NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2023-2024

MA4001 - ENGINEERING DESIGN
MA4012 – MECHATRONICS ENGINEERING DESIGN

April / May 2024 Time Allowed: 2 ½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SIX (6)** pages, including one page of Appendix.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination.

---

1. You are tasked to develop a power assist trolley for senior citizens visiting the wet market.

   The design specifications are as follows:

   - The system must cover loading/unloading of itself and the payload from the car boot.
   - Modification to the car boot is not allowed.
   - The system has to handle a maximum payload of 40 kg.
   - It needs to move between the open carpark and the wet market, which are approximately 25m, away from each other.
   - The system is also expected to ascend and descend 3 steps.
   - During its operation, the user may apply a force, restricted to 50N, to lift, push or pull when operating the machine.
   - You may assume that the steps and car boot are at least 1 meter wide.
   - Figure 1 shows the typical environment that the machine would encounter.

Note: Question 1 continues on page 2.
Figure 1 appears in page 2.

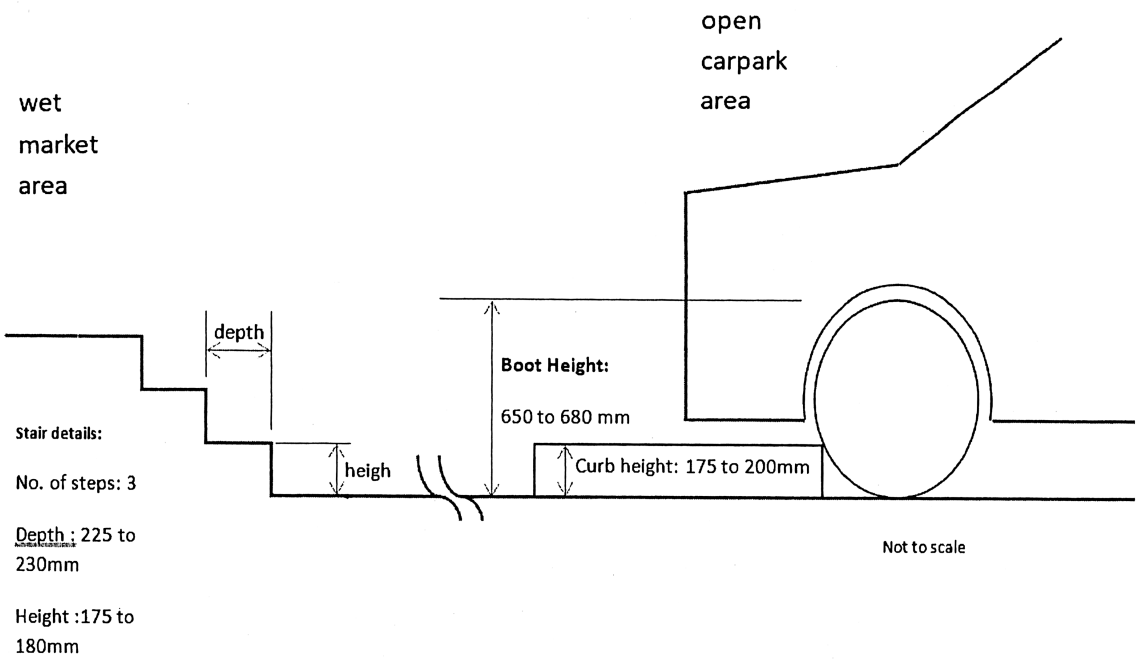

Figure 1: Typical environment the machine will encountered.

(a) (i) Draw an Overall Function Diagram of the system.

(3 marks)

(ii) Develop a Function Analysis diagram of the system to describe the principal function of the machine. Show at least six (6) sub functions. (Function performing the same task will be treated as similar. Up and down will be considered as 1 function). All appropriate flowlines are to be included. Do not include any auxiliary function as they will be addressed in b(i).

(6 marks)

(b) (i) Draw in separate diagrams, 2 auxiliary functions that could improve the operation of the system. Show how they interface with the related sub function. (Color code or shade the auxiliary function)

(4 marks)

(ii) Explain with sketches, 2 solutions to load/unload the system and payload from and to the car boot.

(6 marks)

(c) (i) Besides Clarity and Simplicity, name the other rule of Embodiment design. Explain the effectiveness of implementation control on this rule.

(2 marks)

(ii) Elaborate with examples how you could apply the rule, mentioned in c(i) to two areas of your design.

(4 marks)

Note: Marks will not be awarded twice or more for similar answer provided in any of the above question segment.

2. Shafts A and B have the same cross-sectional area A and length L but different cross-sectional shapes. Shaft A has a solid circular section, while Shaft B has a hollow circular section with the average radius $r = 480$ mm and the wall thickness $t = 25$ mm.

(a) Assume the two shafts are made of the same material. Identify the stiffer one in twisting and how much stiffer it is than the other. Identify the stronger one in twisting strength and how much stronger it is. Formulae provided in the Appendix can be used for calculation.

(12 marks)

(b) Assume the materials steel and titanium alloy are available to make Shafts A and B. Identify which material-shape combination has the lowest mass for a given stiffness in twisting and which material-shape combination has the lowest mass for a given strength in twisting. Show your calculations in arriving at your answer. The material-shape indices are given by $M_2 = (\emptyset_T^e E)^{1/2}/\rho$ and $M_4 = (\emptyset_T^f \sigma_f)^{2/3}/\rho$. The densities, Young's moduli, and strengths of the two materials are given in Table 1.

Table 1: Materials for shafts

Material	Density ρ (Mg/m^3)	Young's modulus E (MPa)	Strength σ_f (MPa)
Steel	8.15	230,000	860
Titanium alloy	4.8	130,000	970

(13 marks)

3 (a) An automation system has the following functions to operate a pump Y1. Momentarily pressing a NO spring return push button X1, Green LED Y2 will light up, pump Y1 will turn on immediately for 10 seconds then both Y1 and Y2 will turn off. Holding down push button X2 for more than 3 seconds, Red LED Y3 will light up, pump Y1 will delay for 5 seconds, then turn on for 10 seconds then both Y1 and Y3 will turn off. Draw a PLC ladder diagram to achieve the above operation.

Use the following I/O:
X1 – NO Push Button
X2 – NO Push Button
Y1 – Pump
Y2 – Green LED
Y3 – Red LED
T1 – 10 sec timer
T2 – 3 sec timer
T3 – 5 sec timer

(15 marks)

Note: Question 3 continues on page 4.

3 (b) A DC motor drives a carriage though a leadscrew and a planetary gearhead. This is shown in Figure 2.

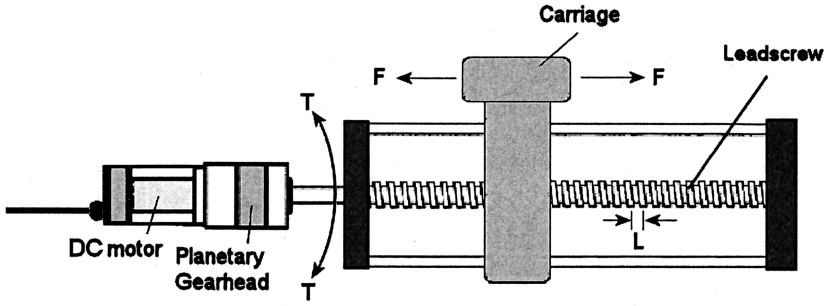

Figure 2

The DC motor has the following manufacturer's data:
Power Rating : 200W
Stall Torque: 5.10Nm
Max. Permissible Speed: 4000rpm
Max. Continuous Torque 477mNm

Leadscrew Drive
Pitch diameter of lead screw: 20mm
Lead of screw L: 4mm (single start)
Coeff of friction of lead screw thread: 0.15

(i) If the planetary gearhead limits the motor speed to a maximum input speed of 3000rpm, select the required gear ratio from Table 2 shown below to allow the carriage to travel at a linear speed of 0.25m/min. Hence, determine the actual speed of the DC motor (rpm) to attain this linear speed.

Table 2

Gearhead diameter	Gear Ratio	Max. Torque	Efficiency (η)
48 mm	43:1	21 Nm	75
48 mm	53:1	24 Nm	75
48 mm	66:1	24 Nm	75
52 mm	74:1	28 Nm	72
52 mm	81:1	28 Nm	72

(4 marks)

(ii) The torque T to move the carriage along the leadscrew with square thread (single start) is given as

$$T = \frac{FD_p}{2}\left[\frac{L + \pi\mu D_p}{\pi D_p - \mu L}\right]$$

F = force to be moved
D_p = Pitch diameter of lead screw
L = Lead of the screw
μ= coeff of friction of lead screw thread

Calculate the force F(N) that the carriage can produce when driven by the 200W DC motor coupled with the selected gearbox in 3b(i).

(6 marks)

4 (a) What is a hydrostatic transmission? List FOUR advantages it typically possesses.
(6 marks)

(b) A double acting cylinder is hooked in the regenerative circuit as shown in Figure 3. The relief valve setting is at 105 bars. The cylinder has a piston diameter of 63 mm and a rod diameter of 25 mm. If the pump flow is 45 lpm, determine the cylinder speed and the load carrying capacity for the

(i) Extending stroke.
(ii) Retracting stroke.

(10 marks)

(c) List a typical application of regenerative circuits. Describe the operation of the regenerative circuit as shown in Figure 3. When the directional control valve is actuated, comment on the cylinder speed and the load carrying capacity for the extending and retracting stroke, and also for the case when the piston area is twice of the rod area.

(9 marks)

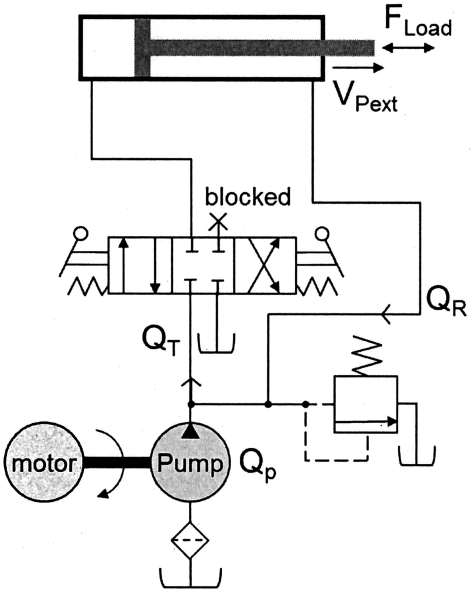

Figure 3: Regenerative Circuit.

END OF PAPER

Appendix – Useful Formulae

1. The shape efficiency factor for elastic twisting is given by $\emptyset_T^e = 7.14K/A^2$, in which K is the section moment for torsion and A is the cross-sectional area. For a solid circular cross-section with radius r, the section moment K is given by $K = \pi r^4/2$; for a hollow circular section with the average radius r and the wall thickness t, $K = 2\pi r^3 t$.

2. The shape efficiency factor for failure in twisting is given by $\emptyset_T^f = 4.8Q/A^{3/2}$, in which Q is the section modulus for torsion and A is the cross-sectional area. For a solid circular cross-section with radius r, the section modulus Q is given by $Q = \pi r^3/2$; for a hollow circular section with the average radius r and the wall thickness t, $Q = 2\pi r^2 t$.

MA4001 ENGINEERING DESIGN
MA4012 MECHATRONICS ENGINEERING DESIGN

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.