December 15, 2021

INSTRUCTIONS

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

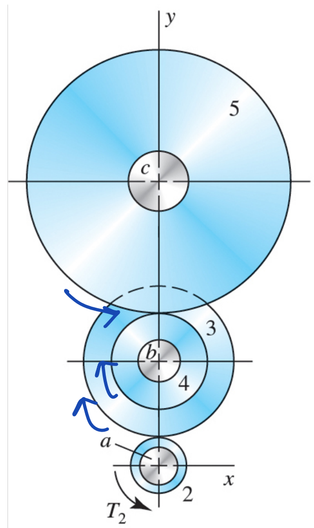
Work appearing on the backside of any exam page will NOT be graded.

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 gear train shown below is driven by torque T_2 applied to shaft a.



- [x] The train value (e) is positive.
- [ ] The train value is negative.
- [ ] The train value can be either positive or negative.
- [ ] Train values are neither positive nor negative.

(b) Why would you choose to include spiral miter gears in a gear train? Select all that apply.

- [ ] To increase the gear ratio.
- [ ] To reduce the gear ratio.

} miter gears are idlers

- [x] To redirect rotation perpendicular to the input.
- [ ] To support lighter loads than a straight miter gear set.
- [x] To support heavier loads than a straight miter gear set.
- [x] To provide smoother engagement than a straight miter gear set.
- [ ] To provide a self-locking miter interface.
- [ ] To increase the output torque.
- [ ] All of the above.
- [ ] None of the above.

(c) Planetary gear sets are more efficient when they are designed without carriers (i.e, arms).

- ○ True
- ● False

In a few words, justify your answer.

Carriers ensure proper alignment.

(d) Helical compression springs with some modifications can be used as helical torsion springs. Briefly explain why and how.

if ends were added to allow the moment to be applied and the pitch was sufficiently small.

(e) Why is analyzing a bolted joint loaded in shear more complex than a similarly configured bolted joint loaded in tension?

Select all that apply.

- ☑ Check/calculate the bolt bearing load.
- ☑ Check/calculate the member bearing load.
- ☑ Check/calculate member tearing across any hole or sets of holes.
- ☑ Check/calculate edge shearing/tearing of member(s).
- ☐ Check/calculate the tension pre-load for the bolt(s).
- ☑ Incorporating friction between members.
- ☑ Incorporating uneven shear loading of bolts due to alignment and tolerances.
- ☑ Incorporating moments introduced by the shearing forces.
- ☐ All of the above.
- ☐ None of the above.

(f) You are working as a structures engineer. A peer has asked you to review their bolted joint design. You are not impressed with their design. Choose three of the following issues and briefly explain the error in your peer's design.

Fill the circle of the three responses you would like to have graded.

◯ Use of Grade 12.9 M16 x 1.5 screws in an Imperial design.

mix of SI and imperial units is bad practic

◯ Use of Grade 12.9 M16 x 1.5 screws to grip a combination of low carbon, brass (gasket), and cast iron members.

The Grade 12.9 is very strong. Not required for a relatively soft grip.

◯ Use of Grade 12.9 M16 x 1.5 screws to be screwed into a cast aluminum housing that is 0.357 inches thick.

threaded hole is not long/deep enough, per Table 8-7

◯ The Grade 12.9 M16 x 1.5 screws are called out as having a length of 83.5 mm.

83.5 mm screws are a custom length. would be more expensive.

◯ Use of 12.9W washers.

The washer doesn't fit over the bolt.

◯ Calculated factors of safety $n_p = 4.3$ and $n_0 = 8.9$.

np is very conservative, showing the bolted joint is overdesigned.

(g) GD&T when prescribed (placed on the model or drawing) and inspected (measured on the actual produced part) correctly allows more parts to be accepted as good (in tolerance) parts, fewer rejects. Briefly explain why.

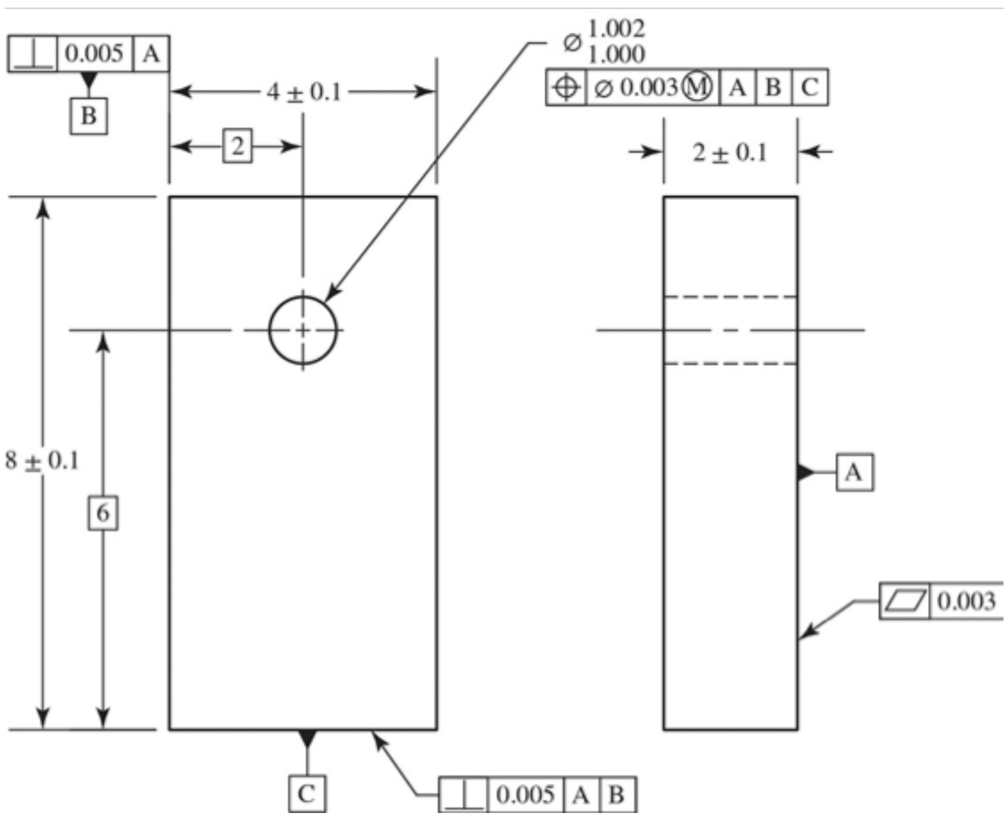
The characteristics of the part are better controlled and toleranced. When combined with MMC, the bonus tolerance allows more manufactured parts to be accepted. GD&T moves away from rectangular tolerance zones and toward 3D cylindrical and plane bounding tolerance zones

(h) The concept and application of "bonus tolerance" is triggered when a design uses feature control frames that include the Ⓜ symbol as part of their tolerance block.

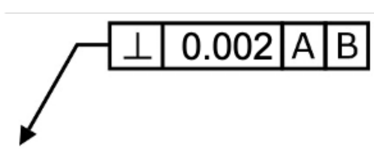
- [x] True
- [ ] False

(i) What is the size and shape of the tolerance zone the centerline of the hole must fall within?

- [ ] ± 0.1, rectangular
- [ ] 0.003, rectangular at MMC
- [x] 0.003, cylindrical at MMC
- [ ] 0.003, cylindrical



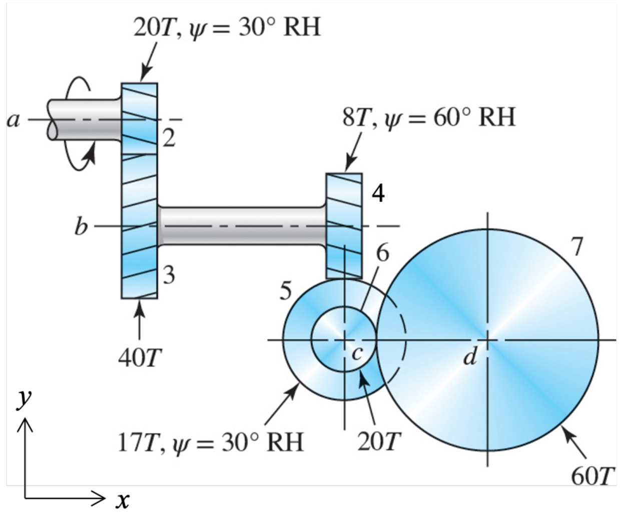
(j) Write the interpretation for the following feature control frame.



The perpendicularity of the surface/plane must fall within a tolerance zone defined by two parallel planes 0.002 units apart and both being perpendicular to datums A and B

PROBLEM No. 2 (5 points)

Shaft a rotates at 1000 rpm in the direction shown (i.e., $-1000\vec{i}$ rpm)



Determine the following.

(a) The speed of shaft d.

(b) Select the gear(s) that function as an idler. Briefly justify your choice.

- ☐ Gear 2
- ☐ Gear 3
- ☐ Gear 4
- ☐ Gear 5
- ☐ Gear 6
- ☐ Gear 7
- ☒ There is not an idler in the gear train.

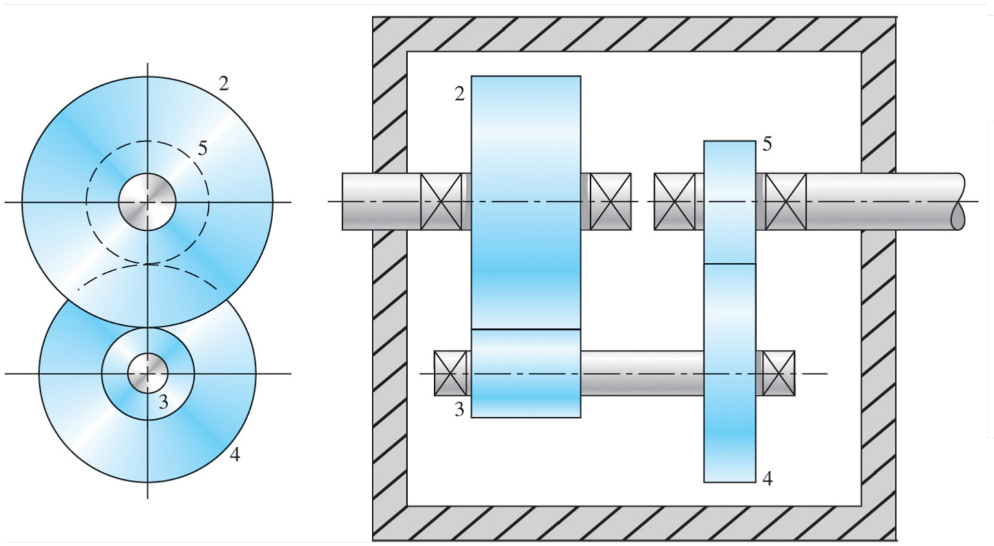
a) $e = \pm \frac{\text{driven}}{\text{driving}} = \pm \frac{20}{40} \cdot \frac{8}{17} \cdot \frac{20}{60} = \pm 0.078$

→ Shaft d rotates at $0.078 \cdot 1000$ rpm $= 78$ rpm

b) no gear appears in both the numerator and the denominator of e; there IS no idler.

PROBLEM No. 3 (5 points)

A compound reverted gear train is to be designed as a speed increaser with an increase of exactly 40 to 1. The input is gear 2 and the output is gear 5.



If gear 2 has 144 teeth and gear 3 has 18 teeth, find the numbers of teeth of gears 4 and 5.

$N_2 + N_3 = N_4 + N_5 \longrightarrow N_4 + N_5 = 144 + 18 = 162$ (1)

$\frac{N_2}{N_3} \cdot \frac{N_4}{N_5} = 40 \longrightarrow \frac{\overset{8}{\cancel{144}}}{\cancel{18}} \cdot \frac{N_4}{N_5} = 40 \longrightarrow \frac{N_4}{N_5} = 5$ (2)

(2) into (1): $5N_5 + N_5 = 162 \rightarrow N_5 = \frac{162}{6} = 27$

$N_4 = 5N_5 = 135$

PROBLEM No. 4 (10 points)

An uncrowned straight-bevel pinion has $N_P = 20$ teeth, a diametral pitch of $P_d = 6$ teeth/inch, and a transmission accuracy number of $Q_v = 8$. The face width is $F = 1.25$ in and the normal pressure angle is $\phi = 20°$.

Both the pinion and the gear are made of through-hardened Grade 2 steel with a Brinell hardness of $H_B = 300$.

The driven gear has $N_G = 60$ teeth.

The gearset has a life goal of 10^9 pinion revolutions with a reliability of 99.9%.

The pitch-line velocity is $v_t = 4000$ ft/min.

The pinion is mounted outboard of its bearings. The gear is straddle-mounted. $\longrightarrow K_{mb} = 1.1$

The straight-bevel gearset is to be analyzed for bending and for wear.

The parameters included in the AGMA analysis for straight-bevel gears are listed below.

Select all of the the parameters that will have different values for the pinion and the gear.

- [ ] W^t
- [ ] K_o
- [ ] K_v
- [ ] K_s
- [ ] K_m
- [ ] K_x
- [x] J – Figure 15-7
- [x] S_t – because of J
- [ ] s_{at}
- [x] K_L – because gear will rotate 1/3 as much as pinion
- [x] S_F
- [ ] K_T
- [ ] K_R
- [x] $S_{wt} = \sigma_{all}$
- [ ] C_P
- [ ] d_P
- [ ] I
- [ ] C_s
- [ ] C_{xc}
- [ ] s_{ac}
- [x] C_L same as K_L
- [ ] C_H
- [x] S_H
- [ ] C_R
- [x] $S_{wc} = (\sigma_c)_{all}$

PROBLEM No. 5 (30 points)

Pressure relief valve systems are typically used in air compressors and pneumatic assemblies to prevent issues due to excess pressure buildup.

These systems use a helical compression spring with a preload F_a to keep the valve closed. The valve opens when the the pressure load exerted by the fluid exceeds F_a.

The spring length is 50 mm when $F_a = 7$ N.

The valve is fully open when the spring compressed to its shut length, where $L_s = 30$ mm.

The spring is made of ASTM A228 music wire. The wire diameter is 1.5 mm and the spring's outside diameter is 11.5 mm.

The spring exhibits linear behavior when loaded.

Determine the following.

(a) Briefly explain why it is appropriate for this spring to have squared and ground ends.

(b) The number of active coils (N_a).

(c) The spring rate (k in N/m).

(d) Using the spring rate found in part (c), the force to compress the spring from the assembled length (50 mm) to the shut length (30 mm). Recall that the spring length is 50 mm when $F_a = 7$ N.

(e) The factor of safety guarding against against yielding when the spring is compressed to its shut length. Use a conservative estimate for the wire's strength.

(f) Do you expect the spring to have infinite life? Use the torsional Goodman failure criterion with Zimmerli data. The spring is peened.

a) because the spring is likely between two flat plates.

b) from Table 10-1

$$L_s = d N_t \rightarrow N_t = \frac{L_s}{d} = \frac{30\text{ mm}}{1.5\text{ mm}} = 20$$

$$N_t = N_a + 2 \rightarrow N_a = 18$$

c) $$k \approx \frac{d^4 G}{8 D^3 N_a} = \frac{(0.0015\text{ m})^4 \cdot 81.7 \cdot 10^9 \text{ N/m}^2}{8\,(0.01\text{ m})^3 \cdot 18} = 2870 \text{ N/m}$$

$$1.5\text{ mm} \cdot \frac{1\text{ in}}{25.4\text{ mm}} = 0.06\text{ in} \rightarrow G = 81.7\text{ GPa (table 10-5)}$$

$$D = OD - d = 10\text{ mm}$$

PROBLEM No. 5 (continued)

d) $F = k\Delta y = 2870 \frac{N}{m} \cdot 0.02m = 57.4\ N$

57.4 N is required in addition to the 7 kN load acting when the spring length is 50 mm.

$\longrightarrow$ the force to shut the spring is 64.4 N.

e) $n = \frac{S_{sy}}{\tau}$

conservative from Table 10-5

$S_{sy} = 0.45\ S_{ut} = 0.45 \frac{A}{d^m} = 0.45 \cdot \frac{2211}{1.5^{0.145}} = 938\ MPa$

$\tau = K_B \frac{8 F_s D}{\pi d^3} = 1.211 \cdot \frac{8 \cdot 64.4N \cdot 0.01\ m}{\pi \cdot (0.0015m)^3} = 588.9\ MPa$

$K_B = \frac{4C+2}{4C-3} = 1.211$

$C = \frac{D}{d} = \frac{10\ mm}{1.5\ mm} = 6.67$

$n = \frac{938}{589} = 1.6$

PROBLEM No. 5 (continued)

f) $$n_f = \left(\frac{\tau_a}{S_{se}} + \frac{\tau_m}{S_{su}}\right)^{-1}$$

$\tau_{max} = 588.9$ MPa (from part e)

$$\tau_{min} = 1.211 \frac{8.7N \cdot 0.01m}{\pi (0.0015m)^3} = 64.0 \text{ MPa}$$

$$\tau_a = (\tau_{max} - \tau_{min})/2 = 262.5 \text{ MPa}$$

$$\tau_m = (\tau_{max} + \tau_{min})/2 = 326.5 \text{ MPa}$$

$$S_{su} = 0.67 S_{ut} = 0.67 \cdot 2084 \text{ MPa} = 1396 \text{ MPa}$$

$$S_{se} = \frac{S_{sa}}{1 - \frac{S_{sm}}{S_{su}}} = \frac{398 \text{ MPa}}{1 - \frac{534 \text{ MPa}}{1396 \text{ MPa}}} = 287.9 \text{ MPa}$$

$$n_f = \left(\frac{262.5}{287.9} + \frac{326.5}{1396}\right)^{-1} = 0.9$$

→ infinite life is not predicted.

PROBLEM No. 6 (25 points)

A bolted joint uses ISO class 9.8 bolts to clamp together two identical aluminum plates.

The plates are each 40-mm thick. $\longrightarrow l = 80\text{ mm}$

The bolts are M12 x 1.75 and are 100 mm long. The hexagonal nuts are 10.8 mm thick. Washers are not used.

The bolted joint will occasionally be disassembled for maintenance.

Determine the following.

(a) The bolt stiffness (k_b in MN/m).

(b) The member stiffness (k_m in MN/m).

(c) The joint constant (C).

(d) To reduce the joint constant C, should you choose smaller bolts (e.g., M10 x 1.5) or larger bolts (e.g., M14 x 2)? Briefly justify your answer.

a) $L = 100\text{ mm}$

$L_T = 2d + 6\text{ mm} = 2 \cdot 12 + 6 = 30\text{ mm}$

$l_d = L - L_T = 70\text{ mm}$

$l_t = l - l_d = 80\text{ mm} - 70\text{ mm} = 10\text{ mm}$

$A_d = \pi \cdot (12\text{ mm})^2/4 = 113.1\text{ mm}^2$

$A_t = 84.3\text{ mm}^2$ (Table 8-1)

$E = 207\text{ GPa}$ (Table 8-8 for steel)

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} = \frac{(113.1\text{ mm}^2)(84.3\text{ mm}^2) \cdot 207\text{GPa}}{(113.1\text{ mm}^2)(10\text{ mm}) + (84.3\text{ mm}^2)(70\text{ mm})}$$

$= 280.7\text{ MN/m}$

PROBLEM No. 6 (continued)

b) $k_m = AEd \exp(Bd/l)$ (Eqn 8-23)

$A = 0.79670$
$B = 0.63816$
$E = 71$ GPa

} for Aluminum (Table 8-8)

$d = 12$ mm
$l = 80$ mm

$k_m = 0.79670 \cdot 71 \text{ GPa} \cdot 12\text{mm} \exp(0.63816 \cdot 12/80)$

$= 746.9$ MN/m

c) $C = \dfrac{k_b}{k_b + k_m} = \dfrac{280.7}{280.7 + 746.9} = 0.27$

d) to reduce C while maintaining k_m, reduce k_b. A smaller bolt will be less stiff → choose the M10 x 1.5 bolt.