ME 452: Machine Design II       Spring Semester 2016

Name of Student: ____________________________________________________

Please circle your Lecture Division Number:   Lecture 1      Lecture 2

MIDTERM EXAM

Wednesday, March 9th, 2016

OPEN BOOK AND CLOSED NOTES

For full credit you must show all your work and calculations clearly and logically on the sheets of paper attached to the end of each problem.

Please use only the blank pages for all your work and write on one side of the paper only.

Please draw any free body diagrams or other diagrams clearly and to a reasonable scale.

At the end of the exam, please staple each problem separately. Staple this cover sheet in front of Problem 1.

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Problem 1 (25 points). The piece of the circular steel shaft shown in Figure 1 is subjected to a bending moment which fluctuates from $M_{\text{max}} = 4000 \text{ in.lb}$ to $M_{\text{min}} = -1200 \text{ in.lb}$ and a torque which fluctuates from $T_{\text{max}} = 8000 \text{ in.lb}$ to $T_{\text{min}} = -2000 \text{ in.lb}$. The radius of the groove is $r = 0.06 \text{ inches}$ and the theoretical stress concentration factors at the groove due to bending and torsion are $K_t = 3.0$ and $K_{tS} = 2.2$, respectively. The ultimate tensile strength and the yield strength of the shaft material are $S_{ut} = 100 \text{kpsi}$ and $S_{yt} = 80 \text{kpsi}$, respectively. The surface of the shaft is ground, the shaft operates at room temperature, a reliability of 99% is required, and miscellaneous effects can be ignored. The size modification factor is $k_b = 0.816$. The infinite life fatigue factor of safety for the critical element of this piece of the shaft is $n_f = 2.5$, and the fatigue stress concentration factors due to torsion are $K_{fs} = K_{tS} = 2$.

(i) Determine the fully corrected endurance strength of the shaft.

(ii) Determine the fatigue stress concentration factor at the groove due to bending. Assume that the fatigue stress concentration factor $K_{fs} = K_f$.

(iii) Using the distortion energy-ASME elliptic failure criterion, determine the diameter, $d$, of the shaft at the groove.
Problem 2 (25 points). The rotating circular steel shaft is supported by two self-aligning bearings at O and H which act as simple supports as shown in Figure 2. The diameters are $D = 2\text{ in}$ and $d = 1.5\text{ in}$ and the radius of the fillet is $r = 0.25\text{ in}$. The shaft is subjected to the constant vertical loads $F_A = 650\text{ lb}$ and $F_B = 500\text{ lb}$ and transmits a repeated torque which varies from $T_{\min} = 0$ to $T_{\max} = 2250\text{ in}.lb$. The yield strength and ultimate tensile strength of the shaft are $S_y = 120\text{ kpsi}$ and $S_u = 160\text{ kpsi}$, respectively. The fully corrected endurance strength of the shaft is $S_e = 60\text{ kpsi}$. The fatigue stress concentration factors for the critical element of the shaft are $K_f = K_{fm} = 2.15$ for normal stresses and $K_{fs} = K_{fs_m} = 1.75$ for shear stresses.

(i) Determine the maximum bending moment at the critical section of the shaft.

(ii) Determine the nominal values of the von-Mises mean stress and the von-Mises alternating stress acting on the critical element of the shaft.

(iii) Using the Langer line, determine the static factor of safety guarding against yielding for the critical element of the shaft. Neglect the effects of stress concentration.

(iv) Using the distortion energy-Goodman criterion of failure, determine the infinite life fatigue factor of safety for the critical element of the shaft. Include the effects of stress concentration.

Figure 2. A rotating steel shaft supported in bearings.
Problem 3 (25 points).

Part I (12 points). A constant radial load of 7.5 kN is acting on a deep-groove ball bearing which is used to help support a transmission shaft. The inner ring of the bearing is to operate at 500 rpm for 2,500 hours continuously and the application has poor bearing seals. The minimum reliability goal for the bearing is 94%. The bearing manufacturer is number 1 in the table of manufacturers, see page 608, Chapter 11 in the text book.

(i) Select the most appropriate deep groove ball bearing for this application.

(ii) Determine the reliability of the selected bearing.

Part II (13 points). Estimate the $L_{10}$ life of a single-row 02-series angular-contact ball bearing with a bore diameter of 90 mm. The bearing is subjected to a constant radial load of 12.5 kN and a constant thrust load of 4.5 kN. The application is a wheel bearing where the outer ring is rotating and the inner ring is stationary.
Problem 4 (25 points). A full journal bearing is lubricated with SAE 30 grade oil and operates at 40°C. The diameter of the journal is 55 mm and the diameter of the bearing is 55.05 mm. The rotational speed of the journal is 50 rev/s.

Part I (13 points). If the radial load acting on the bearing is 2.5 kN and the length of the bearing is 55 mm then determine:
(i) The Sommerfeld number.
(ii) The eccentricity.
(iii) The coefficient of friction.

Part II (12 points). If the radial load is increased to 5 kN and the length of the bearing is increased to 110 mm then using the Raimondi and Body interpolation determine the position of the minimum film thickness.