Theoretical Question 2: Strong Resistive Electromagnets

MARKING SCHEME

Total	Mark(s)	Marking Scheme for Answers
Part A 1.4	(a) 1.0	x-component $B(x)$ of magnetic field (in terms of a, D, I, ℓ, μ_0). ➢ 0.2 for magnetic field $d\vec{B}$ from a current loop. →(a-1)† ➢ 0.2 for expressing $B(x)$ as a definite integral. →(a-2) ➢ 0.2 for carrying out the integration. →(a-2) ➢ 0.3 for expression of $B(x)$. →(a-2) ➢ 0.1 for sign of $B(x)$ or direction of magnetic field.
	(b) 0.4	Current I_0 (in terms of $a, D, B(0), \ell, \mu_0$) to make $B(0) = 10.0$ T. ➢ 0.2 for expression of I_0. →(b-2) ➢ 0.1 for significant figure (or mantissa) with first 2 digits correct. (b-2) ➢ 0.1 for unit and exponent.
Part B 3.0	(c) 1.2	Outward normal force per unit length $\Delta F_n/\Delta s$ (in terms of a, D', I, μ_0). ➢ 0.6 for $\bar{B} = \frac{1}{2}B(0)$. →(c-1) ➢ 0.2 for $B(0)(\text{when } \ell \to \infty) = \mu_0 I/a$. →(b-1) ➢ 0.2 for normal force on wire $\Delta F_n = I\bar{B}\Delta s$. →(c-2) ➢ 0.2 for expression of $\Delta F_n / \Delta s$. →(c-2)
	0.6	Tension F_t along the wire (in terms of a, D', I, μ_0). ➢ 0.2 for resultant of tension forces $-F_t\,\Delta\theta$. →(c-3) ➢ 0.2 for equilibrium condition $\Delta F_n = F_t(2\Delta s/D')$. →(c-4) ➢ 0.2 for expression of tension F_t. →(c-4)
	(d) 0.8	Current I_b at breaking of the turn (in terms of a, b, D, σ_b, μ_0). ➢ 0.2 for tensile stress $F_t/(ab) = \sigma_b$. →(d-1) ➢ 0.2 for $D' = 1.60\,D$. →(d-2) ➢ 0.2 for expression of I_b. →(d-3) ➢ 0.1 for significant figure (or mantissa) with first 2 digits correct. (d-3) 0.1 for unit and exponent.
	0.4	Magnetic field B_b at O when the current is I_b. ➢ 0.2 for expression of B_b. →(d-4) ➢ 0.1 for significant figure (or mantissa) with first 2 digits correct. (d-4) 0.1 for unit and exponent.

Part C 1.0	(e) 0.5	Power density of heat generation in the coil. ➢ 0.1 for expression of current density J in the wire, →(e-1) or volume τ of the wire. →(e-3) ➢ 0.2 for expression of power density. →(e-2) or (e-7) ➢ 0.1 for significant figure (or mantissa) with first 2 digits correct. (e-6) ➢ 0.1 for unit and exponent.
	(f) 0.5	Time rate of change $\dot{T}$ of temperature in the coil. ➢ 0.1 for heat capacity per unit volume $\rho_m c_p$, →(f-1) or heat capacity Mc_p. →(f-3) ➢ 0.2 for expression of $\dot{T}$. →(f-2) or (f-4) ➢ 0.1 for significant figure (or mantissa) with first 2 digits correct. (f-2) 0.1 for unit and exponent.
Part D 4.6	(g) 0.6	Expressions for the inductance L and resistance R of the coil. ➢ 0.1 for flux ϕ_B of a single turn. →(g-1) ➢ 0.1 for definition of $L = N\phi_B/I$. →(g-2) ➢ 0.2 for expression of L. →(g-2) ➢ 0.2 for expression of R. →(g-3)
	0.4	Values of the inductance L and resistance R of the coil. →(g-2) and (g-3) ➢ 0.1*2 for significant figure (or mantissa) with first 2 digits correct. ➢ 0.1*2 for unit and exponent.
	(h) 0.8	Expressions for α and ω (in terms of R, L, and C). ➢ 0.1 for loop equation for voltage. →(h-1) ➢ 0.1 for conditions on α and ω. →(h-4), (h-5) ➢ 0.3 for expression of α. →(h-7) ➢ 0.3 for expression of ω. →(h-9)
	0.4	Values of α and ω. →(h-7) and (h-10) ➢ 0.1*2 for significant figure (or mantissa) with first 2 digits correct. ➢ 0.1*2 for unit and exponent.
	(i) 0.6	Expression for I_m (in terms of α, ω, θ_0, V_0 and C). ➢ 0.1 for condition of maximum current $dI/dt = 0$. ➢ 0.3 for obtaining the instant t_m of maximum current. →(i-1) ➢ 0.2 for expression of I_m. →(i-2)
	0.4	Maximum value $V_{0\mathrm{b}}$ for which I_m will not exceed I_b of Problem (d). ➢ 0.3 for significant figure (or mantissa) with first 2 digits correct.→(i-5) ➢ 0.1 for unit and exponent.

	(j) 1.0	The total amount of heat ΔE dissipated in the coil. ➢ 0.3 for energy E_C supplied by the capacitor up to the time t_m →(j-2) ➢ 0.2 for equality between E_C and the amount of heat ΔE. →(j-2) ➢ 0.3 for expression of total amount of heat ΔE. →(j-3) ➢ 0.1 for significant figure (or mantissa) with first 2 digits correct.→(j-3) ➢ 0.1 for unit and exponent.
	0.4	The temperature increase ΔT of the coil. ➢ 0.1 for expression of ΔT. →(j-4) ➢ 0.2 for significant figure (or mantissa) with first 2 digits correct.→(j-4) ➢ 0.1 for unit and exponent.

†The equation number(s) at the end of a line refers to equation(s) in the SOLUTION sheets.