NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2013-2014

MA3001 – MACHINE ELEMENT DESIGN

April/May 2014 Time Allowed: 2½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **FOUR (4)** pages.
2. Answer **ALL** questions.
3. Marks for each question are as indicated.
4. This is an **OPEN-BOOK** Examination.

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1. The column-bracket connection subjected to eccentric shear is shown in Figure 1. Note that the eccentric vertical load P can be replaced with the same load acting at the centroid plus the couple, $M = Pe$, where e is the eccentricity.

(a) Find the centroid (x, y) of the fastener group given the positions of the eight identical fasteners depicted in Figure 1.

(5 marks)

(b) Find the magnitude of the resultant force experienced by Fastener 8 (located at the lowest right corner shown in Figure 1), if $P = 40$ kN.

(15 marks)

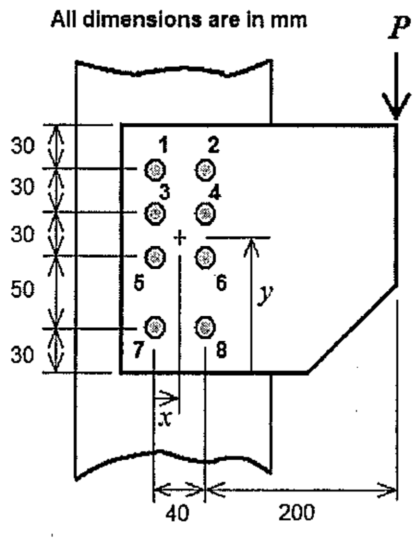

Figure 1

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2. As shown in Figure 2(a), the pulley drive of a uniform shaft is transmitting power to a pinion, which in turn is transmitting power to another machine element. Pulley and pinion diameters are 400 mm and 200 mm, respectively. The angular orientation of the belts, the tangential and radial forces acting on the pinion are shown in Figure 2(b). The shaft is made of plain carbon steel ($s_y = 352$ N/mm^2 and $s_u = 476$ N/mm^2).

(a) Find the magnitude of belt forces F_1 and F_2, if the tension ratio of the belts is 4.

(5 marks)

(b) Sketch the loading and moment diagrams of the shaft with the key values indicated.

(17 marks)

(c) Determine the minimum diameter of the shaft by using the basic shaft design equation on the basis of maximum shear stress theory. Use a design factor of 3 and neglect the correction factor of stress concentration.

(8 marks)

Hint:

$$D^3 = \frac{32N}{\pi s_y}\left(\sqrt{M^2 + T^2}\right)$$

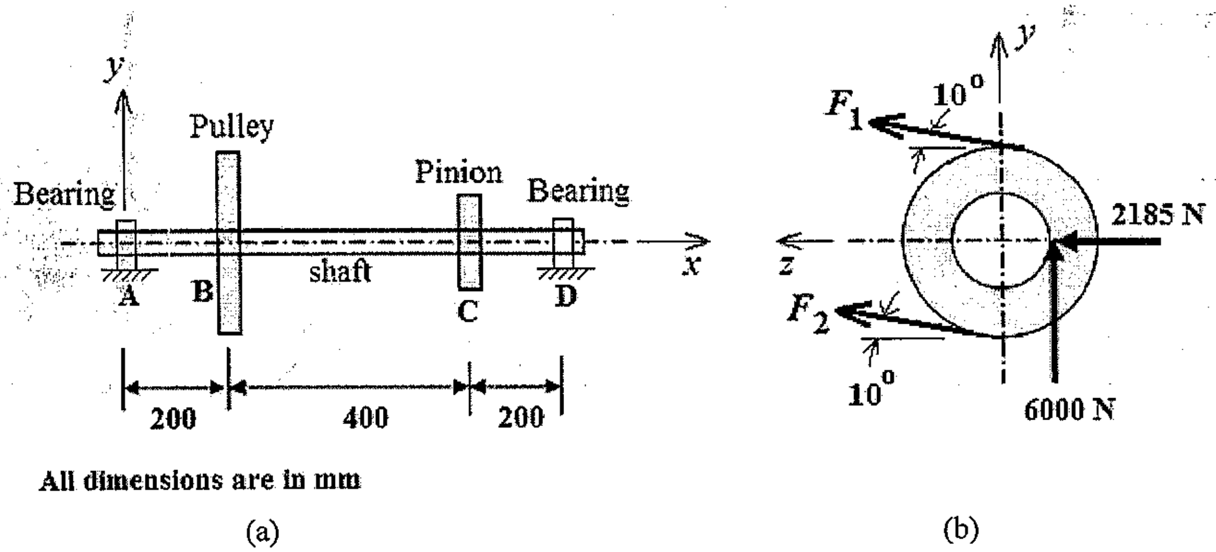

Figure 2

3. An engine transmitting 20 kW at 1200 rpm has its speed reduced in two steps as shown in Figure 3. First it is reduced by approximately 1.5:1 in a V-belt drive; next, a chain reduces the speed further. The driven sprocket is connected to a blower which runs at 355 ± 5% rpm. It is desirable to use an available V-belt pulley of 180 mm diameter as the driving pulley. The centre distance between the V-belt pulleys is approximately 600 mm. Triple-strand No. 50 roller chain is used for the chain drive.

For the belt, you may assume a service factor of 1.1 and a combined correction factor of 0.92 for angle of wrap and length. For the chain, the service factor can be assumed to be 1.1.

(a) Show that the V-belt drive requires FOUR (4) belts of SPA belt cross section and hence determine the required pitch length of the belts.

(12 marks)

(b) Determine the numbers of teeth on the driving and driven sprockets in the chain drive. Hence, determine the pitch length of the chain if the centre distance between sprockets is limited to 700 mm.

(12 marks)

(c) Based on the numbers of teeth found in (b), show by analysis that the chain has been designed adequately for its tensile load.

(6 marks)

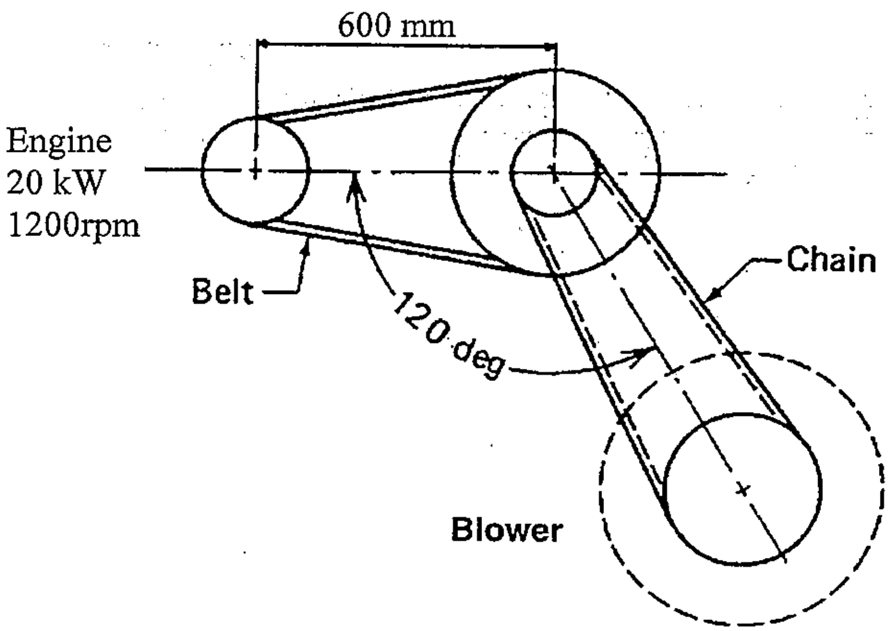

Figure 3

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4. Figure 4 shows a V-belt driving a gear train consisting of spur gears and wormgear sets for the power-feed drive of a production drill press. A spring (not shown) returns the quill rack to its uppermost position each time the clutch is disengaged. The numbers of the teeth are chosen for the change gears 6 and 7 to give the feed of the drill required by the given combination of drill size and material being drilled. Note that the module for gears 6 and 7 is 2 mm while that for pinion 12 is 3.5 mm. All spur gears have a pressure angle of 20°.

If it is assumed that a feed of approximately 2.68 mm/s of the drill is required and that the drill must rotate at 900 rpm in the direction indicated,

(a) What numbers of teeth should be specified for gears 6 and 7?

(10 marks)

(b) What should be the hand of the worm 4? Sketch the directions of rotation of all the gears.

(4 marks)

(c) The gear train requires a power of P (watts) for its operation. Sketch and show the gear forces on the pinion 12 and quill rack. Gear forces can be expressed in terms of the power, P.

(6 marks)

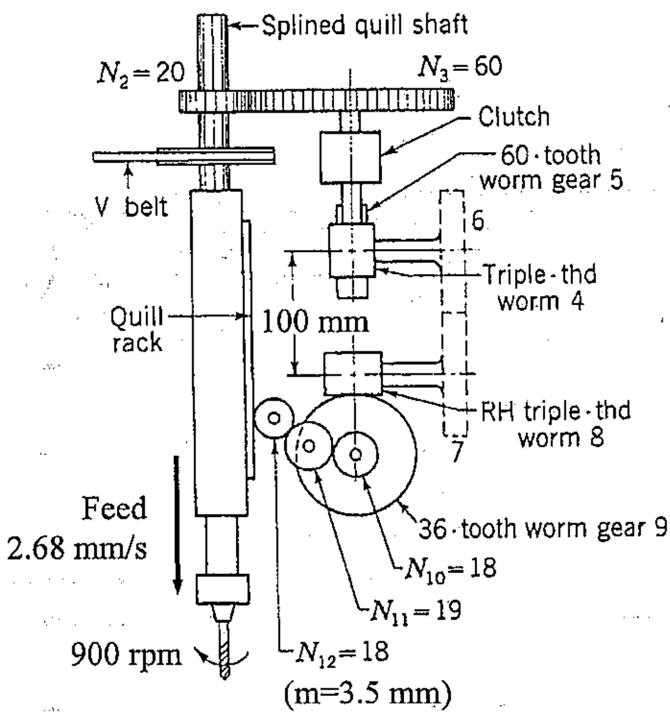

Figure 4

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MA 3001

1 a) y-coordinate of the centroid $= \frac{30 + 80 + 110 + 140}{4}$

$= 90$

∴ centroid of the fastener group = (20, 90)

b) shear force due to P $= \frac{40}{8}$

$= 5$ kN #

$M = Pe$

$= 40000 \times 0.2$

$= 8000$ Nm #

$r = \sqrt{20^2 + 60^2}$

$= 20\sqrt{10}$ mm

$r_{1,2}^2 = 20^2 + 50^2 = 2900$ mm²

$r_{3,4}^2 = 20^2 + 20^2 = 800$ mm²

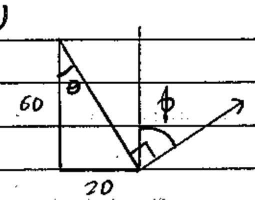
$r_{5,6}^2 = 20^2 + 10^2 = 500$ mm²

$r_{7,8}^2 = 4000$

Secondary force due to moment $= \frac{8000 \times 10^3 \times 20\sqrt{10}}{2(2900) + 2(800) + 2(500) + 2(4000)}$

$= 30851.5$ N #

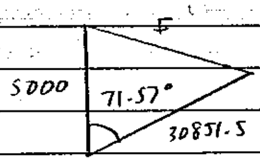
b)



$\tan\theta = \frac{20}{60}$ $\qquad \theta = 18.43°$

$\phi = 90 - 18.43$

$= 71.57°$



$F^2 = 5000^2 + 30851.5^2 - 2(5000)(30851.5)\cos 71.57°$

Resultant force, $F = 29652.6\,N$ #

2a) Taking the balance of moment

$(F_1 \cos 10)\,0.4 + 6000 \times 0.2 - (F_2 \cos 10)(0.4) = 0$ —(1)

$F_2 > F_1$ (the pulley is the driven pulley)

$F_2 = 4F_1$

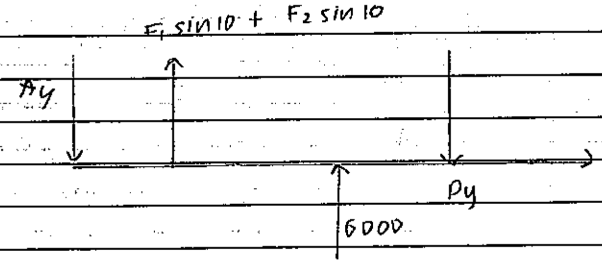
$0.4\cos 10\, F_2 - 0.4\cos 10(0.25F_2) = 6000 \times 0.2$

$0.2954\, F_2 = 1200$

$F_2 = 4062.29\,N$ #

$F_1 = 1015.57\,N$ #

b)



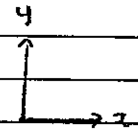
Taking moment about A,

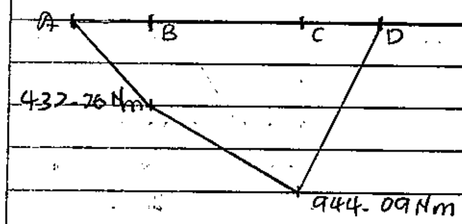
$(1015.57 + 4062.29)\sin 10 \times 0.2 + 6000(0.6) = D_y(0.8)$

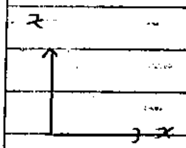
$D_y = 4720.44\,N$ #

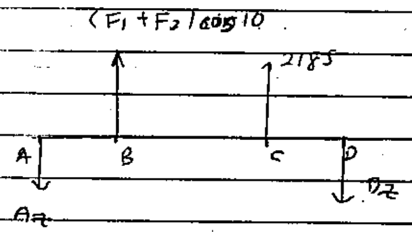
$(1015.57 + 4062.29)\sin 10 + 6000 = 4720.44 + A_y$

$A_y = 2161.32\,N$ #









Taking moment about A,

$(4062.29 + 1015.57)\cos 10 \times 0.2 + 2185 \times 0.6 = D_z \times 0.8$

$D_z = 2888.93\,N$ #

$A_z + 2888.93 = (4062.29 + 1015.57)\cos 10 + 2185$

$A_z = 4296.79\,N$ #

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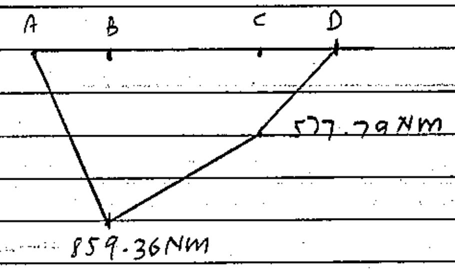


c) $M_{max} = \sqrt{577.79^2 + 944.09^2}$

$= 1106.86 Nm$ #

$T = 6000 \times 0.2$

$= 1200 Nm$ #

$D^3 = \frac{32 \times 3}{\pi \times 352 \times 10^6} \sqrt{1106.86^2 + 1200^2}$

$D = 0.0521 m$

$= 52.1 mm$ #

3.a) Design power $= 20 \times 1.1$

$= 22 kW$

From table A3, SPA belt is required.

$\frac{w_1}{w_2} = \frac{D_1}{D_2} = \frac{3}{2}$

$D_1 = 180 mm$ # (given)

$D_2 = 120mm$

$\therefore D_2 = 118 mm$ (from table A-4) #

$\frac{1200}{w_2} = \frac{180}{118}$ $w_2 = 786.67 rpm$

~~no. of belts need~~

speed ratio $= \frac{180}{118}$

$= 1.525$

Table A-7b, rated power $= 7.41$ kW

$\therefore$ no. of belts needed $= \frac{22}{7.41 \times 0.92}$

$= 3.23$

$\therefore$ 4 belts are needed.

$TBL = 2 \times 0.6 + \frac{\pi}{2}(0.18 + 0.118) + \frac{(0.18 - 0.118)^2}{4 \times 0.6}$

$= 1.6697$ m

$\therefore$ required pitch length $= 1700$ mm #

b) For the chain drive, $\omega_1 = 786.67$ rpm

design power $= \frac{20 \times 1.1}{2.5}$

$= 8.8$ kW #

Table B-4 : $N_1 = 16$ #

$\frac{786.67}{355} = \frac{N_2}{16}$

$N_2 = 35.5$

≈ 36 #

$\frac{786.67}{\omega_2} = \frac{36}{16}$ $\omega_2 = 349.63$ rpm (within the range) #

$\therefore N_1 = 16$ $N_2 = 36$

pitch = 15.875 mm

$TCD = \frac{700}{15.875}$

$= 44.094$ pitches

$TCL = 2 \times 44.094 + \frac{52}{2} + \frac{20^2}{4\pi^2 \times 44.094}$

$= 114.42$ pitches

c) $D_1 = \frac{15.875}{\sin\left(\frac{180}{16}\right)}$

$= 81.373$ mm

$v = \left(\frac{0.0814}{2}\right)\left(\frac{786.67 \times 2\pi}{60}\right)$

$= 3.353$ m/s

$20000 = F \times 3.353$

$F = 5964.8N$ # $(< 650 \times 9.81)$ # Table B-1

∴ chain has been designed adequately for its tensile load.

4a) $r_{12} = \frac{mN}{2} = \frac{(3.5)(18)}{2}$

$= 31.5 \text{ mm}$

$w_{12} = \frac{2.68}{31.5} = 0.085 \text{ rad/s}$

$= \frac{0.085 \times 60}{2\pi}$

$= 0.8117 \text{ rpm}$ #

$\frac{2}{2}(N_6 + N_7) = 100$

$N_6 + N_7 = 100 \quad — (1)$

$\frac{0.8117}{900} = \left(\frac{20}{60}\right)\left(\frac{3}{60}\right)\left(\frac{N_6}{N_7}\right)\left(\frac{3}{36}\right)\left(\frac{18}{19}\right)\left(\frac{19}{18}\right)$

$\frac{N_6}{N_7} = 0.64936$

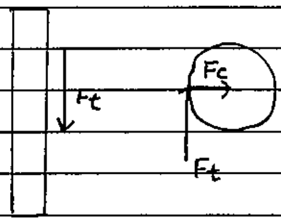
$1.64936 N_7 = 100$

$N_7 = 61$ #
$N_6 = 39$ #

b) ~~Right~~ Left hand

$P = Fv$

c)



$P = F_t(0.00268)$

$F_t = \frac{25000}{67} P$ #

$F_r = \left(\frac{25000}{67} \tan 20\right) P$ #

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2014-2015

MA3001 – MACHINE ELEMENT DESIGN

November/December 2014 Time Allowed: 2½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **FIVE (5)** pages.
2. Answer **ALL** questions.
3. Marks for each question are as indicated.
4. This is an **OPEN-BOOK** Examination.

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1. A bracket is attached to the column by a bolt group as shown in Figure 1.

(a) Which bolt will experience the maximum stress?

(2 marks)

(b) Determine the dimensions of a and b?
(Hint: assuming the centroid of bolt group, C={0, 0})

(6 marks)

(c) Find the shear force at bolt 1.

(12 marks)

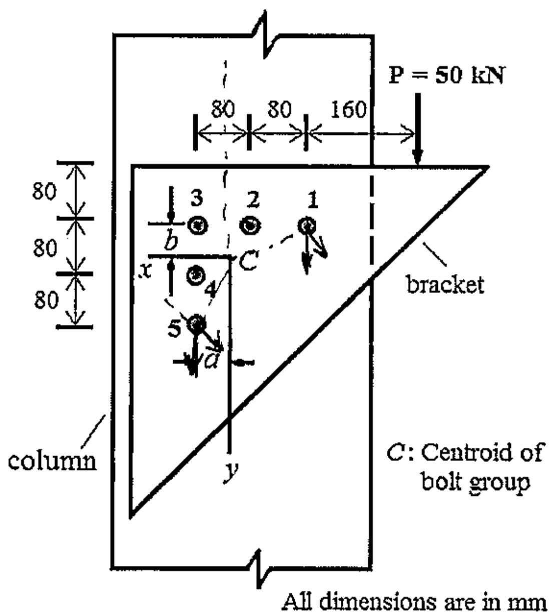

Figure 1

2. Power is transmitted from a motor through a gear E to the pulleys at D and C of a rotating solid shaft AB with machined surface, as shown in Figure 2. The shaft is mounted on bearings at the ends A and B. Figure 2 also shows the magnitude and direction of gear and belt forces and torques acting on the shaft at the respective points. Note that the shaft is made of steel with an ultimate strength of 810 MPa, a yield strength of 605 MPa, and its material endurance strength is given by the relationship $s_n = 0.37s_u$. The stress concentration factor is taken as 1.5 for points C, D, and E of the shaft.

(a) Find the force components acting on the two bearings, A and B.

(5 marks)

(b) Sketch the loading, moment, and torque diagrams of the shaft showing the key values.

(15 marks)

(c) Determine the minimum shaft diameter at the location where the torque and moment are the largest. You may assume a size factor, C_S of 0.80, a reliability of 50% and a factor of safety of 2.

(10 marks)

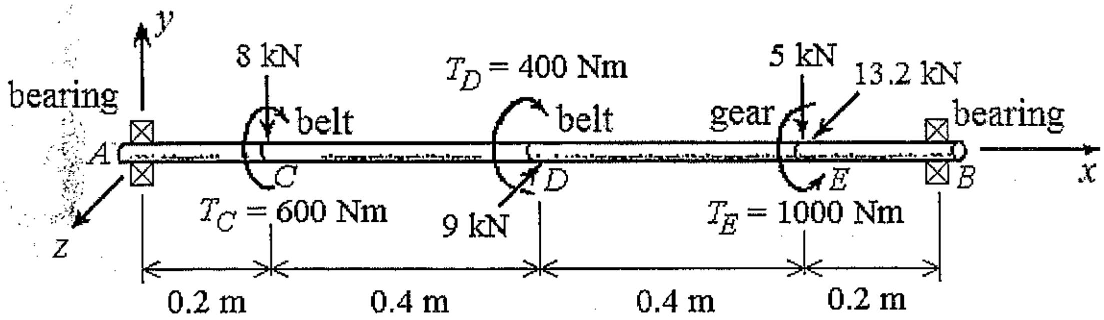

Figure 2

3. A small engine delivers 1.0 kW at 2000 rpm to a driven machine via a V-belt drive at the engine and a chain drive at the driven machine as shown in Figure 3. The driven pulley and the drive sprocket are both mounted on the same shaft. The chain drive uses three strands of No. 25 roller chain with a drive sprocket of 17 teeth and a driven sprocket of 60 teeth. The speed of the driven sprocket is kept at 360 ± 5 rpm. The diameter of the driven pulley is about the same but not exceeding the pitch diameter of the driven sprocket. The sevice factor for the V-belt drive is assumed to be 1.1.

(a) Specify a standard V-belt cross section and select standard diameters for the drive and driven pulleys.

(9 marks)

(b) Determine the number of belts using the selected V-belt section and pulleys in (a). You may use a combined correction factor of 0.92 for the angle of wrap and belt length. C_θ C_L

(5 marks)

(c) Show by analysis that the roller chain has been designed adequately for its tensile strength.

(8 marks)

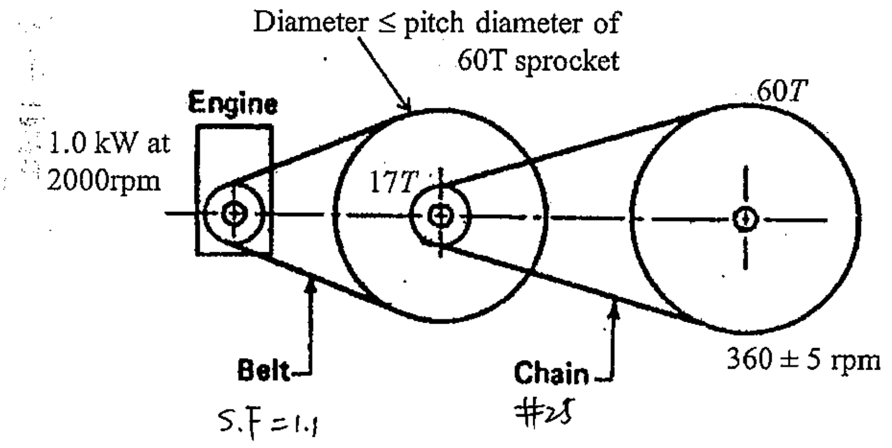

Figure 3

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4. The conventional automotive transmission consisting of helical gears in Figure 4 has three forward speeds and one reverse speed. The synchromesh clutches have been omitted in the interest of simplication. Gear 2 is connected to the engine through the clutch. Gears 3, 4, 5, and 6 are located on the countershaft, with gear 3 being in mesh with gear 2 at all times. Gear 7 is the idler gear and is in mesh with gear 6 at all times. Gears 8 and 9 are splined to the output shaft and are shifted axially into engagement by forks to engage the respective gear as follows:

<u>3 forward speeds of the car</u>

First gear: power flows through gears 2, 3, 5, and 9.

Second gear: power flows through hears 2, 3, 4, and 8.

Third gear: direct drive when internal teeth on gear 8 are moved to engage the external teeth on gear 2.

<u>Reverse speed of the car</u>

Reverse gear: power flows through 2, 3, 6, 7 and 9.

All the helical gears have a normal module of 2 mm, a normal pressure angle of 25° and a helix angle of 30°. The number of teeth on each gear and the hand of helix on the gears are as shown in the figure except for hand of the helices of gears 6 and 7 which have yet to be determined.

(a) Determine the speed ratios for first gear, second gear, third gear and reverse gear, and show their directions of rotation at the output shaft.

(8 marks)

(b) What should be the hand of the helices for gears 6 and 7?

(3 marks)

(c) At the second gear, the torque at the input shaft is 50Nm at 2200 rpm in the direction shown in the figure. Determine the magnitude and show the direction of the forces on gears 3 and 4.

(9 marks)

(d) Determine the dimension Y in view A of Figure 4.

(8 marks)

Note: Figure 4 appears on page 5.

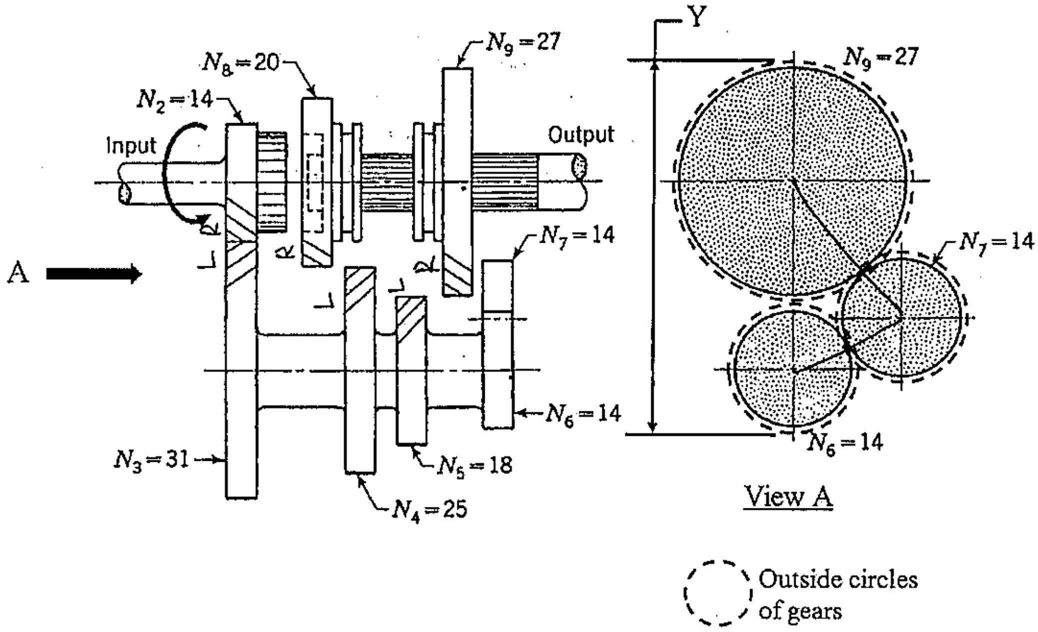

Figure 4

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Nov/Dec 2014

MA3001

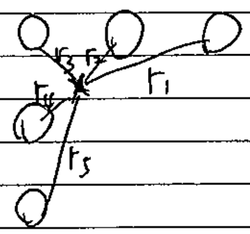
1. (a) Bolt 1 experience maximum stress.

(b) $a = \dfrac{0\times3 + 80\times1 + (80+80)\times1}{5} = 48$ mm

$b = \dfrac{0\times3 + 80\times1 + 160\times1}{5} = 48$ mm

(c) Primary force: $F = 50 \div 5 = 10$ kN

Secondary force: $M = P \cdot e = 50\text{kN} \times (320-48)\text{mm} = 13600$ Nm



$r_1 = r_5 = \sqrt{(160-48)^2 + 48^2} = 121.85$ mm

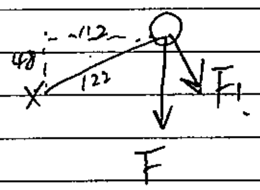
$r_2 = r_4 = \sqrt{(80-48)^2 + 48^2} = 57.69$ mm

$r_3 = \sqrt{48^2 + 48^2} = 67.88$ mm

$F_1 = \dfrac{M \cdot r_1}{r_1^2 + r_2^2 + r_3^2 + r_4^2 + r_5^2}$

$= \dfrac{13600 \times 121.85 \times 10^{-3}}{(121.85^2 \times 2 + 57.69^2 \times 2 + 67.88^2) \times 10^{-6}} = 40460$ N

Resultant Force $= \sqrt{\left(F + F_1 \times \frac{112}{122}\right)^2 + \left(F_1 \times \frac{48}{122}\right)^2}$



$= \sqrt{\left(10000 + 40460 \times \frac{112}{122}\right)^2 + \left(40460 \times \frac{48}{122}\right)^2}$

$= 49759$ N

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2. (a) y direction:

$\Sigma M_{Ay} = 0 \Rightarrow -8 \times 0.2 - 5 \times 1 + F_{By} \times 1.2 = 0 \Rightarrow F_{By} = 5.5kN\ (\uparrow)$

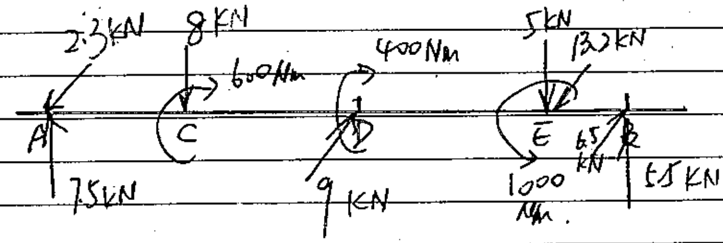
$\Sigma F_y = 0 \Rightarrow F_{Ay} - 8 - 5 + 5.5 = 0 \Rightarrow F_{Ay} = 7.5kN\ (\uparrow)$

z direction:

$\Sigma M_{Az} = 0 \Rightarrow -9 \times 0.6 + 13.2 \times 1 + F_{Bz} \times 1.2 = 0 \Rightarrow F_{Bz} = \frac{9 \times 0.6 - 13.2}{1.2} = -6.5kN$

$\Sigma F_z = 0 \Rightarrow F_{Az} - 9 + 13.2 - 6.5 = 0 \Rightarrow F_{Az} = 2.3kN$

(b)



y-axis:

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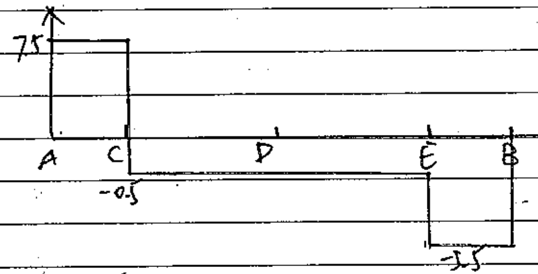
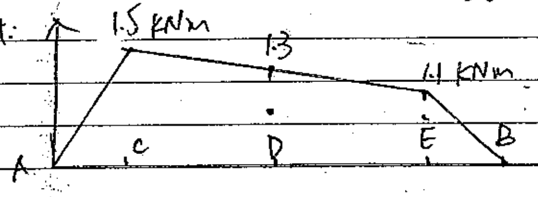


moment:



z-axis:

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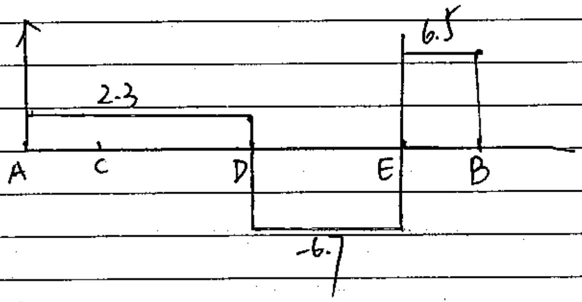

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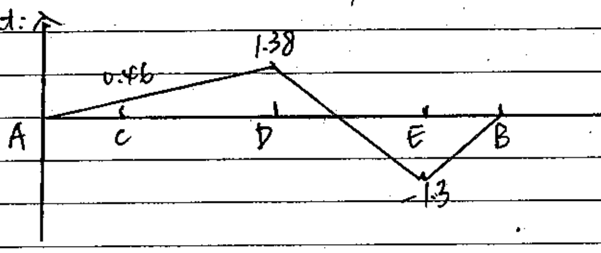

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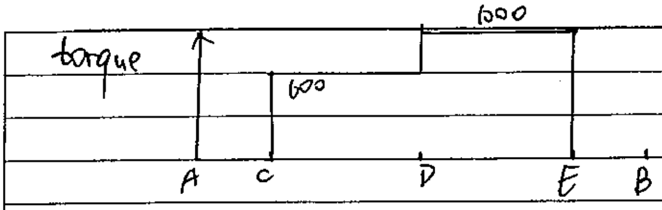


(c) C: $M_y = 1.5\,KNm$ $M_z = 0.46\,KNm$ $T_c = 600$ $M_C = 1.57\,KNm$

D: $M_y = 1.3\,KNm$ $M_z = 1.38\,KNm$, $T_D = 1000$ $M_D = 1.89\,KNm$ (V)

E: $M_y = 1.1\,KNm$ $M_z = -1.3\,KNm$, $T_E = 1000$. $M_E = 1.70\,KNm$

Given $C_s = 0.80$, reliability $= 50\%$, factor of safety $= 2 = N$.
⇓
$C_R = 1.00$

$S_n = 0.37 S_u = 810 \times 0.37 = 299.7\,MPa$

$S_y = 605\,MPa$

$K_{ft} = 1.5$

So $S_n' = S_n \cdot C_s \cdot C_R = 299.7 \times 0.8 \times 1 = 239.76\,MPa$

$$D = \left[\frac{32N}{\pi}\sqrt{\left(\frac{K_{ft}M}{S_n'}\right)^2 + \frac{3}{4}\left(\frac{T}{S_y}\right)^2}\right]^{\frac{1}{3}}$$

$$= \left[\frac{32 \times 2}{3.14}\sqrt{\left(\frac{1.5 \times 1.89}{239.76 \times 10^3}\right)^2 + \frac{3}{4} \times \left(\frac{1000}{605 \times 10^6}\right)^2}\right]^{\frac{1}{3}}$$

$= 0.0624\ m$

Refer to Figure 5-9: $D = 62.4\,mm$, $C_s = 0.79$

$S_n' = 299.7 \times 0.79 \times 1 = 236.76\,MPa$

$$D = \left[\frac{32N}{\pi}\sqrt{\left(\frac{K_{ft}M}{S_n'}\right)^2 + \frac{3}{4}\left(\frac{T}{S_y}\right)^2}\right]^{\frac{1}{3}} = 0.0626\ m = 62.6\,mm.$$

Refer to Figure 5-9: $D = 62.6\,mm$, $C_s = 0.79$ (V)

∴ Minimum shaft diameter is 62.6 mm

#3

3. (a) Design Power = 1.1 KW.
Faster shaft = 2000 rpm } refer to Table A-3 ⇒ SPZ.

#25 chain: pitch = 6.35.

$$D_1 = \frac{P}{\sin(\frac{180}{N_1})} = \frac{6.35}{\sin(\frac{180}{17})} = 34.56\,mm \qquad n_1 = \frac{N_2 n_2}{N_1} = \frac{60\times360}{17} = 1271\ rpm$$

$$D_2 = \frac{P}{\sin(\frac{180}{N_2})} = \frac{6.35}{\sin(\frac{180}{60})} = 121.33\,mm \qquad n_2 = 360 \pm 5\,rpm$$

∵ Driven pulley diameter ≤ pitch diameter of 60T sprocket

∴ Refer to Table A-4: $D_{p2} = 112.\,mm$

$$\frac{W_1}{W_2} = \frac{D_{p2}}{D_{p1}} \Rightarrow \frac{2000}{1271} = \frac{112}{D_{p1}} \Rightarrow D_{p1} = 71.176 \approx 71\ mm \text{ (Table A-4).}$$

Substitute $D_{p1} = 71\,mm$ back to check output speed $360 \pm 5\,rpm$:

$$W_2 = \frac{W_1 D_{p1}}{D_{p2}} = \frac{2000\times71}{112} = 1268 = n_1$$

$$n_2 = \frac{n_1 N_1}{N_2} = \frac{1268\times17}{60} = 359.23\ rpm \quad (\checkmark)$$

∴ $D_{p1} = 71\,mm$, $D_{p2} = 112\,mm$, SPZ.

(b) Designed Power = 1×1.1 = 1.1 KW

Rated Power ⇒ Small sheave diameter = 71 mm
RPM = 2000
speed ratio = $\frac{d_2}{d_1} = \frac{112}{71} = 1.58$ } Table A-7: RP = 1.93

$$\text{No. of Belt} = \frac{DP}{CRP} = \frac{1.1}{0.92\times1.93} = 0.6195 \leq 1 \text{ belt.}$$

∴ The number of belt is 1.

(c) $$P = T_2 W_2 = \frac{F_1 D_2 W_2}{2} \qquad 1000 = \frac{F_1 \times 121.33\times10^{-3} \times 359.23\times\frac{2\pi}{60}}{2} \Rightarrow F_1 = 438.4\,N \approx 44\,kg$$

According to Table B-1: For #25 chain, average tensile strength = 480 kg,
Maximum allowable load = 65 kg.

44 kg < 65 kg. ∴ The roller chain has been designed adequately for its tensile strength.

DISCLAIMER: *The solutions are done by students who scored A or above in this subject. The MAE Club and Campus supplies are not liable or responsible for any errors in the contents of these solutions. Students are advised to take the solutions as a guide rather than absolute answers to exam paper.*

4. (a) first gear: 2-3-5-9 (see from left)

$$(SR)_1 = \frac{N_3 \; N_9}{N_2 \; N_5} = \frac{31 \times 27}{14 \times 18} = 3.32 \quad \text{clockwise}$$

second gear: 2-3-4-8

$$(SR)_2 = \frac{N_3 \; N_8}{N_2 \; N_4} = \frac{31 \times 20}{14 \times 25} = 1.77 \quad \text{clockwise}$$

third gear: 2-8

$(SR)_3 = 1$ clockwise

reverse gear: 2-3-6-7-9

$$(SR)_4 = \frac{N_3 \; N_7 \; N_9}{N_2 \; N_6 \; N_7} = \frac{31 \times 27}{14 \times 14} = 4.27 \quad \text{counter-clockwise}$$

(b) Gear 6 = Left hand
Gear 7: Right hand

(c) $T_2 = 50\,Nm$, $W_2 = 2200$ rpm
normal module $M_n = 2$, $\phi = 25$, $\psi = 30$.
$m = m_n / \cos\psi = 2.31\,mm$ $\quad \tan\phi_t = \tan\phi_n / \cos\psi = \frac{\tan 25}{\cos 30} = 0.538$

Gear 3:

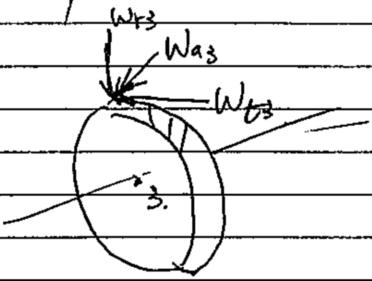
$T_2 W_2 = T_3 W_3$ $\quad T_3 = \frac{T_2 N_3}{N_2} = \frac{50 \times 31}{14} = 110.7\,Nm = T_4$

$D_3 = mN_3 = 2.31 \times 31 = 71.61\,mm$

$W_{t3} = T/(D/2) = 110.7 \div (71.61 \div 2) = 3.09\,kN$

$W_{r3} = W_{t3} \tan\phi_t = 3.09 \times 0.538 = 1.66\,kN$

$W_{a3} = W_{t3} \tan\psi = 3.09 \times \tan 30° = 1.78\,kN$

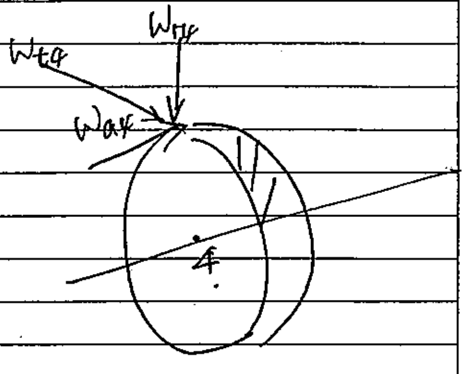


Gear 4: $D_4 = m N_4 = 2.31 \times 25 = 57.75\,mm$

$W_{t4} = \frac{T}{D/2} = \frac{110.7}{(57.75 \div 2)} = 3.83\,kN$

$W_{r4} = W_{t4} \tan\phi_t = 3.83 \times 0.538 = 2.06\,kN$

$W_{a4} = W_{t4} \tan\psi = 3.83 \times \tan 30° = 2.21\,kN$



(d) $D_9 = m N_9 = 2.31 \times 27 = 62.37$ mm

$D_6 = m N_6 = 2.31 \times 14 = 32.34$ mm

Center distance between gear 6 and gear 9 = center distance between gear 2 and 3.

$\therefore D_2 = m N_2 = 2.31 \times 14 = 32.34$ mm

$D_3 = m N_3 = 2.31 \times 31 = 71.61$ mm

$Y = D_2 + D_3 + D_9 + D_6 + 2a = 198.66 + 2 \times 2 = 202.66$ mm

$a = m_n$

= END OF ANSWER =

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2016-2017

MA3001 – MACHINE ELEMENT DESIGN

November/December 2016 Time Allowed: 2½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **FOUR (4)** pages.
2. Answer **ALL** questions.
3. Marks for each question are as indicated.
4. This is an **OPEN-BOOK** Examination.

1(a) Figure 1 shows a bracket for supporting a vertical force of 20 kN acting downwards at a distance of 100 mm from the face of the wall. The bracket is fixed to the steel column by means of four identical bolts, two at A and two at B. The bracket is held against the wall and prevented from tipping about the pivot point C. The four bolts are made of carbon steel ($s_y = 340$ N/ mm^2) and a factor of safety (N) of 3 is applied.

Determine the major diameter of the bolts. State all assumptions made in the calculations.

(16 marks)

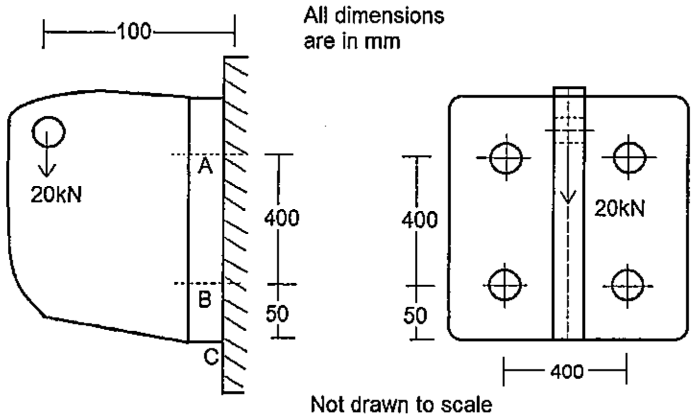


Figure 1

(b) In the design of machine frames, one possibility is to keep the length of beams as short as possible to prevent bending. State what other design considerations that can be made for designing machined parts.

(4 marks)

2. A shaft for a general-purpose gear-reduction unit supports two gears as shown in Figure 2. The 150 mm gear B receives 5 kW power at 250 rpm. The 60 mm gear A delivers the power, with the forces on the gear acting as shown; the gear teeth have a pressure angle of $\phi = 14.5°$. Both gears are keyed (profile) to the shaft of AISI 1040, cold drawn. The fillet radius is 3 mm at bearing D, which has a shaft diameter of 40 mm. The shaft diameter at A is 45 mm.

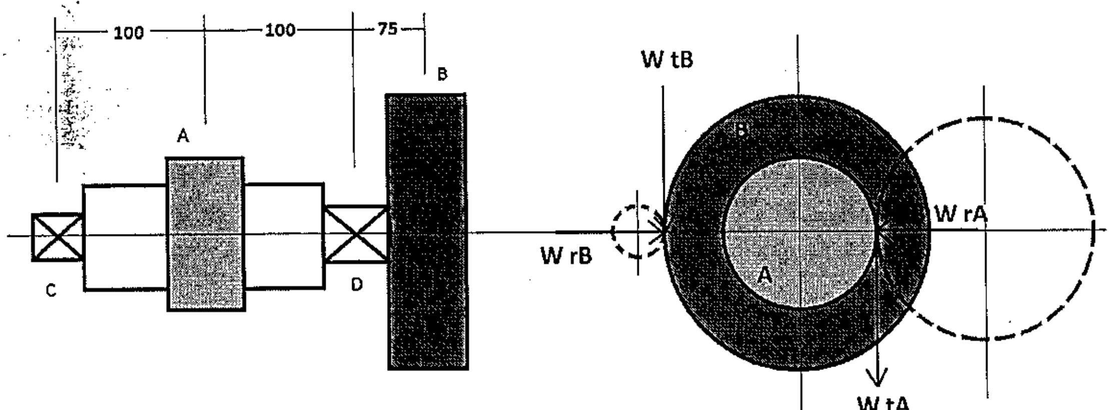
(a) Determine the forces acting on Gear A and Gear B. State all the assumptions made.
(7 marks)

(b) Sketch loading and bending moment diagrams of the shaft.
(7 marks)

(c) Determine the safety factor that the designer had chosen for his design for the shaft diameter at bearing D. State all assumptions made in your calculations. Comment on the choice of using such safety factor.
(7 marks)

(d) Select the most suitable bearing D.
(7 marks)

(e) What are the advantages and disadvantages of having shaft keys in this design?
(2 marks)



All dimensions are in mm. Not drawn to scale.

Figure 2

3. The compound gear train consists of helical gears, bevel gears, worm and wormgear, spur gear and rack as shown in Figure 3. The tooth numbers are given in the parentheses. Bevel gear 2 rotates at 240 rpm in the direction shown and transmits 3.0 kW of power. Helical gears 4 and 5 have a normal module 2.0 mm, normal pressure angle of 20° and helix angle of 25°. Spur gear 10 has a module of 5 mm. The layout of the helical gears is shown in View A.

(a) Determine the speed and direction of rotation of worm 8 and gear 10, and the velocity (magnitude and direction) of the rack 11.

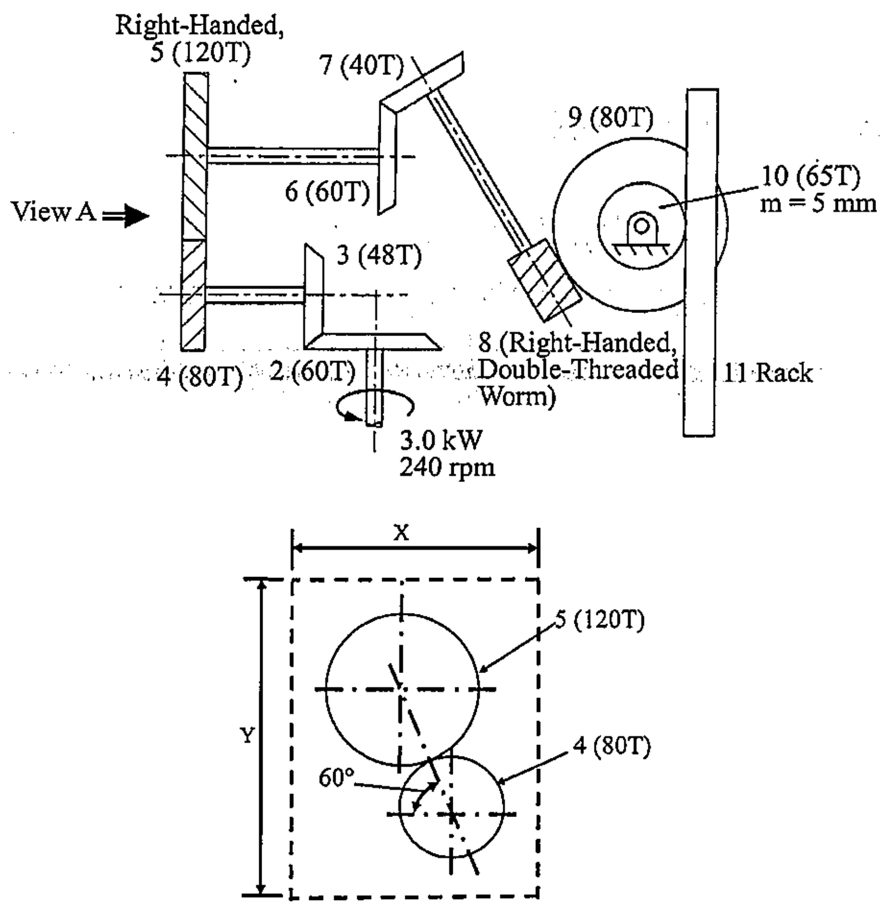
(8 marks)

(b) Determine the minimum dimensions X and Y of a rectangular space that would provide all round clearance of 5 mm for gears 4 and 5.

(8 marks)

(c) Show and determine the magnitude of all the forces acting on gear 5.

(13 marks)



View A

(Figures are not drawn to scale)

Figure 3

21

4. A 1200 rpm normal torque electric motor drives a piston compressor through a V-belt drive as shown in Figure 4. The compressor operates for 18 hours a day and consumes 15 kW. The pulley mounted on the motor shaft rotates at 1200 rpm while the larger pulley mounted on the compressor shaft rotates at 500±5% rpm. The larger pulley has a minimum pitch diameter of 400 mm but not greater than 490 mm.

(a) Specify a standard V-belt cross section and select the standard pitch diameters for the two pulleys.

(10 marks)

(b) Determine the number of belts using the selected V-belt cross section and pulleys in (a). The combined factor for correcting angle of contact and belt length is estimated to be 0.94.

(6 marks)

(c) It is found that an existing single strand of No. 60 roller chain is able to transmit more than the power needed by the same compressor operating with the same motor. All requirements on the rotational speeds remain the same. The pitch diameter of the larger sprocket is also limited to between 400mm and 490mm. Determine the number of teeth on the driving and driven sprockets.

(5 marks)

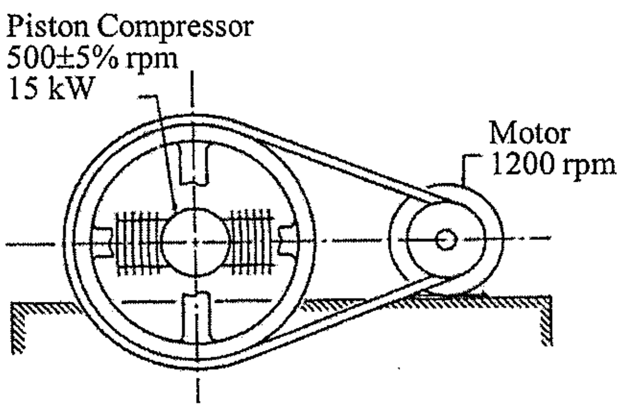


Figure 4

END OF PAPER

1a) direct shear of each bolt $= \frac{20,000}{4} = 5,000\ N \rightarrow Q$

secondary tension $= \frac{20,000\ (0.1)\ (0.45)}{2\ (0.05^2 + 0.45^2)} = 2195.122\ N \rightarrow F$

$N = 3$

$S_y = 340\ N/mm^2 = 340 \cdot 10^6\ N/m^2$

equivalent tensile load $= F_e = \frac{1}{2}\left\{F + \sqrt{F^2 + 4Q^2}\right\}$

$\sigma_e = 340 \cdot 10^6 / 3 = 113333333$ $= \frac{1}{2}\left\{2195.122 + \sqrt{2195.122^2 + 4(5000)^2}\right\}$

$= 6216.6\ N$

equivalent shear load $= Q_e = \frac{1}{2}\sqrt{F^2 + 4Q^2} =$

$\tau_e = \frac{(0.5)\ 340 \cdot 10^6}{3} = 56666666$ $= \frac{1}{2}\sqrt{2195.122^2 + 4 \cdot 5000^2} = 5119\ N$

$A_t = F_e / \sigma_e = \frac{6216.6}{113333333.33} = 5.48\ 10^{-5}\ m^2 \longrightarrow d_1 = 8.353 \times 10^{-3}\ m$

$A_s = Q_e / \tau_e = 5119 / 56666666 = 9.033 \cdot 10^{-5}\ m^2 \longrightarrow d_2 = 0.01072\ m$

$\frac{8.35 \cdot 10^{-3}}{0.8} \rightarrow D_1 = 0.01044\ m \Rightarrow 10.44\ mm \rightarrow 12\ mm$ D12

$D_2 = \frac{0.01072}{0.8} = 0.0134 \rightarrow 13.4\ mm \rightarrow 14\ mm$ D14

b) It's ability to stand against rupture and surface destruction
excess elastic deflection
buckling / overturning
removal of vital surface material

2 a) Assumption : - Energy is fully delivered (no energy loss)

- In the shaft torque (power) coming from A and coming out through B

$T_A = T_B$

- $T_B = \frac{5000}{250/60 \cdot 2\pi} = 191 \text{ Nm}$ $\left(T = P/\omega\right)$

$W_{tB} = T_B / \frac{D_B}{2} = \frac{191}{0.075} = 2546.48 \text{ N}$

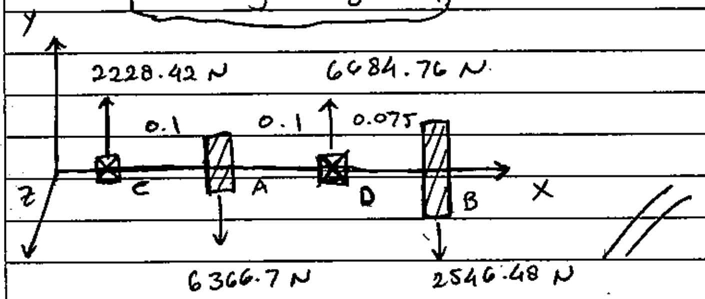
$W_{rB} = W_{tB} \cdot \tan \phi_t = 2546.48 \cdot \tan 14.5° = 658.56 \text{ N}$

- $T_A = T_B$ → no energy loss (same shaft same torque)

$W_{ta} = T_A / \frac{D_A}{2} = \frac{191}{0.03} = 6366.7 \text{ N}$

$W_{ra} = W_{ta} \tan \phi_t = 6366.7 \tan 14.5° = 1646.54 \text{ N}$

b) Loading diagram



$\Sigma T_C = 0$

$6366.7(0.1) - F_D(0.2) + 2546.48(0.275) = 0$

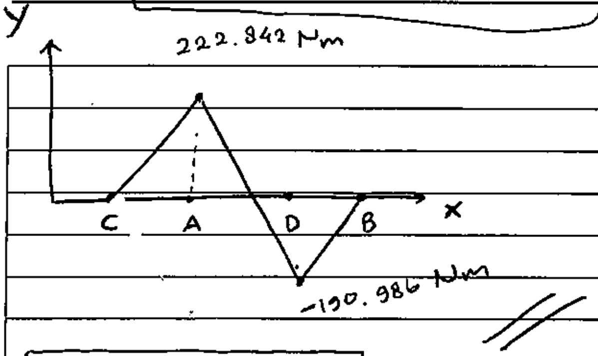
$F_D = 6684.76 \text{ N}$

$\Sigma F = 0$

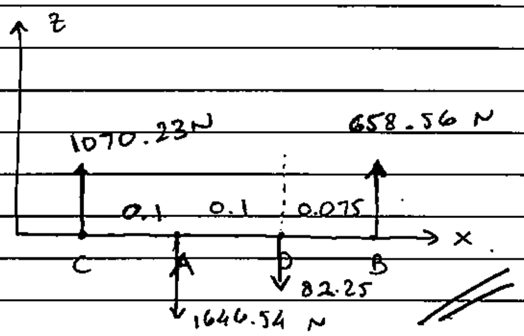
$6366.7 + 2546.48 = 6684.76 + F_C$

$F_C = 2228.42 \text{ N}$

Bending moment diagram 1



Loading diagram 2



$\Sigma T_C = 0$

$1646.54(0.1) - F_D(0.2) - 658.56(0.275) = 0$

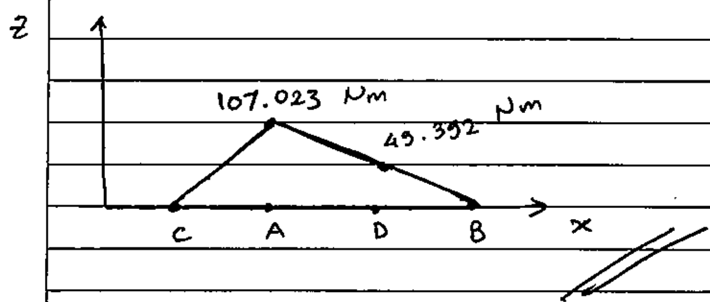
$F_D = -82.25\ N$

$\Sigma F = 0$

$1646.54 + 82.25 - 658.56 - F_C = 0$

$F_C = 1070.23\ N$

Bending moment diagram 2



c) Assumption : using ASME shaft design equation

$$D = \left(\frac{32N}{\pi}\sqrt{\left(\frac{K_{fb}M}{S'_n}\right)^2 + \frac{3}{4}\left(\frac{T}{S_y}\right)^2}\right)^{1/3}$$

- AISI 1040 → $S_y = 490$ MPa.
  $S_u = 552$ MPa.
- Shoulder fillets (sharp) = $K_{fb} = 2.5$

$M_D = \sqrt{(-190.986)^2 + (43.392)^2}$ ← from the diagram at D bending moment

$= 197.27$ Nm

$S'_n = S_n \cdot C_s \cdot C_R$

$C_s = 1$ since 3mm < 7.62 mm

$T_D = T_B = T_A = 191$ Nm

assume using desired reliability 99 % → $C_R = 0.81$

$$0.04 = \left(\frac{32N}{\pi}\sqrt{\left(\frac{2.5 \cdot 197.27}{972 \cdot 10^5}\right)^2 + \frac{3}{4}\left(\frac{191}{490 \cdot 10^6}\right)^2}\right)^{1/3}$$

since $S_u = 552$ MPa.
according to graph Figure 5-8
$S_n \approx 120$ MPa
(I'm using the As-forged)

$N = 1.23$

↑ safety factor is quite low, which means the shaft is working not in the hazardous area.

$S'_n = 1 \cdot (0.81)(120 \cdot 10^6)$
$= 97200000$ Pa.

d) assume $Y = 1.5$, $X = 0.56$ → inner rotates → $V = 1$

$P = XVF_r + YF_a$
$= 0.56 \cdot (6685.27) = 3743.8$ N

$F_{axial} = 0$

$F_r = \sqrt{6684.76^2 + 82.25}$
$= 6685.27$ N → from loading diagram

$$C = P\left(\frac{L_d}{10^6}\right)^{1/k} = 3743.8\left(\frac{10,000 \cdot 60 \cdot 250}{10^6}\right)^{1/3}$$

$= 19891.9$ N

assume, ball bearing
$k = 3$

Choose 6009 !
$C = 22.1$ kN

choose multipurpose gearing
$L_{10} \approx 10,000$ hours

$\frac{F_a}{C_o} = 0 \rightarrow$ since $F_{axial} = 0$

Use 0.014 if $F_a/C_o < 0.014$.

$e = 0.014$

$P = XVF_r = 3743.8$ N $\rightarrow$ since no change in Y

$C_{new} = 19891.9$ N $\rightarrow$ C_{new} will still be the same.

$C_{cat} = 22.1$ kN $> C_{new} \rightarrow$ OK! bearing 6009!

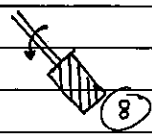
e) Advantage : inexpensive

: can be quickly replace.

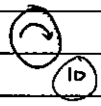
: It protects expensive machinery components

Disadvantage : It is temporary,

3) a) $\frac{240}{Output} = \frac{48}{60} \cdot \frac{120}{80} \cdot \frac{40}{60} \Rightarrow \eta_8 = 300$ rpm



$\frac{300}{Output} = \frac{80}{2} \rightarrow \eta_{10} = 7.5$ rpm

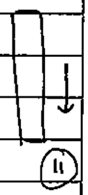


$\omega_{10} = \frac{7.5}{60} \cdot 2\pi = 0.785$ rad/s

$D = 5$ mm $\times$ 65 T $= 325$ mm

$r = 162.5$ mm

$\} \; V = 127.5625$ mm/s



b) $D_5 = 2\text{mm} \times 120 = 240$ mm $\rightarrow r_5 = 120$ mm , $m_5 = 2$mm

$D_4 = 2\text{mm} \times 80 = 160$ mm $\rightarrow r_4 = 80$ mm , $m_4 = 2$ mm

Standart V-belt cross section

SPA

$180 < C < 3(180 + 450)$

$180 < C < 1890$ mm $\rightarrow C = 1050$ mm

$TBL = 2(1050) + 1.57(180 + 450) + \frac{(180 - 450)^2}{4(1050)}$

$= 3106.5$ mm $\rightarrow$ Table A-1 $\rightarrow$ SPA 3150 (12.7 x 10)

b) $C_\theta C_L = 0.94$

Speed ratio $= \frac{450}{180} = 2.5$

Rated power $\rightarrow$ Table A-7 (interpolate) = 5.11 kW

No of belt : $\frac{15000 \times 1.4}{0.94 \times 5110} = 4.37 \approx 5$ belts

c) ~~No. 60 $\rightarrow$ Pitch = 19.05~~

~~use min 17 teeth if space is not an issue.~~

~~$D_1 = \frac{19.05}{\sin(180^\circ/17)} = 103.67$ mm~~

~~Speed ratio about 7 : 1 $\Rightarrow \frac{n_1}{n_2} = 7 = \frac{N_2}{N_1} = \frac{D_2}{D_1}$~~

~~N_2 :~~

No. 60 $\rightarrow$ Pitch = 19.05 mm

DP = W

$= \frac{15(1.\ )}{1} = 15$ kW

$n_1 = 1200$ rpm.

$N_1 = 15$ teeth

Speed ratio $\Rightarrow \frac{1200}{500} = \frac{N_2}{15}$

$N_2 = \approx 36$

$D_2 = \frac{19.05}{\sin(180^\circ/36)} = 218.6$ mm $\rightarrow$ too small.

DON'T FC!

try No. 50 $\rightarrow p = 15.875$ mm

$N_1 = 21$ teeth.

$N_2 = \frac{1200}{500} \cdot 21 = 50.4 \approx 51$ teeth.

$D_2 = 257.9$ mm $\rightarrow$ too small

try No. 40 $\rightarrow$ 12.7 mm

$N_1 = 45$ teeth

$N_2 = \frac{1200}{500} \cdot 45 = 108$ teeth

$D_2 = \frac{12.7}{\sin(\frac{180}{108})} = 436.65$ mm (400mm – 490mm)

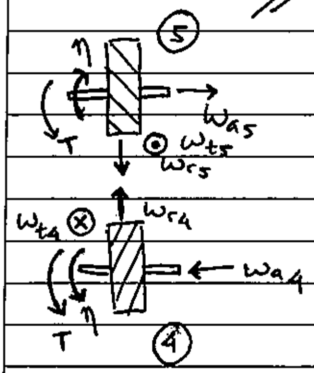
$Y = 5\,mm + 2\,mm + 120\,mm + 200\,mm \sin 60^\circ + 80\,mm + 2\,mm + 5\,mm$

$= 387.2\ mm$

$X = 5\,mm + 2\,mm + 120\,mm + 200 \cos 60^\circ + 80\,mm + 2\,mm + 5\,mm$

$= 314\ mm$

c)



$P = 3000\ W$

$\frac{240}{N_5} = \frac{48}{60}\cdot\frac{120}{80} \rightarrow N_5 = 200\ rpm$

$\omega_5 = 20.94\ rad/s$

$m_t = m_n / \cos\psi = 2/\cos 25^\circ = 2.21\ mm$

$T = 143.24\ Nm$

$W_{t5} = T / \frac{D_5}{2} = \frac{143.24}{\frac{2.21\cdot10^{-3}(120)}{2}} = 1080.24\ N$

$\tan\phi_t = \tan\phi_n / \cos\psi = \tan 20^\circ / \cos 25^\circ$

$\phi_t = 21.88^\circ$

$W_{r5} = W_t \cdot \tan\phi_t = 1080.24 \cdot \tan 21.88^\circ = 433.82\ N$

$W_{a5} = W_t \cdot \tan\psi = 1080.24 \cdot \tan 25^\circ = 503.724\ N$

4) Larger pulley (400 – 490) mm, rotates = 475 – 525 rpm

Design power = 15,000 (1.4) = 21,000 W ← SPA

Assume the belt speed is → 12 m/s

$V_b = \omega \cdot r$ ← $\omega_{small} = \frac{1200}{60}\cdot 2\pi = 125.66\ rad/s$

$12\ m/s = 125.66 \cdot r$

$r = 95.5\ mm \rightarrow D_1 = 190.8\ mm \rightarrow$ Table A-4 → 180 mm

$\frac{D_1}{D_2} = \frac{N_2}{N_1} \Rightarrow \frac{180}{D_2} = \frac{500}{1200} \rightarrow D_2 = 432\ mm = 450\ mm$ (400 – 490)

Check: $\frac{180}{450} = \frac{N_2}{1200} \rightarrow N_2 = 480\ rpm$ (475 – 525 rpm)

Standart V-belt cross section → SPA

$180 < c < 3(180 + 450)$

$180 < c < 1890 \rightarrow c = 1050$ mm

$TBL = 2(1050) + 1.57(180 + 450) + \frac{(180 - 450)^2}{4(1050)} = 3106.5$ mm

Table A-1 → SPA 3150

b) $C_\theta C_L = 0.94$

Speed ratio $= \frac{450}{180} = 2.5$

Rated power → Table A-7 (interpolate) $= 5.11$ kw

No of belt $= \frac{5000}{0.94} \frac{1.4}{5110} = 4.37 \approx 5$ belts

c) No. 60 → pitch $= 19.05$ mm

$DP = \frac{15(1)}{1} = 15$ kW

$n_1 = 1200$ rpm

$N_1 = 15$ teeth

$\frac{1200}{500} = \frac{N_2}{15} \rightarrow N_2 = 36$ teeth

$D_2 = \frac{19.05}{\sin(180°/36)} = 218.6$ mm → too small

try No. 50 → $p = 15.875$ mm

$N_1 = 21$ teeth

$N_2 = \frac{1200}{500} \cdot 21 = 50.4 \approx 51$ teeth

$D_2 = 257.9$ mm → too small

try No. 40 → 12.7 mm

$N_1 = 45$ teeth

$N_2 = \frac{1200}{500} \cdot 45 = 108$ teeth

$D_2 = \frac{12.7}{\sin\left(\frac{180°}{108}\right)} = 436.65$ mm ✓ (400 – 490 mm)

All The Best !

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2017-2018

MA3001 – MACHINE ELEMENT DESIGN

April/May 2018 Time Allowed: 2½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SIX (6)** pages.
2. Answer **ALL** questions.
3. Marks for each question are as indicated.
4. This is an **OPEN-BOOK** examination.

1(a) The plate shown in Figure 1 (not drawn to scale) is fastened to the fixed member by five 10-mm-diameter bolts. Compute the value of the loads P so that the maximum shearing stress in the bolts does not exceed 70 MPa.

State all assumptions clearly.

(8 marks)

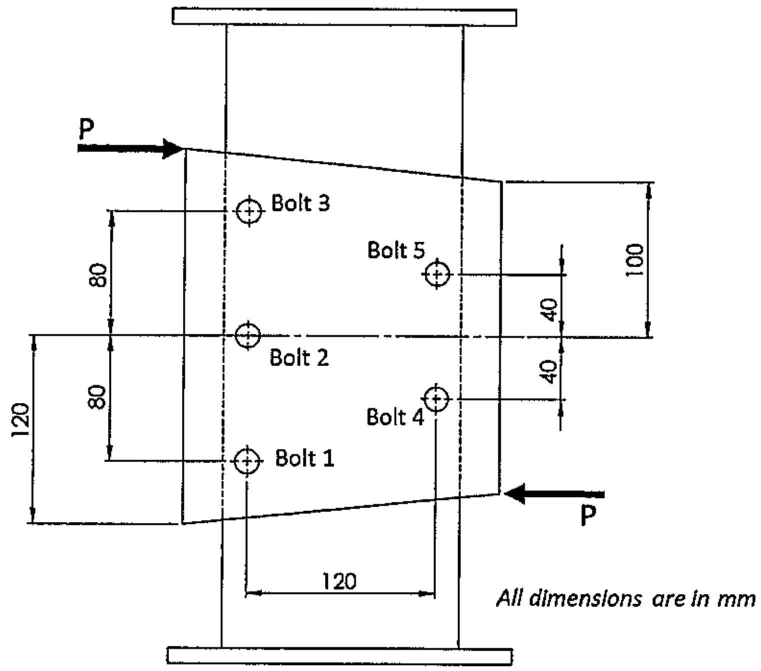


Figure 1

Note: Question 1 continues on page 2.

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(b) There are two identical machined brackets in Figure 2 (not drawn to scale) fastened to the ceiling spaced at 2m apart to support a constant load of 400kg with a safety factor of 3. A total of four bolts are needed to secure each brackets onto the ceiling. The isometric drawing of the machined bracket is shown in the bottom right hand.

Given that the bolts are made of ASTM grade A307. Find the required thread size of the bolts. State all assumptions clearly.

(9 marks)

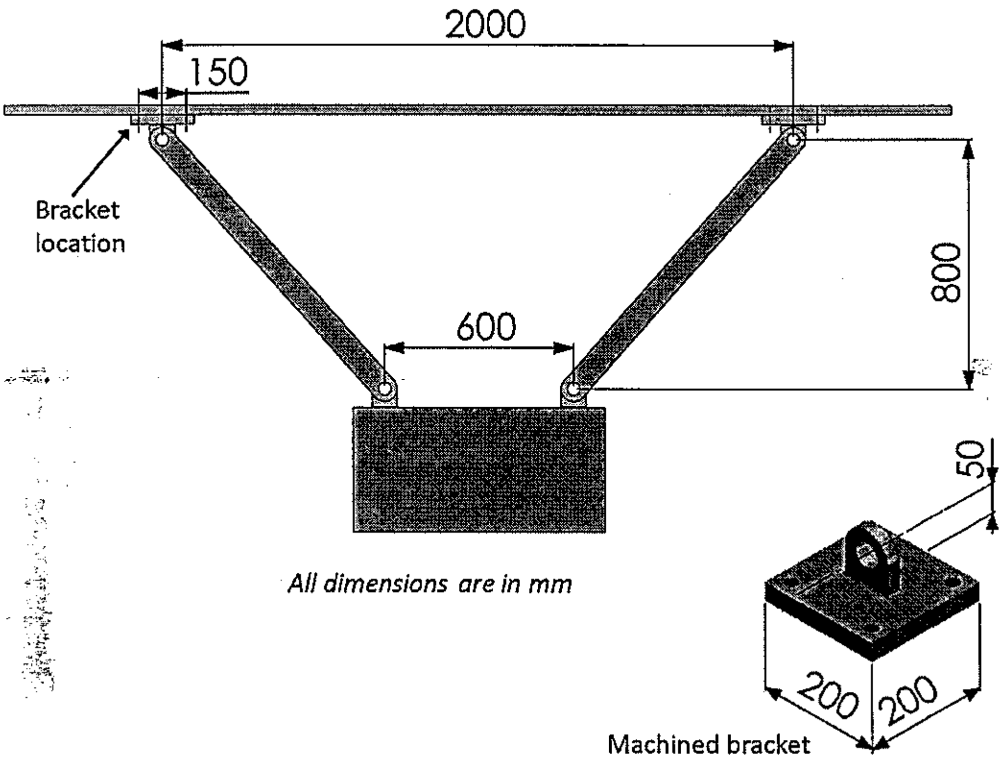

Figure 2

2(a) The shaft system shown in the Figure 3 is part of a grain-drying machine. At point A is a propeller-type fan with a mass of 15kg that requires 9 kW when rotating at 475 RPM. The shaft carries a 250mm diameter V-belt sheave at point C that receives 11.5 kW from a mating sheave (not shown in the figure). Moreover, the shaft is also carrying a 150 mm diameter V-belt pulley at point D that delivers power to a screw conveyor handling the grain (not shown here).

(i) Compute the torque delivered to the shaft at C by the sheave and the total force exerted on the shaft at C by the sheave. The ratio of the belt tension on the tight side to the slack side can be approximated to be 5. State all assumptions made in your calculation.

(4 marks)

(ii) Find the total forces exerted on the shaft by the pulley at D assuming the belt tension ratio to be 3. State all other assumptions made in your calculation.

(3 marks)

(iii) Design the polished shaft using SAE 1137 cold drawn steel based on the above requirements with a safety factor of 3 and desired reliability of 99%. State all assumptions made in your calculation.

(10 marks)

(iv) Find suitable bearings for the shaft at point B and E. State all assumptions clearly.

(5 marks)

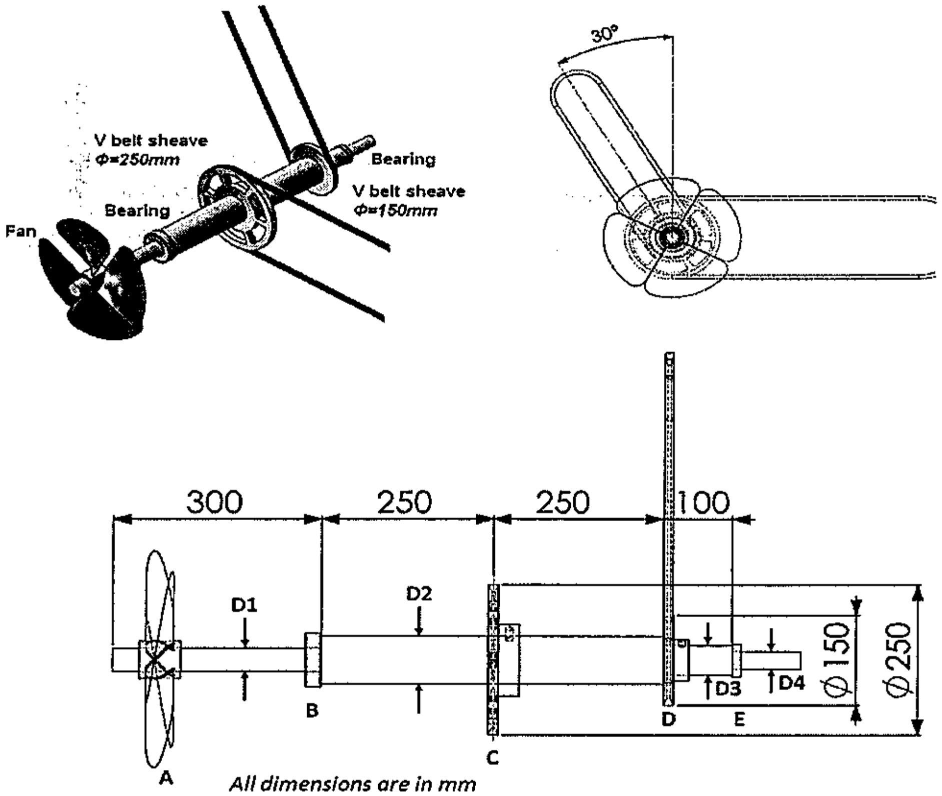

Figure 3

Note: Question 2 continues on page 4.

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(b) The gear in the Figure 4 (not drawn to scale) has a pitch diameter of 150mm, a pressure angle φ of 20 degrees and a helical angle ψ of 45 degrees. The shaft carrying the gear is supported by bearings at points A and B and is connected to a flexible coupling at one end, where it transmits a torque of 170Nm. The gear is equally spaced in between the two bearings as shown in the figure.

(i) The bearing at A will be subjected to both radial and axial loading, while the bearing at B will be subjected to radial loading only. Select bearings that meet a design factor of 2.0 and a life of 500 million cycles. It is important to minimize the bore diameter of each bearing. State all assumptions clearly.

(8 marks)

(ii) Why is flexible coupler preferred in this case? What are the differences between rigid and flexible couplers?

(3 marks)

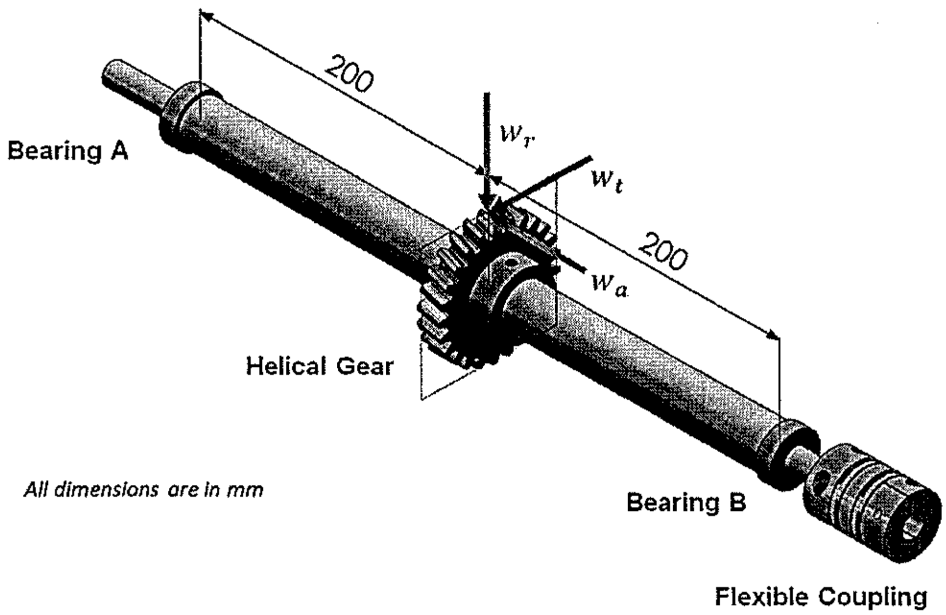

Figure 4

3. A two-speed hoisting winch is shown in Figure 5. The motor drives the drum through helical gears A, B, C and D when the jaw clutch is shifted to the right to give a lower output speed; and through helical gears A, B, E and F when the jaw clutch is shifted to the left to give a higher output speed. The motor transmits 25kW and rotates at 900 rpm in the direction shown in the figure. Data regarding the gears are shown in Table 1. Gears A, C and F are left-handed while gears B, D and E are right-handed.

(a) Determine the inside dimension Y of a rectangular housing that would provide a minimum clearance of 20 mm from the gears.

(10 marks)

(b) Determine the two output speeds and directions of rotation of the drum.

(4 marks)

(c) Determine the axial load and show its direction on each gear B, C and E.

(12 marks)

(d) Show which pair of gears would you change so that the nett axial load on the shaft carrying gears B, C and E will be as small as possible at the two output speeds. With the change, determine the magnitude and direction of smallest nett axial load that the shaft will experience.

(6 marks)

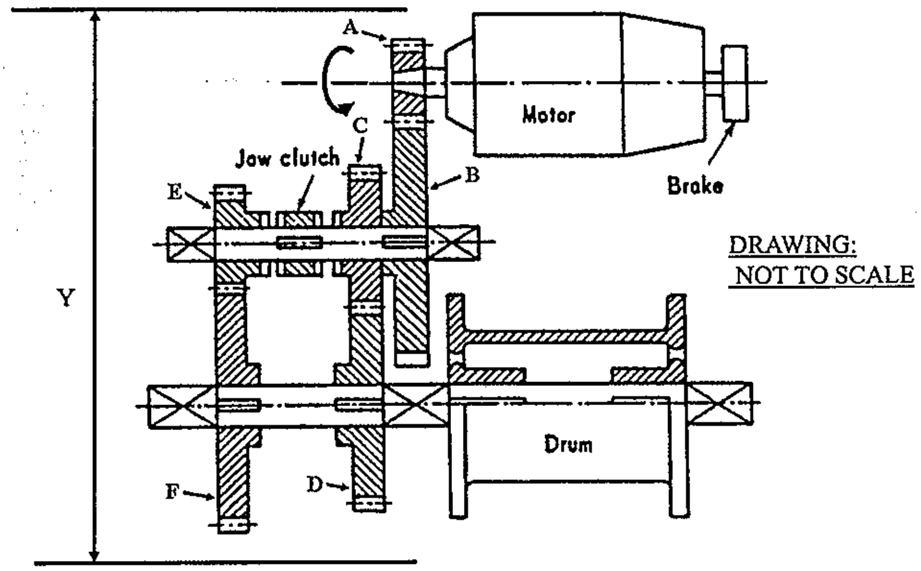

Figure 5

Table 1

Helical Gear	A	B	C	D	E	F
Number of teeth	15	75	20	32	17	20
Normal module	3	3	4	4	6	6
Helix angle	25°	25°	30°	30°	22.43°	22.43°
Normal pressure angle	20°	20°	20°	20°	20°	20°

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4. The drive for a brick machinery as shown in Figure 6 consists of a V-belt speed reduction, a helical gear reduction, a spur gear reduction and driving sprockets. The roller chains, not shown, are driven at a limiting speed of 1.0m/s by the driving sprockets. The pitch diameter of the larger pulley is not to exceed 800 mm and the pitch diameter of the sprockets is 760 mm. The high torque AC motor delivers 15.0 kW at 1200 rpm in the direction shown and is to be operational 12 hours daily.

(a) Determine the rotational speed and direction of rotation of the sprockets at the chain speed of 1.0 m/s.

(2 marks)

(b) Specify a standard V-belt cross section and select standard diameters for the driving and driven pulleys. Hence, determine the number of belts used for the V-belt drive. You may use a combined correction factor $C_\theta C_L$ of 0.90 to account for the corrections of the angle of wrap and belt length.

(13 marks)

(c) Show and label a sketch of the torque and tensions acting on the driving pulley.

(3 marks)

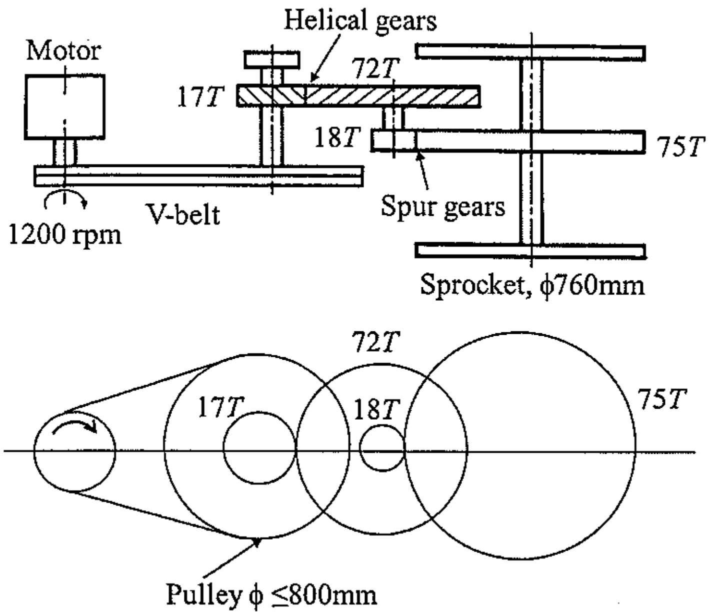

Figure 6

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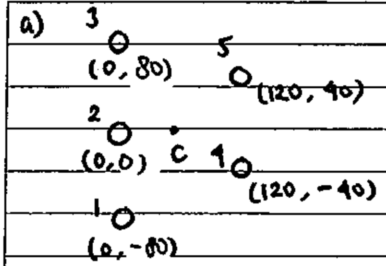
MA3001 2017/18 Sem 2 (April/May 2018)

① a)

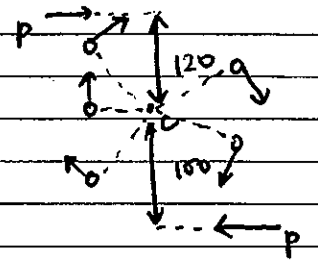


Since all bolt has same diameter, the bolt areas are all the same

$$x_c = \frac{x_1 + x_2 + x_3 + x_4 + x_5}{5} = \frac{0+0+0+120+120}{5} = 48 \text{ mm}$$

$$y_c = \frac{\sum y_i}{5} = \frac{-80+0+80-40+40}{5} = 0 \text{ mm}$$

Since there are 2 forces with same magnitude and acting in opposite direction, there would be no primary shear. However, there still would be secondary shear due to moment caused by these forces.



$$M = P(120) + P(100)$$
$$= 220P$$

Bolt with highest shear would be the one with largest distance from centroid

$$r_i = \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2}$$
$$r_1 = \sqrt{(0-48)^2 + (-80-0)^2} = 93.295 \text{ mm}$$
$$r_2 = \sqrt{(0-48)^2 + (0-0)^2} = 48 \text{ mm}$$
$$r_3 = \sqrt{(0-48)^2 + (80-0)^2} = 93.295 \text{ mm}$$
$$r_4 = \sqrt{(120-48)^2 + (-40-0)^2} = 82.365 \text{ mm}$$
$$r_5 = \sqrt{(120-48)^2 + (40-0)^2} = 82.365 \text{ mm}$$

Hence, largest shear would be experienced by either bolt 1 or 3

Using conventional approach

$$d_r = 0.8d = 0.8(10) = 8 \text{ mm}$$
$$A = \frac{1}{4}\pi d_r^2 = \frac{1}{4}\pi (8)^2 = 16\pi \text{ mm}^2$$
$$F_1 = \frac{(Pe) r_1}{\sum r_i^2} = \frac{(220P)(93.295)}{93.295^2 + 48^2 + 93.295^2 + 82.365^2 + 82.365^2} = 0.61P$$
$$\tau_e = 70 \text{ MPa}$$
$$F_1 = (\tau_e)(A)$$
$$0.61P = (70 \times 10^6)(16\pi \times 10^{-6})$$
$$P = 5768.17 \text{ N}$$

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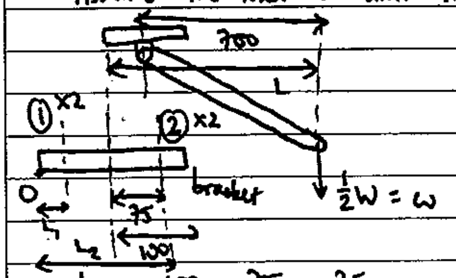
① b) Assume the load is distributed equally to the brackets.



$W = 400 \times 9.8 = 3920\ N$

$\omega = \frac{1}{2}W = 1960\ N$

Assume pivot is as shown on the diagram

$L_1 = 100 - 75 = 25\ mm$

$L_2 = 100 + 75 = 175\ mm$

$L = 700 + 100 = 800\ mm$

$P_{td} = \frac{1}{4}\omega = \frac{1}{4} \times 1960 = 490\ N$

Secondary force would be larger for bolts 2 $(L_2 > L_1)$

$P_{sd2} = \frac{(\omega L) L_2}{2L_1^2 + 2L_2^2} = \frac{1960 \times 800 \times 175}{2(25^2 + 175^2)} = 4390.4\ N$

A307 → $\sigma_e = 138\ MPa$

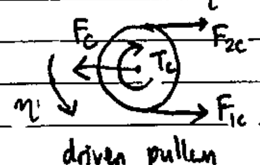
$\frac{\sigma_e}{N} = \frac{(P_{td} + P_{sd2})}{\frac{1}{4}\pi d^2}$

$\frac{1}{4}\pi d^2 = \frac{(490 + 4390.4)}{138 \times 10^6} \times 3 \rightarrow d = 0.0116\ m = 11.62\ mm$

Using conventional approach

$D = \frac{d}{0.8} = 14.53\ mm$

② a) (i) $T_c = \frac{P_c}{\eta} = \frac{11.5 \times 1000}{475 \times 2\pi/60} = 231.19\ Nm$



Assume direction of rotation as shown

$F_{1c} = 5F_{2c}$

$(F_{1c} - F_{2c})(\frac{1}{2}D_c) = T_c$

$(5F_{2c} - F_{2c})(\frac{1}{2} \times 0.250) = 231.19$

$F_{2c} = 462.38\ N$

$F_{1c} = 5F_{2c} = 2311.93\ N$

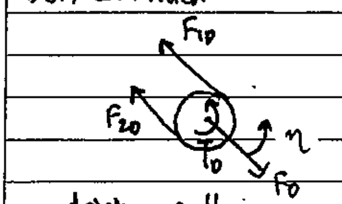
$F_c = F_{1c} + F_{2c} = 2774.32\ N$

(ii) $P_c = P_A + P_D$

$P_D = 11.5 - 9 = 2.5\ kW$

$T_D = \frac{P_D}{\eta} = \frac{2.5 \times 1000}{475 \times 2\pi/60} = 50.26\ Nm$

② a)(ii) Continued



driving pulley

$F_{2D} = 3F_{1D}$

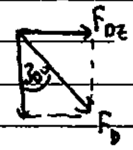
$(F_{2D} - F_{1D})(\frac{1}{2}D_D) = T_D$

$(3F_{1D} - F_{1D})(\frac{1}{2} \times 0.150) = 50.26$

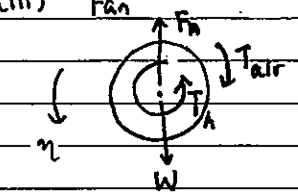
$F_{1D} = 335.06$ N

$F_{2D} = 3F_{1D} = 1005.19$ N

$F_D = F_{1D} + F_{2D} = 1340.25$ N



(iii) Fan

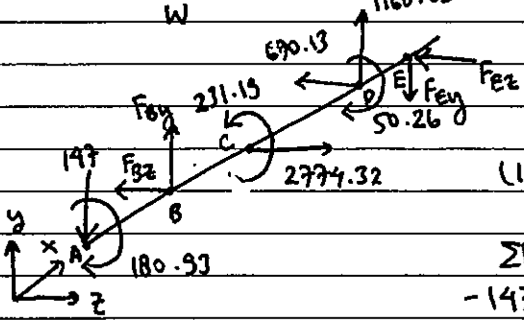


$T_A = \frac{P_A}{\eta} = \frac{9 \times 1000}{475 \times 2\pi/60} = 180.93$ Nm

$F_A = W = 15 \times 9.8 = 147$ N

$F_{Dy} = F_D \cos 30° = 1160.69$ N

$F_{Dz} = F_D \sin 30° = 670.13$ N



y-axis

$\Sigma M_E = 0$

$(147)(900) - F_{By}(600) - (1160.69)(100) = 0$

$F_{By} = 27.05$ N

$\Sigma F_y = 0$

$-147 + 27.05 + 1160.69 - F_{Ey} = 0$

$F_{Ey} = 1040.74$ N

z-axis

$\Sigma M_E = 0$

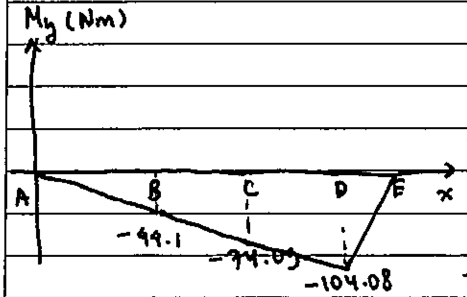
$F_{Bz}(600) - (2774.32)(350) + (670.13)(100) = 0$

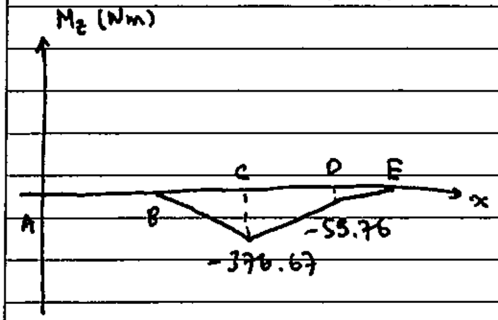
$F_{Bz} = 1506.67$ N

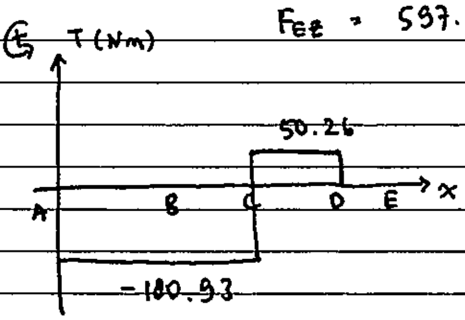
$\Sigma F_z = 0$

$-1506.67 + 2774.32 - 670.13 - F_{Ez} = 0$

$F_{Ez} = 597.52$ N







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(2)

② a) (iii) Continued

SAE 1137 → cold drawn

$S_u = 676$ MPa, $S_y = 565$ MPa, $N = 3$

$C_R = 0.81$ (99% reliability)

$C_s = 0.85$ (Assumed)

$S_n = 340$ MPa (polished)

$S_n' = S_n C_s C_R = 234.09$ MPa

D_1 → use mid of B (interference fit $K_{fb} = 1.0$)

$$D_1 = \left[\frac{32 \times 3}{\pi} \sqrt{\left(\frac{1.0 \times 44.1}{340 \times 10^6}\right)^2 + \frac{3}{4}\left(\frac{180.53}{565 \times 10^6}\right)^2} \right]^{1/3} = 0.02107 \text{ m} = 21.07 \text{ mm}$$

D_2 → use mid of C (interference fit $K_{fb} = 1.0$)

$$M = \sqrt{74.09^2 + 376.67^2} = 383.89 \text{ Nm}$$

$$D_2 = \left[\frac{32 \times 3}{\pi} \sqrt{\left(\frac{1 \times 383.89}{340 \times 10^6}\right)^2 + \frac{3}{4}\left(\frac{180.53}{565 \times 10^6}\right)^2} \right]^{1/3} = 0.03287 = 32.87 \text{ mm}$$

D_3 → use left of D (sharp edge $K_{fb} = 2.5$)

$$M = \sqrt{104.08^2 + 59.76^2} = 120.02 \text{ Nm}$$

$$D_3 = \left[\frac{32 \times 3}{\pi} \sqrt{\left(\frac{2.5 \times 120.02}{340 \times 10^6}\right)^2 + \frac{3}{4}\left(\frac{50.26}{565 \times 10^6}\right)^2} \right]^{1/3} = 0.03002 = 30.02 \text{ mm}$$

D_4 → no load → no minimum diameter

(iv) Bearing B

$P = \sqrt{F_{By}^2 + F_{Bz}^2} = \sqrt{27.05^2 + 1506.67^2} = 1506.91$ N

$L_{10,h} = 15000$ hours (assumed industrial fan)

$n = 475$ rpm

$L_{10} = 15000 \times 475 \times 60 = 0.4275 \times 10^9$ rev

$k = 3$ (ball bearing)

$C = P\,(L_{10}/10^6)^{1/k} = 1506.91\,(0.4275 \times 10^3)^{\frac{1}{3}} = 11.35$ kN

$D_{min} = 21.07$ mm

Select bearing 6205 ($d = 25$ mm, $C_{dyn} = 14.00$ kN)

Bearing E

$P = \sqrt{F_{Ey}^2 + F_{Ez}^2} = \sqrt{1040.74^2 + 597.52^2} = 1200.07$ N

$L_{10,h} = 15000$ hours

$L_{10} = 15000 \times 475 \times 60 = 0.4275 \times 10^9$ rev

$C = 1200.07\,(0.4275 \times 10^3)^{\frac{1}{3}} = 9.04$ kN

D_{min} = none

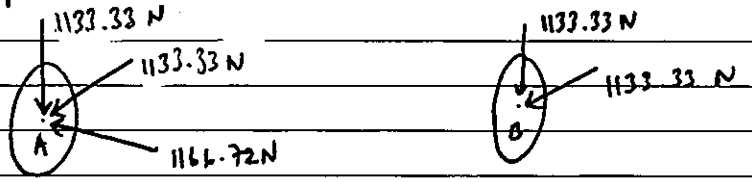
Select bearing 6301 ($d = 12$ mm, $C_{dyn} = 9.75$ kN)

② b)(i) $W_t = \frac{T}{\frac{1}{2}D} = \frac{170}{\frac{1}{2}\times 0.15} = 2266.67$ N

$W_a = W_t \tan\phi_n / \cos\psi = 2266.67 \tan 20° / \cos 45° = 1166.72$ N

$W_r = W_t \tan\psi = 2266.67 \tan 45° = 2266.67$ N

Due to symmetry, the forces will be distributed equally on both bearings (except axial load)



Bearing A

$F_r = \sqrt{1133.33^2 + 1133.33^2} = 1602.77$ N

$F_a = 1166.72$ N

Assume $Y = 1.8$, $X = 0.56$, $V = 1.0$ → deep groove ball bearing

$P_d = VXF_r + YF_a = (1)(0.56)(1.60277) + 1.8(1.16672) = 2.997$ kN

~~$C = P_d\left(\frac{L_d}{10^6}\right)^{\frac{1}{k}} = 2.997\left(\frac{500\times 10^6}{10^6}\right)^{\frac{1}{3}} = 67.03$ kN~~

Table 14-3 → we can use bearing 6311 or 6312 or 6313 (you can check for yourself that 6311 is not enough)

Choose 6312 → $C_o = 52$ kN, $C_{dyn} = 81.9$ kN

$F_a/C_o = \frac{1.16672}{52} = 0.022436$ D = 60 mm

~~e by interpolation $= \frac{0.022436 - 0.021}{0.028 - 0.021}(0.22 - 0.21) + 0.21 = 0.212$~~

$F_a/F_r = \frac{1166.72}{1602.77} = 0.7279 > e$

~~Y by interpolation $= \frac{0.022436 - 0.021}{0.028 - 0.021}(1.99 - 2.15) + 2.15 = 2.117$~~

$P_d = (1)(0.56)(1.60277) + 2.117(1.16672) = 3.367$ kN

~~$C = 3.367\left(\frac{500\times 10^6}{10^6}\right)^{\frac{1}{3}} = 75.304$ kN < 81.9 kN → suitable~~

Bearing B

$P = \sqrt{1133.33^2 + 1133.33^2} = 1602.77$ N $= 1.60277$ kN

~~$C = 1.60277\left(\frac{500\times 10^6}{10^6}\right)^{\frac{1}{3}} = 35.839$ kN~~

Following diameter of bearing A (60 mm)
→ Choose bearing 6212 (D = 60 mm, $C_{dyn} = 47.5$ kN)

② b)(ii) Because there exists axial load, With flexible coupler, it can permit some axial misalignment.

Rigid coupler → doesn't permit relative motion between the 2 shafts it connects
→ precise alignment of shafts
→ bolts in carry torque in shear

Flexible coupler → can transmit torque smoothly
→ permit some axial, angular, radial misalignment

③ a) $m_A = m_B = \frac{3}{\cos 25^\circ} = 3.31$ mm

$m_C = m_D = \frac{4}{\cos 30^\circ} = 4.62$ mm

$m_E = m_F = \frac{6}{\cos 22.43^\circ} = 6.49$ mm

Compare $D_F + \frac{1}{2}D_E$ and $D_D + \frac{1}{2}D_C$

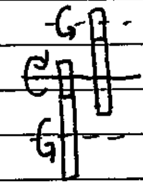
$D_F + \frac{1}{2}D_E = m_F N_F + \frac{1}{2} m_E N_E = 6.49\,(20 + \frac{1}{2}\times 17) = 184.965$ mm

$D_D + \frac{1}{2}D_C = m_D N_D + \frac{1}{2} m_C N_C = 4.62\,(32 + \frac{1}{2}\times 20) = 194.04$ mm → larger

$Y = m_A N_A + \frac{1}{2} m_B N_B + (\frac{1}{2} m_C N_C + m_D N_D) + m_A + m_D + 2c$

$= 3.31\,(15 + \frac{1}{2}\times 75) + (194.04) + 3.31 + 4.62 + 2\times 20$

$= 415.745$ mm



b) A - B - C - D

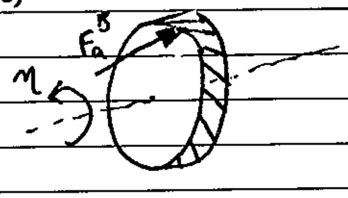
~~$n_D = \left(\frac{N_C}{N_D}\right)\left(\frac{N_A}{N_B}\right) n_A = \frac{20}{32} \times \frac{15}{75} \times 900 = 112.5$ rpm~~

A - B - E - F

~~$n_F = \left(\frac{N_E}{N_F}\right)\left(\frac{N_A}{N_B}\right) n_A = \frac{17}{20} \times \frac{15}{75} \times 900 = 153$ rpm~~

direction for both configurations

c)



driven B (right hand)

$n_B = \frac{N_A}{N_B} n_A = \frac{15}{75} \times 900 = 180$ rpm

$T_B = \frac{P}{n_B} = \frac{25000}{180 \times 2\pi/60}$ ~~$= 1326.29$ Nm~~

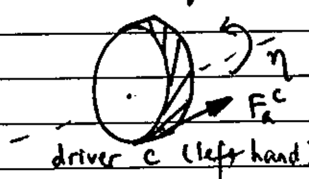
$F_a^B = \frac{T_B}{\frac{1}{2} m_B N_B}$ ~~tan~~ $\psi_B = \frac{1326.29 \times \tan 25^\circ}{\frac{1}{2}\times 3.31 \times 75 \times 10^{-3}}$,

$= 4982.55$ N

$T_C = T_B$ (same power and n)

$F_a^C = \frac{T_C}{\frac{1}{2} m_C N_C}$ ~~tan~~ $\psi_C = \frac{1326.29 \tan 30^\circ}{\frac{1}{2}\times 4.62 \times 20 \times 10^{-3}}$

$= 16574.33$ N



driver C (left hand)

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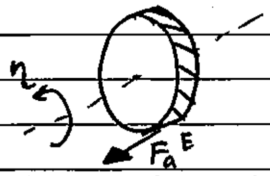
③ c) Continued



$T_E = T_B$ (same power and n)

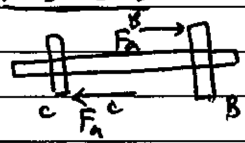
$$F_a^E = \frac{T_E}{\frac{1}{2} m_E N_G} \tan \psi_E = \frac{1326.29 \tan 22.43^\circ}{\frac{1}{2} \times 6.49 \times 17 \times 10^{-3}}$$

$$= 9924.23 \text{ N}$$

driver E (right hand)

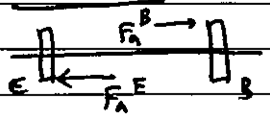
d) Change C to right hand and D to left hand

A - B - C - D



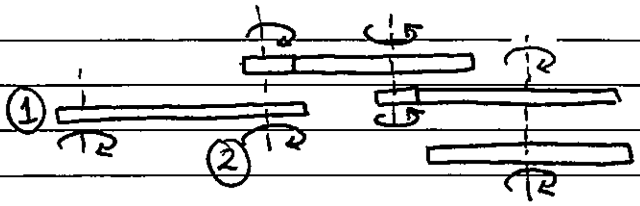
$$\Sigma F_a = F_a^B - F_a^C$$
$$= 4982.55 - 16574.33 = -11591.78 \text{ N}$$
(11.59 kN ←)

A - B - E - F



$$\Sigma F_a = F_a^B - F_a^E$$
$$= 4982.55 - 9924.23 = -4941.68 \leftarrow \text{smallest}$$
(4.94 kN ←)

④ a) $n = \frac{V}{\frac{1}{2}D} = \frac{1}{0.5 \times 0.76} = 2.63 \text{ rad/s} = 25.13 \text{ rpm}$



b) Brick machinery, 12 hrs / day, high torque AC motor → SF = 1.5

→ DP = 1.5 × 15 = 22.5 kW

→ n = 1200 rpm

→ Table A-3 → SPA cross section

~~→ 25.13 rpm $\geq \left(\frac{D_1}{D_2}\right)\left(\frac{17}{72}\right)\left(\frac{18}{75}\right) \times 1200$ rpm → $\frac{D_1}{D_2} \leq 0.36955$~~

$D_2 \leq 800$ mm   or $\frac{D_2}{D_1} \geq 2.706$

→ Choose $D_1 = 125$ mm, $D_2 = 355$ mm

$SR = \frac{355}{125} = 2.84$

$n_{sprocket} = \left(\frac{125}{355}\right)\left(\frac{17}{72}\right)\left(\frac{18}{75}\right) \times 1200 = 23.94 \text{ rpm} < 25.13 \to \text{OK}$

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(4) b) Continued

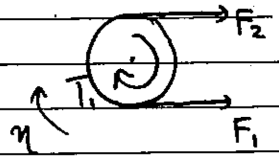
-> Table A-76, $D_1 = 125$ mm, $n_1 = 1200$ rpm, $SR = 2.84$

By interpolation

$$RP = \left(\frac{2.84 - 1.5}{3 - 1.5}\right)(4.35 - 4.27) + 4.27 = 4.34 \text{ kW/belt}$$

-> No of belt $= \frac{DP}{CRP} = \frac{DP}{C_\theta C_L RP} = \frac{22.5}{0.9 \times 4.34} = 5.76 \rightarrow 6$ belts

c)



~~F_1 = tension~~

$$T_1 = \frac{P}{n_1} = \frac{15000}{\frac{2\pi}{60} \times 1200} = 119.37 \text{ Nm}$$

~~$F_1 = \frac{T_1}{\frac{1}{2}D_1} = \frac{119.37}{\frac{1}{2} \times 0.125} = 1909.92$~~