ME 35400 – Machine Design I

Spring 2021: Exam 2

Tuesday, March 30, 2021

Name: _____ **Email:** _____

Instructions:

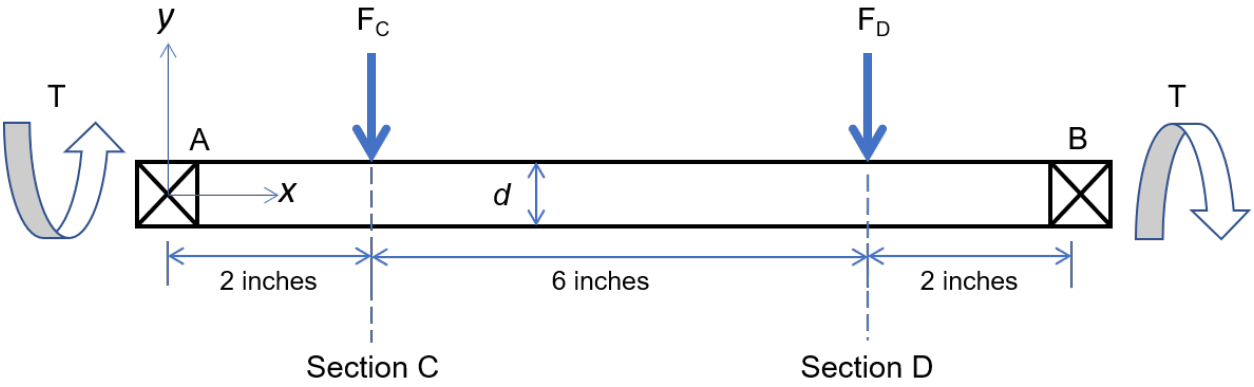
- This is an open book, closed notes exam.
- The use of any online sources, such as Chegg.com is not allowed. Failure to adhere to this will result in a score of 0 on this exam.
- Once completed, please upload a scanned PDF file on Gradescope.

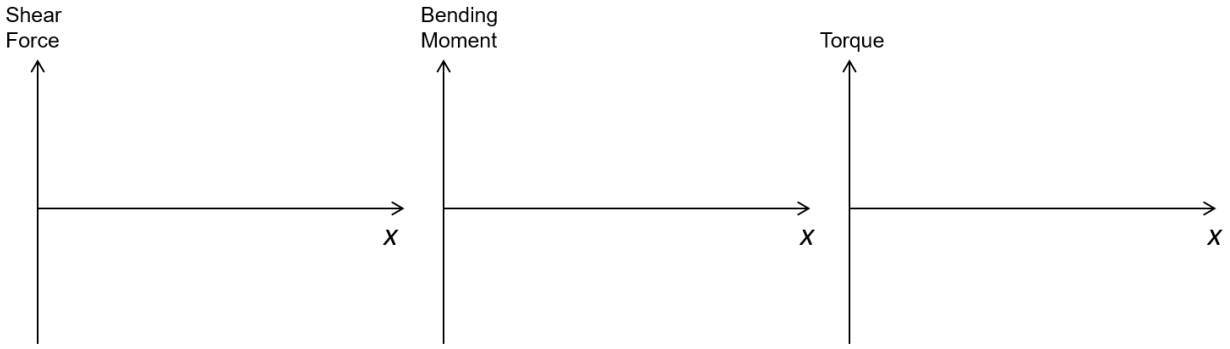
Problem 1 (30 points):

The steel shaft shown below is rotating at 1000 rpm, and is simply-supported at bearings A and B. The shaft has a circular cross-section with an unknown diameter, d. The torque, T, transmitted by the shaft varies from $T_{\min} = -2000$ in-lb and $T_{\max} = +6000$ in-lb. Two constant transverse loads with magnitudes $F_C = 3000$ lb and $F_D = 3000$ lb and directions shown in the figure act on the shaft at sections C and D respectively.

Assume $S_{ut} = 140$ kpsi and $S_y = 120$ kpsi, $S_e = 60$ kpsi (fully corrected). Stress concentration effects at section D are due to features in the shaft for mounting a gear. Assume that the fatigue stress concentration factors for the critical point at section D are $K_f = 1.60, K_{fs} = 1.40$.

(i) Calculate the reaction forces at the bearings A and B.
(ii) Sketch the shear force, bending moment, and torque diagrams for the shaft.
(iii) Calculate the diameter, d, of the shaft for an infinite-life fatigue factor of safety of 2.0 at section D, using the Goodman failure criterion.
(iv) Calculate the diameter, d, of the shaft for a static factor of safety of 2.0 at section D. Include stress concentration for this material.
(v) Which failure criteria (static or fatigue) governs the design at section D, and why?





Problem 2 (25 points):

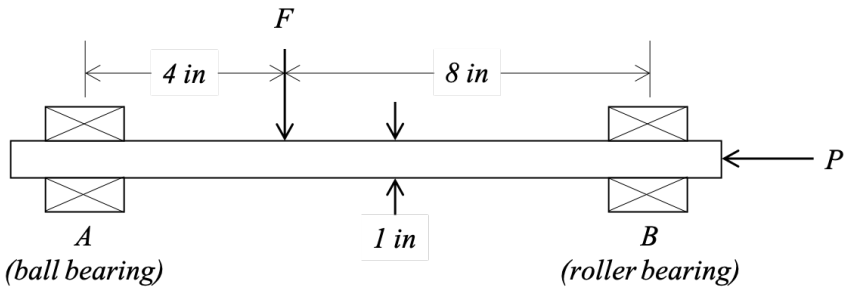
A 1.5 inch diameter shaft transmits a time-varying torque T through a standard rectangular key with a width of $\frac{3}{8}$ inch and a height of $\frac{1}{4}$ inch. The depth of the key-seat in the shaft is $\frac{1}{8}$ inch. The torque T fluctuates between $T_{\min} = +2000$ in-lb and $T_{\max} = +4000$ in-lb.

The material properties of the key are as follows: $S_{ut} = 60$ kpsi, $S_y = 50$ kpsi, and $S_e = 30$ kpsi. The endurance limit S_e is fully corrected and was calculated with $k_c = 1$.

(i) Draw the free body diagram of the key, and show the planes of shear and crushing failure.
(ii) Calculate the length of the key required to achieve a *static* factor of safety of 2.0 under *shear failure*.
(iii) Calculate the length of the key required to achieve a *static* factor of safety of 2.0 under *crushing failure*.
(iv) Calculate the length of the key required to achieve a *fatigue* factor of safety of 2.0 under *shear failure* using the Goodman criterion.
(v) Does the key have an optimal aspect ratio? If not, calculate the optimal width of the key, assuming the same height ($= \frac{1}{4}$ inch).

Problem 3 (20 points):

The rotating shaft shown below is supported by a ball bearing at A and by a roller bearing at B. The ball bearing at A supports both a radial load and an axial load, where the axial load is $P = 400$ lbf. The roller bearing at B supports a radial load only. The bearings' inner rings rotate.



(i) For $F = 1800$ lbf, determine the radial force supported by the ball bearing at A and the radial force supported by the roller bearing at B.

(ii) Catalog data for a deep groove ball bearing that will be used for bearing A are as follow, where the catalog rating life is 10^6 cycles. Determine the bearing life in revolutions for 90% reliability.

Trade No.	For Shaft Dia.	For Housing ID	Wd.	Ring Material	Radial Load Cap., lbs. Dynamic	Static
R16	1"	2"	3/8"	Steel	2,400	1,450

(iii) The roller bearing at B is to have the same life as the the ball bearing at A (i.e., the bearing life determined above). Determine the basic dynamic load rating for the roller bearing at B, for 90% reliability where the catalog rating life is 90×10^6 revolutions.

Problem 4 (25 points):

Given: A full journal bearing is 2.5 inches long with a l/d ratio of 0.5. The bushing bore has a diameter of 5.005 inches. The load is 525 lbf and the journal speed is 800 rev/min. The operating temperature is 145°F and SAE 40 lubricating oil is used.

Find: Determine the following:

(a) The Sommerfeld number
(b) The minimum film thickness, h_o, and the eccentricity of the film, e
(c) The coefficient of friction, f
(d) The lubricant side flow rate, Q_s
(e) The power loss due to friction in units of horsepower (hp)
(f) The operating temperature is now 180°F. Choose the appropriate SAE grade oil to use in order to keep the power loss due to friction the same as determined above. Justify your answer.