NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2023-2024

MA4001 - ENGINEERING DESIGN
MA4011 - ENGINEERING PRODUCT DESIGN
MA4012 – MECHATRONICS ENGINEERING DESIGN

Nov/Dec 2023 Time Allowed: 2 ½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SEVEN (7)** pages.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination.
5. A material selection chart to answer Question 2 will be given separately.

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1 (a) A team of students is tasked with the design of a beach cleaning machine to clean the local beach (photo shown in Figure 1(a)) which is covered with trash washed up by the waves or discarded by careless beach goers. Different types of trash are sometimes covered by the sand as shown in Figure 1(b) which makes cleaning a challenge. The machine will be pulled behind a tractor which also provide power through a shaft which connects to the machine. After brainstorming, they created a Function Analysis diagram shown in Figure 1(c).

Figure 1(a): Photos of a beach covered with trash

Note: Question 1 continues page 2.
Figures 1b & 1c appear on page 2.

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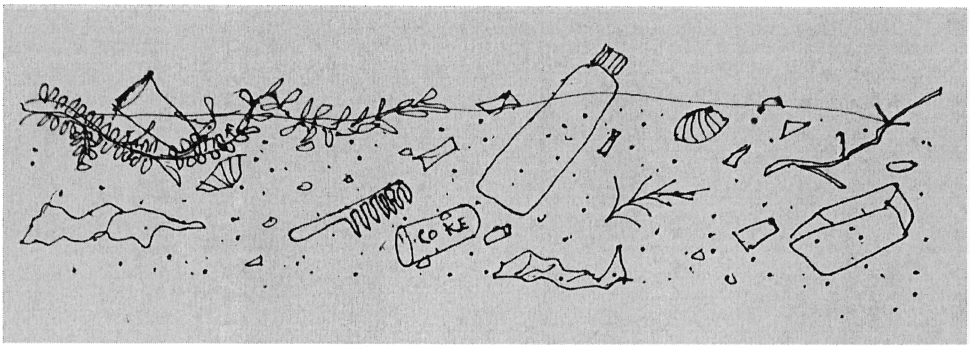

Figure 1(b): Types of trash on a beach, some are submerged in sand

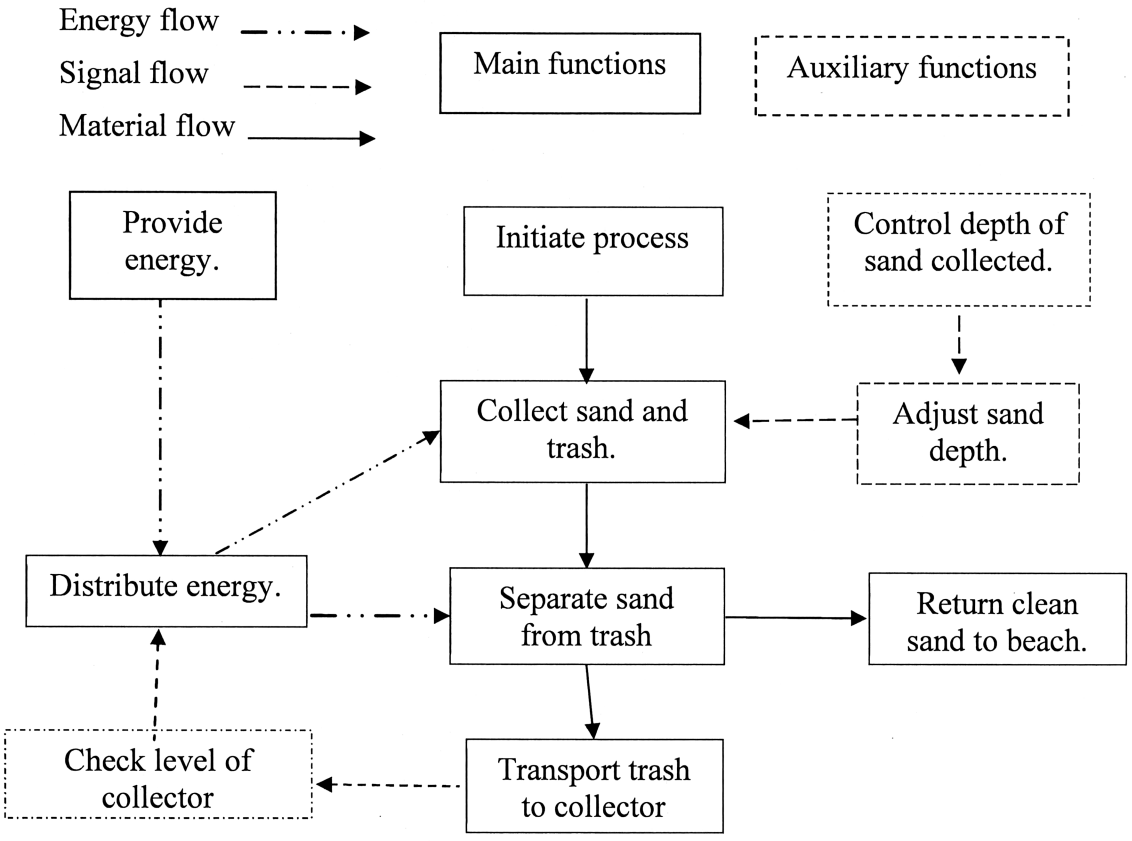

Figure 1(c): Function Analysis Diagram (FAD) developed by the team

Imagine that you are a member of the team:

(i) List FIVE design requirements with short explanatory notes for the beach cleaning machine.

(5 marks)

Note: Question 1 continues on page 3.

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(ii) Explain the purpose of: Function Analysis Diagram (FAD), the Main and Auxiliary functions and Morphological chart.

(3 marks)

(iii) Choose THREE main and ONE auxiliary functions from Figure 1(c), and sketch one technical solution for each function and show their working principles by clearly labelled sketches. Note that simple mechanical devices are preferred, and robotic arms are not considered as appropriate solutions. Oversimplistic sketches are also not acceptable.

(8 marks)

(b) (i) By drawing isometric and exploded drawings of the individual parts, sketch out the force flow lines from the load to the runways of the gantry crane shown in Figure 2.

(3 marks)

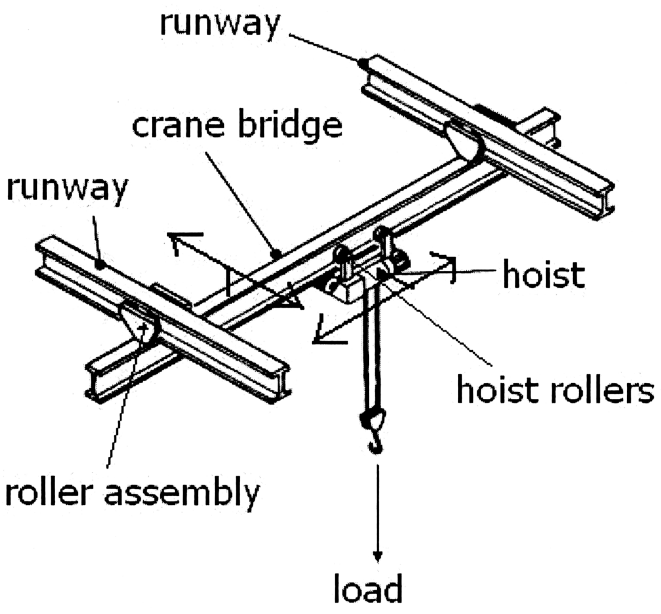

Figure 2: Gantry crane lifting a load

(ii) State the Rules of Embodiment Design, explain the 3 phases of Safety Rule and elaborate how you would apply the rules for Direct, Indirect Safety and Warnings specifically to the product in Figure 2.

(3 marks)

(iii) For Direct Safety, apply FMEA (Failure Modes and Effect Analysis) to ensure the most critical of the component (of your choice in Figure 2) is safe at the maximum design load. Show the steps of FMEA and making suitable assumptions, describe the calculation based upon Mechanics of Solid theory to ensure Direct Safety. Note: There is no need to show numerical calculations, only descriptive answer is needed.

(3 marks)

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2. MAE students are asked to identify suitable materials for a portable deployable bridge, modelled as a set of two beams upon which the wheels of the truck moves to cross a trench or a small lake. The bridge should be *light weight* to be carried in the truck and can be considered as a solid rectangular beam of fixed variables length, L, width, w, and unspecified thickness, t. Under operation, consider the bridge panel to be a simply supported beam with uniformly distributed load, F, (load per unit length) and it should neither deflect more than δ_o nor fail by fracture or yielding. As a general guideline, δ_o should be less than or equal to $L/200$. Answer the following questions:

(a) What are the *function*, *objective(s)*, *constraint(s)*, *free* and *fixed variable(s)* of the design? Explain whether it is a fully determined, over-constrained or under-constrained problem?

(5 marks)

(b) Determine the material performance indices for the bridge design and express a coupling equation relating the material indices, given the following,

- maximum deflection at the centre of the beam is $\delta = (5FL^4/385EI)$,
- bending stress is $\sigma = (FL^2/8Z)$

where, second moment of area, $I = \frac{wt^3}{12}$, section modulus, $Z = \frac{wt^2}{6}$ and E is the Young's modulus.

(10 marks)

(c) Using the material selection chart provided, identify materials for the bridge design if F = 37 *MN/m*, L = 10 *m*, w = 1 *m*, and comment on them. Clearly explain the methodology you adopted and show your work on the chart.

(5 marks)

(d) Considering failure based on the maximum stress to be dominating, identify most suitable bridge material from those listed in Table 1 for minimum cost and environmental impact (measured in terms of energy content in MJ/kg) in-addition to being light-weight. Given the exchange constants for mass (or weight) and energy content as 10 *$/kg* and 25 *$/MJ*, respectively.

(5 marks)

Table 1: Materials choice for deployable bridge.

Material	Density (kg/m^3)	Failure stress (MPa)	Cost, ($/kg)	Energy content (MJ/kg)
Low alloy steel	7800	600	1.0	30
Aluminum alloys	2700	350	3.0	175
CFRP	1500	800	60.0	260
Hard oak wood along grains	850	50	9.0	15

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3 (a) The components of an automation system are shown in Figure 3a.

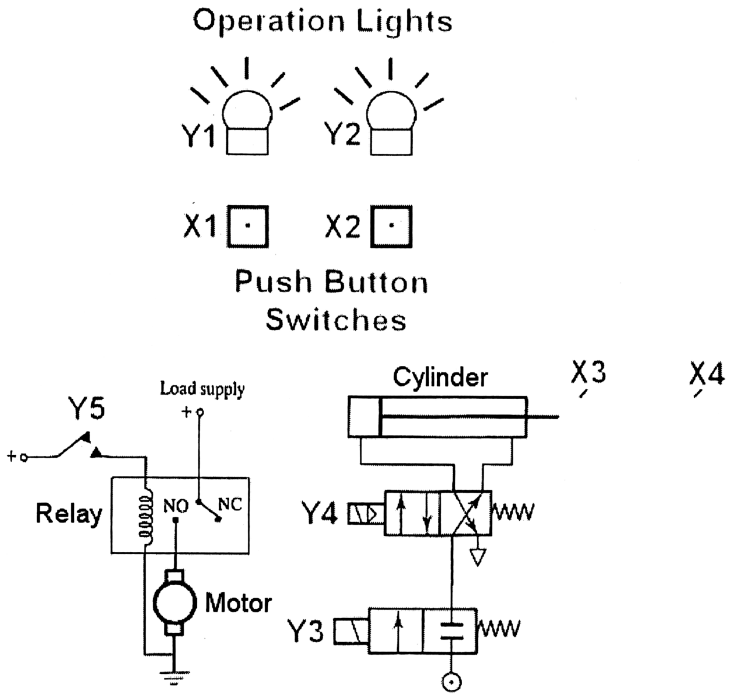

Figure 3a

The operation of the process is described as follows;

When button X1 is momentarily pressed, operation light Y1 will light up and stay on. Main air supply Y3 will then turn on. After 5 secs, pneumatic cylinder Y4 will extend from X3 to X4. When the cylinder has fully extended, Motor Y5 will then turn on and stay on.

When button X2 is momentarily pressed, operation light Y2 will light up and stay on. It will also turn off operation light Y1 immediately. The motor will stop and the cylinder will retract from position X4 to X3 position.

Draw a ladder diagram to achieve the above operation. The ladder diagram must be programmed such that after X2 has turned off the operation, pressing X1 later can start the operation again.

Use T1 for the 5 sec timer.

(14 marks)

Note: Question 3 continues on page 6.

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(b) A design of a hoist is shown in Figure 3b. It is driven by an electric motor coupled to a drum through a 2-stage gear train (Gear set A and Gear Set B). The load is connected to a pulley before it is connected to the drum creating a further 2:1 mechancial advantage for the hoist. The electric motor has a speed of 950 rpm and provides a torque of 15Nm. The drum that the cable coils around has a diameter of 250mm.

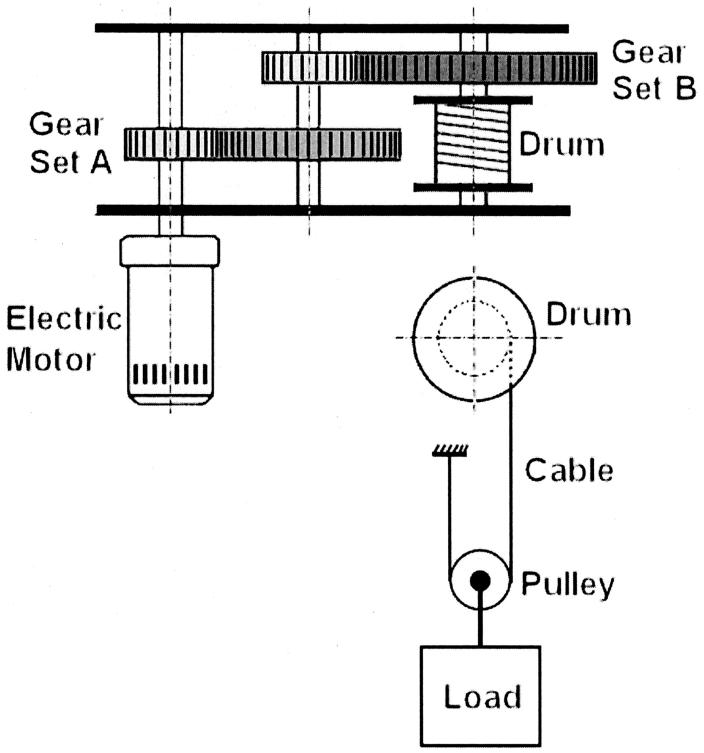

Figure 3b

(i) The load is designed to be hoisted with a linear speed of at least 0.2m/s. Calculate the total gear ratio of the 2-stage gear train in order to achieve this design requirement.

(4 marks)

(ii) Calculate the allowable load (N) that the electric motor can lift through the 2-stage drive train and pulley. The overall efficiency of the hoist system is 70%.

(3 marks)

(iii) Recommend ways to improve the overall efficiency of the hoist system as well as its acceleration response.

(4 marks)

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4. A hydraulic motor is used to drive directly a hoisting drum having a diameter of 0.6m. The maximum hoisting load is 1000 kg. The hydraulic motor rotates at 30 rpm and the pressure drop over the hydraulic motor is 140 bars. The overall efficiency and torque efficiency of the hydraulic motor are 0.90 and 0.94 respectively.

(a) Calculate the hoisting torque of the system, the fluid flow rate to the hydraulic motor and the output power of the hydraulic motor.

(8 marks)

(b) The maximum pressure set by the relief valve is 200 bars, calculate the power required to drive the hydraulic pump when it is operating at 140 bars. The overall efficiency of the hydraulic pump is 0.90.

(5 marks)

(c) Sketch a complete hydraulic circuit of a reversible closed-loop hydrostatic transmission for the hoisting operation. When the direction of rotation of the hoisting drum is suddenly reversed, the hydrostatic transmission will be subjected to pressure surges. Incorporate modifications in the hydraulic circuit to alleviate these pressure surges.

(12 marks)

The hydraulic pump and hydraulic motor efficiencies equations are as follows:

$$ {}^{p}\eta_v = \frac{Q_p}{D_p n_p} \longrightarrow (1) \qquad {}^{m}\eta_v = \frac{D_m n_m}{Q_m} \longrightarrow (4) $$

$$ {}^{p}\eta_t = \frac{D_p P_p}{2\pi T_p} \longrightarrow (2) \qquad {}^{m}\eta_t = \frac{2\pi T_m}{D_m P_m} \longrightarrow (5) $$

$$ {}^{p}\eta_o = \frac{Q_p P_p}{2\pi n_p T_p} \longrightarrow (3) \qquad {}^{m}\eta_o = \frac{2\pi n_m T_m}{Q_m P_m} \longrightarrow (6) $$

$$ {}^{p}\eta_o = {}^{p}\eta_v \times {}^{p}\eta_t \qquad {}^{m}\eta_o = {}^{m}\eta_v \times {}^{m}\eta_t $$

END OF PAPER

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Please read the following instructions carefully:

1. **Please do not turn over the question paper until you are told to do so. Disciplinary action may be taken against you if you do so.**

2. You are not allowed to leave the examination hall unless accompanied by an invigilator. You may raise your hand if you need to communicate with the invigilator.

3. Please write your Matriculation Number on the front of the answer book.

4. Please indicate clearly in the answer book (at the appropriate place) if you are continuing the answer to a question elsewhere in the book.

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