NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2017-2018

MA4001 – ENGINEERING DESIGN
MA4011 – ENGINEERING PRODUCT DESIGN

November/December 2017 Time Allowed: 2½ 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 Q2(c) is given separately.

1(a) A non-governmental organization (NGO) is developing affordable and compatible technologies to help poor island communities in South Asia. One such project is the mechanization of the process of producing coconut cream, see Figure 1(a), a product derived from mature coconuts. Currently, the coconuts are harvested and collected in piles, Figure 1(b), at the coconut plantations. Farmers employ manual laborers to dehusk the coconut and break them into halves. The fleshy part is then scrapped off, ground down and pressed to remove the coconut cream which are all labour intensive processes. As a member of team of mechanical engineering designers, you are charged with the design of a continuous mechanized process taking the coconuts at the start and collecting the cream in large barrels in the last stage, thus improving the productivity of the process. The barrels of cream will be pasturised and canned for export at another factory off-site. You may assume that electrical power is available on-site.

(a) (b)

Figure 1: (a) the coconut milk and (b) a pile of coconuts after harvesting.

Note: Question 1 continues on page 2.

(i) Develop a list of 5 highly specific design requirements for the machine and discuss briefly why they are important.

(5 marks)

(ii) Provide a function analysis diagram for the machine containing not less than 10 sub functions showing clearly the energy, material and signal flows.

(5 marks)

(iii) Select four main sub functions and for each sub function, suggest one technical solution. Show working principles by clearly labelled sketches and animated arrows. Note that simple devices are preferred and robotic arms are not considered as appropriate solutions.

(10 marks)

(b) Since the islands are off-grid in 1(a), the NGO need to provide electrical power for the machine in question 1(a). They turn to renewable energy solutions as the remote islands happen to be endowed with strong breezes. They plan to extract wind energy using wind turbines which have to be low cost and also easily protected from the destructive tropical hurricanes that frequently sweep through the islands. The simple design they produced is shown in sketch in Figure 2 which is a horizontal axis turbine capable of being lowered and tied down at ground level during maintenance and during hurricanes. This design used a number of embodiment design principles. Point out as many as possible and describe which principle is utilized and justify with reasons.

(5 marks)

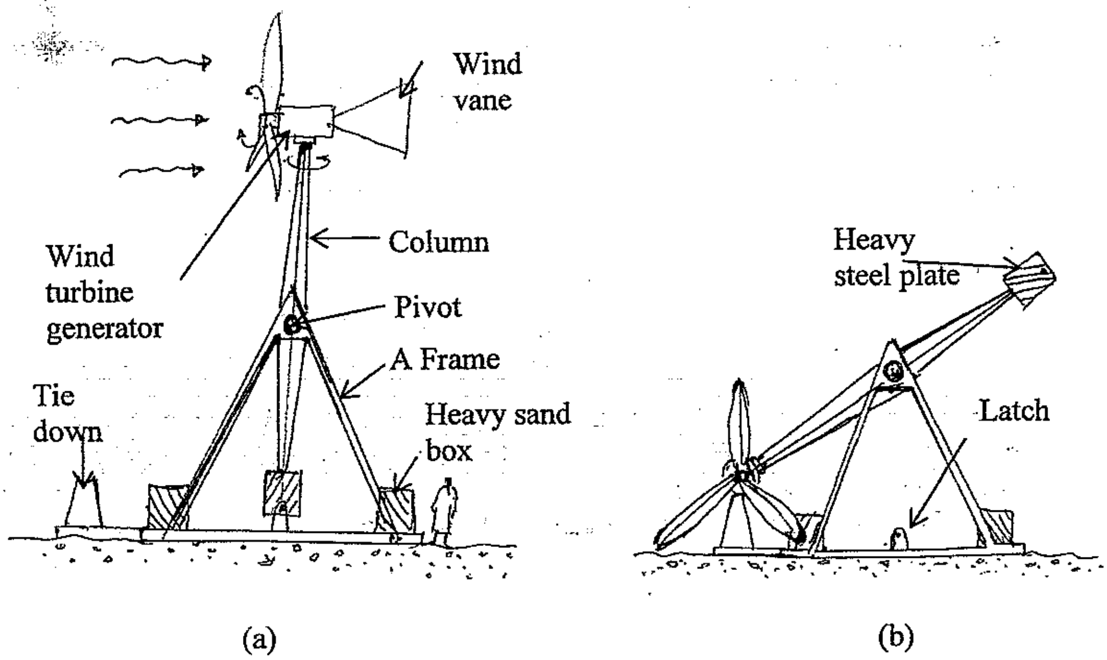


Figure 2: Wind turbine for remote t opical island communities (a) upright and (b) lowered.

2. Material for a *light weight* golf club shafts are to be identified. The golf-club shaft of prescribed length, L, is made into solid circular cross-section of unspecified radius, R. The complex loading is shown schematically in Figure 3(a), where the most dominant being the bending moment, M, and twisting torque, T apart from non-dominant radial force, P, and axial force, F. Under the applied load of M and T, the maximum bending stress should be less than material failure or yield strength and the angle of twist, θ, should be less than θ_o. Answer the following questions:

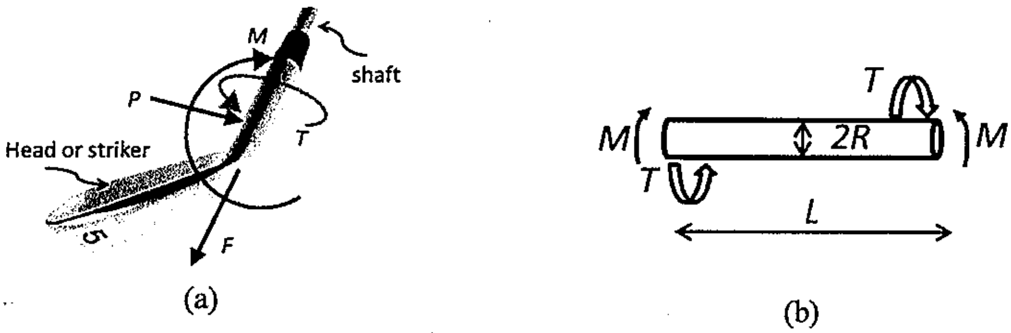


Figure 3(a): Schematic of a golf club, and (b) the beam-shaft design for the prescribed length L and radius R.

(a) Identify the function, objective(s), constraint(s), free and fixed variables of the golf-club shaft. Explain whether this is a fully-determined design, over-constrained or under-constrained and why?

(6 marks)

(b) Develop material performance index or indices for the light weight golf-club shaft. If there is more than one performance index, derive a coupling equation.

(9 marks)

(c) Plot the coupling equation on the material selection chart, given separately, with correct slope and mark the material selection search area on the chart. Identify suitable golf-shaft materials and briefly comment on your choices. Assume the parameters T = 15 Nm, M = 6 Nm, L = 1.5 m and θ_o = 1 rad.

(5 marks)

(d) Now the designer wishes to minimize the cost of the golf-club shaft in addition to its mass when the most active constraint is the angle of twist due to the torque. Using an exchange constant of 15 $/kg for mass, propose a value function for the multiple objectives and identify a suitable material from the list given in Table 1.

(5 marks)

Note: Table 1 appears on page 4.

Table 1: Nominal properties of golf-club shaft material choice

Material	Density (kg/m^3)	Cost ($/kg)	Shear Modulus (GPa)	Yield Strength (MPa)
CFRP	1600	50.00	35	1000
GFRP	1800	35.00	10	200
Low Alloy Steel	7800	0.75	85	800
Mg Alloy	1900	4.00	15	400
Wrought Al	2700	2.50	20	500

Useful Formulae

1) The maximum torsional shear stress in shaft of length, L, is $\tau = \dfrac{TR}{K}$ and the angle of twist is $\theta = \dfrac{TL}{GK}$, where, G, is the shaft material shear modulus, R is radius and K is polar (or twisting) moment of area.
2) The maximum bending stress in a circular cross-section beam of radius, R, subjected to bending moment, M, is $\sigma = \dfrac{MR}{I}$, where I is the second moment of area.
3) Second moment of area, I, and polar moment of area, K, for solid circular cross-section of radius, R, are $I = \left(\pi R^4/4\right)$ and $K = \left(\pi R^4/2\right)$, respectively.

3(a) A design of an automatic heating press is shown in Figure 4. The function of the heating press is to automatically flatten warped 300mm vinyl discs.

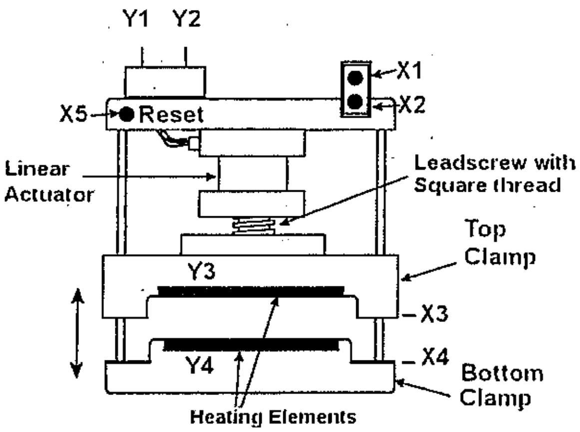


Figure 4: Heating press.

To flatten a warped vinyl disc, the vinyl disc is placed in between the top and bottom clamp. If either of the buttons (X1 or X2) are pressed, the top clamp (driven by the linear actuator) will extend and the top clamp will lower to meet the bottom clamp (The power to the linear actuator will remain on). The respective heating elements will then come on for 5 mins. After 5 mins, the heating elements will be turned off and the top clamp will be retracted back by the linear actuator to its original position and then power off. To make the linear actuator extend, Y1 must be active. To make the linear actuator retract, both Y1 and Y2 must be active.

The heating press detects the position of the top clamp to be either fully extended or retracted by the sensing of the input signals from X3 or X4. X3 detects when the top clamp is fully retracted and X4 detects when the top clamp is fully extended.

If the operator wishes to operate the heating press process with the top heating element only, he presses button X1. If the operator wishes to operate the heating press process with the bottom heating element, he presses button X2. If the operator wishes to operate the heating press process with both top and bottom heating elements active, he presses both buttons X1 and X2 simultaneously. The operator only needs to press either of the X1 or X2 buttons momentarily to start the pressing process.

Should the operator want to end the cycle immediately, he just needs to momentarily press the reset button X5. The heating element will turn off immediately and the top clamp will retract back to its original position.

Use T1 for the 5 min timer.
Use auxiliary relays M1, M2 and M5 to hold the state of the push buttons X1, X2 and X5 respectively.

Draw a ladder diagram to automate the above process.

(18 marks)

Note: Question 3 continues on page 6.

/0

(b) (i) The linear actuator used in the heating press design in question 3(a), uses a square thread leadscrew to drive the top clamp up or down. The relationship of the torque T to turn the leadscrew to move the clamp up and down the screw with square thread is given as;

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

Where 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

The mass of the top clamp is 5kg. If the desired clamping force needed is to be 200N on the vinyl disc, calculate the torque needed to drive the leadscrew to achieve this clamping force when the vinyl disc is being pressed.

Take D_p = 20mm
L = 2mm (single start)
μ=0.15

(4 marks)

(ii) Why are square threads the preferred thread design for power leadscrews and not metric (v-thread) or acme thread (Figure 5)?

(3 marks)

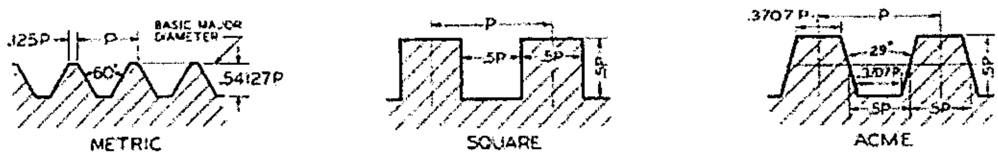


Figure 5: Metric, square and acme screw thread.

4(a) A hydraulic pump have a theoretical delivery of 35 lit/min, a volumetric efficiency of 90% and an overall efficiency of 85%. It drives a hydraulic cylinder having a bore diameter of 110 mm, a rod diameter of 65 mm and a stroke length of 700 mm.

(i) Determine the extension and retraction velocities of the hydraulic cylinder.

(ii) Calculate the time required for the hydraulic cylinder to complete one cycle.

(iii) If the hydraulic cylinder is required to raise a load of 30,000 N, determine the system hydraulic pressure and the power required to drive the pump during operation.

(iv) Sketch a complete hydraulic circuit diagram for the above system by incorporating a counterbalance valve, which creates a back-pressure to prevent the load running away when the cylinder is retracting. A 3-position, 4-way, double solenoid, spring center, directional valve is to be used for controlling the direction of the hydraulic cylinder

(15 marks)

(b) The cost of in-house manufacturing a component consists of buying the raw material and 3000 pieces are to be made. The estimated cost of raw material is $2 per piece. and each piece takes 1.5 hours of manufacturing. The labour cost is $8 per hour. An overhead of 50% of labour cost must be included in the calculation cost. An initial investment of $20,000 is necessary for machinery and training. A vendor is proposing to provide the component at a price of $30 per piece.

(i) Determine, from financial point of view, whether it is better to buy the component from the vendor or manufacture the component in-house.

(ii) From the quality viewpoint the company prefers in-house manufacturing. Calculate the break-even volume if the selling price is $40.00 per piece.

(10 marks)

END OF PAPER

1(a) (i) The 5 highly specific design requirements are:

a. Affordability
↳ This is to ensure that the community is financially capable of purchasing the machine.

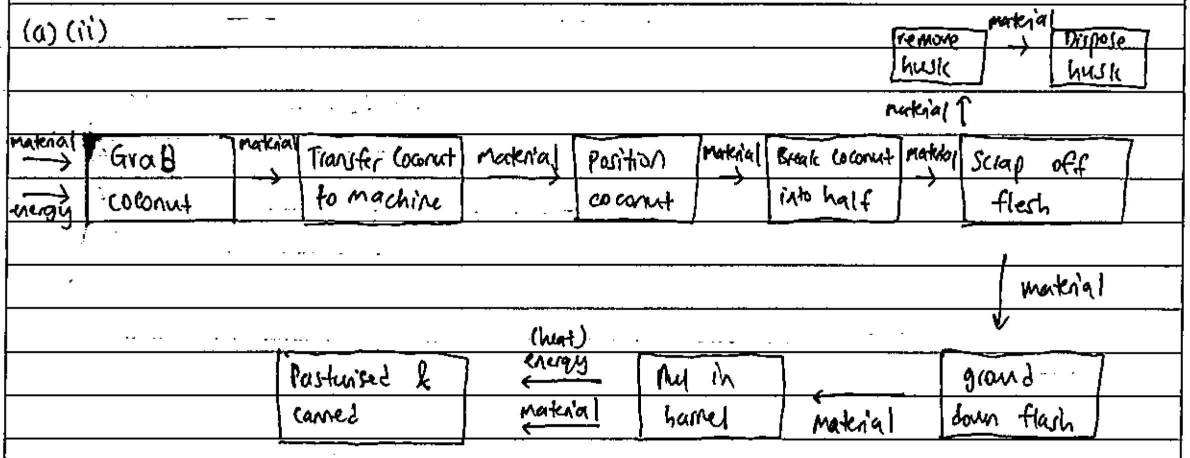
b. Corrosion Resistant
↳ Due to the environment that the machine will be placed, it will be subjected to wear and tear from the environmental condition. As such, a corrosion resistent material should be considered during the design phase.

c. Energy - Saving
↳ The machine is being used in rural areas. As such, there maybe poor power supply.

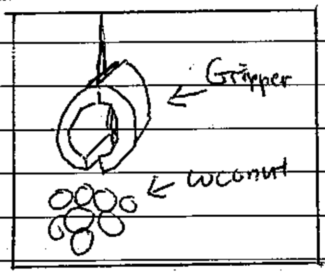
d. Auto mated process
↳ This is to reduce the labour-intensive processes.

e. Simplicity
↳ It is to ensure that the machine can be operated easily by the consumers.

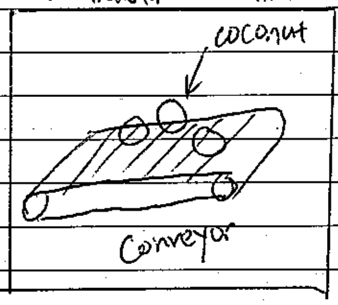
(a) (ii)



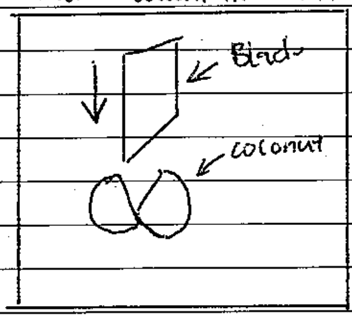
(iii) 1. Grab Coconut



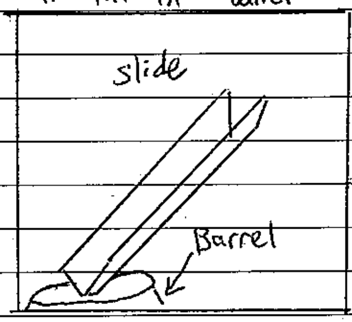
2. Transfer Coconut



3. Break Cocont into half



4. Put in barrel



(b) 1. Force Transmission

↳ Centre of column has a broader width. As such, to ensure uniform stress, the force is spread out evenly within the structure.

2. Stability

↳ The heavy steel plate is utilised to aid with the balancing of moment forces.

3. Division of task

↳ Dual leg frame is being used to help distribute the load.

4. Self-help

↳ A wind vane is used to balance the interaction of forces at the top of the structure.

2(a) Function: Shaft designed for golf club

objective: Minimise mass

constraint: (1) Max. bending stress less than yield strength $\sigma_{max} \le \sigma_y$

(2) $\theta < \theta_o$

Free variables: Radius, R

Fixed variables: Length, L

This is an over-constrained design with 2 constraints and 1 free variable.

(b) First constraint:

$$\sigma_{max} \le \sigma_y$$

$$\sigma_{max} = \frac{MR}{I} \quad -(1)$$

$$m = \rho A L = \rho \pi R^2 L$$

$$\Rightarrow R = \sqrt{\frac{m}{\rho \pi L}} = \left(\frac{m}{\rho \pi L}\right)^{\frac{1}{2}} \quad -(2)$$

*Note: M - bending moment

m - mass

subst. (2) into (1), $I = \frac{\pi R^4}{4}$

$$\sigma_{max} = \frac{MR}{\frac{\pi R^4}{4}} = \frac{4M}{\pi R^3} = \frac{4M}{\pi \left[\frac{m}{\rho \pi L}\right]^{3/2}}$$

$$m^{3/2} = \frac{4M[\rho \pi L]^{3/2}}{\pi \sigma_{max}}$$

$$m = \left[\frac{4M}{\pi \sigma_{max}}\right]^{2/3} [\rho \pi L] \ *$$

Hence, to minimise mass, we must maximise: $M_1 = \frac{\rho}{(\sigma_{max})^{\frac{2}{3}}}$

DISCLAIMER: *The solutions are done by students who scored A or above in this subject. MAE Club and Campus supplies are not liable or responsible for any errors in the contents of these solutions. Students are advised to take the solutions as a guide rather than absolute answers to exam paper.*
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Second constraint:

~~$\sigma_{max} \le \sigma_y$~~ $\theta \le \theta_0$

$$\theta = \frac{TL}{GK}$$

~~Sin~~ subst. $K = \frac{\pi R^4}{2}$

$$\theta = \frac{2TL}{\pi R^4 G} = \frac{2TL}{\pi G}\left[\frac{\rho \pi L}{m}\right]^2$$

$$m^2 = \frac{2L^3 T \rho^2 \pi}{G\theta}$$

$$m = \sqrt{\frac{2L^3 T \rho^2 \pi}{G\theta}}$$

Here, minimise mass by maximising, $M2 = \frac{\sqrt{G\theta}}{\rho}$

Coupling equation:

$$\frac{M1}{M2} = \frac{\frac{\rho}{(\sigma_{max})^{2/3}}}{\frac{\sqrt{G\theta}}{\rho}} = \frac{1}{(\sigma_{max})^{2/3}\sqrt{G\theta}}$$

(c) As there are no charts provided, this part can't be completed.

2(d) Since required to minimise cost and most active constraint is the angle of twist,

$$C = C_m M$$

$$M = \sqrt{\frac{2L^3 T \rho^2 \pi}{G\theta}}$$

$$V = \alpha M + C_m M$$

$$= \alpha\left[\sqrt{\frac{2L^3 T \rho^2 \pi}{G\theta}}\right] + C_m\left[\sqrt{\frac{2L^3 T \rho^2 \pi}{G\theta}}\right]$$

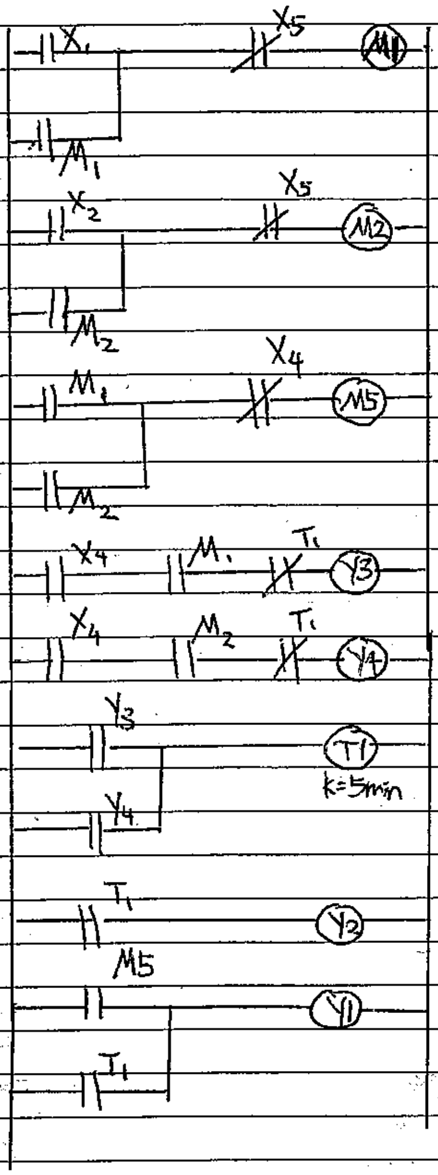
$$\tilde{V} = \alpha\left[\frac{\rho}{\sqrt{G}}\right] + C_m\left[\frac{\rho}{\sqrt{G}}\right]$$

$$= (\alpha + C_m)\left[\frac{\rho}{\sqrt{G}}\right]$$

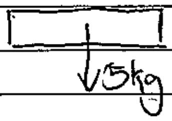
- Find values of $\tilde{V}$ and take the lowest $\tilde{V}$

material	ρ	C_m	G	$\tilde{V}$
CFRP	⋮	⋮	⋮	V_1
GFRP	⋮	⋮	⋮	V_2
Mg Alloy	⋮	⋮	⋮	V_3
⋮	⋮			⋮

3a)



b) i)



$W = mg$

$= (5)(9.81) = 49.05N$

F = Force Required = $200 - 49.05$

$F = 150.95N$.

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

L, D_p, μ given

$F = 150.95N$.

Thus,

$$T = \frac{150.95}{2}\left(\frac{0.011425 \times \left(\frac{20}{1000}\right)}{0.06253}\right)$$

$$= 0.276\,Nm$$

ii) Square thread is being used as they are the most effective and most efficient. In general, square thread has the least friction as compared to the other threads. As compared to metric & Acme thread, square thread has lesser edged sides which does not result in a high tendency for wear & tear to occur.

4a i)

$$Q_{Actual} = 35 \times 0.9 = 31.5\ \ell/min$$

$$Q_{Ext} = A_{Bore} V_{Ext}$$

$$A_{Bore} = \pi\left(\frac{110}{2}\right)^2\ mm^2$$

Thus, $V_{Ext} = 0.05523\ m/sec$

$$Q_{Ret} = A_{annular} V_{Ret}$$

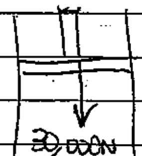
$$A_{annular} = A_{Bore} - A_{rod}$$

Thus, $V_{Ret} = 0.0849\ m/sec$

ii) Total time = Ext time + Ret time

$$= \frac{0.7}{0.05523} + \frac{0.7}{0.0849} = 20.9\ sec$$

(ii)



$$30{,}000 = P \times A_{Bore}$$

$$P = 3.156\,KPa$$

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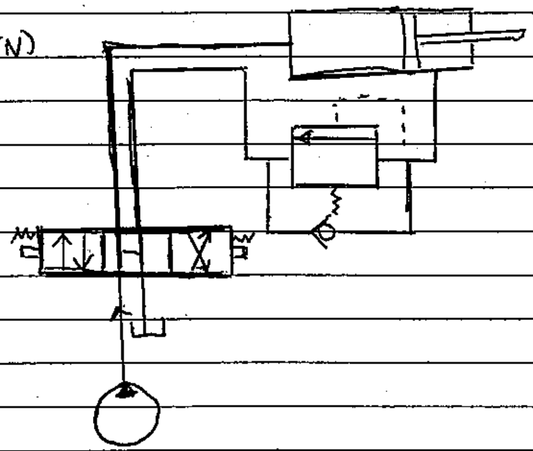
~~iii~~ Power = F×V

$= 30{,}000 \times V_{Ext}$

$= 1656.9\ W$ //

iv)



bi) In-house

Cost of raw material : 3000(2) = \$6000

Labour Cost : 8(1.5)(3000) = \$36000

Overhead : (0.5)(36000) = \$18 000

Total Cost : \$6000 + \$36000 + \$18000 + ~~20~~ \$20000 = \$80 000 //

↑ Initial Investment

Vendor { 30 × 30 000 = \$90 000 //

Thus, in-house better //

ii) Let X be the amount of component.

$40(X) = 2X + 8(1.5)(X) + 0.5(0.8)(1.5)(x) + 20\,000$

Solve for X,

$X = 10000$ //

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2018-2019

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

April/May 2019 Time Allowed: 2½ hours

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SEVEN (7)** pages inclusive of **ONE (1)** page of appendix.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. This is a **CLOSED-BOOK** examination.

1(a) You are a member of a design team working for an agricultural equipment company. Your current project is to develop a seed planting machine. The mechanization of seed planting will reduce the work load of farmers, dependence of the seasonal manpower as well as improve productivity. All kinds of seeds can be planted; in this case they are similar to corn used in making pop corn. They are to be planted in loose soil in rows, evenly at the same distance apart and at a constant depth and then covered with soil. Each seed is also planted with a pellet of fertilizer. At the same time the soil around the seed and fertilizer is wetted by water to encourage seed germination. Figure 1 shows the optimum conditions to be achieved by the machine. You may assume that the machine will be towed by or mounted on a tractor which also provides the electrical, hydraulic or mechanical power that your machine will need.

Figure 1: Optimum placement for seed, fertilizer pellet and wetted zone.

Note: Question 1 continues on page 2.

As a member of the design team entrusted with the design of the product, provide the following:

(i) A function analysis diagram for the machine containing not less that 10 functions showing clearly the energy, material and signal flows. Highlight which functions are main and auxiliary functions by different colour or border symbols. Explain the meaning of main and auxiliary functions.

(8 marks)

(ii) For 3 (three) main functions, suggest one technical solution for each function and show their working principles by clearly labelled, well drawn sketches. Note that simple mechanical devices are prefered and robotic arms are not considered as appropriate solutions.

(6 marks)

(iii) For 1 (One) auxiliary function, explain your reasons for it and suggest one technical solution for each auxiliary function by clearly labelled, well drawn sketches. Oversimplistic sketches are not acceptable.

(2 marks)

(b) Figure 2 shows a large industrial hammer for large metal sheets. The up/down motion of the hammer is generated through a rotary to linear oscillatary motion conversion by a crank slider mechanism. The structural support for the hammer is designed to cater for the large sheet width. Sketch and explain the device and forces generated. Identify with justifications, the embodiment principle/s used in the equipment.

(3 marks)

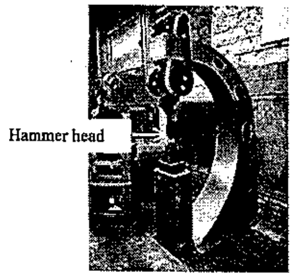


Figure 2: A hammering equipment.

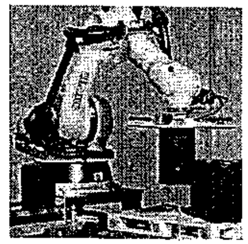


Figure 3: An industrial pick and place robot.

(c) The Safety Rule is mandatory and is applied in three stages, i.e. direct, indirect and warnings, explain these three stages.

(3 marks)

(d) For a large industrial robot shown in the Figure 3 above which is deployed, for example, in factories carrying out heavy lifting or car manufacturing, explain how the three stages in the safety rule, may be implemented.

(3 marks)

2. Three types of shafts have the same cross-sectional area A and length L but different cross-sectional shape. Type 1 has a solid circular cross-section. Type 2 has a hollow circular cross-section with the average radius r = 500 mm and the wall thickness t = 60 mm. Type 3 has a solid equilateral triangle cross-section.

(a) Provided that the three types of shafts are made of the same material, rank them according to their twisting strength though calculation. Calculate to demonstrate how much stronger is the strongest type of shaft than the other two types of shafts. Formulae provided in the Appendix can be used for calculation.

(12 marks)

(b) Provided that the materials of aluminum, steel and fiber-reinforced polymer (CFRP) can be used to make the three types of shafts, identify through calculation which material-shape combination has the lowest mass for a given strength. The material-shape index for failure in twisting is given by $M_4 = (\phi_T^f \sigma_f)^{2/3}/\rho$, where ϕ_T^f is the shape efficiency factor.

(13 marks)

Table 1: Materials for shafts.

Material	Density ρ (kg/m^3)	Strength σ_f (MPa)
Aluminum	2650	280
Steel	7200	825
CFRP	1480	355

3(a) An automation system has the following PLC controlled pneumatic circuit shown in Figure 4.

The pneumatic circuit is shown in its default start position.

The sequence of the pneumatic circuit is as follows;

Press start button (X1), main air supply (Y1) turns on, then ...
A+, 2 sec, B-, B+, B-, B+, A-, (sequence stops)

Press and hold down stop button (X0) at any time, pneumatic cylinders A and B return to original positions (A-, B+) then and only then turn off the main air supply (Y1) after which the stop button (X0) can be released.

Draw a PLC ladder diagram to achieve the required operation.

Use
T1 for 2 sec timer
C1 for counter
M1 for auxiliary relay

(13 marks)

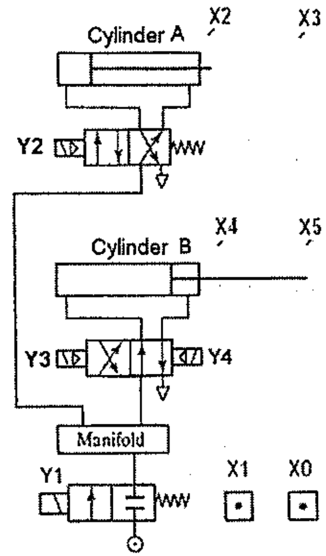


Figure 4: Pneumatic circuit.

Note: Question 3 continues on page 5.

(b) A motor and gearbox is to be selected to drive a hoist (Figure 5). The drum has to rotate at a minimum speed of 20rpm and achieve a hoisting speed of 0.4m/s for the load. Two suitable motors with their respective specifications are listed as follows:

Motor A 4 Pole, 50Hz, 400 VAC, Mechanical Power 2kW, (Slip 3%)
Motor B 6 Pole, 50Hz, 400 VAC, Mechanical Power 2kW, (Slip 3%)

Two possible gearboxes are available for connection to these motors.

Gearbox 1 45:1 reduction (85% efficiency)
Gearbox 2 62:1 reduction (80% efficiency)

Recommend the best motor gearbox combination that will allow the highest load capacity with this design requirement. Calculate the diameter (m) of the drum and the maximum hoisting load capacity (kg).

(12 marks)

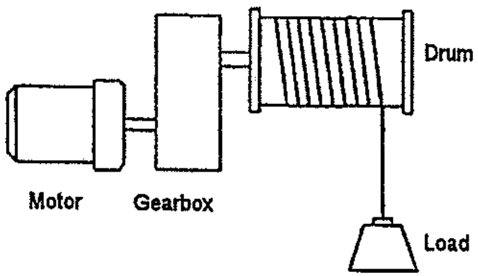


Figure 5: Hoist.

4(a) A hydraulic cylinder having a bore diameter of 125 mm, a rod diameter of 80 mm and a stroke of 350 mm is to fully extend and retract in a total time of 15 seconds. The extend thrust to be exerted by the cylinder is 20,000 kg and the retract thrust is 10,000 kg. Determine the followings:

(i) The system pressure when the hydraulic cylinder is extending.
(ii) The system pressure when the hydraulic cylinder is retracting.
(iii) The hydraulic pump delivery required.
(iv) The actual hydraulic pump displacement, if the volumetric efficiency is 90% and the pump is being driven at 1440 rpm.
(v) The maximum power input to the hydraulic pump if the torque efficiency is 85%

(12 marks)

(b) What are the five general types of problem that can occur during operation in a hydraulic system? Using a flow chart, list the procedures in the troubleshooting process for finding the problems in a hydraulic system.

(8 marks)

(c) Machine A costs $8500 and has annual operating cost of $4500. Machine B costs $6500 and has annual operating cost of $6000. Each machine has an economic life of 10 years. If the minimum required rate of return is 10%, which machine is more economical?

You may refer to Table 2 below, for the summary of compound interest factors.

(5 marks)

Table 2

Item	Conversion	Algebraic Relation	Factor	Factor Name
1	P to F	$F = P(1+i)^n$	$(F/P, i, n)$	Single payment, compound amount factor
2	F to P	$P = \frac{F}{(1+i)^n}$	$(P/F, i, n)$	Single payment, present worth factor
3	A to P	$P = A\frac{(1+i)^n - 1}{i(1+i)^n}$	$(P/A, i, n)$	Uniform payment, present worth factor
4	P to A	$A = P\frac{i(1+i)^n}{(1+i)^n - 1}$	$(A/P, i, n)$	Capital recovery factor
5	A to F	$F = A\frac{(1+i)^n - 1}{i}$	$(F/A, i, n)$	Uniform series, compound amount factor
6	F to A	$A = F\frac{i}{(1+i)^n - 1}$	$(A/F, i, n)$	Sinking fund factor

17

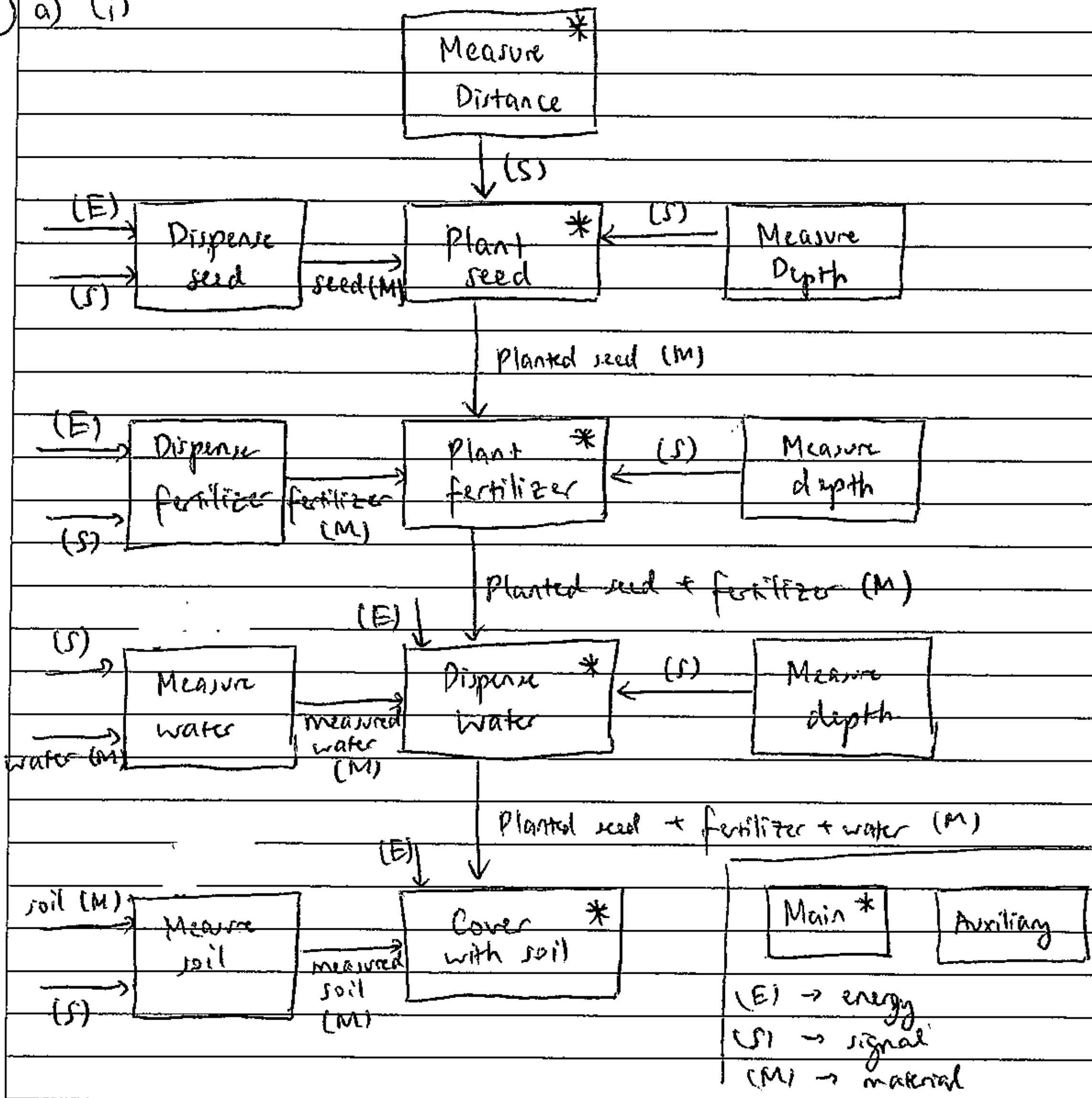
Appendix – Useful Formulae

1. The shape efficiency factor for failure in twisting is given by $\phi_T^f = 4.8Q/A^{3/2}$, 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 for torsion Q is given by $Q = \pi r^3/2$; for a hollow circular section with the average radius r and wall thickness t, $Q = 2\pi r^2 t$; for a solid equilateral triangle cross-section with length a, $Q = a^3/20$.

End of Paper

MA4001 Apr / May 2019

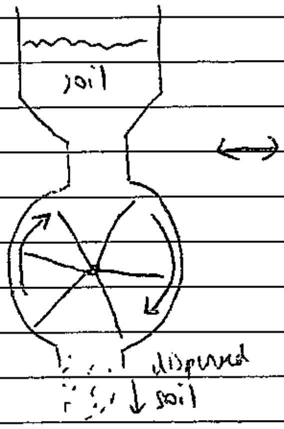
① a) (i)

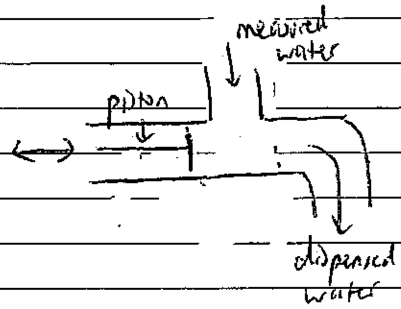


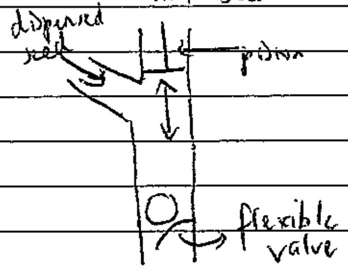
Main functions : Functions crucial to operation of the product, handle all the critical functions of the product

Auxiliary functions : Functions to compliment, support, or improve main functions

① a) (ii) Cover with soil — Dispense water — Plant seed



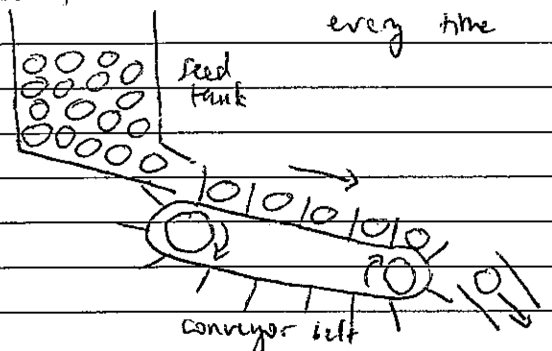




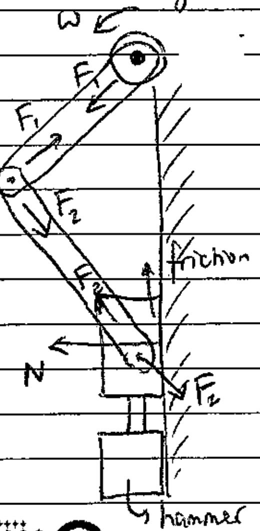
flexible valve will open if piston pushes the seed, thus planting the seed

(iii) ~~Measure water → to make sure the dispensed water is of the appropriate amount~~

Dispense seed → to make sure only one seed is dispensed every time



b)



Each link will undergo tension and compression cyclically. The slider would be pushed by the force transmitted through the links, overcoming the friction and pushing the hammer.

Principles used:

- Force transmission → thicker cross section around joints for uniform stress

(1)

c) - Direct : Design the product to have enough redundancy to prevent hazard
- Indirect : To limit the damage in case failure occurs
- Warnings : As a last resort. Inform user / passerby on possible dangers and area of dangers.

d) - Direct : Use stronger material & reinforce around joints
- Indirect : Put surrounding cover around the robot
- Warnings : Put warning ~~on~~ to warn user to not stand closely to robot while it's active

(2)

$A = A_2 = 2\pi r_2 t_2 = 2\pi \times 0.5 \times 0.06 = 0.1885\ m^2$

$A_1 = A_2 = \pi r_1^2$

$0.1885 = \pi r_1^2 \rightarrow r_1 \approx 0.2449\ m = 244.9\ mm$

$A_3 = A_2 = \frac{1}{4} a^2 \sqrt{3}$

$0.1885 = \frac{1}{4} a^2 \sqrt{3} \rightarrow a \approx 0.6597\ m = 659.7\ mm$

a) $Q_1 = \frac{1}{2}\pi r_1^3 = \frac{1}{2}\pi\ (0.2449)^3 = 0.02307\ m^3$

$Q_2 = 2\pi r_2^2 t_2 = 2\pi\ (0.5)^2 (0.06) = 0.09425\ m^3$

$Q_3 = \frac{1}{20} a^3 = \frac{1}{20} \times 0.6597^3 = 0.01436\ m^3$

$\phi_T^f = \frac{4.8Q}{A^{\frac{3}{2}}}$

Since $A_1 = A_2 = A_3$, we can compare ϕ_T^f by directly comparing Q.
The higher the Q value, the better its twisting strength

Strongest : cross section 2 hollow circular

2nd strongest : cross section 1 circular

$\frac{\phi_{T2}^f}{\phi_{T1}^f} = \frac{Q_2}{Q_1} = \frac{0.09425}{0.02307} = 4.085$

3rd strongest : cross section 3 triangle

$\frac{\phi_{T2}^f}{\phi_{T3}^f} = \frac{Q_2}{Q_3} = \frac{0.09425}{0.01436} = 6.563$

② b) $M_4 = \left(\phi_T^f\right)^{\frac{2}{3}} \left(\frac{\sigma_f}{\rho}\right)^{\frac{2}{3}}$

Based on ϕ_T^f alone, cross section 2 is the strongest.
Hence, we need to find material with highest value of $\frac{(\sigma_f)^{\frac{2}{3}}}{\rho}$

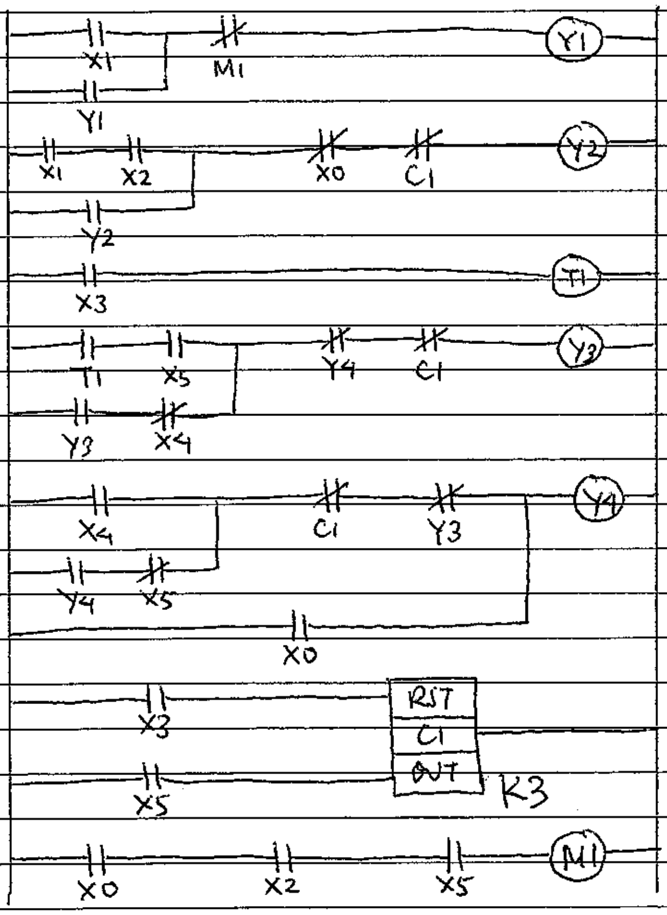
Aluminium → $\frac{(\sigma_f)^{\frac{2}{3}}}{\rho} = \frac{(280)^{\frac{2}{3}}}{2650} = 0.01615 \ \frac{(MPa)^{\frac{2}{3}}}{kg/m^3}$

Steel → $\frac{(\sigma_f)^{\frac{2}{3}}}{\rho} = \frac{(825)^{\frac{2}{3}}}{7200} = 0.01222 \ \frac{(MPa)^{\frac{2}{3}}}{kg/m^3}$

CFRP → $\frac{(\sigma_f)^{\frac{2}{3}}}{\rho} = \frac{(355)^{\frac{2}{3}}}{1480} = 0.03388 \ \frac{(MPa)^{\frac{2}{3}}}{kg/m^3}$

∴ Strongest : CFRP with hollow circular cross section 2

③ a)



DISCLAIMER: *The solutions are done by students who scored A or above in this subject. MAE Club and Campus supplies are not liable or responsible for any errors in the contents of these solutions. Students are advised to take the solutions as a guide rather than absolute answers to exam paper.*

Should there be any mistake identified, please proceed to the Facebook link encoded in the QR code to feedback or submit correct answers. The link is: http://bit.ly/2lW2C32

(8) b) $n_A = \frac{f_A \times 120}{P_A} \times 0.97 = \frac{50 \times 120}{4} \times 0.97 = 1455$ rpm

$n_B = \frac{f_B \times 120}{P_B} \times 0.97 = \frac{50 \times 120}{6} \times 0.97 = 970$ rpm

=> Calculate drum rotation speed (output speed)

Motor A, GB1 → $n_d = \frac{1455}{45} = 32.33$ rpm

Motor A, GB2 → $n_d = \frac{1455}{62} = 23.46$ rpm

Motor B, GB1 → $n_d = \frac{970}{45} = 21.55$ rpm

Motor B, GB2 → $n_d = \frac{970}{62} = 15.64$ rpm → not acceptable < 20 rpm

=> Torque at output $= \frac{\text{GB efficiency} \times \text{motor power}}{\text{output speed}}$

Motor A, GB1 → $T = \frac{0.85 \times 2000}{\frac{2\pi}{60} \times 32.33} = 502.13$ Nm

Motor A, GB2 → $T = \frac{0.80 \times 2000}{\frac{2\pi}{60} \times 23.46} = 651.27$ Nm

Motor B, GB1 → $T = \frac{0.85 \times 2000}{\frac{2\pi}{60} \times 21.55} = 753.30$ Nm

=> Calculate drum diameter $= 2 \times \frac{\text{hoisting speed}}{\text{output speed}}$

Motor A, GB1 → $D = 2 \times \frac{0.4}{\frac{2\pi}{60} \times 32.33} = 0.236$ m

Motor A, GB2 → $D = 2 \times \frac{0.4}{\frac{2\pi}{60} \times 23.46} = 0.325$ m

Motor B, GB1 → $D = 2 \times \frac{0.4}{\frac{2\pi}{60} \times 21.55} = 0.354$ m

③ b) → Calculate load capacity → $\frac{1}{2} mgD = T$

$$m = \frac{2T}{gD}$$

Motor A, GB1 → $m = \frac{2 \times 502.13}{9.81 \times 0.236} = 433.77$ kg

Motor A, GB2 → $m = \frac{2 \times 651.27}{9.81 \times 0.325} = 408.54$ kg

Motor B, GB1 → $m = \frac{2 \times 753.30}{9.81 \times 0.354} = 433.83$ kg

∴ Max hoisting load capacity is 433.83 kg
Achievable by using motor B and gearbox 1
Drum diameter = 0.354 m

④ a) (i) Extending

$$p = \frac{mg}{\frac{1}{4}\pi D^2} = \frac{20000 \times 9.81}{\frac{1}{4}\pi \times 0.125^2} = 15.99 \text{ MPa}$$

(ii) Retracting

$$p = \frac{mg}{\frac{1}{4}\pi (D^2 - d^2)} = \frac{10000 \times 9.81}{\frac{1}{4}\pi (0.125^2 - 0.08^2)} = 13.54 \text{ MPa}$$

(iii) $t_e + t_r = 15$

$$Q_e = Q_r$$

$$\frac{\frac{1}{4}\pi D^2 \times \text{stroke}}{t_e} = \frac{\frac{1}{4}\pi (D^2 - d^2) \times \text{stroke}}{15 - t_e}$$

$$125^2 (15 - t_e) = (125^2 - 80^2) t_e$$

$$t_e = 9.43 \text{ s} \quad ; \quad t_r = 15 - t_e = 5.57 \text{ s}$$

$$Q_e = \frac{\frac{1}{4}\pi \times 0.125^2 \times 0.35}{9.43} = 4.55 \times 10^{-4} \text{ m}^3/\text{s}$$

$$= 27.33 \text{ lpm}$$

With allowance → $Q = 1.2 Q_e = 5.47 \times 10^{-4} \text{ m}^3/\text{s}$

$$= 32.75 \text{ lpm}$$

(4) a) (iv) $\eta_v = \dfrac{Q}{D_p n_p}$

$0.90 = \dfrac{32.79}{D_p \times 1440} \rightarrow D_p = 0.0253 \ l/rev = 25.30 \ cm^3/rev$

(v) Max pressure is during extension $= 15.99$ MPa

Max input power $= \dfrac{PQ}{\eta_v \eta_T}$

$= \dfrac{15.99 \times 10^6 \times 5.47 \times 10^{-4}}{0.9 \times 0.85}$

$= 11433 \ W = 11.43 \ kW$

b) 5 General types of problems : Pressure, flow, leakage, heat, noise & vibration

Service manual → service history → initial inspection → list of symptoms ↓

specific problem statement ← general problem statement ← basic calculations

↓

tests to accept / reject specific problem statement → teardown for visual inspection & verification

c) $P_A = 8500 + 4500 \times \dfrac{(1+0.1)^{10} - 1}{0.1(1+0.1)^{10}} = \$36,150$

$P_B = 6500 + 6000 \times \dfrac{(1+0.1)^{10} - 1}{0.1(1+0.1)^{10}} = \$43,367$

$\therefore P_A < P_B$

Machine A is more economical

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2019-2020

MA4001 – ENGINEERING DESIGN
MA4011 – ENGINEERING PRODUCT DESIGN

November/December 2019 Time Allowed: 2½ 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 Q2a(iii) and Q2b are given separately.

1(a) When one needs to go to the beach for some recreation or to swim, one expects to find a pristine beach with clean soft sand underfoot. Many beaches nowadays are covered with trash washed up by the waves or discarded by careless beach goers. A dirty beach looks like the photo in Figure 1(a). Different types of trash are sometimes covered by the sand as shown in Figure 1(b) which makes cleaning a challenge. Design a machine that can clean the beaches by a mechanised method. The machine will be pulled behind a tractor such as the one shown in Figure 1(c) which also provides power to operate the machine by means of a rotating or power takeoff shaft. Assume that the tractor's engine can provide all necessary mechanical power through the shaft. Electrical power is also provided by means of electric cables but is only for small loads such as rear lights etc.

Figure 1(a): Photo of a beach covered with trash.

Note: Question 1 continues on page 2.
Figures 1(b) and (c) appear on page 2.

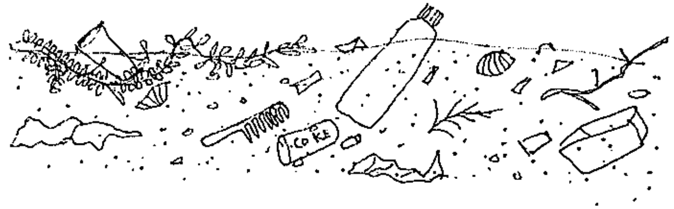


Figure 1(b): Types of trash on a beach with some submerged in sand.

Figure 1(c): Typical example of power take off shaft (upper) behind a tractor driving a machine, the black rod (lower) is the towing bar.

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

(5 marks)

(ii) Provide a function analysis diagram for the machine containing not less than ten functions showing clearly the energy, material and signal flows. Highlight which functions are main and auxiliary functions by different colour or border symbols. Explain the meaning of main and auxiliary functions.

(6 marks)

(iii) For four main functions, suggest 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. Over simplistic sketches are also not acceptable.

(8 marks)

Note: Question 1 continues on page 3.

4(a) A hydrostatic transmission operating at 105 bars has the following characteristics:

Hydraulic Pump	Hydraulic Motor
Displacement = 100 cm^3 per revolution.	Displacement
Volumetric efficiency = 85 %	Volumetric efficiency = 94 %
Torque efficiency = 90 %	Torque efficiency = 92 %
Speed = 1000 rpm	Speed = 600 rpm

(i) Determine the displacement of the hydraulic motor,
(ii) Determine the hydraulic motor output torque.

(10 marks)

(b) A hydraulic accumulator is a device that stores the potential energy of an incompressible fluid held under pressure by an external source against some dynamic force. Describe four applications of accumulators.

(6 marks)

(c) A new product has the following cost structure over one month of operation.

Labour cost = \$2.50 per unit,
Material cost = \$5.00 per unit,
General & administrative expenses = \$1200,
Depreciation on equipment = \$5000,
Factory expenses = \$800,
Sales & distribution overhead = \$1000,
Profit = \$1.00 per unit,

(i) Determine the break-even point for the production units.

(ii) What sales price would be needed for the product to breakeven at 2500 units?

(iii) Sketch the break-even curve showing relation between fixed and variable costs and profit before taxes.

(9 marks)

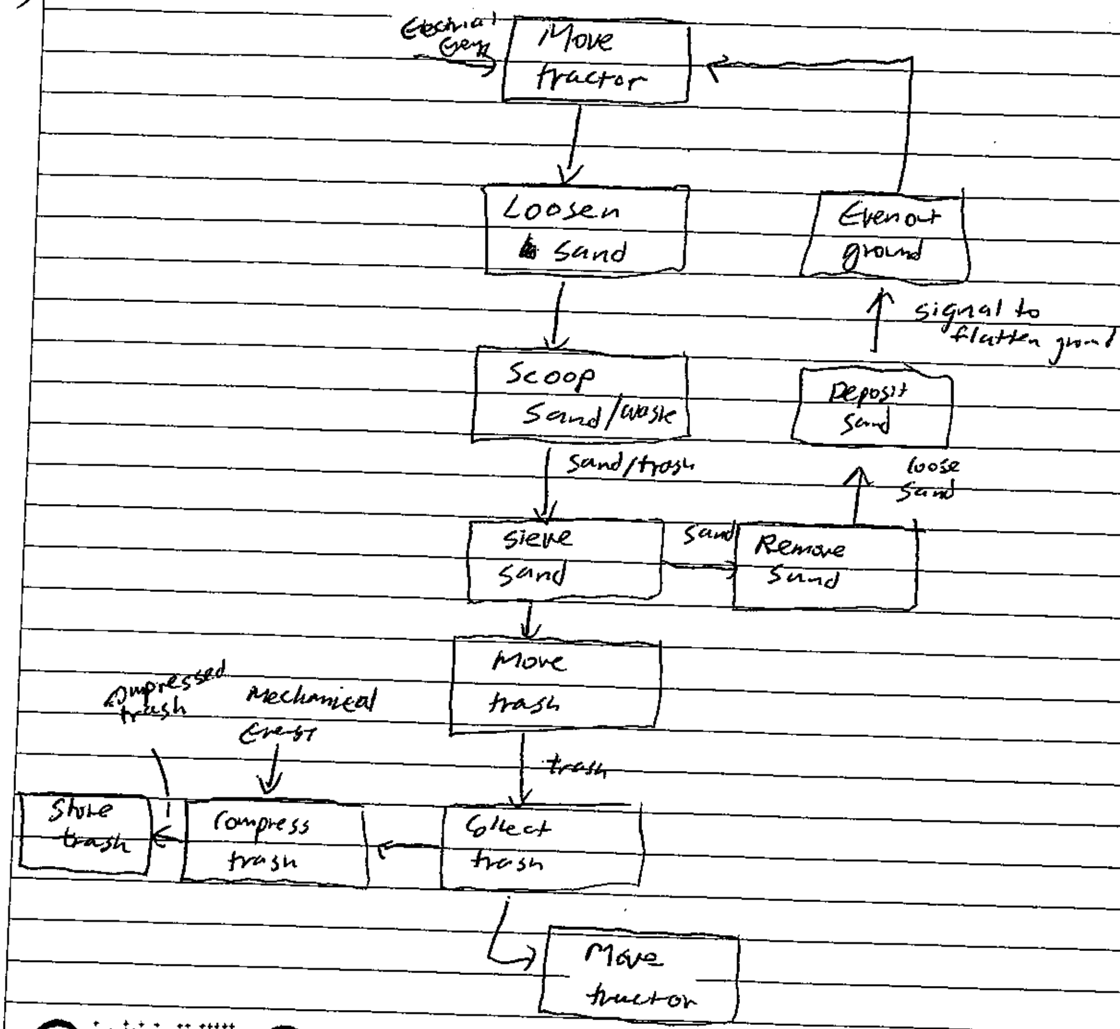
End of Paper

MA4001 S1 19/20 ~~Qn 3 Not~~ Qn 2 Not provided

1a(i)

Quiet	Minimum disturbance to beach goers
Low pollution	Won't pollute beach
Easy to operate	Low skill required to use
One man operation	Only require 1 man power, low labour
Weather proof	Can withstand rain or hail
Portable	Can be easily move/ transported
Easy to refuel	Topup of material is easy
Large storage	Able to store lots of trash

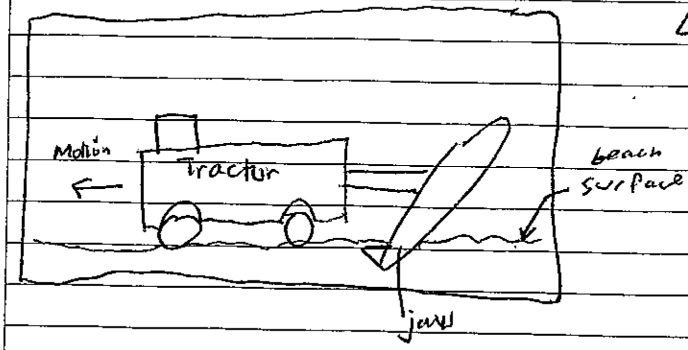
(ii)



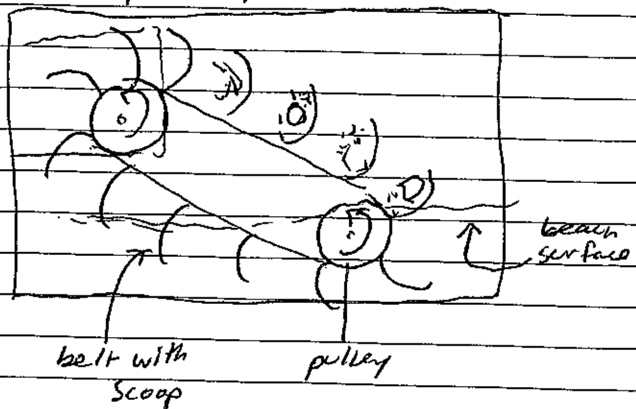
1a(ii) Main function comprises of the main objective of the system.
Auxiliary function to support and complement to main function

Loosen sand

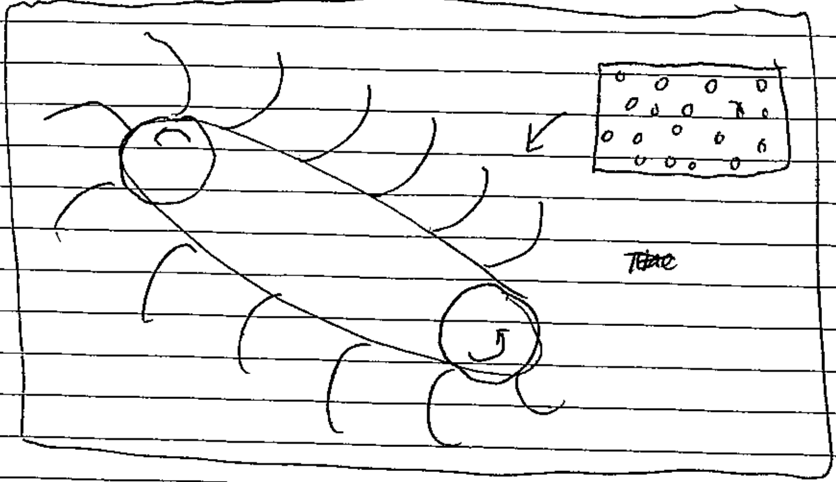
Loosen beach surface



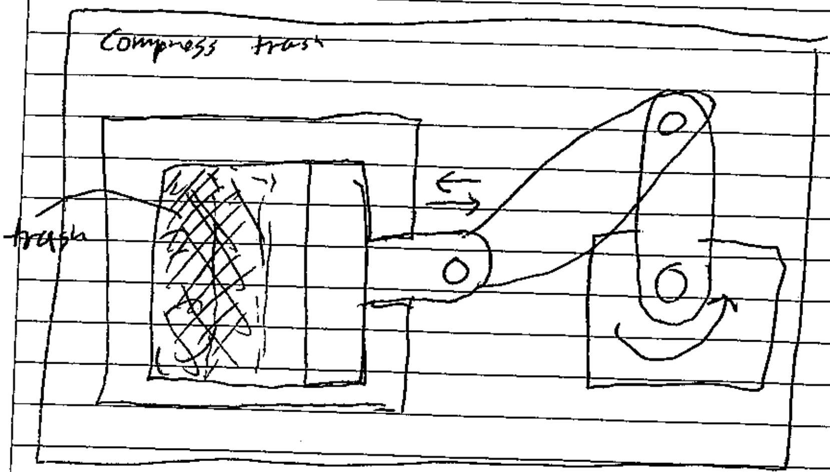
Scoop sand/trash



Sieve sand



The belt and scoop contains small holes to allow sand to sieve through while retaining larger trash.



Trash compartment to compress trash in order to store more trash

1 b

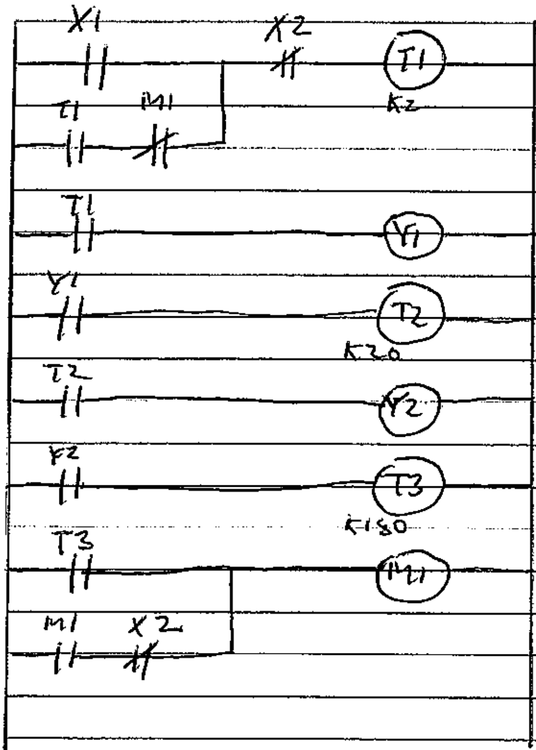
Fig 2a

— Division of tasks, there are 3 planet gears to even the load.

figure 2b

- Force transmission, the width of the arm is increasing as it approaches the load

3a)



X2 is built at downstream of X1

3bi) From the graph, max power is around $\frac{300 \times 2\pi}{60} \times 0.15$

$= 4.712\ W$

ii) It is suitable to run the motor at 300 ± 5% rpm as 5% range is generally acceptable engineering tolerance.

285 - 315 rpm

4a) i)

$\frac{Q_p}{D_p n_p} = 0.85$

$Q_p = 0.85\ (100)(1000) =$

$\frac{D_m n_m}{Q_m} = 0.94$

$D_m = 0.94\ (0.85 \times 100 \times 1000) / 600$

$= 133.17\ cm^3/rpm$

ii)

$\eta_t = \frac{2\pi T_m}{P_m D_m}$

$0.92 = \frac{2\pi T_m}{105\times10^5\ (133.17\times10^{-6})}$ D_m is in m^3/rev

$T_m = 204.7$ Nm

4b) Emergency Power source
- Incase of power failure to operate critical circuit function

Auxiliary Power source
- To supplement the pump where the cycle time will allow a charge to be stored for peak requirements

Hydraulic shock absorber
- ~~Circuit~~ For circuit where sudden impact loads, quick stops, or reversal with heavy loads are a characteristics of the systems
- Accumulators should be installed as close to the shock source as possible

Leakage compensator
- In circuits necessary to hold loads for long periods of time.

4c i) Fixed cost = 1200 + 5000 + 800 + 1000 = 8000 — f

Variable cost = 5+2.5 = 7.5 per unit — v

Unit sale price = 7.5+1 = ~~8.5 per unit~~ 8.5 per unit — p

$pQ = Qv + f$

$8.5Q = 7.5Q + 8000$

$Q = 8000$

ii) $p(2500) = 2500(7.5) + 8000$

$p = \$10.7$

iii)