INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

Spring, End-Semester 2016-17

Date of Examination : 24th April, 2017 **Session:** AN **Duration:** 3 hrs **Total Marks:** 50

Subject No. : ME30602 **Subject Name** : Design of Machine Elements

Department/Center/School : Mechanical Engineering

Note: Question paper consists of two parts. Answer both parts. Make any assumptions necessary, however, state your assumptions clearly. Answer legibly. Highlight the answers.

PART A - Answer the following six questions **(Each question carries 5 marks)**

Q 1) Consider the rotating shaft subjected to bending in Figure 1. The fully corrected endurance strength of the shaft material is 350 MPa and its ultimate tensile strength is 900 MPa. The shaft is subjected to fully reversed stresses. Estimate the cycles to failure for the shaft when it is subjected to bending force $F = 28$ kN. Static stress concentration factor at the fillet region is $K_t = 1.65$ and the fatigue strength fraction $f = 0.81$. The notch senstivity factor

$$q = \frac{1}{1+\sqrt{a/r}}, \quad a = 0.246 - 3.08\,10^{-3}\,S_{ut} + 1.51\,10^{-5} S_{ut}^2 - 2.67\,10^{-8}\,S_{ut}^3$$

170.5

where S_{ut} is in kpsi and "a" is in inches. Note that 1 kpsi = 6.895 MPa and 1 in = 25.4 mm. Note that fatigue *strength*

$$S_f = aN^b, \text{ where } a = \frac{(fS_{ut})^2}{S_e}, \; b = -\frac{1}{3}\log\left(\frac{fS_{ut}}{S_e}\right)$$

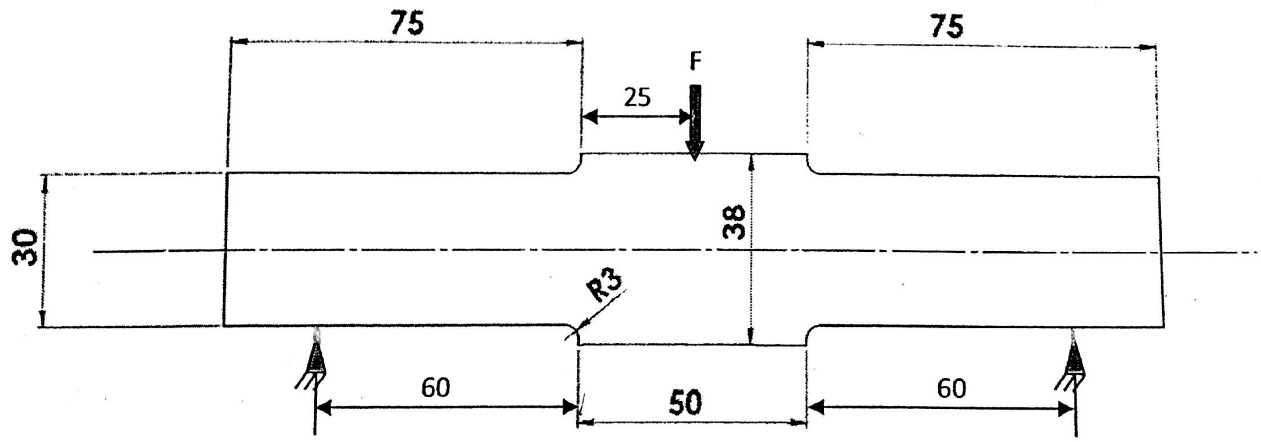

Figure 1: Schematic of the rotating circular shaft subjected to bending.
All dimensions are in mm.

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Q 2) A cantilever beam of circular cross section with diameter d and length 300 mm is subjected to a transverse load of 5 kN and a torque of 2 kN-m at its tip. Determine the diameter d of the beam if you want the beam to have a factor of safety of 2.5 against failure using modified-Mohr criterion. The material for the beam is ASTM Grade 40 Cast Iron (S_{ut} = 293 MPa, S_{uc} = 970 MPa).

Q 3) A gearset consists of a 16-tooth pinion driving a 40-tooth gear. The module m = 5 mm, and the addendum and dedendum are m and 1.25m, respectively. The gears are cut using a pressure angle of 20°. For this problem, do the following:

(a) Compute the circular pitch, the center-to-center distance, and the radii of the base circles.

(b) In mounting these gears, the center-to-center distance was incorrectly made 2.5 mm larger. Compute the new values of the pressure angle and the pitch-circle diameters.

Q 4) A 02-Series, 30 mm bore diameter cylindrical roller bearing is subjected to variable loading given in the table below. Estimate the life of the bearing for a reliability of 0.9. Basic dynamic loading rating and static load rating for the bearing are C_{10} = 22.4 kN and C_0 = 12.0 kN.

Run up cycles L_i (revs)	Radial Load - F_{ri} (N)	Axial load – F_{ai} (N)	Equivalent Radial Load - F_{ei} (N)	Application Factor – a_{fi}	
200	2670	1350	3550	1.10	3905
300	1350	1350	2800	1.25	3500
900	3350	1350	3920	1.10	4312
1200	1675	1350	2980	1.25	3725

Q 5 State whether the following statements are TRUE or FALSE

(a) For a large lot, bearing fatigue life is seen to follow Gaussian distributions

(b) Bearing fatigue life depends on loads they bear as well as the desired reliability

(c) Involute gear teeth profile can give conjugate motion

(d) Mohr-Columb failure criterion is more appropriate for low carbon steel, while von-mises yield criterion is more appropriate for grey cast iron

(e) Fatigue strength drops with cycles to failure for medium carbon steel even beyond 1 million loading cycles, while fatigue strength for aluminum alloys reaches a constant value (endurance limit) beyond 1 million loading cycles

(f) Notch sensitivity factor for annealed, low carbon steel would be close to one, while that for hardened high carbon steel would be close to zero

(g) Notch sensitivity factor lies in between 0 to 1

(h) Base circle diameters for gears are contant, while pitch circle diameters vary with center to center distance between the gear and pinion.

(i) Spur gears give larger speed reduction as compared to worm gear sets

(j) In weld design, welds are taken to fail from weld throat

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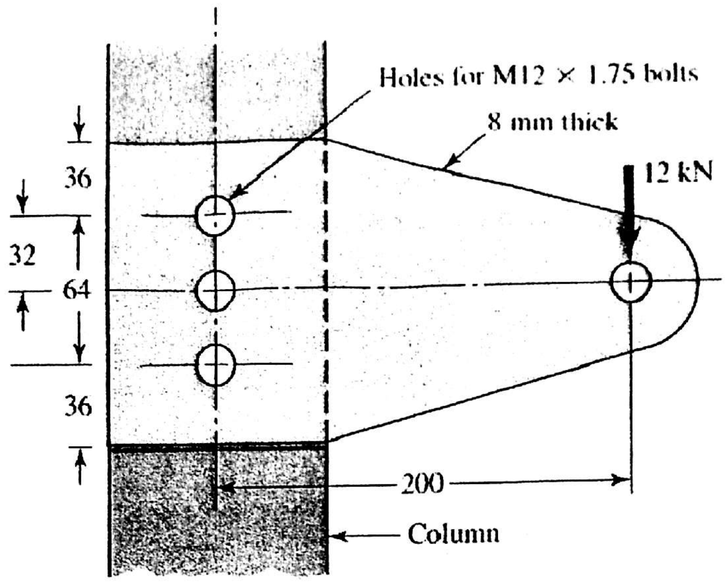
Q 6) The cantilever bracket is bolted to a column with three M12 x 1.75 ISO 5.8 bolts (see Figure 2). The bracket is made from AISI 1020 hot-rolled steel. Assume that the bolt threads do not extend into the joint. Find the factor of safety for the shear failure mode for the bolts. Tensile stress area for the bolt is $A_t = 84.3$ mm^2, minimum proof strength is 380 MPa, minimum tensile strength is 520 MPa, and minimum yield strength is 420 MPa.

Sut



$$\frac{12000 \times 0.2 \times 0.032}{0.032^2 + 0.032^2}$$

Figure 2

PART B - Answer any two of the following three questions **(Each question carries 10 marks)**

Q 7) The desired parameters for a spur gear set are as follows:

Pressure Angle, ϕ	20°
Gear Ratio, m_G	4
Center to center distance, c	200 mm
Pinion Material	2.5% Chrome Steel Grade 2 with Hardness HB 300
Gear Material	2.5% Chrome Steel Grade 2 with Hardness HB 300
Quality Number Q_v	10 (precession gearing)
Load distribution factor K_H (gear and pinion)	1.3
Overload Factor (K_o)	2
Desired Reliability on life	0.99 ($Z_R = 1, Y_Z = 1$)
Desired Pinion Life, N	10^8 cycles
Power Rating, H	25 kW
Pinion Speed, n	2000 rpm
Face width, b	50 mm
Ratio of rim thickness to tooth depth	1.5
Contact strength for gear and pinion (S_C)	1185 MPa
Surface finish factor (K_s)	1.1 (pinion), 1.15 (gear)
Rim thickness factor K_B (gear and pinion)	1.22
Elastic modulus (N/mm^2) and Poissons ratio (for gear and pinion)	200000, 0.3

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For this gear set find the following:

(a) Find the number of pinion teeth, gear teeth, and module.
(b) Determine the factors of safety against bending (S_F) and pitting failure (S_H) for the pinion teeth. Take temperature factor $Y_\theta = 1$, geometric factor $Y_J = 0.27$ for the pinion teeth, hardness ratio factor $Z_w = 1$. Assume any other missing factor appropriately.

USEFUL FORMULAE FOR GEARS:

$$Np \geq \frac{2}{(1+2m_G)\sin^2\emptyset}\left[m_G + \sqrt{m_G^2 + (1+2m_G)\sin^2\emptyset}\right]$$

AGMA stress equations in SI units for bending:

$$\sigma = W^t K_o K_v K_s \frac{1}{bm_t}\frac{K_H K_B}{Y_J}$$

where m_t is the transverse module. AGMA stress equations in SI units for pitting (contact) stress is:

$$\sigma_c = Z_E\sqrt{W^t K_o K_v K_s \frac{K_H}{d_{w1} b}\frac{Z_R}{Z_I}}, \quad Z_E = \left[\frac{1}{\pi\left(\frac{1-v_P^2}{E_P}+\frac{1-v_G^2}{E_G}\right)}\right]^{1/2}$$

where d_{w1} is the pitch circle diameter. Allowable stresses in bending:

$$\sigma_{all} = \frac{S_t}{S_F}\frac{Y_N}{Y_\theta Y_Z}$$

Allowable stresses in contact pitting:

$$\sigma_{c,all} = \frac{S_C}{S_H}\frac{Z_N Z_W}{Y_\theta Y_Z}$$

Allowable bending stress:

$$S_t = 0.7255\, H_B + 153.6 \text{ MPa}$$

Stress cycle factor for bending, stress cycle factor for pitting, geometry factor for pitting resistance are:

$$Y_N = 1.3558 \times N^{-0.0178}, \qquad Z_N = 1.4488 \times N^{-0.023}, \qquad Z_I = \frac{\cos\emptyset \sin\emptyset}{2}\left(\frac{m_G}{m_G+1}\right)$$

Dynamic factor (with V in m/s):

$$K_v = \left(\frac{A+\sqrt{200V}}{A}\right)^B, \qquad B = 0.25(12-Q_v)^{2/3}, \qquad A = 50 + 56(1-B)$$

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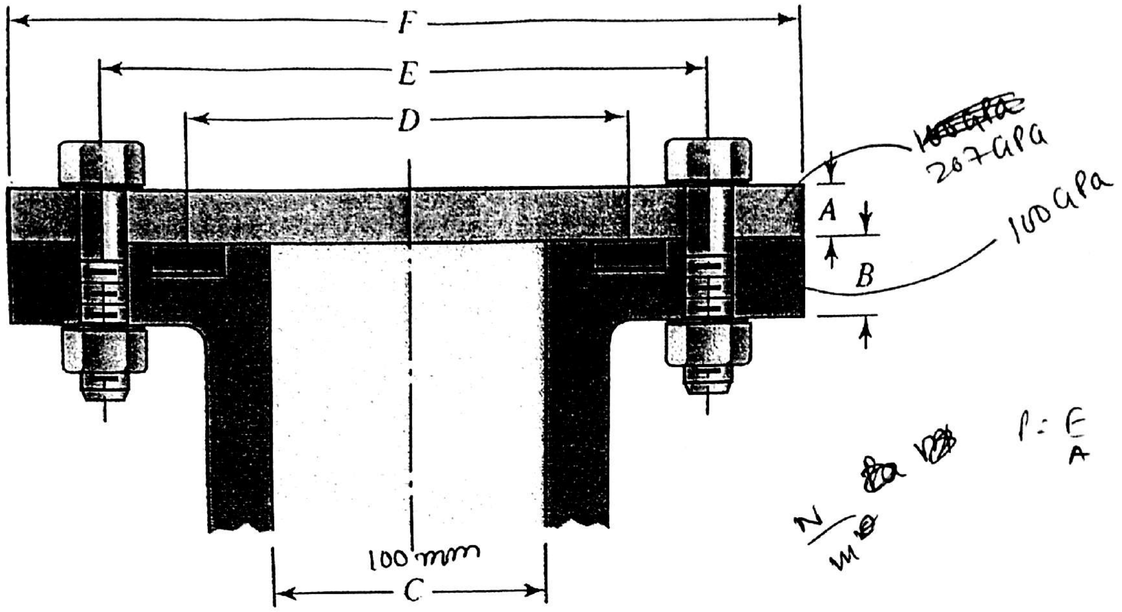
Q 8) Figure 3 shows bolted connection between a steel (E = 207 GPa) cylinder head and grade 40 cast iron (E = 100 GPa) cylinder. It has twelve M12 x 1.75 bolts (A_t = 84.3 mm², E = 207 GPa) of grade ISO 9.8 (minimum strength values: S_p = 650 MPa, S_{ut} = 900 MPa, S_y = 720 MPa, S_e = 140 MPa), and a sealing gasket that is NOT a part of the members that carry the external load. The bolts are to be reused. The relevant dimensions are: A = 20 mm, B = 20 mm, C = 100 mm, D = 150 mm, E = 250 mm, F = 350 mm. Consider the half-apex angle of the pressure-cone to be 30 degrees. Length of the bolt is 60 mm. Height/thickness of the nut is 12 mm. Length of unthreaded portion of the bot is 20 mm, and length of the threaded portion is 40 mm. Pretension in the bolt is taken as $F_i = 0.75\,F_p$

Determine the fatigue factor of safety for infinite life (using modified-Goodman criterion) and factor of safety against yielding if the cylinder is subject to a fluctuating pressure between 25 MPa and 10 MPa.

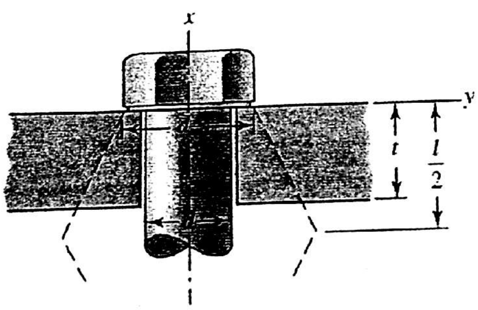


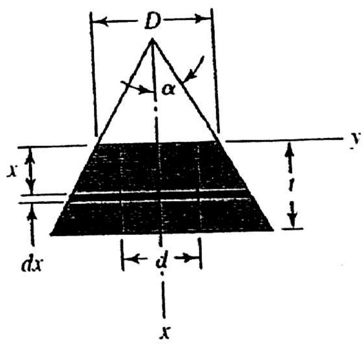
$P = \frac{F}{A}$

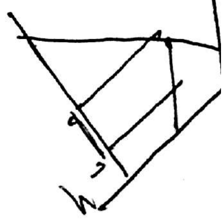
N/m^2

Figure 3: Bolted connection between steel cylinder head and Grade 40 cast iron cylinder. Geometric parameters are A = 20 mm, B = 20 mm, C = 100 mm, D = 150 mm, E = 250 mm, F = 350 mm.

Useful Formulae For Fasteners:







Member stiffness (for one conical segment of thickness t):

$$k = \frac{P}{\delta} = \frac{\pi E d \tan\alpha}{\ln \dfrac{(2t\tan\alpha + D - d)(D + d)}{(2t\tan\alpha + D + d)(D - d)}}$$

Take $D = d_w = 1.5d$

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Q 9) Consider the double-reduction spur-gear train shown in Figure 4. The free body diagrams of the shafts are also shown in the figure (right). The shaft AB is rotating at 1200 rpm (rev per min). A gear train system with 10 kh life and ensemble reliability of 0.99 is desired. The Weibull parameters for the bearings are $x_0 = 0.02$, $\theta - x_0 = 4.439, b = 1.483$. The load application factor is 1.2. For shaft AB, specify a matched pair of 02-series cylindrical roller bearings from Table 1. Loads in Figure 4 are specified in lbf. Convert using 1 lbf = 4.45 N. Note that if each of the six bearings in the gear train have same reliability R_D, then $R_D = 0.99^{1/6}$. Note that dimension less life measure

$$x = \frac{L}{L_{10}} = x_0 + (\theta - x_0)\left(ln\frac{1}{R}\right)^{1/b}$$

and load-life function at constant reliability is given by $FL^{1/a}$ = constant, with a = 10/3 for roller bearings.

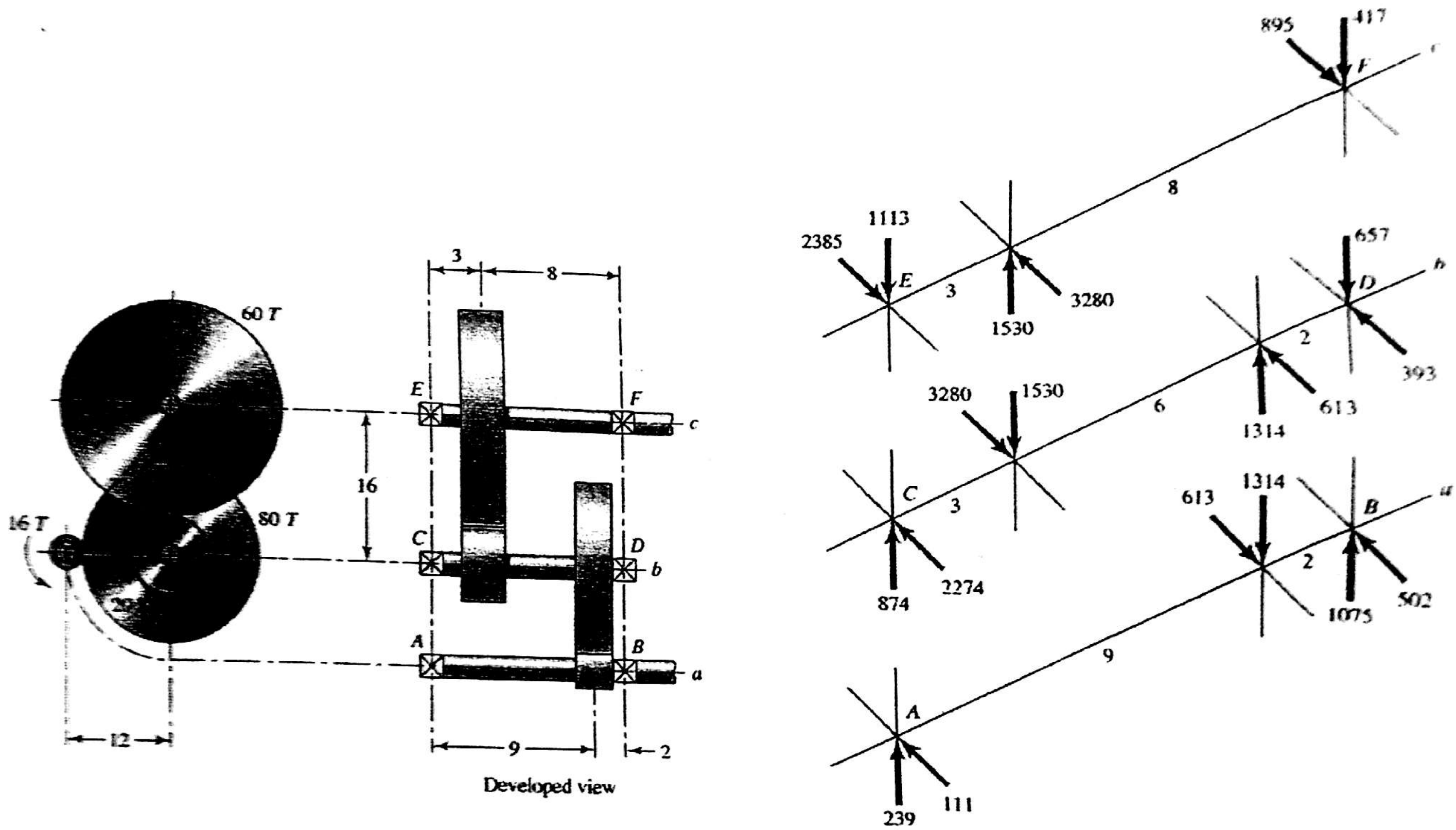

Figure 4: A spur gear train.

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		[illegible] Series		
Bore, mm	OD, mm	Width, mm	Load Rating, [illegible] C_{10}	C_0
25	52	15	16.8	8.8
30	62	16	22.4	12.0
35	72	17	31.9	17.6
40	80	18	41.8	24.0
45	85	19	44.0	25.5
50	90	20	45.7	27.5
55	100	21	56.1	34.0
60	110	22	64.4	43.1
65	120	23	76.5	51.2
70	125	24	79.2	51.2
75	130	25	93.1	63.2
80	140	26	106	69.4
85	150	28	119	78.3
90	160	30	142	100
95	170	32	165	112
100	180	34	183	125
110	200	38	229	167
120	215	40	260	183
130	230	40	270	193
140	250	42	319	240
150	270	45	446	260

Table 1: Dimensions and load ratings for cylindrical roller bearings.

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