l*/*d* = 0.025/0.05 = 1/2 ⇒ *φ* = 330 *Ans.*

From part (*a*), ε = (εx2 + εy2)1/2 = [(0.5964)2 + (0.4342)2]1/2 = 0.74

*h*0 = *c* (1 −*ε*) = 25(10−6) (1 − 0.74) = 6.5 (10−6) m = 6.5 μm *Ans.*

*φ* = atan (*εy* / *εx* ) = atan (0.4342 / 0.5964) = 36.10 *Ans.*

The answers for (*a*) and (*b*) are somewhat different because film thickness and attitude angle predicted by Raimondi and Boyd is a numerical solution of the complete Reynolds equation, while the short bearing solution neglects circumferential flow. In addition, a small amount of error is contained in the curve fitted mobility expressions of Eq. 12-35. *Ans.*

**12-22** *(a*) Δt = (0.5 deg)(1 s / 200 rad)(π rad / 180 deg) = 43.633(10-6) s

*c* = 25(10-6) m

*l* = 0.025 m

*d* = 0.050 m

*μ* = 7(10-3) N-s/m2

Using the procedure outlined in Example 12-7, the results after two Euler time steps are

*t* = 0 s *t* = 43.633(10-6) s *t* = 87.266(10-6) s

(0 deg) (0.5 deg) (1.0 deg)

*Fx* (N) 3000 2999.886 2999.543

*Fy* (N)0 26.17961 52.35722

*F* (N)3000 3000 3000

cos *α* 1 0.999962 0.999848

sin *α* 0 0.008727 0.017452

*εξ* −0.8 −0.715563 −0.640985

*εη* −0.3 −0.279094 −0.260960

*M*0 1.430331 1.264414 1.128209

*Mξ* 5.721322 5.057655 4.512834

*Mη* 1.214102 1.047618 0.913754

*Mx*5.721322 5.048321 4.496200

*My*1.214102 1.091714 0.992375

****(rad/s) 100 100 100

*F(c/r)2/*

*(μld/c)* 8.571429(10-3) 8.571429(10-3) 8.571429(10-3)

*vx* m/s) 4.978990(10-2) 4.398464(10-2) 3.921912(10-2)

*vy* (m/s) 8.406591(10-3) 7.574801(10-3) 6.915238(10-3)

*εx* −0.8 −0.713100 −0.636471

*εy* −0.3 −0.285328 −0.272453

Plotting eccentricity ratio components at 720 successive Euler time steps from *t* = 0 s (0 deg) to *t* = 3.1416(10-2) s (360 deg) gives the following journal orbit:



*Ans.*

Values of journal eccentricity ratio at selected times:

time (deg) *εx* *εy* *ε*

0.0 −0.8000 −0.3000 0.8544

90.0 0.2507 0.6240 0.6725

180.0 −0.6222 0.4211 0.7513

270.0 −0.4456 −0.5995 0.7469

360.0 0.5972 −0.4399 0.7418 *Ans.*

(*b*) The periodic orbit is approaching a circle of radius 0.74. Cyclic minimum film thickness is identical to that in part (*a*). If an observer is attached to the moving load, the load and journal appear to be non-rotating, while the sleeve appears to rotate at a constant angular velocity of −200 rad/s (clockwise). *Ans.*

**12-23** *(a*) Δt = (0.5 deg) (1 s / 200 rad) (π rad / 180 deg) = 43.633(10-6) s

*c* = 25(10-6) m

*l* = 0.025 m

*d* = 0.050 m

*μ* = 7(10-3) N-s/m2

Using the procedure in Example 12-7, the results after two Euler time steps are

*t* = 0 s *t* = 43.633(10-6) s *t* = 87.266(10-6) s

(0 deg) (0.5 deg) (1.0 deg)

*Fx* (N) 3000 2999.971 2999.886

*Fy* (N) 0 13.08993 26.179606

*F* (N) 3000 3000 3000

cos *α* 1 0.999990 0.999862

sin *α* 0 0.004363 0.008727

*εξ* −0.8 −0.714338 −0.638753

*εη* −0.3 −0.282214 −0.266716

*M*0 1.430331 1.262100 1.124280

*Mξ* 5.721322 5.048399 4.497118

*Mξ* 1.214102 1.058145 0.931923

*Mx* 5.721322 5.043734 4.488815

*My*1.214102 1.080162 0.971132

****(rad/s) 100 100 100

*F(c/r)2/*

*(μld/c)* 8.571429(10-3) 8.571429(10-3) 8.571429(10-3)

*vx* m/s) 4.978990(10-2) 4.394533(10-2) 3.915625(10-2)

*vy* m/s) 8.406591(10-3) 7.475784(10-3) 6.732986(10-3)

*εx*−0.8 −0.713100 −0.636401

*εy*−0.3 −0.285328 −0.272280

Plotting eccentricity ratio components at 2880 successive Euler time steps from *t* = 0 s (0 deg) to *t* = 0.125664 s (1440 deg) gives the following journal orbit



*Ans.*

Values of journal eccentricity ratio at selected times:

time (deg) *εx* *εy* *ε*

0.0 −0.8000 −0.3000 0.8544

360.0 −0.8679 0.0123 0.8679

720.0 0.9191 −0.0073 0.9191

1080.0 −0.9417 0.0056 0.9417

1440.0 0.9559 −0.0047 0.9559 *Ans.*

(*b*) The minimum film thickness is slowly approaching zero. If an observer is attached to the moving load, thejournal appears to have a counterclockwise angular velocity of +100 rad/s, while the sleeve appears to have a clockwise angular velocity of −100 rad/s. The average angular velocity of journal and sleeve is zero, resulting in pure squeeze motion from the viewpoint of the load. *Ans.*

**12-24** Since the load is identically zero, the first term on the right hand side of Eq. (12-34) is zero, so that

\_\_

d**e**/dt = ω **k** x**e** (*a*)

With *c* = 25(10-6) m, the eccentricity vector and its magnitude at equilibrium as found from Problem 12-21 is

**e** =*c***ε** = 25(10−6)(0.5964 **i** + 0.4362 **j**)

= 14.91(10−6) **i** + 10.91(10−6) **j** m

*e* = **e** = {[14.91(10−6)]2 + [10.91(10−6)]2}1/2 = 18.47 (10−6) m

= 18.47 μm

According to Eq. (*a*), the instantaneous velocity vector of the journal center is always 90 degrees to the journal eccentricity vector. Therefore, the journal center moves along a circle of radius 18.47 μm. The journal orbit angular velocity is ½ the journal angular velocity. *Ans.*

**12-25** Sample calculation for engine speed *N* = 3000 rev/min:

From Ex. 12-8, *P*cyl = 7(106) N/m2, *A*cyl = 0.0043 m2, *M*rec = 0.64 kg, *M*rot = 0.41 kg,

*R* = 0.0864/2 = 0.0432 m (1/2 stroke), *c* = 20(10-6) m, *μ* = 0.004332 N-s/m2, *l* = 0.0253 m, *d* = 0.0506 m.

*ω* = 2 π*N*/ 60 = 2 π (3000)/60 = 314.16 rad/s

*8MrotRωc2/[μl3d] =*

{ 8(0.41)(0.0432)(314.16)[(20)(10-6)]2 } / [(0.004332)(0.02533)(0.0506)] =

5.0

*M*rec/*M*rot = 0.64/0.41 = 1.56

From Fig. 12-38,*h*min/*c* ≈ 0.23, so *h*min ≈ (0.23)[20(10-6)] = 4.6(10-6) m = 4.6μm.

Repeat the calculation for *N* in the range 500 – 8000 rev/min and plotting gives



*Ans.*

Checking applicability of the chart using Eqs. (12-36) and (12-37)



 Repeat the calculation for *N* in the range 500 – 8000 rev/min and plotting gives

*Ans.*

From Eq. (12-36), applicability is based on *P*cyl*A*cyl 7 *F*rot. Thus, the chart is applicable for engine speeds > 4700 rev/min.

Over the range of applicability, the film thickness is above the danger level. Therefore, the design is acceptable for engine speeds in the range 4700 to 8000 rev/min. No claim to design acceptability is possible from the chart for speeds below 4700 rpm.*Ans.*

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**12-26** Given: Oiles SP 500 alloy brass bushing, *L* = 19.05 mm, *D* = 19.05 mm, *Using T*∞ = 21°C, *F* = 1798 N, *N* = 250 rev/min, and *w* = 0.101 mm.  , 

Table 12-9: *PV*max = 1.64 MPa\*m/s, *P*max = 24.5 MPa, *V*max = 0.51 m/s



*PV* = 4.95 (0.25) = 1.23 MPa\*m/s < 1.64 MPa\*m/s *O.K.*

Table 12-9: *K* = 1207(10−10) m3⋅s/(N⋅m⋅s)

*P = F/* (*DL*) = 1798/ [19.05(19.05)] = 4.95 MPa

*V* = *πDN* = *π* (0.01905)4.17 = 0.25 m/s

Eq. (12-43) can be written as



Solving for *t*,



Cycles = *Nt* = 250 (68012) = 17.003 (106) cycles *Ans*.

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**12-27** Given: Oiles SP 500 alloy brass bushing, *w*max = 0.05 mm for 1000 h, *N* = 200 rev/min,

*F* = 448 N, CR = 15.3 W/(m2∙oC), *T*max = 149 oC, *fs* = 0.03, and *nd* = 2.

Using Eq. (12-49) with *ndF* for *F*, *fs* = 0.03 from Table 12-10, and CR = 15.3

W/(m2C), gives



From Table 12-12, the smallest available bushing has an ID = 25.4 mm, OD = 34.92 mm, and *L* = 50.8 mm. With *L*/*D* = 50.8/25.4 = 2, this is inside of the recommendations of Eq. (12-44). Thus, for the first trial, try the bushing with ID = 25.4 mm, OD =34.92 mm, and *L* = 50.8 mm. Thus,

Eq. (12-42): 



Eq. (12-40): 

*PV* = 0.69(265.67) = 36.13 MPa mm/s < 1640 MPa mm/s (OK)

Eq. (12-43), with Table 12-9:

*w =KndFNt /(3L)*

= 1207(10-20)(2)(448)(200/60)(1000)(3600)/[(3)(0.0508)] = 0.000851 mm < 0.0254 mm (OK)

Answer Select ID = 25.4 mm, OD =34.92 mm , and *L* = 50.8 mm.