 Name: solution

July 22, 2022

INSTRUCTIONS

Begin each problem in the space provided.

If your solution does not follow a logical thought process, it will be assumed to be in error.

Your submitted exam must be your work and must not be copied from other sources.

GUIDELINES FOR ZOOM PROCTORING

— Mute yourself but your audio should remain on for the duration of the exam in order to hear any instructions or announcements of clarifications.

— Your webcam and audio should remain on for the duration of the exam. Webcams should be located off to one side so that your hands and desk materials are visible in the frame. Your face does not need to be visible in the frame.

— Open a chat window at the start of the exam and keep it visible throughout the exam. The chat window will allow you to correspond with the proctor, but you will not be allowed to correspond with your peers.

— The proctor may ask you to show the room in which you are working as well as other materials in order to ensure academic integrity of the assessment.

— The exam will be e-mailed to you at the beginning of the exam.

— You may print the exam and work on those pages, view the exam on your computer and work problems on blank pages, or work the exam on a tablet.

— Questions for the proctor should be asked during the exam using the chat window.

— Clarifications made by the proctor during the exam will be made vocally and in the chat window.

— When you have completed the exam, you should scan/save your work as a single PDF file and upload the exam to Gradescope.

— If you lose your connection during the exam, be patient, continue working, and wait for the connection to return. If the connection does not recover within a couple of minutes, then you may be asked to take a make-up oral exam (via Zoom) in place of the written exam.

— The exam will be recorded, with only the course instructor having preliminary access to the recording. The video recording will only be reviewed for the purpose of identifying potential cheating incidents and will be deleted after one week from when the exam was completed if no cheating allegations have been made. If a cheating allegation has been made, then the recording will be retained until the cheating incident has been resolved. Any student accused of cheating will be allowed to review the video recording as part of their due process. All incidents of academic misconduct will be referred to the Office of the Dean of Students who will be provided access to recordings, as well as other supporting documentation to utilize in their process of determining potential violations of University policies on academic dishonesty.

PROBLEM No. 1 (10 points)

Problem 1 consists of 4 questions. Each question is worth 2.5 points.

(a) Which type of fit would you assemble with a rubber mallet?

- ◯ Clearance
- ● Transition
- ◯ Interference

(b) Which of the following are tool steels?

- ☐ AISI 1006
- ☐ AISI 1015
- ☐ AISI 1020
- ☐ AISI 1035
- ☐ AISI 1045
- ■ AISI 1060
- ■ AISI 1095

(c) Which type of lubrication is shown below?

- ◯ Hydrostatic
- ◯ Hydrodynamic
- ● Elastohydrodynamic (EHD)

(d) Which type of lubrication is stable?

- ◯ Thin film
- ● Thick film

PROBLEM No. 2 (15 points)

A journal bearing has a shaft diameter of 75 mm and is designed with a close running fit. Determine the following.

a) The maximum and minimum shaft diameters.

b) The maximum and minimum bushing bore diameters.

c) The minimum clearance for the journal bearing.

a) for clearance fit

$D_{max} = D + \Delta D \quad D_{min} = D \quad$ (hole)

$d_{max} = d + \delta_F \quad d_{min} = d + \delta_F - \Delta d \quad$ (journal)

free running fit is H8/f7 from Table 7-9

$d_{max} = 75\text{ mm} + (-0.03) = 74.97\text{ mm}$

↖ f from Table A-12

$d_{min} = 75 + (-0.03) - 0.03 = 74.94\text{ mm}$

↖ IT7 Table A-11

b) $D_{min} = 75$

$D_{max} = 75 + 0.046 = 75.046\text{ mm}$

↖ IT8 Table A-11

c) $C_{min} = \dfrac{D_{min} - d_{max}}{2} = \dfrac{75 - 74.97}{2} = 0.015\text{ mm}$

PROBLEM No. 3 (15 points)

The needle roller thrust bearing shown supports an axial load of 10 kN.

The load is shared between 12 cylindrical rollers, with the rollers being 4 mm in diameter and 10 mm long.

The rollers are in contact with flat washers. Both the rollers and the washers are steel (E = 207 GPa, ν = 0.3).

Determine the following.

a) The largest value of τ_{max}.

b) The location where the largest value of τ_{max} occurs. Express your answer in mm.

from Figure 3-40 $\tau_{max} = 0.3\ p_{max}$, $\frac{z}{b} = 0.786$

a) $p_{max} = \frac{2F}{\pi b l} = \frac{2 \cdot 833\,N}{\pi \cdot 4.319 \cdot 10^{-5} \cdot 0.01\,m} = 1227\ MPa$

$$b = \sqrt{\frac{2F}{\pi l} \frac{(1-\nu_1^2)/E_1 + (1-\nu_1^2)/E_1}{1/d_1 + 1/d_2}} = \sqrt{\frac{2 \cdot 833\,N}{\pi \cdot 0.01\,m} \frac{2 \cdot (1-0.3^2)/207e9}{1/0.004\,m}}$$

$= 4.319 \cdot 10^{-5}\ m = 0.043\ mm$

$F = 10\ kN/12 = 833\ N$

$l = 0.01\ m$

$\nu_1 = \nu_2 = 0.3$

$E_1 = E_2 = 207 \cdot 10^9$

$\tau_{max} = 368\ MPa$

b) $z = 0.786\,b = 0.033\ mm$

PROBLEM No. 4 (30 points)

A helical extension spring is made of music wire. The spring has wire diameter 0.055 in, outside coil diameter 0.5 in, and free length $L_0 = 3$ in. The spring is wound with an initial tension of $F_i = 1.2$ lbf.

Determine the following.

a) The number of body coils, N_b.

b) The number of active coils, N_a.

c) The spring rate, k.

d) The static load that will yield the spring at location A. Assume $r_1 = D/2$.

e) Using the static load found in part (d), find the factor of safety for yielding the spring's body coils. Which will yield first? Location A or the body coils? What is the spring's deflection when yielding occurs?

a) $L_0 = 2(D-d) + (N_b+1)d$

$N_b = \frac{L_0 - 2(D-d)}{d} - 1 = \frac{3 - 2(0.445-0.055)}{0.055} - 1 = 39.4$

$L_0 = 3$ in

$D = OD - d = 0.5\text{ in} - 0.055\text{ in} = 0.445\text{ in}$

b) $N_a = N_b + \frac{G}{E} = 39.4 + \frac{11.85\text{ Mpsi}}{29\text{ Mpsi}} = 39.8$ coils

c) $k = \frac{d^4 G}{8D^3 N_a} = \frac{(0.055\text{ in})^4 \cdot 11.85 \cdot 10^6\text{ lbf/in}^2}{8 \cdot (0.445\text{ in})^3 \cdot 39.8} = 3.9$ lbf/in

d) $\sigma_A = S_y = F\left[K_A \frac{16D}{\pi d^3} + \frac{4}{\pi d^2}\right]$

$S_y = 0.75\, S_{ut} = 229.6$ kpsi (← Table 10-7)

(but could be 0.65 from Table 10-7) $= 198.9$ kpsi

$S_{ut} = \frac{A}{d^m} = \frac{201}{(0.055)^{0.145}} = 306$ kpsi

$$K_A = \frac{4C_1^2 - C_1 - 1}{4C_1(C_1 - 1)} = 1.101$$

$$C_1 = \frac{2r_1}{d} = \frac{D}{d} = \frac{0.445\,in}{0.055\,in} = 8.1$$

$$F = \frac{229.6\ kpsi}{1.101 \cdot \frac{16 \cdot 0.445in}{\pi(0.055in)^3} + \frac{4}{\pi(0.055in)^2}} = 14.9\ lbf$$

$= 12.9\ lbf$

e) $$n_y = \frac{S_{sy}'}{\tau} = \frac{137.7\ kpsi}{118\ kpsi} = 1.2$$

$= 1.3$

$$\tau = K_B \cdot \frac{8FD}{\pi d^3} = 1.17 \cdot \frac{8 \cdot 14.9\ lbf \cdot 0.445in}{\pi(0.055in)^3} = 118\ kpsi$$

$= 102.2$ kpsi

$$K_B = \frac{4C+2}{4C-3} = \frac{4 \cdot 8.1 + 2}{4 \cdot 8.1 - 3} = 1.17$$

$$S_{sy} = 0.45\ S_{ut} = 137.7\ kpsi$$

location A will fail first.

$$y = \frac{F - F_i}{k} = \frac{14.9\ lbf - 1.2\ lbf}{3.9\ lbf/in} = 3.5\ in$$

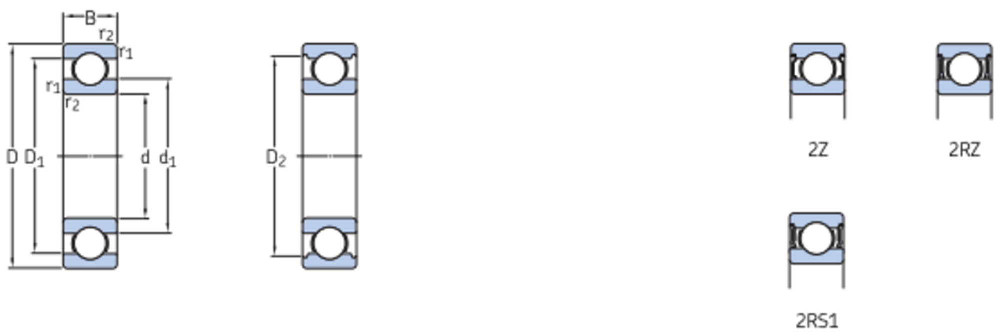
$= 3\ in$

PROBLEM No. 5 (15 points)

A single-row deep-groove ball bearing with a 65-mm bore (specifications shown below with rating life 10^6 cycles) is loaded with a 2.835-kN axial load and a 7-kN radial load. The outer ring rotates at 500 rpm.

1.1 Single row deep groove ball bearings

d **65 – 70** mm



Principal dimensions			Basic load ratings		Fatigue load limit	Speed ratings		Mass	Designations	
			dynamic	static		Reference speed	Limiting speed[1]		Bearing open or capped on both sides	capped on one side[1]
d	D	B	C	C_0	P_u					
mm			kN		kN	r/min		kg	–	
65	120	23	58,5	40,5	1,73	12 000	7 500	1	▸ 6213	–

Determine the following.

a) The equivalent radial load that will be experienced by this particular bearing.

b) Is this bearing expected to carry the load with 95% reliability for 10,000 hours?

a) $F_e = X_i V F_r + Y_i F_a = 0.56 \cdot 1.2 \cdot 2.835 + 1.63 \cdot 7$

$= 13.3 \text{ kN}$

$\frac{F_a}{C_0} = \frac{2.835 \text{ kN}}{40.5 \text{ kN}} = 0.07$

$e = 0.27$

$\frac{F_a}{VF_r} = \frac{2.835}{1.2 \cdot 7} = 0.3375 > 0.27 \rightarrow i = 2$

$X_2 = 0.56 \quad Y_2 = 1.63$

b) $a_1 F_R L_R^{1/a} = F_D L_D^{1/a}$

$a_1 = 0.64$

$F_R = 58.5$ kN

$L_R = 10^6$ cycles

$a = 3$

$F_D = ?$

$L_D = 10000 \text{ hr} \cdot 500 \frac{\text{rev}}{\text{min}} \cdot \frac{60 \text{ min}}{\text{hr}} = 3 \cdot 10^8$ cycles

$$F_D = \frac{0.64 \cdot 58.5 \cdot (10^6)^{1/3}}{(3 \cdot 10^8)^{1/3}} = 5.6 \text{ kN}$$

$F_e > F_D$ → bearing not expected to carry this load.

PROBLEM No. 6 (15 points)

A full journal bearing is 56 mm long. The shaft journal has diameter 56 mm. The bushing has a bore diameter of 56.05 mm.

The load is 15 kN and the journal speed is 460 rpm.

The operating temperature is 65°C and SAE 50 lubricant is used.

Determine the following.

a) The minimum oil-film thickness.
b) The power loss due to friction.
c) The maximum pressure in the lubricant.

a) $S = \left(\frac{r}{c}\right)^2 \frac{\mu N}{P} = \left(\frac{28}{0.025}\right)^2 \cdot \frac{0.05 \text{ Pa}\cdot\text{s} \cdot 7.67}{4.78 \cdot 10^6 \text{ Pa}} = 0.1$

$r = 28$ mm

$c = \frac{56.05 - 56}{2} = 0.025$ mm

$\mu = 50$ mPa·s (Fig 12-3)

$N = 460 \frac{\text{rev}}{\text{min}} \cdot \frac{1\text{min}}{60\text{s}} = 7.67$ rev/s

$P = \frac{W}{2rl} = \frac{15000 \text{ N}}{0.056\text{m} \cdot 0.056\text{m}} = 4.78$ mPa

for $l/d = 1$ $S = 0.1$ $\frac{h_0}{c} = 0.35$ (Fig 12-15)

$h_0 = 0.35 \cdot 0.025$ mm $= 0.00875$ mm

b) $P = T\omega = f r W \omega$

$\frac{r}{c} f = 2.8$ (Fig 12-17)

$f = 2.8 \cdot \frac{0.025}{28} = 0.0025$

$P = 0.0025 \cdot 0.028\ m \cdot 15000\ N \cdot 7.67 \frac{rev}{s} \cdot \frac{2\pi\ rad}{rev}$

$= 50.6\ W$

c) $\frac{P}{P_{max}} = 0.4$ (Figure 12-20)

$P_{max} = 4.78\ MPa / 0.4 = 11.95\ MPa$