S4 Design and Applied Technology Practice Paper (Set 2): Structures and Loads, Mechanical Drives, Stress and Strain, Electronic Circuits, Energy and Power, Product Specification and Production Cost

S4 | Design and Applied Technology | Time: 75 minutes | Total: 100 marks | 24 questions

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Part A - Structures and Loads (16 marks)

Show the formula or working and state the units.

1. A simply supported beam of span 4.0 m carries a uniformly distributed load of 12 kN/m and a point load of 24 kN at mid-span. Find the total load on the beam and the reaction at each support (the beam is symmetric). [4]

Answer: UDL = 12 x 4.0 = 48 kN; total load = 48 + 24 = 72 kN. By symmetry each reaction is 72 / 2 = 36 kN.

2. A cantilever 2.5 m long carries a downward point load of 6 kN at its free end (self-weight neglected). Find the bending moment at the fixed end and state which face is in tension. [4]

Answer: Moment = 6 x 2.5 = 15 kNm. The downward load sags the cantilever, so the top face at the fixed end is in tension and the bottom face in compression.

3. A bracket fails at a load of 90 kN and is designed to carry a working load of 36 kN. Find the factor of safety and explain why a value greater than 1 is required. [4]

Answer: Factor of safety = 90 / 36 = 2.5. A value above 1 allows for material defects, uncertainty in load estimates, fatigue and accidental overload, so the part does not fail in normal service.

4. A beam deflects 9 mm under an 18 kN load. Assuming linear elastic behaviour, find the deflection when the load rises to 27 kN, and state whether the proportion still holds beyond yield. [4]

Answer: Deflection = 9 x (27 / 18) = 13.5 mm. Beyond yield the material deforms plastically, so deflection is no longer proportional to load and the linear relation fails.

Part B - Mechanical Drives (17 marks)

Use the speed-ratio relations for gears and belt drives, with units.

5. A driving gear with 60 teeth runs at 900 rev/min and drives a 20-tooth gear. Find the ratio and the output speed, and state whether the drive steps up or down. [5]

Answer: Ratio = 60 / 20 = 3; output speed = 900 x 3 = 2700 rev/min. The driven gear has fewer teeth and turns faster, so it is a step-up drive and torque falls accordingly.

6. A 150 mm diameter pulley runs at 400 rev/min and drives a 300 mm pulley by belt. Find the driven speed. [4]

Answer: 150 x 400 = 300 x n, so n = 200 rev/min. Belt speed is the same on both pulleys, so doubling the diameter halves the speed.

7. A lead screw has a pitch of 2.5 mm. Find the travel of the nut for 40 turns, and state what happens if the pitch becomes 5 mm with the same number of turns. [4]

Answer: Travel = 2.5 x 40 = 100 mm. Doubling the pitch doubles the travel to 200 mm for the same turns, but the torque needed per turn increases.

8. A belt runs on a pulley of diameter 0.20 m turning at 600 rev/min. Find the belt speed (take pi = 3.14159, 2 decimal places). [4]

Answer: Speed = pi x 0.20 x 600 / 60 = 6.28 m/s. Convert rev/min to rev/s and use the diameter in metres.

Part C - Stress and Strain (17 marks)

Give stress in N/mm2 (MPa) and state the formula used.

9. A member of cross-sectional area 250 mm2 carries a tensile load of 20 kN. Find the tensile stress. [4]

Answer: Stress = force / area = 20000 N / 250 mm2 = 80 N/mm2 (80 MPa). Convert kN to N first.

10. The same member is made of a material with Young modulus 200 000 N/mm2 and has a gauge length of 500 mm. Find the strain and the extension of the gauge length. [5]

Answer: Strain = stress / E = 80 / 200000 = 4.0 x 10^-4; extension = 4.0 x 10^-4 x 500 = 0.20 mm.

11. An aluminium alloy part has a mass of 2.7 kg and a volume of 1.0 x 10^-3 m3. Find its density and explain why light materials are preferred for car parts. [4]

Answer: Density = mass / volume = 2.7 / 0.001 = 2700 kg/m3. Lower density means less mass, so less energy is needed for acceleration and braking, fuel use falls and suspension loads are reduced.

12. A steel sheet measures 1.2 m x 2.4 m x 3 mm and the density of steel is 7850 kg/m3. Find the volume and the mass (to 0.001 kg). [4]

Answer: Thickness 3 mm = 0.003 m; volume = 1.2 x 2.4 x 0.003 = 0.00864 m3; mass = 0.00864 x 7850 = 67.824 kg.

Part D - Electronic Circuits (17 marks)

State the formula used; give current in A or mA and power in W.

13. Three resistors of 220 ohm, 330 ohm and 450 ohm are connected in series across a 12 V supply. Find the total resistance, the current and the voltage across the 330 ohm resistor. [5]

Answer: Total resistance = 220 + 330 + 450 = 1000 ohm; current = 12 / 1000 = 0.012 A (12 mA); voltage across 330 ohm = 0.012 x 330 = 3.96 V.

14. A 240 ohm resistor is connected across 12 V. Find the current through it and the power it dissipates, and explain why the power appears as heat. [4]

Answer: Current = 12 / 240 = 0.05 A; power = 12 x 0.05 = 0.6 W. Electrons collide with the lattice, transferring kinetic energy to lattice vibration, so the energy leaves as heat.

15. A potential divider has 8 kohm and 4 kohm in series across 12 V, with the output taken across the 4 kohm resistor. Find the output voltage. [4]

Answer: Output = 12 x 4 / (8 + 4) = 4 V. The output is the same fraction of the supply as that resistor is of the total resistance.

16. A 300 ohm resistor is connected in parallel with a 600 ohm resistor. Find the equivalent resistance and explain why it must be smaller than either resistor. [4]

Answer: Equivalent resistance = (300 x 600) / (300 + 600) = 200 ohm. Parallel paths give extra routes for current, so total current rises at the same voltage and the equivalent resistance falls.

Part E - Energy and Power (17 marks)

Give energy in kWh or kJ and show the working.

17. An extractor fan rated 1.5 kW runs 4 hours a day for 30 days. Find the monthly energy use in kWh and the electricity cost at 1.2 dollars per kWh. [5]

Answer: Energy = 1.5 x 4 x 30 = 180 kWh; cost = 180 x 1.2 = 216 dollars.

18. A motor takes 2.0 kW of input power and delivers 1.6 kW of mechanical output. Find the efficiency and state where the remaining energy goes. [4]

Answer: Efficiency = 1.6 / 2.0 x 100% = 80%. The remaining 0.4 kW is lost as heat and sound, mainly in winding resistance, bearing friction and core loss.

19. Water of mass 2 kg is heated through 40 K; the specific heat capacity of water is 4.2 kJ/(kg K). Find the energy needed, and the time in seconds for a 1.5 kW heater with no heat loss. [4]

Answer: Energy = 2 x 4.2 x 40 = 336 kJ; time = 336 / 1.5 = 224 s. Since 1 kW = 1 kJ/s, dividing kJ by kW gives seconds.

20. Using the 180 kWh monthly consumption above, and 0.7 kg of carbon dioxide per kWh, find the indirect monthly emissions and suggest one measure that cuts both energy and emissions. [4]

Answer: Emissions = 180 x 0.7 = 126 kg. Example measure: use a DC inverter fan or a timer that switches it off automatically, cutting running hours and power for the same ventilation.

Part F - Product Specification and Cost (16 marks)

Give costs in dollars and state where each figure comes from.

21. A part uses 18 dollars of material and 0.5 hour of labour at 120 dollars per hour; overhead is 20% of material plus labour. Find the unit cost and the cost of a batch of 500. [4]

Answer: Labour = 0.5 x 120 = 60 dollars; overhead = (18 + 60) x 20% = 15.6 dollars; unit cost = 18 + 60 + 15.6 = 93.6 dollars; batch cost = 93.6 x 500 = 46 800 dollars.

22. A shaft has a nominal diameter of 25.0 mm with a tolerance of plus or minus 0.2 mm. Find the acceptable range, judge a part measured at 25.3 mm, and find the reject rate when 3 of 200 parts are out of tolerance. [4]

Answer: Acceptable range 24.8 mm to 25.2 mm; 25.3 mm exceeds the upper limit by 0.1 mm and is rejected; reject rate = 3 / 200 x 100% = 1.5%.

23. A product sells for 90 dollars, variable cost is 60 dollars per unit and fixed cost is 24 000 dollars per month. Find the contribution per unit and the monthly break-even quantity. [4]

Answer: Contribution = 90 - 60 = 30 dollars; break-even quantity = 24 000 / 30 = 800 units. Output below 800 units makes a loss.

24. A small assembly project has three operations taking 4, 3 and 2 days. Find the total lead time in sequence; find the lead time if 2 days of overlap are allowed; and state the quality-control risk of overlapping. [4]

Answer: Sequential lead time = 4 + 3 + 2 = 9 days; with 2 days overlap = 9 - 2 = 7 days. Risk: later work starts before earlier work is finished or inspected, so any defect in the earlier stage widens the rework and raises cost.
