German University in Cairo
Faculty of Engineering and Material Science.
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Bar Code

Engineering Design II, EDPT 602
Spring Semester 2007 / 2008
Final Exam

Instructions: **Read Carefully Before Proceeding.**

1- Calculators of any type are allowed.
2- **For all numerical problems, use a maximum of four (4) significant figures**
3- Write your solutions in the space provided.
4- **The exam consists of (6) Questions.**
5- This exam booklet contains (28) pages including this cover page.
6- Attempt all problems within the time limits.
7- Total time allowed for this exam is **(180) *minutes***

Good Luck!

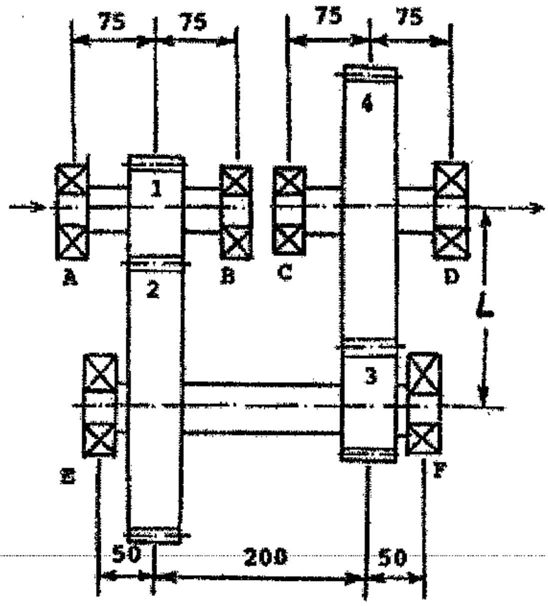
Question #	1	2	3	4	5	6	Total
Max. Score	25	15	10	20	15	15	100
Obtained Score							

Question 1: (points)

The layout of a two-stage coaxial gear reducer is shown in the figure below (the input and output shafts are coaxial), the first stage is a pair of spur gears where the number of teeth of the pinion (1) and gear (2) are 22 and 55 respectively and the module is 4 mm.

The second stage is a pair of helical gears:

a) select the normal module, the number of teeth and the helix angle for the second stage (gears 3, 4) such that the total transmission ratio of the gear box is 7.5
   The available standard modules are 3, 3.5, 4, 4.5 and 5 mm.
   The normal pressure angle is 20° and the helix angle is required to be between 20° and 30°.
b) If the input power to this reducer is 10 kW at 1500 rpm, what would be the maximum output torque from this gear box.



Question 1: $\boxed{25}$

a) $i_T = i_1 \times i_2$, $i_1 = \dfrac{N_2}{N_1} = \dfrac{55}{22} = 2.5$

$\therefore 7.5 = 2.5 \times i_2$

$\therefore i_2 = \dfrac{7.5}{2.5} = 3$ ——— 5

Choose $N_3 = 17$ tooth.

$\because i_2 = 3 = \dfrac{N_4}{N_3} = \dfrac{N_4}{17}$ ——— 5

$\therefore N_4 = 3 \times 17 = 51$ tooth.

$L = \dfrac{m}{2}(N_1 + N_2) = \dfrac{4}{2}(22 + 55) = 154$ mm 2

examples of other Answers

3 (m)	3.5	4	3
23 (N_p)	20	18	24
69 (N_g)	60	54	72
26.35° (ψ)	24.62°	20.76°	20.76°

$L = \dfrac{m_n}{2\cos\psi}(N_3 + N_4)$

$154 = \dfrac{4}{2}(17 + 51)\dfrac{1}{\cos\psi}$

$\therefore \psi = 27.979°$ $(20° < 27.979° < 30°)$

5 ✓

b) $i_T = \dfrac{n_i}{n_o}$

$\therefore 7.5 = \dfrac{1500}{n_o}$

$\therefore n_o = 200$ r.p.m ——— 3

$T_o = \dfrac{H}{\omega_o} = \dfrac{10 \times 10^3}{\left(\dfrac{2\pi * 200}{60}\right)}$

$= 477.465$ N·m ——— 5

Question 2: (points)

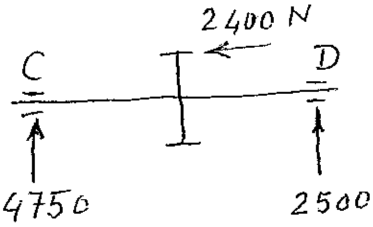
For a gear box similar to that shown in the first question, the axial force on gear (4) is found to be 2400 N directed towards bearing C. Select suitable taper roller bearings to be mounted at C & D if the radial forces at C and D are 4750 N and 2500 N respectively. The two bearings are identical and are mounted face to face (according to the attached SKF table), the gear is rigidly fixed to the shaft which has journal diameters (at the bearings) of about (25 – 30) mm.
The designed service live of the bearings is 12 kh at an average shaft speed of 150 rpm and an application factor of 1.2

Problem 2 : $\boxed{15}$

The bearings are identical

Face to Face. (case 2 from SKF table)

Let $Y_C = Y_D = 1.5$



$$\frac{F_{rC}}{Y_C} > \frac{F_{rD}}{Y_D}$$

$$0.5\left(\frac{4750}{1.5} - \frac{2500}{1.5}\right) = 750$$

$\therefore K_a = 2400 > 750$

$\therefore$ Case 2b will be applied. ——— ②

$$F_{aD} = \frac{0.5 F_{rD}}{Y_D} = \frac{0.5 \times 2500}{1.5} = 833.33 \text{ N}$$ ——— ②

$$F_{aC} = K_a + F_{aD} = 2400 + 833.33 = 3233.33 \text{ N}$$ ——— ②

$$P_C = 0.4 F_{rC} + Y_C F_{aC} = 0.4 \times 4750 + 1.5 \times 3233.33 = 6750 \text{ N}$$ ②

$$C = k_A P\left(\frac{L_D}{L_R} \cdot \frac{n_D}{n_R}\right)^{1/a} = 1.2 \times 6750 \left(\frac{12 \times 10^3}{500} \cdot \frac{150}{\left(\frac{100}{3}\right)}\right)^{3/10} =$$

$$C = 4.889 P = 32999.86 \text{ N}$$ ——— ②

From the tables choose bearing 32205 B $(25 \times 52 \times 19.25)$ ②

with $C = 35800$ N , $C_o = 44000$ N , $Y = 1.05$, $e = 0.57$

$$\therefore \frac{F_{rC}}{Y_C} > \frac{F_{rD}}{Y_D}, \quad K_a > 0.5\left(\frac{F_{rC}}{Y_C} - \frac{F_{rD}}{Y_D}\right), \quad Y_C = Y_D$$ Case 2b

$$\because F_{aC} = K_a + \frac{0.5 F_{rD}}{Y_D} = 2400 + \frac{0.5 \times 2500}{1.05} = 3590.47 \text{ N.}$$

$$\frac{F_{aC}}{F_{rC}} = \frac{3950.47}{4750} = 0.756 > e$$

$$\therefore P_C = 0.4 \times 4750 + 1.05 \times 3590.47 = 5669.99 \text{ N}$$ ①

$$C = 4.889 \times 5669.99 = 27720.59 \text{ N}$$ ——— ②

< 35800

$\therefore$ the bearing is suitable

(also bearings (30305 , 31305 ; 33205)

C = 44600 N   C = 38000 N   C = 47000 N

(32006)

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Question 3: (points)

A sliding bearing of 42 mm diameter and 42 mm length supports a radial load of 3.6 kN and has a journal speed of 3000 rpm. SAE 30 oil is introduced to the bearing and working at an average temperature of 70 °C. For a radial clearance of 0.025 mm the power loss due to friction in this bearing.

Question 3 : $\boxed{10}$

For the SAE 30 oil at 70°C working temp;

$\mu = 18$ mPa.s ——— 1

$N = \frac{3000}{60} = 50$ rev./s ——— 1

$p = \frac{W}{l.d} = \frac{3.6 \times 10^3}{42 \times 42} = 2.041$ MPa ——— 1

$S = (\frac{r}{c})^2 \frac{\mu N}{p} = \left(\frac{42}{2 \times 0.025}\right)^2 \frac{18 \times 50}{10^3 \times 2.041 \times 10^6}$

$S = 0.311$ ——— 2

from Figure :

$(\frac{r}{c}) f = 6.2$ ——— 1

$(\frac{42}{2 \times 0.025}) f = 6.2$

$\therefore f = 0.074$ ——— 1

$T = W_f \cdot r = f.W.r$

$= 0.074 \times 3.6 \times 10^3 \times \frac{42}{2} \cdot \frac{1}{10^3}$

$= 0.5594$ N.m ——— 1

$H = T.\omega = 2\pi N * T$

$= 2\pi \times 50 \times 0.5594$

$= 175.74$ W ——— 2

Question 4: (points)

A straight-tooth bevel pinion (mounted outboard), has 20 teeth and a 3 mm module drives a 60 teeth gear (mounted inboard) ($K_H = 1.1$ for both pinion and gear), at a shaft angle of 90°. Both gears are formed by hobbing ($Q_v = 5$) and are made of grade 1 steel hardened to 280 HB. The face width is 32 mm and the pressure angle is 20°. The pinion is driven by a 3.5 kW motor at 900 rpm. Based on 90% reliability, general industrial use, uniform driving machinery and moderate shocks in driven machinery ($K_o = 1.5$) determine the factors of safety guarding against bending and surface fatigue of these gears. (take Y_N and Z_N equal to 0.95 and $C_{xc} = 1.5$, $K_s = 1$ and $C_p = 191\ (MPa)^{0.5}$)

Assume the value of unity to all factors which are not given (review the data sheet first)

Problem 4: $\boxed{20}$

$$W_t = \frac{H}{v}$$

$$v = \omega . r = \frac{2\pi n}{60} \times \frac{mN}{2} = \frac{2\pi \times 900}{60} \times \frac{3 \times 20}{2} \frac{1}{10^3} = 2.827 \text{ m/s} \quad 2$$

$$\therefore W_t = \frac{3.5 \times 10^3}{2.827} = 1238.06 \text{ N} \quad 3$$

$$\sigma_b = \frac{W_t}{b.m.J} \cdot K_v \cdot K_o \cdot K_S \cdot K_H$$

$$J_p = 0.25 \; 1, \quad J_g = 0.202 \; 1$$

$$\sigma_{b_p} = \frac{1238.06}{32 \times 3 \times 0.25} \times 1 \times 1.5 \times 1 \times 1.1 = 85.117 \text{ MPa} \quad 2$$

$$\sigma_{b_g} = \frac{1238.06}{32 \times 3 \times 0.202} \times 1 \times 1.5 \times 1 \times 1.1 = 105.34 \text{ MPa} \quad 2$$

$$\sigma'_{FP} = 0.3\,HB + 14.48 \text{ MPa} = 0.3 \times 280 + 14.48 = 98.48 \text{ MPa.} \quad 1$$

$$\sigma_{FP} = \sigma'_{FP} \cdot \frac{Y_N}{Y_\theta Y_Z} = 98.48 \frac{0.95}{1 \times 0.85} = 110.06 \text{ MPa.} \quad 1$$

$$n_p = \frac{\sigma_{FP}}{\sigma_{bp}} = \frac{110.06}{85.117} = 1.293 \quad 1$$

$$n_g = \frac{110.06}{105.34} = 1.045 \quad 1$$

$$\sigma_c = C_p \sqrt{\frac{W_t}{b.\,d_p\,I} \cdot K_v \cdot K_o \cdot K_S \cdot K_H \cdot C_{xc}}$$

$$= 191 \sqrt{\frac{1238.06}{32 \times (3 \times 20) \times 0.0825} \times 1 \times 1.5 \times 1 \times 1.1 \times 1.5} = 840.07 \text{ MPa} \quad 2$$

$$\sigma'_{HP} = 2.35\,HB + 162.89 \text{ MPa} \quad 1$$

$$\sigma'_{HP} = 2.35 \times 280 + 162.89 = 820.89 \text{ MPa}$$

$$\sigma_{HP} = \sigma'_{HP} \frac{Z_N C_H}{Y_\theta Y_Z} = 820.89 \frac{0.95 \times 1}{1 \times 0.85} = 917.46 \text{ MPa} \quad 1$$

$$\therefore n_c = \left(\frac{\sigma_{HP}}{\sigma_c}\right)^2 = \left(\frac{917.46}{820.89}\right)^2 = (1.117)^2 = 1.25 \quad 1$$

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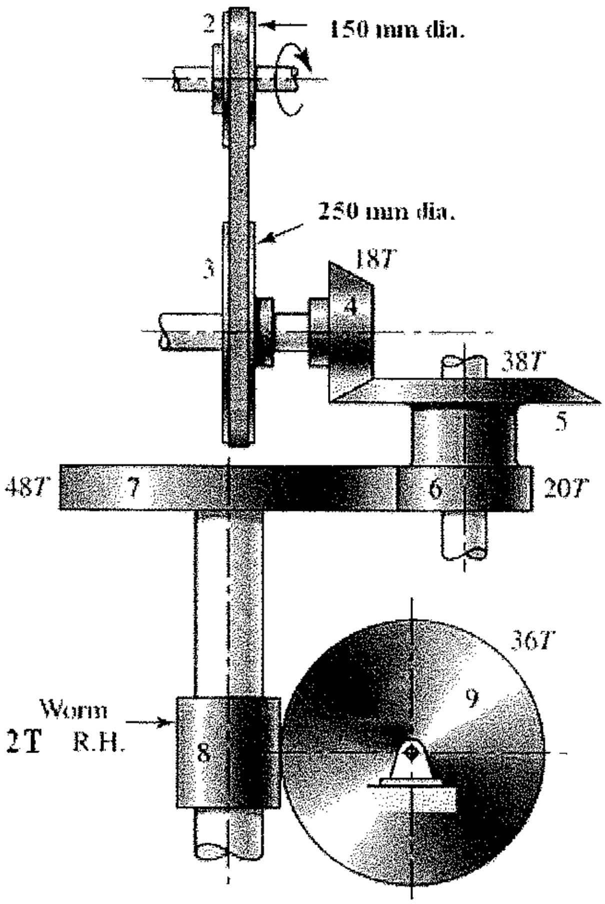
Question 5: (points)

The mechanism train shown consists of two belt-pulleys and three sets of gears. Pulley (2) rotates at 3000 rpm in the direction shown. Determine the speed (rpm) and the direction of rotation (CW or CCW) of worm wheel (gear) (9).

The 2- tooth case-hardened worm (8) of forged steel is to drive a 36-tooth sand-cast bronze gear (9), the worm has an axial pitch of 7.5mm, a 14.5° normal pressure angle, a pitch diameter of 30 mm and its right-hand helix teeth are ground and polished. If the gear has 18 mm effective face width and the coefficient of friction between the worm and wheel teeth is 0.04



Determine:

a- The speed (rpm) and the direction of rotation (CW or CCW) of the worm wheel (9)

b- the maximum power that could be transmitted through this worm gearing set.

c- the efficiency of the worm-gear set.

Question 5: $\boxed{15}$

a) $i_T = i_1 \cdot i_2 \cdot i_3 \cdot i_4$

$$i_1 = \frac{D_2}{D_1} = \frac{250}{150} = \frac{5}{3} = 1.667$$

$$i_2 = \frac{38}{18} = 2.111$$

$$i_3 = \frac{48}{20} = 2.4$$

$$i_4 = \frac{36}{2} = 18$$

$$\therefore i_T = 152$$

$$i_T = \frac{n_2}{n_g} \Rightarrow 152 = \frac{3000}{n_g}$$

$$\therefore n_g = 19.737 \text{ rpm}, \ (CW)$$

2 1

b) $p_{x_{worm}} = p_{t_{gear}}$

$$\therefore p_t = 7.5 \text{ mm}$$

$$l = N_w \cdot p_x = 2 \times 7.5 = 15 \text{ mm (the lead)}$$

$$\tan \lambda = \frac{l}{\pi d_w} = \frac{15}{80\pi} = 0.1591$$

$$\therefore \lambda = 9.043^\circ \quad 2$$

$$V_W = \frac{2\pi n_W}{60} \times \frac{d_W}{2} = \frac{2\pi (18 n_g)}{60} \times \frac{30}{2}$$

$$= \frac{2\pi \times 18 \times 19.737}{60} \times \frac{30}{2} = 558.05 \text{ mm/s}$$

$$= 0.558 \text{ m/s} \quad 1$$

$$V_s = \frac{V_W}{\cos\lambda} = \frac{0.558}{0.9876} = 0.565 \text{ m/s} \quad 1$$

$$d_g = \frac{P_t \cdot N_g}{\pi} = \frac{7.5 \times 36}{\pi} = 85.94 \text{ mm} \quad (1)$$

From tables:

$K_v = 0.5822$, $K_m = 0.8145$, $K_s = 700$

The loading capacity:

$$W_{g_t} = \beta K_s (d_g)^{0.8} \cdot F_e \cdot K_m \cdot K_v$$

$$= 0.0131 \times 700 \times (85.94)^{0.8} \times 18 \times 0.8145 \times 0.5822$$

$$= 2760.33 \text{ N} \quad (2)$$

$$W_f = \frac{\mu W_{gt}}{\mu \sin\lambda - \cos\phi_n \cos\lambda} = \frac{0.04 \times 2760.33}{0.04 \times 0.1572 - 0.9681 \times 0.9876}$$

$$= -116.25 \text{ N} \quad (1)$$

The max. power that could be transmitted:

$$H = H_o + H_l$$

$$= V_{gt} * W_{gt} + V_s * W_f$$

$$V_{g_t} = \frac{2\pi n_g}{60} \times \frac{d_g}{2} = \frac{2\pi \times 19.737}{60} \cdot \frac{85.94}{2 \times 10^3} = 0.0888 \text{ m/s}$$

$$\therefore H = 0.0888 \times 2760.33 + 0.565 \times 116.25$$

$$= 310.83 \text{ W} \quad (2)$$

The efficiency:

$$\eta = \frac{H_o}{H_o + H_l} = \frac{245.12}{310.83} = 0.788$$

(2)

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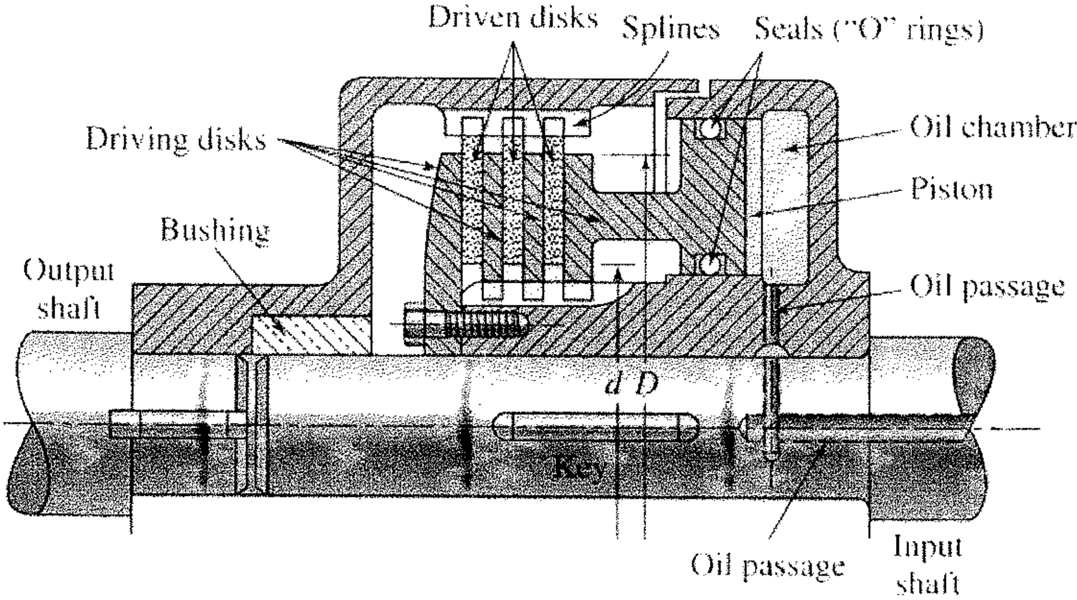
Question 6: (points)

The multi-disk friction clutch shown below is operated hydraulically, the axial piston motion and force come from oil in an annular chamber, which is connected by oil passages to an external source of pressure. Three driving disks of "friction material" are externally splined to the housing that is keyed to the driving (left) shaft. Two steel disks and the piston are internally splined to the housing keyed to the driven (right) shaft, and an end plate is fastened.

Based on both the uniform wear and uniform pressure theories determine the maximum torque that this clutch could transmit if the coefficient of friction between plates is 0.25, the outer diameter D and inner diameter d of the friction plates are 160 mm and 80 mm respectively and the maximum allowable pressure of friction plates is 1.25 MPa.

To increase the transmitting capacity of this clutch, we have several alternatives Write down only three of them.



Question # 6: $\boxed{15}$

a) Uniform Wear:

$$F = \frac{\pi P_{max} d}{2} (D - d)$$

$$T = m \frac{fF}{4} (D + d)$$

$$\therefore F = \frac{\pi (1.25) 80}{2} (160 - 80) = 12566.37 \text{ N}$$ 3

$$T = 6 \times \frac{0.25 \times 12566.37}{4 \cdot (10^3)} (160 + 80)$$

$$= 1130.97 \text{ N.m}$$ 3

b) Uniform Pressure:

$$F = \frac{\pi P}{4} (D^2 - d^2)$$

$$T = m \frac{fF}{3} \frac{(D^3 - d^3)}{(D^2 - d^2)}$$

3

$$F = \frac{\pi (1.25)}{4} ((160)^2 - (80)^2) = 18849.55 \text{ N}$$

$$T = 6 \times \frac{0.25 \times 18849.55}{3 \times 10^3} \frac{((160)^3 - (80)^3)}{((160)^2 - (80)^2)}$$

$$= 1759.29 \text{ N.m}$$ 3

c) i) $D \uparrow$ $d \downarrow$

ii) $\mu \uparrow$

iii) $m \uparrow$

3

iv) $P_{max} \uparrow$, $F \uparrow$