 Name: Solution

May 4, 2022

INSTRUCTIONS

Begin each problem in the space provided. If additional space is required, use the paper provided to you.

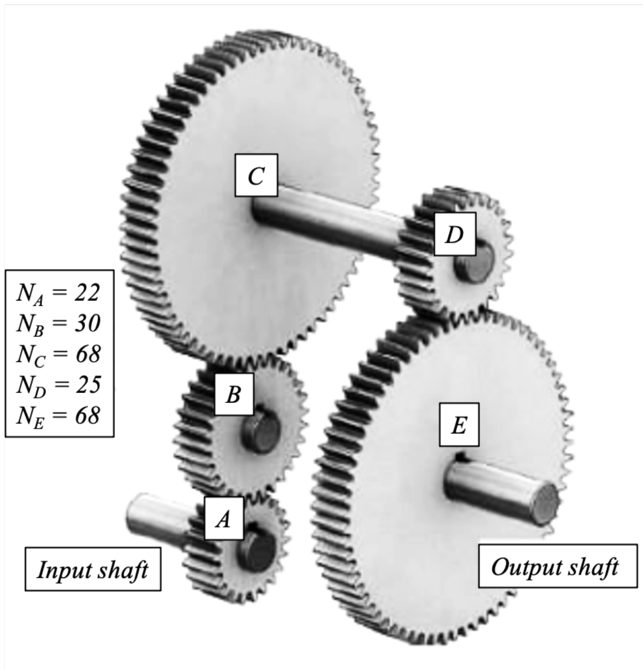
Work appearing on the backside of any exam page will NOT be graded.

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

PROBLEM No. 1 (25 points)

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

(a) The input of the compound gear train shown is gear A and the output is gear E.



Identify the idler(s) in the gear train.

- ☐ Gear A
- ☑ Gear B
- ☐ Gear C
- ☐ Gear D
- ☐ Gear E

Gear B is the only gear in the gear train that is both driving and being driven.

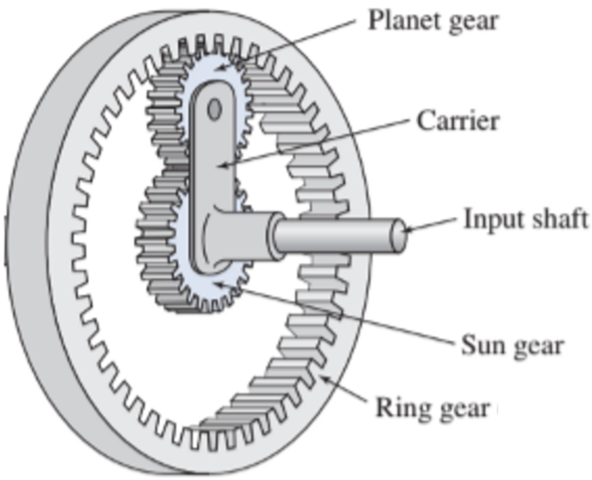
(b) Why are spur gears more efficient than helical gears?

There is more sliding contact when helical gears mesh → more friction.
Helical gears also generate axial loads.

(c) For the planetary gear-set shown, the input shaft is attached to the carrier and rotates at 900 rpm. The ring gear is fixed. The ring gear diameter is 6.5 inches.

The sun gear has 18 teeth.

The sun, planet and ring gears all have a diametral pitch of 12 teeth/inch.



$$\frac{d_{sun}}{2} + d_{planet} = \frac{d_{ring}}{2}$$

$$d_{sun} = \frac{18\text{ teeth}}{12\text{ teeth/in}} = 1.5\text{ in}$$

$$d_{planet} = \frac{6.5\text{ in}}{2} - \frac{1.5\text{ in}}{2} = 2.5\text{ in}$$

$$N_{planet} = 2.5\text{ in} \cdot 12\text{ teeth/in} = 30\text{ teeth}$$

Determine the number of teeth on the planet gear.

(d) For the planetary gear-set in part (c), determine the angular velocity of the planet gear if the carrier rotates at 900 rpm. Do the carrier and planet rotate in the same direction or in opposite directions?

$$N_r \cancel{w_r}^{0} - N_p w_p - (N_r - N_p) w_c = 0$$

$$N_r = 6.5\text{ inch} \cdot 12\text{ teeth/in} = 78\text{ teeth}$$

$$w_p = -\frac{(78-30)}{30} \cdot 900\text{ rpm} = -1440\text{ rpm}$$

(e) A steel bolt is used used with a nut to clamp a 3 inch sandwich of aluminum. If the clamped material is changed from aluminum to copper, how will the joint stiffness constant be changed?

- ● C will decrease
- ○ C will remain the same
- ○ C will increase
- ○ Cannot be determined with the given information

$E_{Al} < E_{cu}$ (Table 8-8)

k_m increases as E increases

$\rightarrow k_{m,Al} > k_{m,cu}$

$C = \frac{k_b}{k_b + k_m} \rightarrow$ if k_m increases then C decreases.

(f) What are the advantages of course-threaded fasteners over fine-threaded fasteners? Choose all that apply.

- ☐ Course-threaded fasteners are stronger in tension — false; A_t is smaller
- ☐ Course-threaded fasteners have better adjustment accuracy — false; pitch is larger
- ☑ Course-threaded fasteners are more resistant to thread stripping — true; more area per thread to resist
- ☐ Course-threaded fasteners have better fatigue life — false; see Hw 12
- ☑ Course-threaded fasteners have faster assembly speed — true; advance farther with each turn.

(g) What is the torque needed to tighten a lubricated 1/2-20 SAE Grade 8 bolt to 80% of its proof strength?

$T = KF_i d = K \cdot 0.8\, S_p A_t\, d$

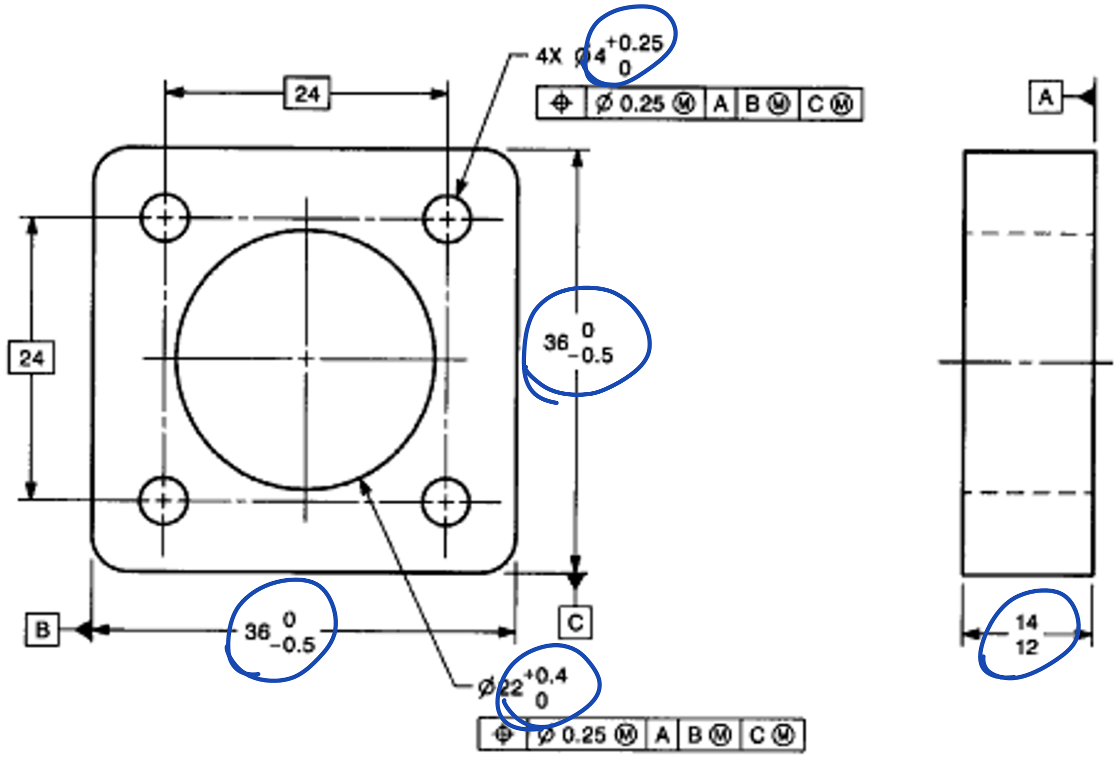
$= 0.18 \cdot 0.8 \cdot 120000 \text{ psi} \cdot 0.1599 \text{ in}^2 \cdot 0.5 \text{ in} = 1381 \text{ in-lbf}$

(h) An engineer designs a part with perfect geometry in CAD, but the produced part is never perfect.

Which approach allows for more manufacturing flexibility and larger tolerances by specifying the design intent of the part instead of the specific geometry?

- ○ Traditional Dimensioning and Tolerancing (TD&T)
- ● Geometric Dimensioning and Tolerancing (GD&T)

(i) A GD&T drawing of a simple part is shown below. Circle all of the size attributes.



(j) What was the most interesting thing you learned in ME 354 this semester? Describe why in two or three sentences.

it depends.

PROBLEM No. 2 (XX points)

An external spur gearset consists of a 18-tooth pinion and a 30-tooth gear. The pinion diameter is 1.5 inches and the gear diameter is 2.5 inches. Both gears have 20° full-depth teeth. The pinion rotates at 5100 rpm.

Determine the following.

(a) Complete the table on the next page with the variables needed to analyze the **pinion** for wear with the AGMA equation.

The life goal is 10^7 revolutions of the pinion.

The quality number is 6.

The gears are 4340 through-hardened grade 1 steels, heat-treated to 250 Brinell, core and case.

The load is moderate shock and the power is smooth.

The reliability is 95%.

(b) The face width of the pinion (F) to achieve $S_H = 1.6$.

(c) The power transmitted by the gearset in hp.

$$V = \omega r = 5100 \frac{\text{rev}}{\text{min}} \cdot \frac{2\pi\ \text{rad}}{\text{rev}} \cdot \frac{1.5\ \text{in}}{2} \cdot \frac{\text{ft}}{12\ \text{in}} = 2003\ \text{ft/min}$$

$$I = \frac{\cos\phi_t \sin\phi_t}{2 m_N} \frac{m_G}{m_G + 1} = \frac{\cos 20 \sin 20}{2 \cdot 1} \cdot \frac{1.67}{2.67} = 0.1$$

$\phi_t = 20°$ (given)

$m_N = 1$ for spur gears (from text)

$$m_G = \frac{N_G}{N_P} = \frac{30}{18} = 1.67$$

$S_c = 322 \cdot 250 + 29100$ psi $= 109600$ psi (Fig 14.5)

for Grade 1 through-hardened steel gears.

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	100 lbf	Given
K_o	1.25	for uniform source and moderate shock load.
K_v	1.6	for V = 2000 ft/min, $Q_v = 6$, Fig. 14-9
K_s	1	from roadmap
K_m	1.7	Given
d_P	1.5 in	given
C_f	1	from roadmap
I	0.1	See page 5
S_c	109600 psi	Table 14-6 → Fig 14.5
Z_N	1	Fig 14-15 for 10^7 cycles
C_H	1	needed for gear only.
K_T	1	assume temp < 250°F
K_R	0.885	Eqn. 14-38

$$K_R = 0.658 - 0.0759 \ln(1 - 0.95)$$

PROBLEM No. 2 (continued)

b) $$S'_H = \frac{S'_c \cancel{Z_N}^{1} \cancel{C_H}^{1} / \cancel{K_T}^{1} K_R}{\sigma_c}$$

$$\sigma_c = \frac{109600 \text{ psi} / 0.885}{1.6} = 77400 \text{ psi}$$

$$\sigma_c = C_p \left(W^t K_o K_v K_s \frac{K_m}{d_p F} \frac{C_f}{I} \right)^{1/2}$$

$$F = W_t K_o K_v \cancel{K_s}^{1} \frac{K_m}{d_p} \frac{\cancel{C_f}^{1}}{I} \Big/ \left(\frac{\sigma_c}{C_p} \right)^2$$

$$= \left(100 \text{ lbf} \cdot 1.25 \cdot 1.6 \cdot 1.7 / 1.5 \text{ in} \cdot 0.1 \right) \Big/ \left(\frac{77400 \text{ psi}}{2300 \sqrt{\text{psi}}} \right)^2$$

$$F = 2 \text{ in}$$

c) $$H = \frac{\overset{\text{in lbf}}{W^t} \; \overset{\text{in ft/min}}{V}}{33000} = \frac{100 \cdot 2000}{33000} = 6.06 \text{ hp}$$

PROBLEM No. 3 (XX points)

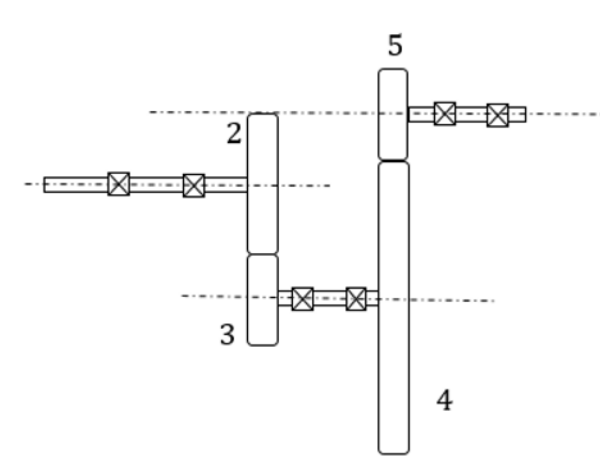
The compound gear train shown uses gear 2 as the input and gear 5 as the output. *Note that the figure is not drawn to scale.*

The gear train is a speed reducer and needs to be designed for an exact train ratio of:

$$\frac{\omega_2}{\omega_5} = 35$$

Determine the minimum number of teeth on each gear for smallest overall size of the gear train, while avoiding interference for a pressure angle of 20°.

The module is constant for all gears in the gear train.



$$w_2 = \frac{N_3}{N_2} w_3 = \frac{N_3}{N_2} w_4 = \frac{N_3}{N_2}\frac{N_5}{N_4} w_5$$

$$w_4 = \frac{N_5}{N_4} w_5$$

$$\frac{w_2}{w_5} = \frac{N_3}{N_2}\frac{N_5}{N_4} = 35$$

$\frac{N_3}{N_2} = 5$ and $\frac{N_5}{N_4} = 7$ — or — $\frac{N_3}{N_2} = 7$ and $\frac{N_5}{N_4} = 5$.

also constrained by $N_3 + 2N_2 = N_4 + N_5$

use eqn. 13-11 to find smallest # of teeth on pinion.

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

for $m=5$ $N_p = 15.74 \rightarrow$ need at least 16 teeth

for $m=7$ $N_p = 16.099 \rightarrow$ need at least 17 teeth.

option ①

for $\frac{N_3}{N_2} = 5$, $\frac{N_5}{N_4} = 7$ and $N_3 + 2N_2 = N_4 + N_5$

$5N_2 + 2N_2 = N_4 + 7N_4 \quad \rightarrow N_2 = \frac{8}{7} N_4$

N_4 must be $> 17 \rightarrow$ choose multiple of 7

$N_4 = 21 \quad N_2 = 24$

$N_5 = 7N_4 = 147 \quad N_3 = 5N_2 = 120$

check: $2N_2 + N_3 = N_4 + N_5$

$2 \cdot 24 + 120 = 168 = 147 + 21$ ✓

option ②

for $\frac{N_3}{N_2} = 7$ $\frac{N_5}{N_4} = 5$ and $N_3 + 2N_2 = N_4 + N_5$

$$7N_2 + 2N_2 = N_4 + 5N_4 \rightarrow N_2 = \frac{6}{9} N_4$$

N_2 must be > 17 $\rightarrow$ choose multiple of 6

$$\boxed{\begin{array}{ll} N_2 = 18 & N_4 = 27 \\ N_3 = 7N_2 = 126 & N_5 = 5N_4 = 135 \end{array}}$$

check: $2 \cdot N_2 + N_3 = N_4 + N_5$

$2 \cdot 18 + 126 = 162 = 27 + 135$ ✓

choose option with smaller $N_4 + N_5$

option 1: $N_4 + N_5 = 168$

option 2: $N_4 + N_5 = 162$

$\rightarrow$ choose option 2.

PROBLEM No. 4 (25 points)

h t_2 d

A 0.5-in gray cast iron plate and a 1-in gray cast iron plate are joined with a 3/8-16 SAE Grade 5 steel screw. The 1-in plate is threaded through its entire thickness.

Determine the following.

(a) A suitable length for the screw.

(b) The bolt stiffness, k_b.

(c) The member stiffness, k_m.

(d) The joint stiffness constant, C.

(e) The preload in the bolt for a permanent connection, F_i.

(f) The factor of safety for infinite life using the Goodman criterion if the joint is loaded from $P_{min} = 1000$ lbf to $P_{max} = 2500$ lbf.

a) Follow Table 8-7

$h = 0.5$ in

$t_2 = 1$ in

$t_2 \geq d = 0.375$ in

$l = h + d/2 = 0.5 + \frac{0.375}{2} = 0.6875$ in

$L > h + 1.5d = 0.5\text{in} + 1.5 \cdot \frac{3}{8}\text{in} = 1.0625$ in

from A-17 choose $L = 1.25$ in

b) $L_T = 2d + \frac{1}{4}$ in $= 2 \cdot \frac{3}{8}$ in $+ \frac{1}{4}$ in $= 1$ in

$l_d = L - L_T = 1.25 - 1 = 0.25$ in

$l_t = l - l_d = 0.6875 - 0.25 = 0.4375$ in

PROBLEM No. 4 (continued)

$A_d = \frac{\pi}{4} \cdot (0.375 in)^2 = 0.1104 \ in^2$

$A_t = 0.0775 \ in^2$ (Table 8-2)

$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{0.0775 \cdot 0.1104 \cdot 30 \cdot 10^6}{0.1104 \cdot 0.4375 + 0.0775 \cdot 0.25} = 3800 \ kips/in$

$E = 30.0$ Mpsi for steel bolt (Table 8-8)

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

$A = 0.77871$ $B = 0.61616$ for gray cast iron (Table 8-8)

$k_m = 0.77871 \cdot 14.5 \cdot 10^6 \ psi \cdot 0.375 in \exp(0.61616 \cdot 0.375 in / 0.6875)$

$= 5925 \ kips/in$

d) $C = \frac{k_b}{k_b + k_m} = \frac{3800}{3800 + 5925} = 0.39$

e) $F_i = 0.9 S_p' A_t = 0.9 \cdot 85000 \frac{lbf}{in^2} \cdot 0.0775 in^2 = 5928.75 \ lbf$

$S_p' = 85$ kpsi (table 8-9)

f) $$n_f = \frac{S_e(S_{ut} - \sigma_i)}{S_{ut}\sigma_a + S_e(\sigma_m - \sigma_i)}$$

$S_e = 18.6$ kpsi (Table 8-17)

$S_{ut} = 120$ kpsi (Table 8-9)

$\sigma_i = 0.9\, S_p = 76.5$ kpsi

$$\sigma_a = \frac{C(P_{max} - P_{min})}{2A_t} = \frac{0.39(2500 - 1000\ \text{lbf})}{2 \cdot 0.0775\ \text{in}^2} = 3774\ \text{psi}$$

$$\sigma_m = \frac{C(P_{max} + P_{min})}{2A_t} + \sigma_i = \frac{0.39(2500 + 1000)}{2 \cdot 0.0775\ \text{in}^2} + 76.5\ \text{kpsi} = 85300\ \text{psi}$$

$$n_f = \frac{18.6(120 - 76.5)}{120 \cdot 3.8 + 18.6(85.3 - 76.5)} = 1.3$$