August 5, 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.

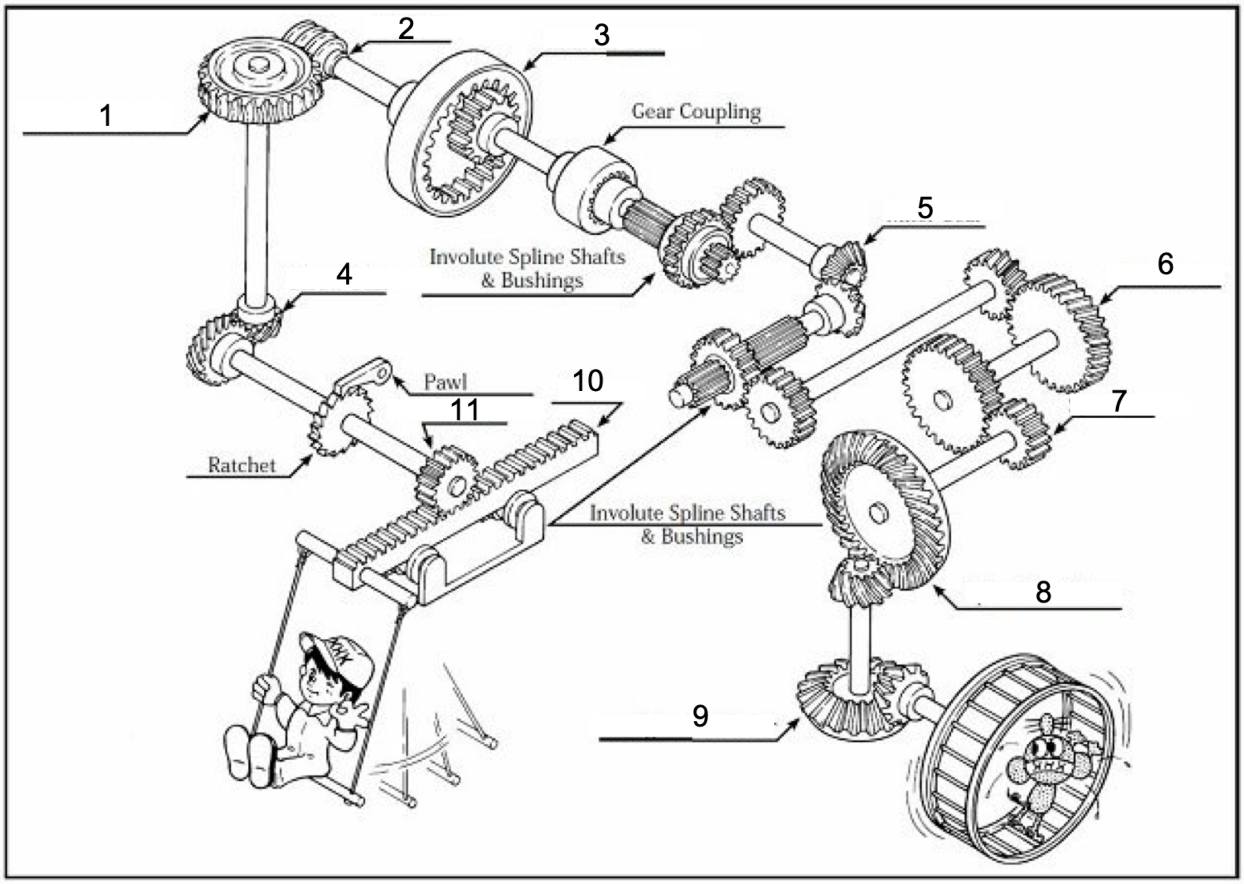
PROBLEM No. 1 (25 points)

Problem 1 consists of 10 questions. Each question is worth 2.5 points.

(a) Gears should be designed so that exactly one pair of teeth are in contact at all times.

- ○ True
- ● False

(b) Match each of the terms with the correct gear in the figure.



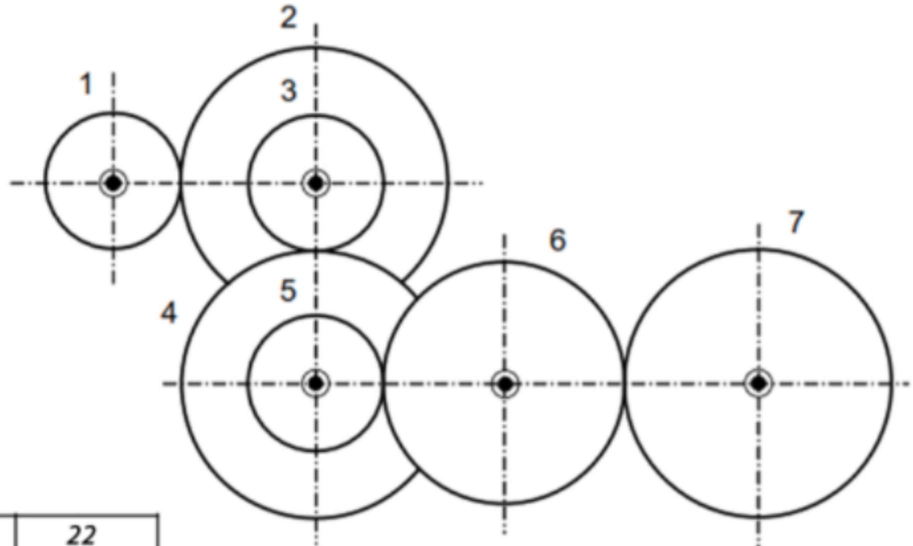
6 Helical gear	10 Rack	9 Straight bevel gear
3 Internal gear	4 Screw gear	2 Worm
5 Miter gear	8 Spiral bevel gear	
11 Pinion	7 Spur gear	1 Worm wheel

can be swapped

(c) Which of the following are conserved in a spur gearset?

- [x] transmitted load
- [x] power
- [ ] torque
- [ ] angular velocity

(d) What is the train ratio e for this gear train? Gear 1 is the input and Gear 7 is the output. Include the correct sign in your answer.



N_1	22
N_2	60
N_3	24
N_4	54
N_5	26
N_6	42
N_7	64

$$e = + \frac{N_1 N_3 N_5 \cancel{N_6}}{N_2 N_4 \cancel{N_6} N_7} = \frac{22 \cdot 24 \cdot 26}{60 \cdot 54 \cdot 64} = 0.0662$$

even # of meshes

(e) For the gear train in part (d), if the input gear (gear 1) rotates at 100 rpm counterclockwise, what angular velocity of the output gear? Clockwise or counterclockwise?

$$\frac{w_7}{w_2} = 0.0622 \rightarrow \quad w_7 = 6.22 \text{ rpm} \quad \text{ccw}$$

(f) For the gear train in part (d), if the input gear (gear 1) is driven with 50 lbf-ft of torque, how much torque is delivered by the output gear?

$$\frac{T_2}{T_7} = 0.0622 \rightarrow \quad T_7 = 755 \text{ ft-lbf}$$

(or in-lbf... whatever the length unit)

(g) Which threaded fastener will be stronger when loaded axially?

- ◯ 1/4-20
- ● 1/4-28

(h) A 3/8-16 steel bolt is used to clamp 1.5 in of material. Find a suitable bolt length.

$L > l + H = 1.5 + 0.328125 \rightarrow$ choose $L = 2$ in

$H = \frac{21}{64}$ in from Table A-31

(i) For the bolted joint in part (h), determine the bolt stiffness, k_b.

$k_b = 1934$ kips/in

(j) For a member stiffness $k_m = 1200$ MN/m, find k_b for the joint stiffness constant to be $C = 0.2$.

$$k_b = \frac{C}{1-C} k_m = \frac{0.2}{1-0.2} \cdot 1200 \text{ MN/m} = 300 \text{ MN/m}$$

PROBLEM No. 2 (30 points)

A 20° spur pinion with 20 teeth and a diametral pitch of 8 transmits 0.2 hp to a 36-tooth gear.

The pinion speed is 3055 rpm and the gears are grade 2, 0.75-in face width, through-hardened steel at 350 Brinell, uncrowned, manufactured to a No. 6 quality standard, and considered to be of open gearing quality installation. The power source is uniform but the driven machine has moderate shock.

The pinion life is 10^6 cycles and the reliability is 96%.

Determine the following.

a) Complete the table on the next page using the AGMA equations for this gearset.

b) Calculate S_H for the pinion.

c) Will S_H be higher or lower for the gear as compared to the pinion? Briefly justify your answer.

Will be higher because materials are same but gear rotates less cycles.

$$W^{(t)} = \frac{33000\ H}{V} = \frac{33000 \cdot 0.2}{2000} = 3.3\ \text{lbf}$$

$H = 0.2$ hp

$$d_p = \frac{20\ \text{teeth}}{8\ \text{teeth/in}} = 2.5\ \text{in}$$

$$V = r_p \omega = 1.25\ \text{in} \cdot 3055\ \frac{\text{rev}}{\text{min}} \cdot \frac{2\pi\ \text{rad}}{\text{rev}} \cdot \frac{\text{ft}}{12\ \text{in}} = 2000\ \text{ft/min}$$

$$I = \frac{\cos\phi_t \sin\phi_t}{2 m_N} \frac{m_G}{m_G+1} = \frac{\cos 20 \sin 20}{2 \cdot 1} \cdot \frac{1.8}{1.8+1} = 0.1033$$

$$m_G = \frac{36}{20} = \frac{N_G}{N_P} = 1.8$$

$m_N = 1$ for spur gears

$$\sigma_c = C_p \left(W^t K_o K_v K_s \frac{K_m}{d_p F} \frac{C_f}{I}\right)^{1/2} = 2300\sqrt{\text{psi}} \left(3.3\,\text{lbf} \cdot 1.25 \cdot 1.6 \cdot 1 \cdot \frac{1.7}{2.5 \cdot 0.75} \cdot \frac{1}{0.1033}\right)^{1/2}$$

$= 17505$ psi

$$S_H = \frac{S_c Z_N C_H / K_T K_R}{\sigma} = \frac{156450 \cdot 1.137 \cdot 1 / 1 \cdot 0.9023}{17505} = 11.3$$

PROBLEM No. 2 (continued)

Include units in order to receive full credit.

Clearly describe how each variable was obtained (e.g., show the calculation, identify the equation, list the reference table/figure).

Variable	Pinion	Supporting work, assumption and/or reference
C_p	$2300\ \sqrt{psi}$	Table 14-8 for steel pinion + gear
W^t	3.3 lbf	see p. 5
K_o	1.25	Fig 14-7 for uniform power, mod. driven
K_v	1.6	Fig 14-9 for V = 2000 ft/min, $Q_v = 6$
K_s	1	AGMA recommendation
K_m	1.7	Given
d_P	2.5 in	See p. 5
C_f	1	Fig 14-18
I	0.1033	See p. 5
S_c	156.450 Kpsi	Fig 14-5 for Grade 2, $H_B = 350$ $349.350 + 34300 = 156450$
Z_N	1.137	Fig 14-15 $Z_N = 2.466(10^6)^{-0.056} =$
C_H	1	for gear only
K_T	1	assume $T < 250°F$
K_R	0.9023	Eqn. 14-38 $0.658 - 0.0759 \ln(1-0.95)$

PROBLEM No. 3 (20 points)

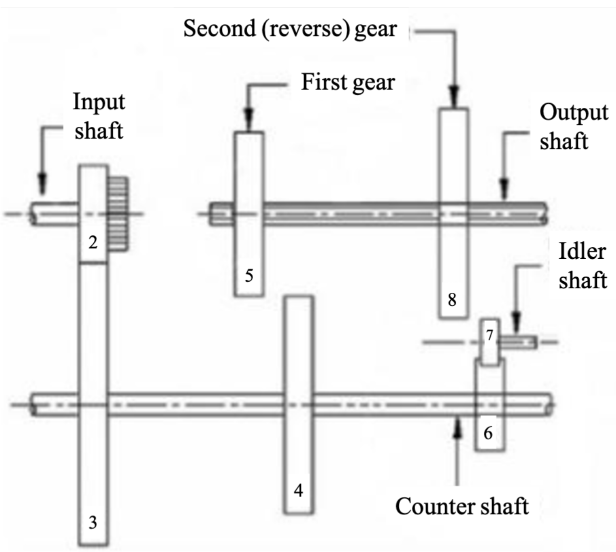
A two-stage double-reduction speed reducer is shown below. All gears are 20° spur gears and the module is constant throughout the gearset.

The input shaft of the speed reducer rotates clockwise at 3000 rpm.

The speed reducer delivers 1.5 kW to a machine at two different speeds, depending on which gear on the output shaft is meshing with which gear on the counter shaft.

- First gear: when gear 5 meshes with gear 4, the output shaft rotates at 1000 rpm clockwise.
- Second (reverse) gear: when gear 8 meshes with gear 7, the output shaft rotates at 500 rpm counterclockwise.

The input shaft and the output shaft are aligned.



Determine the following.

a) For first gear, find the minimum number of teeth on each gear (N_2, N_3, N_4, and N_5) while avoiding interference for full-depth teeth.

b) Having found N_2 and N_3 in part (a), find the number of teeth on gears 6, 7, and 8 to achieve the required output speed. You need not consider interference when designing second (reverse) gear.

a) $e = +\dfrac{N_2}{N_3}\dfrac{N_4}{N_5} = \dfrac{\omega_5}{\omega_2} = \dfrac{1000 \text{ rpm}}{3000 \text{ rpm}} = \dfrac{1}{3}$

2 meshes so $e > 0$

$N_2 + N_3 = N_4 + N_5$ for shafts to be aligned.

$N_3 = 3N_2$ and $N_4 = N_5$ -or- $N_5 = 3N_4$ and $N_2 = N_3$

for $k=1$ $\phi = 20°$ and $m=3$ use eqn. 13-11

$$N_p = \frac{2\cancel{k}^{\,1}}{(1+2\cancel{m}_{3})\sin^2\cancel{\phi}_{20}}\left(\cancel{m}_{3}+\sqrt{\cancel{m}_{3}^{2}+(1+2\cancel{m}_{3})\sin^2\cancel{\phi}_{20}}\right) = 14.98$$

→ minimum number of pinion teeth is 15.

$N_2 = 15$ $\quad N_3 = 3N_2 = 45$

for $N_4 + N_5 = N_2 + N_3 = 60$ -and- $\frac{N_4}{N_5} = 1 \rightarrow N_4 = N_5 = 30$

b) for shafts to be aligned

$$r_2 + r_3 = r_6 + 2r_7 + r_8$$

-or- $N_2 + N_3 = 60 = N_6 + 2N_7 + N_8$

$$e = -\frac{N_2 N_6 \cancel{N_7}}{N_3 \cancel{N_7} N_8} = \frac{1000\,\text{rpm}}{500\,\text{rpm}} = 2$$

3 meshes
→ $e<0$

for $\frac{N_2}{N_3} = \frac{1}{3}$ $\quad \frac{N_6}{N_8} = 6$

the problem is underconstrained, so there are multiple choices that work.

Choose $N_6 = 30$ $\quad N_8 = 5 \rightarrow N_7 = \frac{60-30-5}{2} = 12.5$

must have an integer, so try again

choose $N_6 = 24$ $N_8 = 4$ $N_7 = \dfrac{60-24-4}{2} = 16$

another option :

$N_6 = 36$ $N_8 = 6$ $N_7 = 12$

if chose $N_2 = N_3 = 30$ teeth from part (a)

then $\dfrac{N_6}{N_8} = 2$

options:

N_6	N_8	N_7
12	6	21
16	8	18
20	10	15
24	12	12
28	14	9
32	16	6

* many different combinations are possible.
(many = 8)

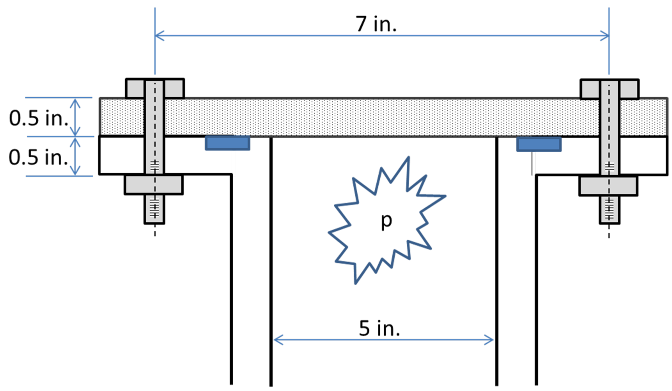
PROBLEM No. 4 (25 points)

The cylindrical pressure vessel and the head shown below are made of aluminum.

There are five steel 1/2 in-13 UNC grade 8 bolts holding the head on the cylindrical pressure vessel.

The bolts are to be permanently tightened.

The internal pressure, p, fluctuates between 0 and 400 psi.



Determine the following.

a) The torque needed to tighten each bolt.

b) The bolt length, L, in inches.

c) The bolt stiffness, k_b.

d) The member stiffness, k_m.

e) The joint stiffness constant, C.

f) The yielding factor of safety, n_p.

g) The overload factor of safety, n_L.

h) The joint separation factor, n_0.

i) The factor of safety for infinite life using the Goodman criterion, n_f.

a) $T = KF_i d = 0.2 \cdot 15.32 \text{ kips} \cdot 0.5 \text{ in} = 7.66 \text{ kip-in}$
$= 638 \text{ ft-lbf}$

$k = 0.2$ (assume)

$F_i = 0.9F_p$ for permanent connection

$S_p = 120$ kpsi for Grade 8 (Table 8-9)

$F_i = 0.9 S_p A_t = 0.9 \cdot 120 \text{ kpsi} \cdot 0.1419 \text{ in}^2 = 15.32 \text{ kips}$

$A_t = 0.1419 \text{ in}^2$

b) from Table 8-7

$l = 1$ in

$H = \frac{7}{16}$ in (Table A-31 for regular hexagonal)

$L > 1 + \frac{7}{16}$ in $\rightarrow$ round up to 1.6 in from Table A-17

c) $k_b = \dfrac{A_d A_t E}{A_d l_t + A_t l_d} = \dfrac{0.1963 \cdot 0.1419 \cdot 30 \cdot 10^6}{0.1963 \cdot 0.65 + 0.1419 \cdot 0.35} = 4715$ kip/in

$A_d = \frac{\pi}{4}(0.5 \text{ in})^2 = 0.1963 \text{ in}^2$

$A_t = 0.1419 \text{ in}^2$ (Table 8-2)

$L_T = 2d + \frac{1}{4} \text{in} = 2 \cdot \frac{1}{2} \text{in} + \frac{1}{4} \text{in} = 1.25$ in

$l_d = L - L_T = 1.6 - 1.25 = 0.35$ in

$l_t = l - l_d = 1 \text{ in} - 0.35 \text{ in} = 0.65$ in

$E = 30$ Mpsi (Table 8-8)

d) use eqn. 8-23 since grip is entirely Aluminum.

$k_m = AEd \exp(Bd/l)$

from Table 8-8 for Aluminum

$A = 0.79670$ $B = 0.63816$ $E = 10.3$ Mpsi

$$k_m = 0.79670 \cdot 10.3 \cdot 10^6\,\text{psi} \cdot 0.5\,\text{in}\ \exp(0.63816 \cdot 0.5\,\text{in}/1\,\text{in})$$
$$= 5645\ \text{kip/in}$$

-or- use 8-22

$$k_m = \frac{0.5774\,\pi E d}{2 \ln\left(5\,\frac{0.5774\,l + 0.5d}{0.5774\,l + 2.5d}\right)} = 5529\ \text{kip/in}$$

e) $$C = \frac{k_b}{k_b + k_m} = 0.455$$ (a little bit high)

f) $$n_p = \frac{S_p A_t}{CP + F_i} = \frac{120000\,\text{psi} \cdot 0.1419\,\text{in}^2}{0.455 \cdot 1570\,\text{lbf} + 15320\,\text{lbf}} = 1.1$$

From the pressure in the cylinder @ P_{max}

$$P_{total} = 400\,\text{psi} \cdot \frac{\pi}{4} \cdot (5\,\text{in})^2 = 7853\ \text{lbf}$$

This is shared between 5 bolts $\rightarrow P = 1570\ \text{lbf}$

g) $$n_L = \frac{S_p A_t - F_i}{CP} = \frac{120000\,\text{psi} \cdot 0.1419\,\text{in}^2 - 15320\,\text{lbf}}{0.455 \cdot 1570\,\text{lbf}} = 2.4$$

h) $$n_0 = \frac{F_i}{P(1-C)} = \frac{15320\,\text{lbf}}{1570\,\text{lbf}\,(1 - 0.455)} = 17.9$$

i) $n_f = \dfrac{S_e(S_{ut} - \sigma_i)}{\sigma_a(S_{ut} + S_e)}$ (eqn 8-45) for $F_{min}=0$

$S_e = 23.2$ kpsi (Table 8-17)

$S_{ut} = 150$ kpsi (Table 8-9)

$\sigma_i = \dfrac{F_i}{A_t} = \dfrac{15320 \text{ lbf}}{0.1419 \text{ in}^2} = 107.9$ kpsi

$\sigma_a = \dfrac{CP}{2A_t} = \dfrac{0.455 \cdot 1570 \text{ lbf}}{2 \cdot 0.1419 \text{ in}^2} = 2517$ psi

$n_f = \dfrac{23.2(150 - 107.9)}{2.517(150 + 23.2)} = 2.2$