UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
JANUARY 2025 SEMESTER

COURSE	**:**	**MEB3023/MFB3023 - MECHANICAL ENGINEERING DESIGN**
DATE	**:**	**10 APRIL 2025 (THURSDAY)**
TIME	**:**	**2.30 PM - 5.30 PM (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **SIXTEEN (16)** pages in this Question Booklet including the cover page and appendix.

ii. **DOUBLE-SIDED** Question Booklet.

1. a. An upside-down "A" shaped frame as shown in **FIGURE Q1(a)**, is to be bolted to a horizontal ceiling steel beam using two ISO 8.8 bolts. The size of each bolt is M16 x 2. The frame is to support the 35kN radial load. The total grip length, L_G = 42 mm, includes the thickness of the steel beam, the *A* frame feet, and the steel washer used. Modulus of elasticity for steel, E = 207 GPa. Ignore the weight of the frame and assume the height of a regular hexagonal nut as 14.8 mm. Proof strength of ISO 8.8 class bolt is 600 MPa.

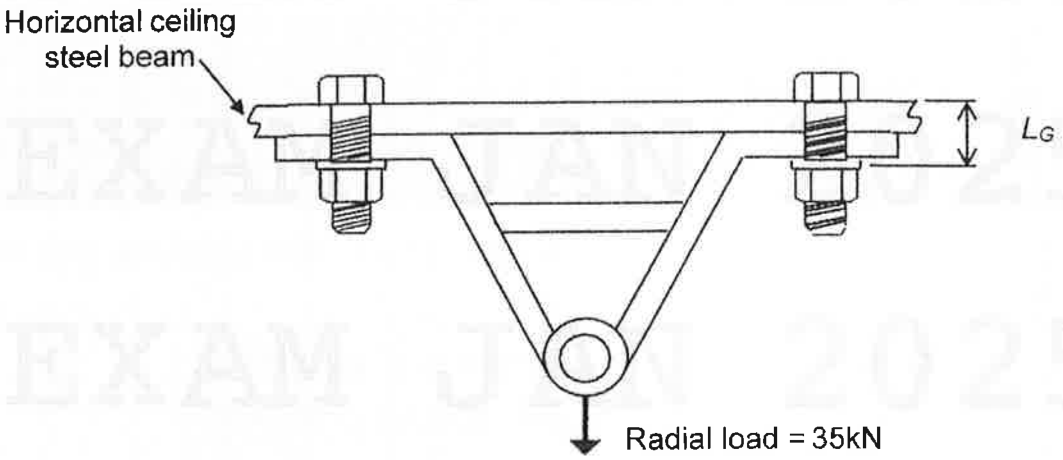

FIGURE Q1(a): An upside down "A" shaped frame

i. If the connection is permanent and the fasteners are lubricated, estimate the required tightening torque, when the value of torque coefficient (K) is 0.2.

[4 marks]

ii. Determine the stiffness of bolts, k_b and the stiffness of the members, k_m if the tensile stress area of the bolt is 157 mm^2.

[6 marks]

iii. Calculate the percentage of the load taken by the bolts and the members. Suggest a way to increase the percentage of load on the members.

[3 marks]

b. A shaft made up of mild steel is required to transmit 100 kW at 300 rpm. The supported length of the shaft is 3 meters. It carries two pulleys, each weighing 1500 N, supported at 1 meter from the two ends, respectively. Assuming safe value of stress as 60 MPa, determine the minimum diameter of the shaft, required to transmit the load.

[12 marks]

2. a. A polyamide A-3 flat belt 150 mm wide as shown is **FIGURE Q2(a)** is used to transmit 11 kW under light shock conditions where K_s = 1.25, and a factor of safety equal to or greater than 1.1 is appropriate. The pulley rotational axes are parallel and in the horizontal plane. The shafts are 2.4 m apart. The 150 mm driving pulley rotates at 1750 rev/min in such a way that the loose side is on top. The driven pulley is 450 mm in diameter. The factor of safety is for unquantifiable exigencies. Assume the specific weight of belt is 11,000 N/m³.

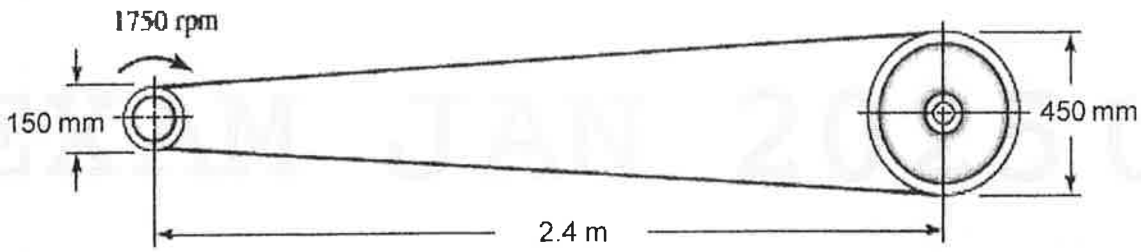

FIGURE Q2(a): Flat belt drive system (Drawing is not-to-scale)

i. Estimate the centrifugal tension F_c and the torque T.

[5 marks]

ii. Evaluate the stresses F_1, F_2, F_i and allowable power H_a.

[8 marks]

iii. Estimate the factor of safety and suggest if it is satisfactory.

[4 marks]

b. In a mechanical system where a chain is used to transmit power, what factors contribute to the most significant chain wear and how can you mitigate this wear to optimize the lifespan of the chain.

[8 marks]

3. a. A certain application requires a ball bearing with the inner ring rotating. The required design life of the bearing is 30,000 hours at a speed of 300 rev/min. The radial load is 1.898 kN and an application factor of 1.2 is appropriate. The reliability goal is 0.90. Typical Weibull parameters are given in **TABLE Q3(a)**.

TABLE Q3(a): Weibull Parameters

Manufacturer	Rating Life (Revolutions)	Weibull Parameters Rating Lives		
		x_o	$(\theta - x_o)$	b
1	$1\ (10^6)$	0.02	4.439	1.483

Estimate the necessary bearing parameters and choose a 02-series deep-groove ball bearing from the Table in **APPENDIX**. Approximate its reliability.

[12 marks]

b. A gear set consists of a 16-tooth pinion driving a 40-tooth gear. The diametral pitch is 2, and the addendum and dedendum are 1/P and 1.25/P, respectively. The gears are cut using a pressure angle of 20^0.

i. Compute the circular pitch, the center distance and the radii of the base circle.

[5 marks]

ii. In mounting these gears, the center distance was incorrectly made ¼ inch larger. Compute the new values of the pressure angle and the pitch circle diameters.

[8 marks]

4. a. A complex engineering design network can be described by a reliability block diagram shown in **FIGURE Q4(a)**, where individual component reliabilities are given inside the blocks. In subsystem A, two components must operate for the subsystem to function successfully. Subsystem C has true parallel reliability.

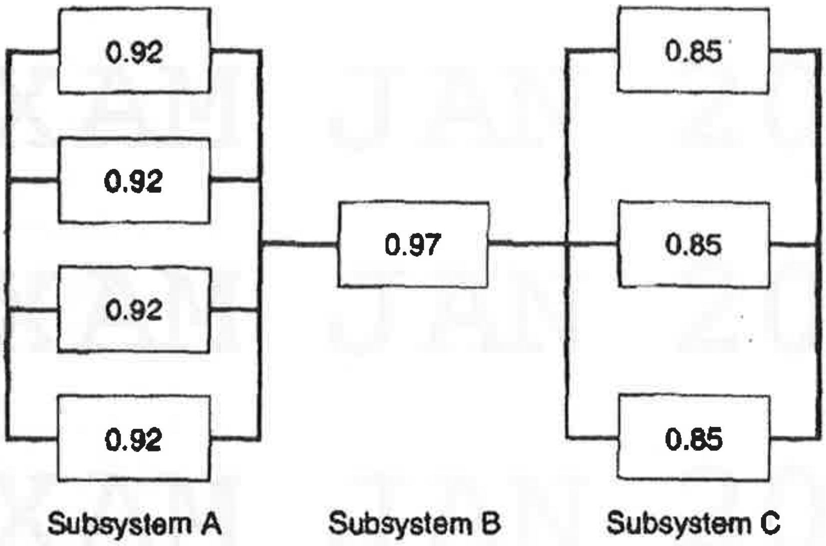

FIGURE Q4(a): Reliability Block diagram

i. Evaluate the reliability of each subsystem and the overall system reliability.

[9 marks]

ii. Identify the weak link in the reliability diagram and suggest a way to improve the reliability of the weakest link in the process.

[4 marks]

b. A heavy steel crane hook is being designed to support ladles filled with molten steel as they are transported through the steel mill. Usually, two crane hooks are needed for each ladle. Three design concepts have been proposed as below:

i. Built up from flame cut steel plates, welded together
ii. Built up from flame-cut steel plates, riveted together
iii. A monolithic cast steel hook

FIGURE Q4(b) shows the objective tree for the design of a crane hook. The design criteria by which the concepts will be evaluated are (1) material cost, (2) manufacturing cost, (3) time to produce a replacement hook if one fails, (4) durability, (5) reliability, (6) reparability. Using 11-point Likert scale, evaluate the best design concept.

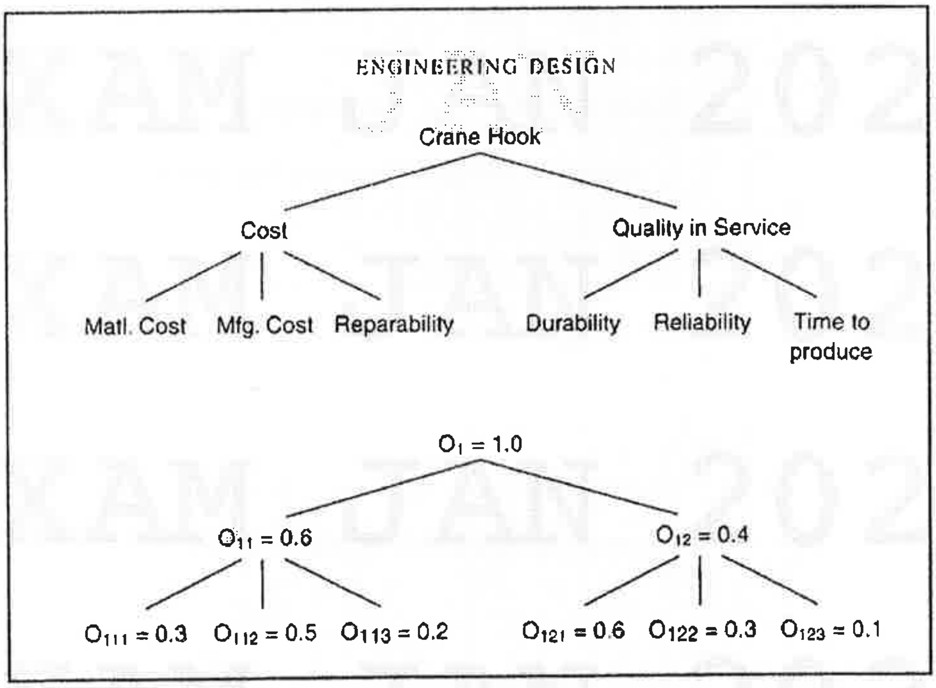

FIGURE Q4(b): Objective tree for the design of a crane hook.

[12 marks]

-END OF PAPER-

APPENDIX

Fasteners:

Fastener length (round up using Table A–17*):

For Fig. (*a*): $L > l + H$

For Fig. (*b*): $L > h + 1.5d$

Threaded length L_T: Inch series:

$$L_T = \begin{cases} 2d + \frac{1}{4}\text{ in}, & L \leq 6 \text{ in} \\ 2d + \frac{1}{2}\text{ in}, & L > 6 \text{ in} \end{cases}$$

Metric series:

$$L_T = \begin{cases} 2d + 6 \text{ mm}, & L \leq 125 \text{ mm}, d \leq 48 \text{ mm} \\ 2d + 12 \text{ mm}, & 125 < L \leq 200 \text{ mm} \\ 2d + 25 \text{ mm}, & L > 200 \text{ mm} \end{cases}$$

Length of unthreaded portion in grip: $l_d = L - L_T$

Length of threaded portion in grip: $l_t = l - l_d$

Area of unthreaded portion: $A_d = \pi d^2/4$

Area of threaded portion: A_t from Table 8–1 or 8–2

Fastener stiffness: $k_b = \dfrac{A_d A_t E}{A_d l_t + A_t l_d}$

Member stiffness: $\dfrac{k_m}{Ed} = A \exp(Bd/l)$

Load Percentage $C = K_b / (K_b + K_m)$

$T = K F_i d$ *where K is the torque coefficient*

$F_i = 0.9 F_p$ *where Fp is the proof load*

$F_p = A_t S_p$ where S_p = Proof strength & A_t is tensile stress area

Table 8-8

Stiffness Parameters of Various Member Materials[†]

[†]*Source:* J. Wileman, M. Choudury, and I. Green, "Computation of Member Stiffness in Bolted Connections," *Trans. ASME, J. Mech. Design*, vol. 113, December 1991, pp. 432–437.

Material Used	Poisson Ratio	Elastic GPa	Modulus Mpsi	A	B
Steel	0.291	207	30.0	0.787 15	0.628 73
Aluminum	0.334	71	10.3	0.796 70	0.638 16
Copper	0.326	119	17.3	0.795 68	0.635 53
Gray cast iron	0.211	100	14.5	0.778 71	0.616 16
General expression				0.789 52	0.629 14

Gears

$$W_t = \frac{60{,}000H}{\pi d n}$$

$pP = \pi$ *p = circular pitch & P = diametral pitch*

$r_b = r\cos\phi$

$$d = Nm$$

Where, N = number of teeth, m = module and d = diameter of gear

Torque$_{(shaft)}$ *= tangential force*$_{(gear)}$ *x radius*

Belts:

$$\theta_d = \pi - 2\sin^{-1}\left(\frac{D-d}{2C}\right) \qquad \theta_D = \pi + 2\sin^{-1}\left(\frac{D-d}{2C}\right)$$

$$\theta = \pi - 2.Sin^{-1}\left(\frac{D_1 - D_2}{2C}\right)$$ *where C = Center distance of Pulleys*

$$L_p = L + L_c$$

$$C = 0.25\left\{\left[L_p - \frac{\pi}{2}(D+d)\right] + \sqrt{\left[L_p - \frac{\pi}{2}(D+d)\right]^2 - 2(D-d)^2}\right\}$$

$$V = \frac{\pi D N}{60}$$

$$H_a = K_1 K_2 H_{tab}$$

$$H_d = H_{nom} K_s n_d$$

$$N_b \geq \frac{H_d}{H_a}$$

$$F_c = K_c \left(\frac{V}{1000}\right)^2$$

$$F_1 = F_c + \frac{\Delta F \exp(f\phi)}{\exp(f\phi) - 1}$$

$$F_2 = F_1 - \Delta F$$

$$F_i = \frac{F_1 + F_2}{2} - F_c$$

$$n_{fs} = \frac{H_a N_b}{H_{\text{nom}} K_s}$$

$$N_P = \left[\left(\frac{K}{T_1}\right)^{-b} + \left(\frac{K}{T_2}\right)^{-b}\right]^{-1}$$

$$t > N_p L_p / 3600\,V$$

Power transmitted by belt drive, $P = (T_1 - T_2).\,V$

$$\frac{T1}{T2} = e^{\mu\theta}$$ *where* μ is the friction between belt & pulley.

$$(F_1)_a = bF_a C_P C_V$$

Where C_p is pulley correction factor & C_v is the velocity correction factor.

Bearings:

$$x_D = \frac{L}{L_{10}} = \frac{60.L_D.n_D}{L_{10}}$$

$$C_{10} = a_f F_D \left[\frac{x_D}{x_0 + (\theta - x_0)(\ln 1/R_D)^{1/b}} \right]^{1/a}$$

$$R_D = \exp\left[-\left(\frac{x_D - x_0}{\theta - x_0} \right)^b \right]$$

$$x_B = x_D \left(\frac{F_D}{F_B} \right)^a$$

$$R = \exp\left(-\left\{ \frac{x_D \left(\frac{a_f F_D}{C_{10}} \right)^a - x_0}{\theta - x_0} \right\}^b \right)$$

Shaft:

$$P = 2\, \pi\, n\, T / 60$$

$$(T_{eq})^2 = (T)^2 + (M)^2$$

$$T_{eq.} = (\pi / 16).\, D^3 .\, T$$

True Parallel Reliability:

$$R_{system} = 1 - (1 - R_A)(1 - R_B) \ldots (1 - R_n)$$

The reliability of an n-out-of-m system:

$$R_{n|m} = \sum_{i=n}^{m} \binom{m}{i} R^i (1 - R)^{m-i}$$

$$\binom{m}{i} = \frac{m!}{i!\,(m-i)!}$$

Table 11.2: Dimensions and Load Ratings for Single-Row 02-Series Deep Groove and Angular-Contact Ball Bearings

Table 11–2

Dimensions and Load Ratings for Single-Row 02-Series Deep-Groove and Angular-Contact Ball Bearings

Bore, mm	OD, mm	Width, mm	Fillet Radius, mm	Shoulder Diameter, mm		Load Ratings, kN			
						Deep Groove		Angular Contact	
				d_S	d_H	C_{10}	C_0	C_{10}	C_0
10	30	9	0.6	12.5	27	5.07	2.24	4.94	2.12
12	32	10	0.6	14.5	28	6.89	3.10	7.02	3.05
15	35	11	0.6	17.5	31	7.80	3.55	8.06	3.65
17	40	12	0.6	19.5	34	9.56	4.50	9.95	4.75
20	47	14	1.0	25	41	12.7	6.20	13.3	6.55
25	52	15	1.0	30	47	14.0	6.95	14.8	7.65
30	62	16	1.0	35	55	19.5	10.0	20.3	11.0
35	72	17	1.0	41	65	25.5	13.7	27.0	15.0
40	80	18	1.0	46	72	30.7	16.6	31.9	18.6
45	85	19	1.0	52	77	33.2	18.6	35.8	21.2
50	90	20	1.0	56	82	35.1	19.6	37.7	22.8
55	100	21	1.5	63	90	43.6	25.0	46.2	28.5
60	110	22	1.5	70	99	47.5	28.0	55.9	35.5
65	120	23	1.5	74	109	55.9	34.0	63.7	41.5
70	125	24	1.5	79	114	61.8	37.5	68.9	45.5
75	130	25	1.5	86	119	66.3	40.5	71.5	49.0
80	140	26	2.0	93	127	70.2	45.0	80.6	55.0
85	150	28	2.0	99	136	83.2	53.0	90.4	63.0
90	160	30	2.0	104	146	95.6	62.0	106	73.5
95	170	32	2.0	110	156	108	69.5	121	85.0

Table 17.14: Belt Length Correction Factor K_2

Length Factor	Nominal Belt Length, m				
	A Belts	B Belts	C Belts	D Belts	E Belts
0.85	Up to 0.88	Up to 1.15	Up to 1.88	Up to 3.2	
0.90	0.95–1.15	1.2–1.5	2.03–2.4	3.6–4.05	Up to 4.88
0.95	1.2–1.38	1.55–1.88	2.63–3.0	4.33–5.25	5.25–6.0
1.00	1.5–1.88	1.95–2.43	3.2–3.95	6.0	6.75–7.5
1.05	1.95–2.25	2.63–3.0	4.05–4.88	6.75–8.25	8.25–9.75
1.10	2.4–2.8	3.2–3.6	5.25–6.0	9.0–10.5	10.5–12.0
1.15	3.0 and up	3.95–4.5	6.75–7.5	12.0	13.5–15.0
1.20		4.88 and up	8.25 and up	13.5 and up	16.5

*Multiply the rated power per belt by this factor to obtain the corrected power.

Table 17-16

Some V-Belt Parameters*

Belt Section	K_b	K_c
A	220	0.561
B	576	0.965
C	1 600	1.716
D	5 680	3.498
E	10 850	5.041
3V	230	0.425
5V	1098	1.217
8V	4830	3.288

*Data courtesy of Gates Rubber Co., Denver, Colo.

Table 17-11

Length Conversion Dimensions (Add the Listed Quantity to the Inside Circumference to Obtain the Pitch Length in mm)

Belt section	A	B	C	D	E
Quantity to be added	32	45	72	82	112

Table 17.17: Durability Parameters for some V-Belt sections

Belt Section	10^8 to 10^9 Force Peaks		10^9 to 10^{10} Force Peaks		Minimum Sheave Diameter, mm
	K	b	K	b	
A	2999	11.089			75
B	5309	10.926			125
C	9069	11.173			215
D	18 726	11.105			325
E	26 791	11.100			540
3V	3240	12.464	4726	10.153	66
5V	7360	12.593	10 653	10.283	177
8V	16 189	12.629	23 376	10.319	312

Table 17.13 : Angle of Contact Correction Factor K_1 for VV* and V-Flat drives.

$\frac{D-d}{C}$	θ, deg	K_1 VV	K_1 V Flat
0.00	180	1.00	0.75
0.10	174.3	0.99	0.76
0.20	166.5	0.97	0.78
0.30	162.7	0.96	0.79
0.40	156.9	0.94	0.80
0.50	151.0	0.93	0.81
0.60	145.1	0.91	0.83
0.70	139.0	0.89	0.84
0.80	132.8	0.87	0.85
0.90	126.5	0.85	0.85
1.00	120.0	0.82	0.82
1.10	113.3	0.80	0.80
1.20	106.3	0.77	0.77
1.30	98.9	0.73	0.73
1.40	91.1	0.70	0.70
1.50	82.8	0.65	0.65

*A curve fit for the VV column in terms of θ is
$K_1 = 0.143\,543 + 0.007\,46\,8\,\theta - 0.000\,015\,052\,\theta^2$
in the range $90° \leq \theta \leq 180°$.

Table 17.12: Power Ratings of Standard V-belts

Belt Section	Sheave Pitch Diameter, mm	Belt Speed, m/s 5	10	15	20	25
A	65	0.35	0.46	0.40	0.11	
	75	0.49	0.75	0.84	0.69	0.28
	85	0.60	0.98	1.17	1.64	0.84
	95	0.69	1.16	1.43	1.49	1.28
	105	0.77	1.30	1.64	1.78	1.63
	115	0.83	1.41	1.82	2.01	1.93
	125 and up	0.87	1.51	1.97	2.21	2.16
B	105	0.80	1.18	1.25	0.94	0.16
	115	0.95	1.48	1.71	1.55	0.92
	125	1.07	1.74	2.09	2.06	1.57
	135	1.19	1.95	2.42	2.49	2.10
	145	1.28	2.14	2.69	2.87	2.57
	155	1.36	2.31	2.94	3.19	2.98
	165	1.43	2.45	3.16	3.48	3.34
	175 and up	1.50	2.58	3.35	3.74	3.66
C	150	1.37	1.98	2.03	1.40	
	175	1.85	2.94	3.46	3.31	2.33
	200	2.21	3.66	4.54	4.74	4.12
	225	2.49	4.21	5.38	5.86	5.51
	250	2.72	4.66	6.05	7.16	6.63
	275	2.89	5.03	6.59	7.46	7.53
	300 and up	3.05	5.33	7.06	8.13	8.28
D	250	3.09	4.57	4.89	3.80	1.01
	275	3.73	5.84	6.80	6.34	4.19
	300	4.26	6.91	8.36	8.50	6.85
	325	4.71	7.83	9.70	10.30	9.10
	350	5.09	8.58	10.89	11.79	11.04
	375	5.42	9.25	11.86	13.13	12.68
	400	5.71	9.85	12.76	14.32	14.17
	425 and up	5.98	10.37	13.50	15.37	15.44
E	400	6.48	10.44	13.06	13.50	11.41
	450	7.40	12.46	15.82	17.16	16.04
	500	8.13	13.95	18.05	20.07	19.69
	550	8.73	15.14	19.84	22.53	22.75
	600	9.25	16.11	21.34	24.54	25.22
	650	9.70	17.01	22.60	26.19	27.38
	700 and up	10.00	17.68	23.72	27.68	29.17