UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
JANUARY 2024 SEMESTER

COURSE	**:**	**MEB3023 - MECHANICAL ENGINEERING DESIGN**
DATE	**:**	**2 APRIL 2024 (TUESDAY)**
TIME	**:**	**9.00 AM - 12.00 NOON (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 **FOURTEEN (14)** pages in this Question Booklet including the cover page and appendices.

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

1. Engineering design is always aimed at achieving high level of reliability for a new design despite constraints likely to originate from the customer, compliance requirement from standards, and limitations in technical knowhow.

   a. Describe **THREE (3)** methods which can be used in engineering design practice to improve reliability of a new design.

   [10 marks]

   b. **FIGURE Q4** shows a reliability block diagram for an engineering system. Determine the overall system reliability.

   [10 marks]

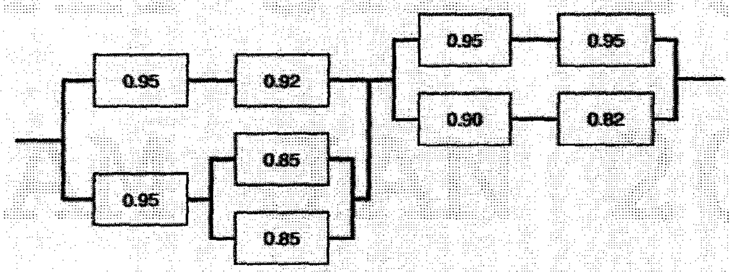

FIGURE Q4

   c. Discuss how to get the system reliability if the numbers in the reliability block diagram represent failure rate.

   [5 marks]

2. **FIGURE Q2** shows a spring support (in shattered form) for a pipe. The support was intended to restrain the pipe movement induced by fluid flow and outside sources such as wind and seismic events. It is reported that the spring has failed due to hydrogen embrittlement. You, as an engineer, are required to design a replacement for the spring assuming the following specification:

TABLE Q2

Parameter	Value
Total weight on the spring	10 kN
Maximum deflection from free length	not more than 50 mm
Minimum wire diameter	10 mm
Outside diameter	100 mm
Total number of coils	14

FIGURE Q2

a. Design the helical coil compression spring. Include all the necessary assumptions

[15 marks]

b. Perform an assessment on the following:

   i. the new design to confirm if the spring might buckle in service, and

   [5 marks]

   ii. the implications on static deflection if **TWO (2)** springs are to be used. Assume that the load is equally shared among the two springs.

   [5 marks]

3. General assembly drawing of a 5" pipeline smart plug is shown in **FIGURE Q3.** In operation, the gripper and seal need to be sufficiently in contact with the inner wall of a pipe (not shown in the figure) to avoid any potential leak of the blocked fluid. Assuming collinearity in the assembly of the plug, the stud (shaft) experiences axial tensile load while the rest of the components are exposed to compressive and contact loads. The loading originates from the toque, T applied on the hexagonal (HEX) nuts.

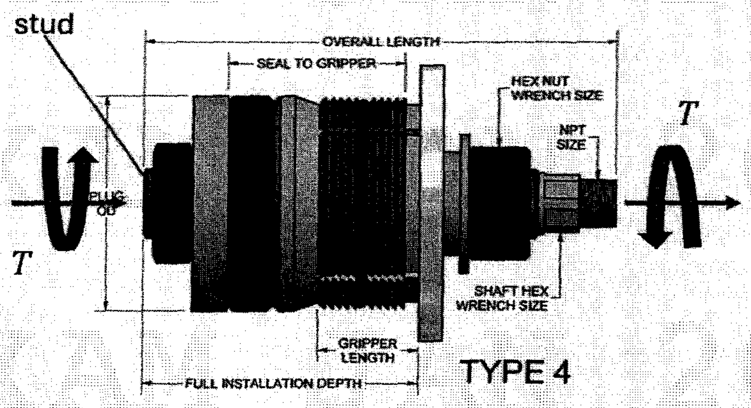

FIGURE Q3

a. Representing material properties of the stud by modulus of elasticity, E, strength, σ_f and density, ρ , formulate the equation for the performance index if the design limiting factor is

   i. strength of the stud, and

   [5 marks]

   ii. stiffness of the stud. Assume cost coefficient, c in USD/kg

   [5 marks]

b. Candidate materials for the stud is provided in **TABLE Q3.**

TABLE Q3

Material	σ_f, MPa	E, GPa	ρ, kg.m^{-3}	Approximate Cost. $/kg
AISI 1020 HR	207	207	7805	0.06
AISI 1020 CD	390	207		0.07
AISI 1040 Q&T	552	207		0.08
AISI 4140 Q&T	1140	207		0.18
Titanium Alloy (Ti-6Al-4V)	830	114	4429	1.56

i. Using the solution in **part (a)(i)**, select the best material based on performance and cost.

[5 marks]

ii. Select the best material using weighted decision matrix method if the selection criteria and weightage for relative importance of each criterion to the function are as stated below:

- Strength (0.3), density (0.1), cost (0.35), performance index for stiffness (0.25)

[10 marks]

4. The concept for a conveyor system driven by an electric motor through a v-belt drive and double-reduction grearbox is shown in **FIGURE Q4**. The power supplied by the electric motor is 150 kW. All the gears are expected to be spur gears with a pressure angle of 20°.

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	

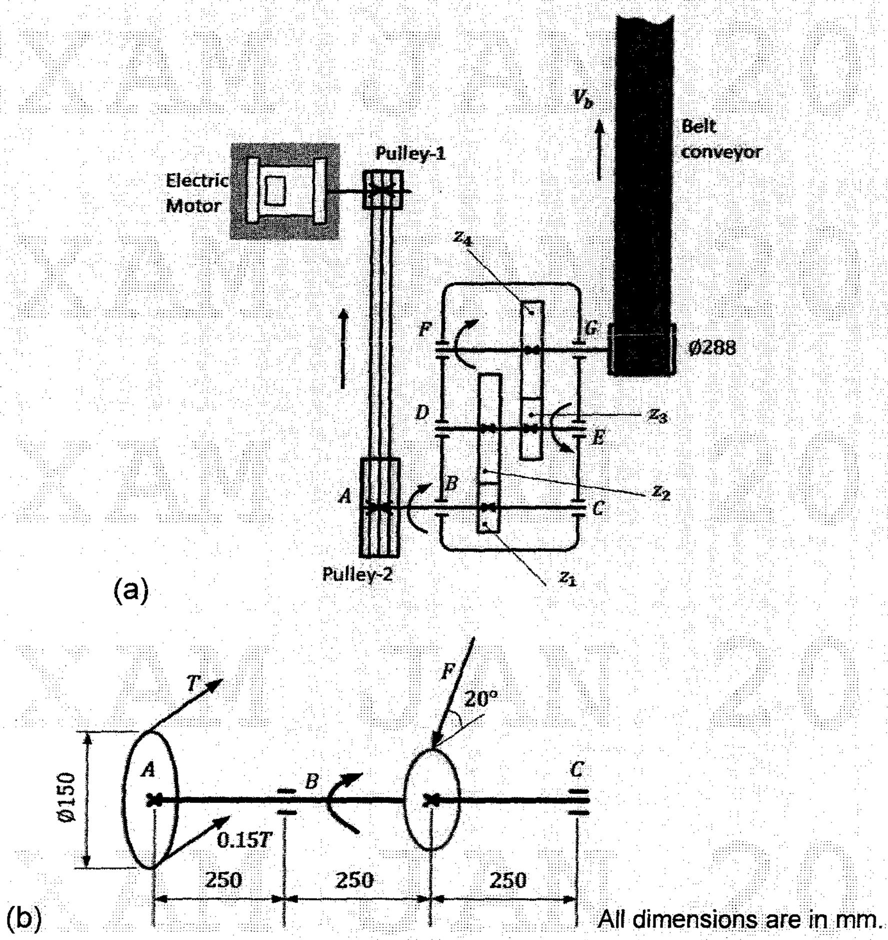

FIGURE Q4

a. Determine pitch diameters of the gears.

[5 marks]

b. If shaft ABC rotates at 2850 RPM, calculate the corresponding speed, V_b of the conveyor.

[5 marks]

c. Design shaft ABC by assuming AISI-1035 HR steel and a safety factor of 1.5 for the shaft material.

[10 marks]

d. Referring to **part 1(c)**, select cylindrical roller bearings for use at supports B and C. Assume that the desired life and reliability of one bearing is 50,000 hours and 0.9, respectively. A load application factor of 1.3 is considered appropriate.

[5 marks]

- END OF PAPER -

APPENDIX - A

FORMULAE FOR DESIGN CALCULATION

A.1 FLAT BELT DRIVE

- Corrected allowable power or power capacity:

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

where,

K_s is the service factor and

n_d the design factor for exigencies

- Torque: $T = H_{nom} K_s n_d / (2\pi n/60)$
- The factor of safety: $n_{fs} = H_a / H_{nom} K_s$

A.2 HELICAL COMPRESSION SPRINGS

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

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

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

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

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

<u>Note:</u> 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