S5 Design and Applied Technology Practice Paper (Set 2)

Senior Secondary Design and Applied Technology

S5 Design and Applied Technology Set 2: 24 parts, 100 marks, 60 min on gear ratio, lever efficiency, tensile stress, power cost, solar efficiency and break-even.

Question 1: Gear Train and Output Speed

A gearbox drives a 48-tooth output gear from a 12-tooth input gear. The motor runs at 1200 rpm with an input torque of 0.8 N m and the transmission efficiency is 90%.

#	Question	Answer and marking notes
1	Calculate the gear ratio and the output speed of the driven gear (1 decimal place).	Ratio = teeth out / teeth in = 48 / 12 = 4.0; output speed = 1200.0 / 4.0 = 300.0 rpm (speed reduced, torque increased).
2	Ignoring losses, calculate the ideal output torque; then find the actual output torque at 90% efficiency.	Ideal torque = 0.8 x 4.0 = 3.2 N m; actual = 3.2 x 0.9 = 2.88 N m.
3	Calculate the input power of the motor and the output power of the gearbox in W (2 decimal places).	omega = 2 x pi x 1200.0 / 60 = 125.66 rad/s; P_in = 0.8 x 125.66 = 100.53 W; P_out = 2.88 x (2 x pi x 300.0 / 60) = 90.48 W (90% of input).
4	If the driven gear is replaced by a 36-tooth gear, find the new ratio and output speed, and state how the torque changes.	New ratio = 36 / 12 = 3.0; new speed = 1200.0 / 3.0 = 400.0 rpm; because the ratio falls from 4.0 to 3.0, speed rises and torque falls (about 0.75 times the previous value).

Question 2: Moments, Levers and Efficiency

A crowbar lifts a 240 N load 0.30 m from the fulcrum; the effort is applied 1.20 m from the fulcrum. The lever efficiency is 80% and the load rises 0.15 m.

#	Question	Answer and marking notes
5	Calculate the ideal effort (friction ignored) and the mechanical advantage.	Moments: F x 1.2 = 240.0 x 0.3, so F = 240.0 x 0.3 / 1.2 = 60.0 N; MA = effort arm / load arm = 1.2 / 0.3 = 4.0.
6	Allowing for 80% efficiency, find the actual effort required.	Actual effort = 60.0 / 0.8 = 75.0 N.
7	Calculate the useful output work, the distance moved by the effort, and the input work.	Output work = 240.0 x 0.15 = 36.0 J; effort distance = 0.15 x 4.0 = 0.6 m; input work = 75.0 x 0.6 = 45.0 J.
8	Verify the efficiency from the input and output work, and explain where the remaining energy goes.	Efficiency = 36.0 / 45.0 = 0.8, matching the stated 80%; the other 9.0 J becomes heat and sound at the pivot friction and the sliding contact.

Question 3: Tensile Stress, Strain and Safety Factor

A steel tie rod of diameter 12 mm and length 1.5 m carries a tensile force of 9 kN. The steel has a yield strength of 250 MPa and Young modulus of 200 GPa.

#	Question	Answer and marking notes
9	Calculate the cross-sectional area (2 decimal places) and the tensile stress in MPa.	A = pi x (d/2)^2 = pi x 36 = 113.1 mm^2; stress = F / A = 9000.0 / 113.1 = 79.58 MPa.
10	Using that stress, calculate the safety factor (2 decimal places).	Safety factor = yield strength / working stress = 250.0 / 79.58 = 3.14, above 2, so the design is acceptable.
11	Calculate the strain and the extension in mm (2 decimal places).	Strain = 79.58 / 200000.0 = 0.000398; extension = 0.000398 x 1500.0 = 0.6 mm.
12	If the force rises to 18 kN, recalculate the stress and safety factor and judge whether it is still safe.	Stress = 18000.0 / 113.1 = 159.15 MPa; safety factor = 250.0 / 159.15 = 1.57, below 2, which is not advisable under shock or fatigue loading; use a larger diameter or stronger steel.

Question 4: Electrical Power, Resistance and Energy Cost

A 2000 W kettle rated 220-240 V boils water in 6 minutes when supplied at 230 V. Electricity costs 1.20 HKD per kWh.

#	Question	Answer and marking notes
13	Calculate the current drawn at 230 V (2 decimal places).	I = P / V = 2000.0 / 230.0 = 8.7 A.
14	Calculate the resistance of the heating element (2 decimal places).	R = V^2 / P = 230.0^2 / 2000.0 = 26.45 ohm (check with V / I).
15	Calculate the energy used per boil in kWh and the cost.	Energy = 2.0 kW x 0.1 h = 0.2 kWh; cost = 0.2 x 1.2 = 0.24 HKD.
16	Calculate the total energy and cost for one boil a day over 30 days; if the supply drops to 220 V with unchanged resistance, find the new power and current.	30-day energy = 0.2 x 30 = 6.0 kWh, cost = 6.0 x 1.2 = 7.2 HKD; at 220 V, P = 220.0^2 / 26.45 = 1829.9 W and I = 220.0 / 26.45 = 8.32 A, about 8.5% below the rated 2000.0 W.

Question 5: Solar Panel Efficiency and Payback

A 1.6 m x 1.0 m solar panel has 18% efficiency. The site receives an average irradiance of 850 W/m2 and 4.5 peak sun hours per day. The installed system costs 6,000 HKD.

#	Question	Answer and marking notes
17	Calculate the panel area and the solar power incident on it.	Area = 1.6 x 1.0 = 1.6 m2; incident power = 1.6 x 850.0 = 1360.0 W.
18	Using 18% efficiency, calculate the electrical output power.	Electrical output = 1360.0 x 0.18 = 244.8 W.

#	Question	Answer and marking notes
19	Calculate the daily and annual energy output in kWh, and the yearly saving at 1.20 HKD per kWh.	Daily = 244.8 x 4.5 / 1000 = 1.1 kWh; yearly = 1.1 x 365 = 401.5 kWh; saving = 401.5 x 1.2 = 481.8 HKD per year.
20	Calculate the simple payback period in years (1 decimal place) and state two factors that would shorten it.	Payback = 6000.0 / 481.8 = 12.5 years; shortening factors include higher electricity tariffs, cheaper or more efficient panels, and more sun hours (better tilt, less shading).

Question 6: Material Usage, Cost and Break-even

A 2440 mm x 1220 mm metal sheet costs 480 HKD. Each part uses 0.45 m2 of sheet, 60 parts are required and the cutting wastage is 12%. Labour is 42 HKD per unit and fixed cost is 1,800 HKD.

#	Question	Answer and marking notes
21	Calculate the area of one sheet and the material cost per square metre (area to 4 decimal places).	Area = 2.44 x 1.22 = 2.9768 m2; cost per m2 = 480.0 / 2.9768 = 161.25 HKD.
22	Calculate the net material for 60 parts, the requirement including 12% wastage, and the minimum number of sheets to buy.	Net = 0.45 x 60 = 27.0 m2; with wastage = 27.0 x 1.12 = 30.24 m2; sheets = 30.24 / 2.9768 = 10.16, so buy 11 sheets (round up).
23	Calculate the total material cost and the material cost per part.	Material cost = 11 x 480.0 = 5280.0 HKD; per part = 5280.0 / 60 = 88.0 HKD.
24	If the selling price is 190 HKD per unit, find the contribution per unit and the break-even quantity against fixed cost.	Variable cost = 88.0 + 42.0 = 130.0 HKD; contribution = 190.0 - 130.0 = 60.0 HKD; break-even = 1800.0 / 60.0 = 30 units.