UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	**:**	**MEB3023 - MECHANICAL ENGINEERING DESIGN**
DATE	**:**	**13 AUGUST 2024 (TUESDAY)**
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 appendices.

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

1. Engineering design involves material selection and creating provisions to address any potential causes that could lead to unreliability in the final product.

   a. Describe **FOUR (4)** general factors that must be considered in selecting a material for a mechanical product such as power screw, helical compression springs, shafts, and gears.

   [8 marks]

   b. Discuss **THREE (3)** design-related provisions that can be used to ensure the reliability of a new product.

   [6 marks]

   c. Clusters of moving loading arms (MLAs) are commonly used for loading and unloading operations in the crude oil transportation business. In one specific design, an MLA cluster may have one hydraulic processing unit (HPU) providing the energy needed to operate four MLAs. **FIGURE Q1** shows a reliability block diagram for such a design. At any given time, the operator can choose which MLA to operate. However, for safety reasons, it is not allowed to run more than one MLA simultaneously.

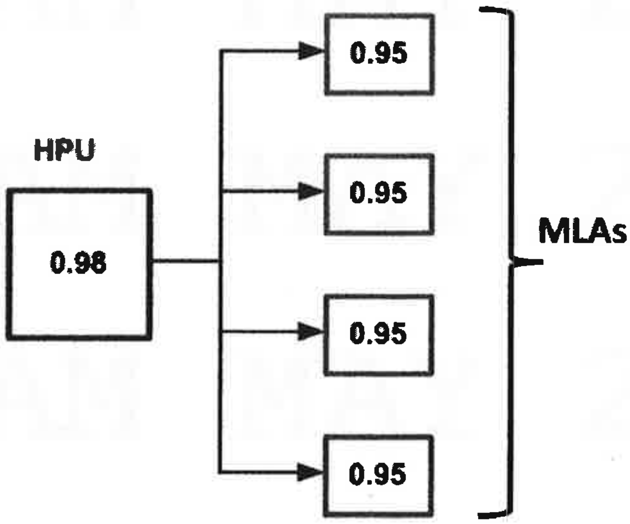


FIGURE Q1

i. Determine the system reliability for a given loading or unloading operation.

[6 marks]

ii. Discuss how to get the system reliability if the numbers in the reliability block diagram represent failure rates.

[5 marks]

2. A pantograph is commonly used in modern electric-driven trains, tramways, and buses to transfer power through contact with an overhead electrical line. The pantograph allows the vehicle to draw high-voltage electricity from the overhead wires while traveling at high speeds. **FIGURE Q2** shows spring-loaded pantograph as conceived by EC Engineering company. The spring is essential to provide a constant contact force between the pantograph's current-collecting shoe and the overhead contact wire. This spring force is crucial for maintaining reliable electrical contact and efficient power transfer.

TABLE Q2

Parameter	Value
Total force on the spring	70 to 100 N
Maximum deflection from free length, L_0	not more than 50 mm
Minimum wire diameter, d	5 mm
Outside diameter, OD	100 mm
Material	ASTM A229 (density, $\rho = 7850$ kg/m^3)

As a mechanical engineer, you are required to design the spring, assuming the specification provided in **TABLE Q2**. Your design analysis needs to include:

a. calculation of the free length,

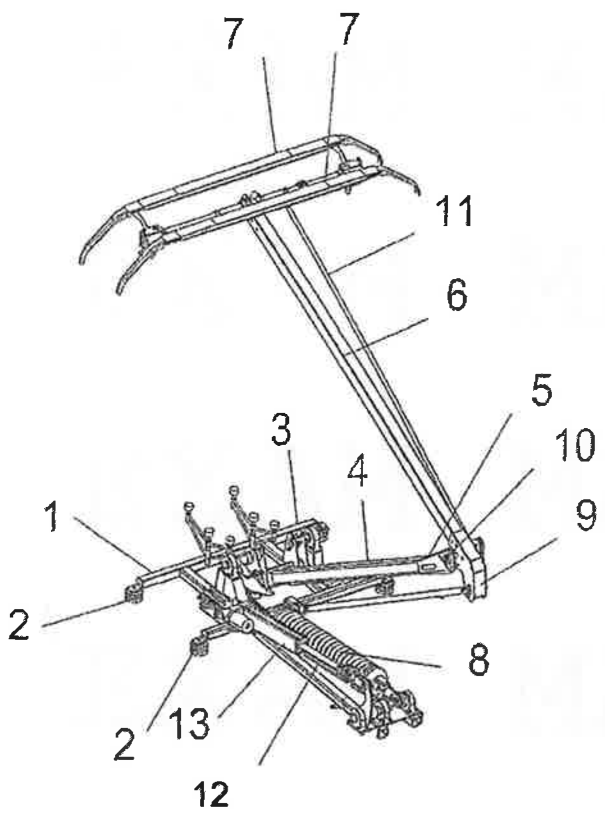
[15 marks]

b. assessment of the potential for buckling, and

[5 marks]

c. estimation of natural frequency of the spring.

[5 marks]



No.	Name
1	Frame
2	Support insulator
3	Eccentric shaft
4	Girder
5	Fork
6	Upper arm
7	Contact shoes
8	Tension spring
9	Boom
10	Articulated joint
11	Radius arm
12	Spindle
13	Lifting drive

FIGURE Q2

3. Bolted joints are widely used in industrial applications due to their high strength, ease of assembly, cost-effectiveness, and flexibility. The upside-down steel A frame shown in **FIGURE Q3** is to be bolted to steel beams on the ceiling of a machine room using ISO grade 8.8 bolts (S_p = 600 MPa, E = 207 GPa). This frame is designed to support the 40 kN vertical load as illustrated. The total bolt grip is 48 mm, which includes the thickness of the steel beam, the A-frame feet, and the steel washers used. The bolts are size M20 × 2.5. The rest of the specification are as stated in **TABLE Q3**.

TABLE Q3

Parameter		Value
Nut hight, H (mm)		8
Bolt dimensions	L_T (mm)	46
	l_t (mm)	14
	l_d (mm)	34
	A_t (mm^2)	245
Washer outer diameter, d_w (mm)		39

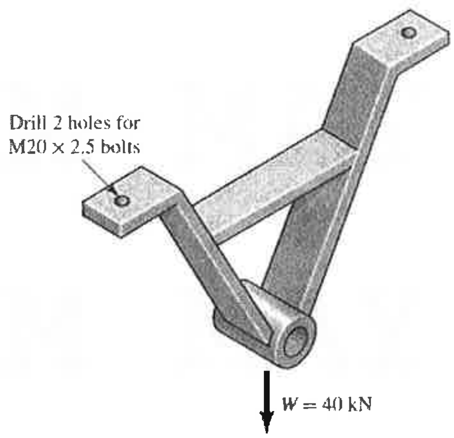


FIGURE Q3

a. Determine

i. the stiffness of the bolt and steel members, respectively, and

[10 marks]

ii. the tightening torque required for the joint to be permanent, assuming lubricated fasteners.

[5 marks]

b. Assess the factor of safety guarding the bolted joint against

i. yielding, and

[5 marks]

ii. overload.

[5 marks]

4. You are required to design a power transmission system for a belt conveyor driven by a 150 kW electric motor through a v-belt drive and double-reduction grearbox as shown in **FIGURE Q4**. The conveyor drive end will operate at 475 rpm. The gearbox will utilize spur gears with a 20° pressure angle. A safety factor of 1.5 is considered adequate for the shaft design.

TABLE Q4

	Gear 1	Gear 2	Gear 3	Gear 4
Number of Teeth, Z_i $(i = 1,2,3,4)$	16	48	18	36
Module (mm)	5		7	

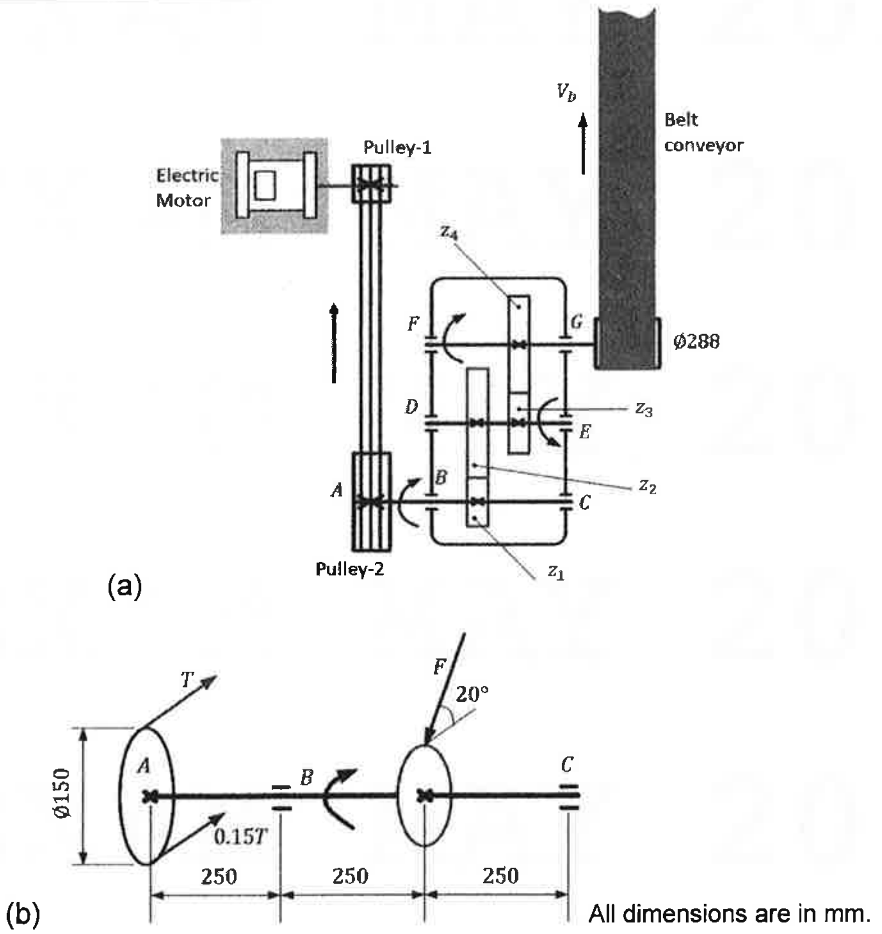


FIGURE Q4

a. Determine

i. pitch diameters of the gears, and

[5 marks]

ii. rotational speed of shaft ABC.

[5 marks]

b. Design shaft ABC by assuming AISI-1035 HR steel and based on the geometry data provided in **FIGURE Q4(b)**.

[10 marks]

c. Select a suitable cylindrical roller bearing for use at supports B and C, assuming a desired life of 50,000 hours and reliability of 0.9. A load application factor of 1.3 is considered appropriate.

[5 marks]

- END OF PAPER -

APPENDIX - A

FORMULAE FOR RELIABILITY AND DESIGN CALCULATION

A.1 Reliability

- Combination formula: $C(m,n) = \binom{m}{n} = \frac{m!}{n!(m-n)!}$
- System in series: $R_s = R_A \times R_B \times R_C \times \ldots \times R_n = \prod_{i=1}^{n} R_i$
- System in parallel:

$$R_s = 1 - (1 - R_A) \times (1 - R_B) \times \ldots \times (1 - R_n) = 1 - \prod_{i=1}^{n}(1 - R_i)$$

- n –out-of-m system: $R_{\left(\frac{n}{m}\right)} = \sum_{i=n}^{m} \binom{m}{n} R^i (1-R)^{m-i}$

A.2 HELICAL COMPRESSION SPRINGS

- Spring Index: $C = \frac{D}{d}$
- Minimum Tensile Strength: $S_{ut} = \frac{A_p}{d^m}$
- Shear Stress: $\tau = K_B \times \frac{8FD}{\pi d^3}$
- Shear Stress correction factor: $K_B = \frac{4C+2}{4C-3}$
- The condition for absolute stability is the free length: $L_0 < 2.63\frac{D}{\alpha}$
- Spring stiffness: $k = \frac{F}{y} = \frac{d^4 G}{8D^3 N_a}$

  where F is the force, N_a is the number of active coils, and y is the deflection.
- Torsional yield strength for music wire and hard-drawn steel spring:

$$S_{sy} = 0.45\, S_{ut}$$

- Natural frequency of helical compression spring:

$$f = \sqrt{\frac{k}{m}} \quad \text{where } m = \left(\frac{1}{4}\right)\pi^2 d^2 D N_a \rho; \ \rho \text{ is density.}$$

A.3 SHAFT DESIGN

- Shear stress, $\tau_{xy} = \frac{cT}{J}$, where $J = \frac{\pi d^4}{32}$
- Bending stress, $\sigma_x = \frac{cM}{I}$, where $I = \frac{\pi d^4}{64}$
- Principal stress, $\sigma_1 , \sigma_2 = \frac{\sigma_x}{2} \pm \sqrt{\tau_{xy}^2 + \frac{\sigma_x{}^2}{4}}$,
- Von Mises Stress: $\sigma_e = (\sigma_1{}^2 + \sigma_2{}^2 - \sigma_1\sigma_2)^{0.5}$ or

$$\sigma_e = \left(\sigma_x{}^2 + 3\tau_{xy}{}^2\right)^{0.5}$$

- The Distortion Energy Theory predicts that failure will not occur if: $\sigma_e < \frac{S_y}{n_S}$ or

$$d^3 > \frac{16}{\pi\sigma_e}(4M^2 + 3T^2)^{0.5}.$$

Where, d is the shaft diameter.

A.4 BEARING SELECTION

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

$$x_D = \frac{60 \times (\text{Required Design Life in hours}) \times n_D}{10^6}$$

Where,

F_D	maximum radial load in kN
R_D	reliability goal.
n_D	rotational speed in rev/min
a_f	load application factor.
a	a constant and is 3 for ball bearings.
b	Weibull parameter and is equal to 1.483.
x_0	Weibull parameter and is equal to 0.02.
θ	Weibull parameter and is equal to 4.459.

A.5 THREADED MEMBERS

- Equivalent stiffness of a bolt, $k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$
- Equivalent stiffness of a member, $k_m = \frac{0.5774\pi E d}{ln\left[\left(\frac{1.1547t+D-d}{1.1547t+D+d}\right)\left(\frac{D+d}{D-d}\right)\right]}$

  Where t is the total grip, d is the bold diameter, and $D = 1.5d$

- Bolt torque: $T = K \times F_i d$
- Initial tension,
  - $F_i = 0.75\mathrm{A_t} S_p$ for non-permanent connection, and
  - $F_i = 0.90\mathrm{A_t} S_p$ for permanent connection.
- Yielding factor of safety: $n_p = \frac{S_p A_t}{CP + F_I}$
- Overload factor: $n_L = \frac{S_p A_t - F_i}{CP}$

TABLE A.1: Torque Factor K

Bolt Condition	K
Non-plated, black finish	0.30
Zinc-plated	0.20
Lubricated	0.18
Cadmium-plated	0.16
With Bowman Anti-Seize	0.12
With Bowman-Grip nuts	0.09

APPENDIX - B

TABLES FOR DESIGN RELEVANT DATA

B.1 TABLES FOR SPRING DESIGN

TABLE B.1: Formulae for the Dimensional Characteristics of Compression Springs.

Material	Type of Spring Ends			
	Plain	Plain & Ground	Squared or Closed	Squared & Ground
End coils, N_e	0	1	2	2
Total Coils, N_t	N_a	$N_a + 1$	$N_a + 2$	$N_a + 2$
Free Length, L_O	$pN_a + d$	$p(N_a + 1)$	$pN_a + 3d$	$pN_a + 2d$
Solid Length, L_S	$d(N_t + 1)$	dN_t	$d(N_t + 1)$	dN_t
Pitch, p	$(L_O - d)/N_a$	$(L_O / (N_a + 1)$	$(L_O - 3d)/N_a$	$(L_O - 2d)/N_a$

N_a is the number of active coils.

TABLE B.2: Constants A and m of $S_{ut} = A/d^m$ for Estimating Minimum Tensile Strength of Common Spring Wires (Source from Design Handbook, 1987, Associated Spring).

Material	ASTM No.	Exponent m	Diameter, mm	A, MPa, mm^m	Relative Cost of Wire
Music Wire	A228	0.145	0.10-6.5	2211	2.6
OQ & T Wire	A229	0.187	0.5-12.7	1855	1.3
Hard Drawn Wire	A227	0.190	0.7-12.7	1783	1.0
Chrome-Vanadium Wire	A232	0.168	0.8-11.1	2005	3.1
Chrome-Silicon Wire	A401	0.108	1.6-9.5	1974	4.0

TABLE B.3: Maximum Allowable Torsional Stresses for Helical Compression Springs in Static Application.

Material	Type of Spring Ends	
	Before Set Removed (including K_w and K_B)	After Set Removed (includes K_S)
Music wire and cold-drawn carbon steel	45	60-70
Hardened and tempered carbon and low-alloy steel	50	65-75
Austenitic stainless steels	35	55-65
Nonferrous alloys	35	55-65

TABLE B.4: Mechanical Properties of Some Spring Wires

Material	Elastic Limit, Percent of S_{ut}		Diameter, d, mm	E, GPa	G, GPa
	Tension	Torsion			
Music wire A228	65-75	45-60	< 0.8	203.4	82.7
			0.8 – 1.6	200	81.7
			1.61 – 3	196.5	81.0
			> 3	193	80.0
HD Spring A227	60-70	45-55	< 0.8	198.6	80.7
			0.8 – 1.6	197.9	80.0
			1.61 – 3	197.2	79.3
			> 3	196.5	78.6
Oil Tempered A229	85-90	45-50		196.5	77.2
Valve Spring A230	85-90	50-60		203.4	77.2

Note: Torsional yield strength for music wire and hard-drawn steel spring: $S_{sy} = 0.45S_{ut}$

TABLE B.5: End-Condition Constants α for Helical Compression Springs

End Condition	Constant α
Spring supported between flat parallel surfaces (fixed ends)	0.5
One end supported by flat surface perpendicular to spring axis (fixed); other end pivoted (hinged)	0.707
Both ends pivoted (hinged)	1
One end clamped; other end free	2

B.3 TABLES FOR SHAFT MATERIAL

TABLE B.6: Deterministic ASTM Minimum Tensile and Yield Strengths for Some Hot-Rolled (HR) and Cold-Drawn (CD) Steels.

AISI No.	Processing	Tensile Strength, MPa	Yield Strength, MPa	Brinell Hardness
1006	HR	300	170	86
	CD	330	280	95
1010	HR	320	180	95
	CD	370	300	105
1015	HR	340	190	101
	CD	390	320	111
1018	HR	400	220	116
	CD	440	370	126
1020	HR	380	210	111
	CD	470	390	131
1030	HR	470	260	137
	CD	520	440	149
1035	HR	500	270	143
	CD	550	460	163

B.4 TABLES FOR STANDARD CYLINDERICAL ROLLER BEARINGS

TABLE B.7: Dimensions and load ratings for 02-Series and 03-Series Cylindrical Roller Bearings.

	02-Series				03-Series			
Bore, mm	OD, mm	Width, mm	Load Rating, kN C_{10}	C_0	OD, mm	Width, mm	Load Rating, kN C_{10}	C_0
25	52	15	16.8	8.8	62	17	28.6	15.0
30	62	16	22.4	12.0	72	19	36.9	20.0
35	72	17	31.9	17.6	80	21	44.6	27.1
40	80	18	41.8	24.0	90	23	56.1	32.5
45	85	19	44.0	25.5	100	25	72.1	45.4
50	90	20	45.7	27.5	110	27	88.0	52.0
55	100	21	56.1	34.0	120	29	102	67.2
60	110	22	64.4	43.1	130	31	123	76.5
65	120	23	76.5	51.2	140	33	138	85.0
70	125	24	79.2	51.2	150	35	151	102
75	130	25	93.1	63.2	160	37	183	125
80	140	26	106	69.4	170	39	190	125
85	150	28	119	78.3	180	41	212	149
90	160	30	142	100	190	43	242	160
95	170	32	165	112	200	45	264	189
100	180	34	183	125	215	47	303	220
110	200	38	229	167	240	50	391	304
120	215	40	260	183	260	55	457	340
130	230	40	270	193	280	58	539	408
140	250	42	319	240	300	62	682	454
150	270	45	446	260	320	65	781	502