ME 35400 – Machine Design I
Spring 2021: Final Exam
Monday, May 03, 2021

Name: _____   **Email:** _____

Instructions:

- This is an open book, closed notes exam.
- The use of any online sources, such as Chegg.com is not allowed. Failure to adhere to this will result in a score of 0 on this exam.
- Once completed, please upload a scanned PDF file on Gradescope.

Problem 1 (25 points)

A spur-gear set with gear ratio $m_G = 5$, a diametral pitch of $P = 12$ teeth per inch transmits 5 horsepower. The rotational speed of the pinion is 1000 rpm. The center distance between the gear and the pinion is 6 inches. All of the teeth are full-depth with a 20° pressure angle.

The following parameters and AGMA factors are known for pinion:

- Overload Factor, $K_o = 1.25$
- Rim Thickness Factor, $K_B = 1.0$
- Dynamic Factor, $K_v = 1.1$
- Surface Condition Factor, $C_f = 1.0$
- Size Factor, $K_s = 1.1$
- Geometry Factor, $I = 0.13$
- Load Distribution Factor, $K_m = 1.2$
- Elastic Coefficient, $C_p = 2300 \sqrt{\text{psi}}$
- Face width, $F = 1$ inch

Calculate

(i)   the pitch diameters of the pinion and the gear.
(ii) the number of teeth on pinion and the gear.
(iii) the minimum number of teeth for the pinion to prevent interference. Is the interference constraint met for pinion? Why or why not?
(iv) the AGMA bending stress for the pinion.
(v)   the AGMA contact stress for the pinion.
(vi) the probability of failure of the pinion due to bending if it is manufactured using Grade 1 carburized and hardened steel. It is designed to last for 10^7 cycles with a bending factor of safety is 2.0 under room temperature.

Problem 2 (30 points):

The torsion spring shown in the schematic below is made of music wire.
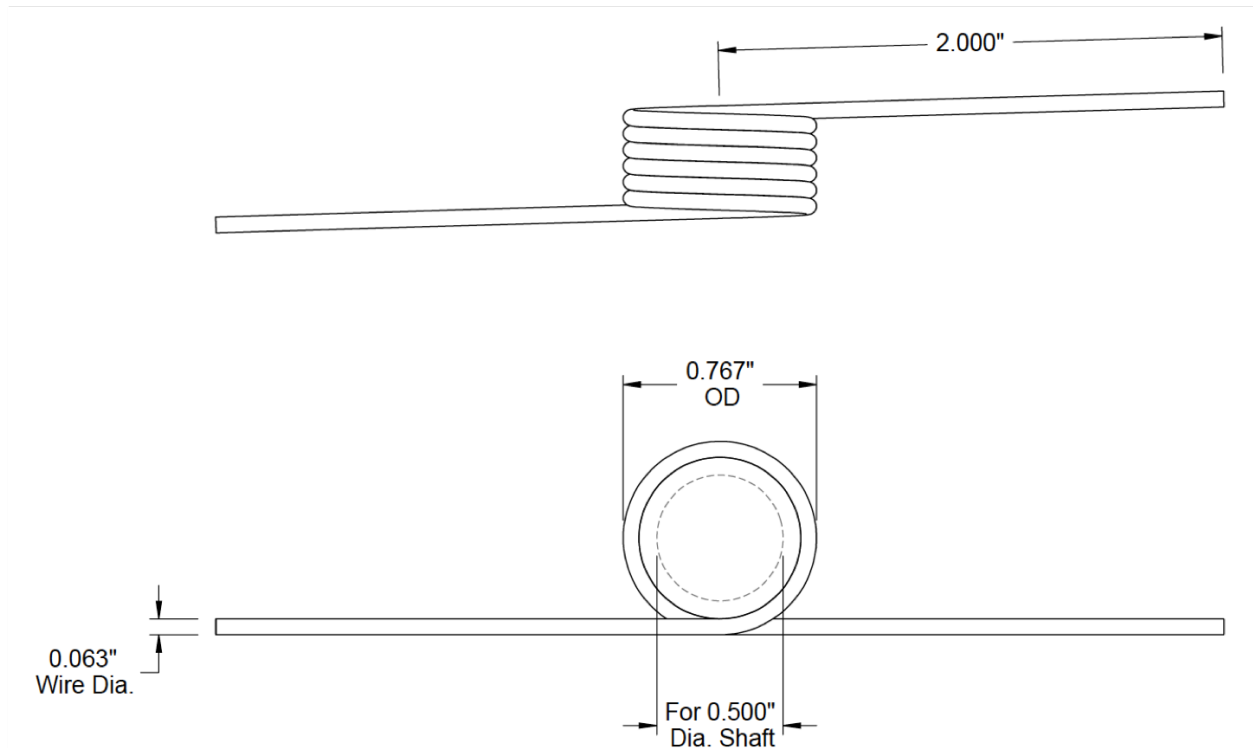
Calculate:

(i) The angle β and number of body turns (N_b).
(ii) The wire's yield strength (S_y) and ultimate tensile strength (S_{ut}).
(iii) The spring index (C).
(iv) The spring rate (k'). Express your answer in units of torque/turn.
(v) For a factor of safety guarding against yielding of 1, what is the static load that can be applied to the spring?
(vi) For a factor of safety for infinite life of 1.5 using the Goodman failure criterion, what is the spring's endurance limit (S_e) for a load that varies between 2 and 4 in-lbf?

Problem 3 (30 points)

Given: Two identical aluminum plates are compressed with one bolt and nut. Washers are used under the head of the bolt and with the nut, as shown in the figure. The system has the following properties:

- Bolt: steel; UNC-$\frac{1}{4}$-20; SAE Grade 7; rolled threads; $S_{ut} = 120$ kpsi; $E_{bolt} = 30$ Mpsi
- Washers: steel; ID $= 0.281$ in; OD $= 0.625$ in; thickness $= 0.065$ in; $E_{washer} = 30$ Mpsi
- Nut: steel; height $= \frac{7}{32}$ in; $E_{nut} = 30$ Mpsi
- Plates: aluminum; $E_{plate} = 10.3$ Mpsi; $S_{ut} = 47$ kpsi; $S_y = 25$ kpsi; thickness $= 2.25$ in
- Loading: Preload $= 3000$ lbs; External loading fluctuates from 1000 lbs to 2000 lbs

Find: Determine the following:

(i) A suitable length for the bolt, rounded up to the nearest $\frac{1}{4}$ in.
(ii) The overall stiffness of the members, k_m.
(iii) The joint stiffness, C.
(iv) If the washers are removed from the joint, calculate a new value for the overall joint stiffness, C. Justify your answer.
(v) For the bolt, determine the following:
   (a) The load factor guarding against joint separation, η_o
   (b) The load factor guarding against exceeding the proof load, η_L
   (c) The yielding factor of safety, η_p
   (d) The factor of safety guarding against fatigue using the modified Goodman criterion, η_f
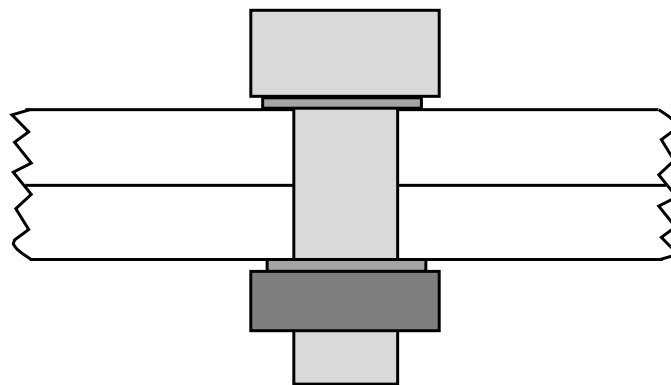
Problem 4 (15 points)

A multi-disc plate clutch has six friction pairs ($N = 6$) with a disk outer diameter of 7.0 inches and an inner diameter of 4.0 inches. The coefficient of friction is 0.25. The maximum pressure is 120 psi.

(i) Calculate the axial force F and the transmitted torque, T using the uniform wear model.
(ii) Calculate the axial force F and the transmitted torque, T using the uniform pressure model.
(iii) What is the torque capacity of this clutch when it is new? Explain why.