The Hashemite University
Faculty of Engineering
Mechanical Engineering Department

Machine Design II
Spring 2018
Instructor: Dr. Ala Hijazi

Midterm Exam

Name: key
Student #:

Part I – Closed Book

Please Read Questions Carefully – Good Luck!

(~~X~~ 15 points)

1. For the following statements circle the correct answer.

In journal bearings, lubricant side leakage decreases as the bearing length increase. — **(T)** F

The frictional power loss in journal bearings increases as the *SAE* grade number of the lubricant increase. — **(T)** F

For gears, in general, a failure due to wear is more preferred than a failure due to bending. — **(T)** F

Spur gears are preferred (over helical gears) for transmitting motion between shafts rotating at high speeds. — T **(F)**

An extension spring has a pre-tension of *5 N* and a spring rate of *2.5 N/mm*. If the spring is subjected to a tensile load of *20 N*, the deflection of the spring will be:

a) *8 mm*
(b) *6 mm*
c) *4 mm*
d) *2 mm*

For helical wire springs, which of the following does not affect the spring rate?

a) Wire diameter
(b) Shear yield strength of the wire
c) Coil diameter
d) Number of body coils

Hydrostatic lubrication occurs when:

a) Lubricant is introduced between surfaces that are in sliding contact.
(b) Lubricant is introduced between surfaces at high pressure (using an external pump).
c) Lubricant is introduced between surfaces that are in rolling contact.
d) Lubricant supply is reduced under hydrodynamic lubrication condition.

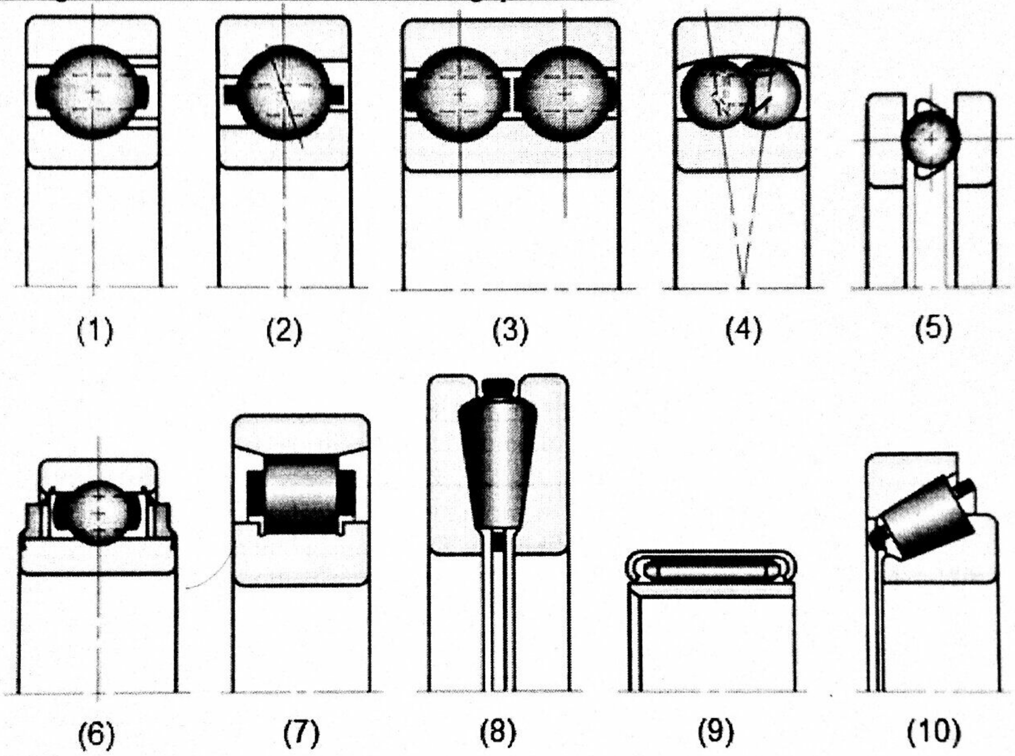
For a journal bearing operating under steady thick-film (hydrodynamic) lubrication condition, which of the following is true?

a) The wear rate depends on the rotational speed.
b) The minimum film thickness is larger than the radial clearance.
c) The lubricant is supplied at high pressure using a pump.
(d) None of the above.

Two compression springs are made of the same wire (same diameter & material) and have the same pitch, coil diameter, and total number of coils. One of the two springs has plain ends and the other has plain and ground ends. The two springs are subjected to the same value of compressive force. Which of the following is true?

- (a) The spring with plain ends will deflect more.
- b) The spring with plain and ground ends will deflect more.
- c) Both springs will have the same deflection.
- d) The given information is not sufficient.

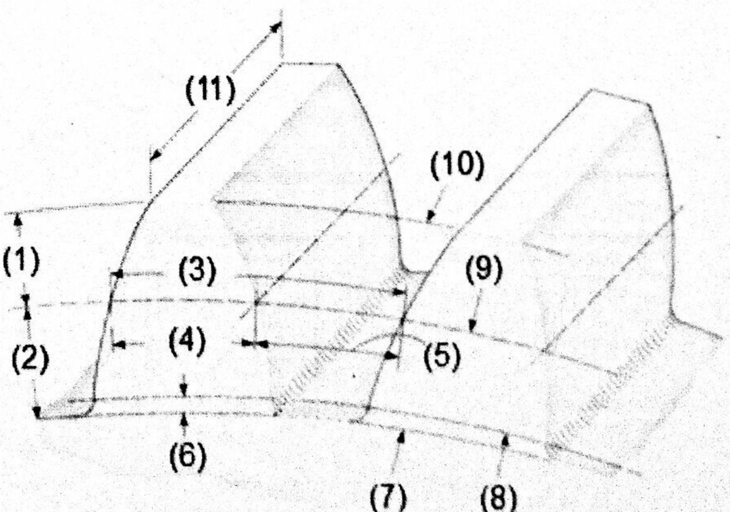
Refer to the figure below to answer the following questions.



The bearing that can withstand large shaft misalignments is: 4
The bearing that is protected against lubricant leakage and contamination is: 6
The bearing that is used when the radial clearance between shaft and housing is small is: 9
The bearings that can take thrust load only are: 5 4 8
The bearings that can take radial load only are: 7 4 9
For 1 and 7, if the overall dimensions are the same, the one that takes more radial load is: 7
The bearing that can take large radial load but very small thrust load is: 1

Refer to the adjacent figure to answer the following questions.

The dedendum circle is: 7
The addendum is: 1
The clearance is: 6
The pitch circle is: 9
The face width is: 11
The circular pitch is: 3
The width of space is: 5

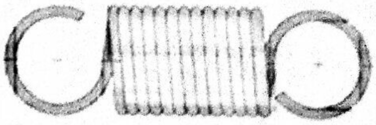


Part II – Open Book **Name:** key

23

(~~22~~ *points*)

2. The extension spring shown is made of gauge-*26* music wire and it has 15 body turns and *10 N* pre-tension. When the spring is subjected to *40 N* of tension it will extend *30 mm*.



a) Find the free length of the spring.

Table A-28 ~ $d = 1.6$ mm

3 Points

$L_o = (2C - 1 + N_b)\,d$

$C = D/d = 16.32/1.6 = 10.2 \Rightarrow L_o = (2*10.2 - 1 + 15)1.6 = 55.04$ mm

$L_o = 55.04$ mm

b) Find the spring constant.

2 Points

$\underline{k} = \frac{F - F_i}{y} = \frac{40-10}{30} = 1$ N/mm

$k = 1$ N/mm

c) Find the mean coil diameter and the outer diameter of the spring.

Table 10-5 ~ $E = 200$ GPa & 81.7 GPa

$N_a = N_b + G/E = 15 + 81.7/200 = 15.41$ turns

6 Points

$k = \frac{d^4 G}{8 D^3 N_a} \Rightarrow \underline{D} = \sqrt[3]{\frac{d^4 G}{8 k N_a}} = \sqrt[3]{\frac{(1.6)^4 (81.7*10^3)}{8(1)(15.41)}} = 16.32$ mm

$\underline{OD} = D + d = 16.32 + 1.6 = 17.92$ mm

$D = 16.32$ mm

$OD = 17.92$ mm

d) Is the pretension within the preferred range?

$\tau_i = \frac{8 F_i D}{\pi d^3} = \frac{8(10)(16.32)}{\pi (1.6)^3} = 101.46$ MPa

4 Points

$(\tau_i)_{Pref} = \frac{231}{e^{0.105C}} \pm 6.9\left(4 - \frac{C-3}{6.5}\right) = 79.16 \pm 19.96 = 59.2, 99.12$ MPa

$101.46 > 99.12$

Not in range

e) Find the maximum tensile stress in the hook under a load of *40 N*.

4 Points

$\sigma_A = (K)_A \frac{16 F D}{\pi d^3} + \frac{4F}{\pi d^2}$, $(K)_A = \frac{4C^2 - C - 1}{4C(C-1)} = \frac{4(10.2)^2 - 10.2 - 1}{4(10.2)(10.2-1)} = 1.08$

$\Rightarrow \underline{\sigma_A} = (1.08)\frac{16(40)(16.32)}{\pi(1.6)^3} + \frac{4(40)}{\pi(1.6)^2} = 875.7 + 19.9 = 899.6$ MPa

$\sigma = 895.6$ MPa

f) Find the factor of safety for the hook in bending.

Table 10-4 ~ $A = 2211$ & $m = 0.145$, $S_{ut} = A/d^m = 2065.3$ MPa

4 Points

Table 10-7 $\Rightarrow \underline{S_y} = 0.75\, S_{ut} = 1549$ MPa

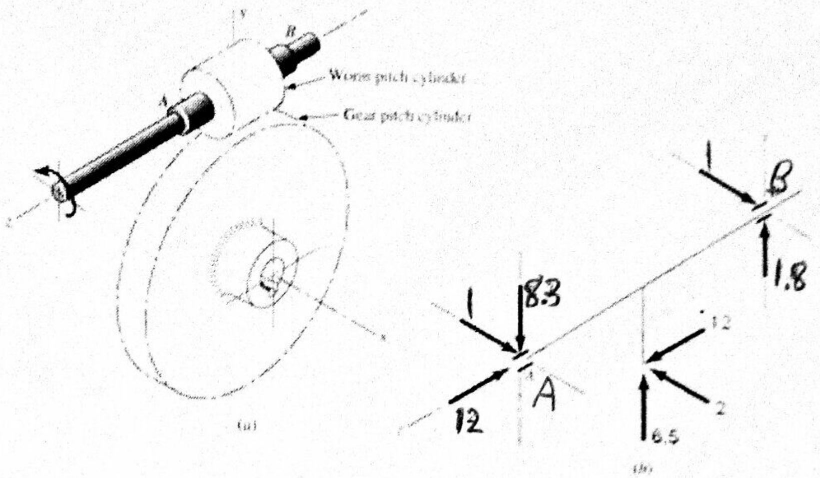
$\Rightarrow \underline{n} = S_y/\sigma = 1549/895.6 = 1.73$

$n = 1.73$

(21 points)

3. Two Timken tapered roller bearings *HM88630 cone & HM88610 cup* (from Fig 11-15) are used in the direct-mount configuration to support the shaft at locations ***A*** and ***B*** (the loads in the figure are in ***kN***).

(The weibull distribution parameters are $\mathbf{x_o} = 0$, $\boldsymbol{\theta} = 4.5$ *and* $\mathbf{b} = 1.5$*).*



a) Find the induced axial loads on the bearings at locations ***A*** and ***B***.

6 Points

Fig 11-15 ~ $C_{10} = 18400\,N$ & $K = 1.07$

$F_{rA} = \sqrt{1^2 + 8.3^2} = 8.36\,kN$, $F_{rB} = \sqrt{1^2 + 1.8^2} = 2.06\,kN$

$F_{iA} = \dfrac{0.47 F_{rA}}{K_A} = 3.67\,kN$, $F_{iB} = \dfrac{0.47 F_{rB}}{K_B} = 0.904\,kN$

$F_{iA} = 3.67\,kN$

$F_{iB} = 0.904\,kN$

b) Find the equivalent radial loads for the bearings at locations ***A*** and ***B***.

5 Points

$3.67 < (0.904 + 12)$

$\Rightarrow F_{eA} = 0.4 F_{rA} + K_A (F_{iB} + F_{ae})$

$= 0.4 * 8.36 + 1.07(0.904 + 12) = 17.15\,kN$

$F_{eB} = F_{rB} = 2.06\,kN$

$F_{eA} = 17.15\,kN$

$F_{eB} = 2.06\,kN$

c) Find the expected life of the bearing at location ***A*** at rated reliability.

5 Points

$C_{10} L_{10}^{1/a} = F L^{1/a}$

$\Rightarrow L = \left(\dfrac{C_{10}}{F}\right)^a L_{10} = \left(\dfrac{18400}{17150}\right)^{10/3} (90 * 10^6)$

$\Rightarrow L = 113.8 * 10^6\ rev$

$L = 113.8 * 10^6\ rev$

d) Find the reliability that the bearing at location ***B*** will survive 5×10^9 revolutions.

5 Points

$R = 1 - \left[\dfrac{x_D \left(\dfrac{a_f F_D}{C_{10}}\right)^a - x_0}{\theta - x_0} \right]^b$, $x_D = \dfrac{5 * 10^9}{90 * 10^6} = 55.5$

$\Rightarrow R = 1 - \left[\dfrac{55.5 \left(\dfrac{1 * 2.06}{18.4}\right)^{10/3} - 0}{4.5 - 0} \right]^{1.5} = 0.9992$

$R = 0.9992$

(21 points)

4. A circumferential-groove pressure fed bearing has a journal diameter of *40 mm* and the radial clearance between the journal and the bearing is *0.02 mm*. The bearing is lubricated with *SAE 30* oil and the lubricant is supplied at a gage pressure of *220 kPa*. The length of each of the two half-bearings is *20 mm*. The angular speed of the journal is *1200 rpm* and the radial steady load is *1.68 kN*. Knowing that the average film temperature at steady state conditions is *85° C*, find:

a) The Sommerfeld number.

$N = 1200\ rpm = 20\ rev/s$, $r = 40/2 = 20\ mm$

$$P = \frac{W}{4rl'} = \frac{1680}{4(20)(20)} = 1.05\ MPa$$

5 Points

Fig 12-13, SAE-30 & $T = 85°$ ~ $\mu \simeq 10.5\ mPa.s$

$$\Rightarrow S = \left(\frac{r}{c}\right)^2 \frac{\mu N}{P} = \left(\frac{20}{0.02}\right)^2 \frac{(10.5*10^{-3})(20)}{1.05*10^6} = 0.2$$

$S = 0.2$

b) The minimum film thickness. $l'/d = 20/40 = 1/2$

3 Points

Fig 12-16 ~ $h_o/c \simeq 0.32$

$$\Rightarrow h_o = 0.32 * 0.02 = 0.0064\ mm$$

$h_o = 0.0064\ mm$

c) The coefficient of friction.

Fig 12-18 ~ $\frac{r}{c} f \simeq 5.6$

3 Points

$$\Rightarrow f = 5.6\left(\frac{0.02}{20}\right) = 0.0056$$

$f = 0.0056$

d) The maximum lubricant temperature.

$$\Delta T_c = \frac{978(10^6)}{1+1.5\epsilon^2} \frac{(f\frac{r}{c}) S W^2}{P_s r^4} = \frac{978(10^6)}{1+1.5(0.68)^2} \frac{(5.6)(0.2)(1.68)^2}{(220)(20)^4}$$

6 Points

$$\Rightarrow \Delta T_c = 51.86\ °C$$

$$\Rightarrow T_{max} = T_{avg} + \Delta T/2 = 85 + 51.86/2 = 110.9\ °C$$

$T_{max} = 110.9\ °C$

e) The power loss due to friction.

4 Points

$$H_{loss} = H_{gen} = fWr(2\pi N) = 0.0056 * 1680 * 0.02 * 2\pi * 20 = 23.6\ W$$

$H_{loss} = 23.6\ W$

(20 points)

5. A speed reducer unit consists of a 25-tooth 20° pressure angle spur pinion and a 50-tooth gear. The diametral pitch is 10 teeth/in, the face width is 1 in, and the quality standard for both gears is No. 8. Both gears are through-hardened grade-1 steel where the Brinell hardness of the gear is 250 and that of the pinion is 300. The unit transmits power from an electric motor (uniform torque) to an air compressor (considered to have moderate shock). The pinion rotates at an angular speed of 2000 rpm and its life goal is 10^7 cycles. If the desired reliability for the set is 0.98, find the maximum horsepower that can be transmitted based on bending performance of the pinion. *Use* $K_S = K_m = K_B = 1$.

Gear	Pinion	Both		
# of teeth = 50	# of teeth = 25	Spur, $\phi = 20$	F = 1 in	uniform-moderate shock
St.-Gr.1-thru hard.	St.-Gr.1-thru hard.	$P = 10$ teeth/in	$Q_v = 8$	
BH = 250	BH = 300	$R^2 = 0.98$		
	$n = 2000$ rpm			
	$N = 10^7$ cycles			

[2 Points] Fig 14-17 ~ $K_o = 1.25$

[2 Points] $d_p = \frac{N_p}{P} = \frac{25}{10} = 2.5$ in , $V = \pi d_p n_p / 12 = \pi(2.5)(2000)/12 = 1309$ ft/min

[2 Points] Fig 14-9 ~ $K_v \simeq 1.29$

[2 Points] Fig 14-6 ~ $J_p = 0.36$

[2 Points] $\Rightarrow (\sigma)_p = W^t K_o K_v K_s \frac{P}{F} \frac{K_m K_B}{J} = W^t (1.25)(1.29)(1) \frac{10}{1} \frac{(1)(1)}{0.36} = (44.79) W^t$ Psi

[2 Points] Fig 14-2 $S_t = 77.3(300) + 12800 = 35990$ Psi

[2 Points] $R = \sqrt{0.98} = 0.99 \Rightarrow K_R = 1$, $K_T = 1$

[1 Point] Life = 10^7 cycles $\Rightarrow Y_N = 1$

[1 Point] $\Rightarrow (\sigma_{all})_p = \frac{S_t}{S_F} \frac{Y_N}{K_T K_R} = \frac{35990}{1} \frac{1}{1 * 1} = 35990$ Psi

[2 Points] $(\sigma)_p = (\sigma_{all})_p \Rightarrow (44.79) W^t = 35990 \Rightarrow W^t = 803.5$ N

[2 Points] $\Rightarrow$ max. horsepower $H = \frac{W^t V}{33000} = 31.87$ hp **Ans.**