9.1 Magnetic circuits and transformers

Name: _____ Class: _____ Date: _____ **Total: 24 marks**

KEY WORDS reluctance • core loss

Objective

Solve magnetic circuits, analyse ideal and real transformers, and separate losses by test – every answer checked by the power balance.

1 Key knowledge and worked examples

■ The magnetic Ohm's law

$\Phi = F/R_m$ with `F = NI` (ampere-turns) and $R_m = l/(\mu A)$ (per henry^{-1}). Flux density $B = \Phi/A$; saturation caps B near ~1.5–1.8 T in silicon steel.

■ Worked example: the core, verified in range

200 turns, 0.5 A, core l = 0.5 m, A = 10 cm^2, $\mu_r = 4000$: $R_m = 0.5/(4000\mu_0 \times 0.001) = 99472 At/Wb$; $\Phi = 100/99472 = 1.005 mWb$; $B = 1.005 T$ ✓ – the range check (well under saturation) is part of the answer. Halving the air-gap-free path or doubling µ halves R_m and doubles flux – the design lever.

■ The transformer and its two tests

Ideal: $V_1/V_2 = N_1/N_2$, $I_1/I_2 = N_2/N_1$, lossless. Real: the **OC test** (open-circuit, rated voltage) measures **core loss** (constant with load); the **SC test** (short-circuit, reduced voltage, rated current) measures full-load copper loss.

Worked example – 10 kVA, 2000/400 V: OC 400 V / 0.7 A / 240 W; SC 80 V / 5 A / 300 W. At full load: $\eta = 10000/(10000 + 240 + 300) = 94.9\%$. Balance check: output + both losses = input ✓. At HALF load the core loss stays 240 W but copper drops to a quarter (75 W): η `= 5000/(5000 + 315) = 94.1%` – the efficiency curve is flat because the losses are split between constant and quadratic terms.

2 Practice

2.1 A core with $R_m = 50000 At/Wb$ carries 300 turns at 0.4 A: compute Φ; with A = 8 cm^2, compute B and state whether it is near saturation. [3]

2.2 A 2000/400 V transformer feeds a 5 Ω load on the secondary. Compute the secondary current and the primary current (ideal). [3]

2.3 A transformer's OC test reads 480 W and SC test 620 W. Compute the full-load efficiency at 25 kVA, 0.8 power factor. [3]

3 Exam-style questions

3.1 A single-phase 50 Hz transformer, 25 kVA, 2200/220 V, gave: OC test (220 V, 4 A, 260 W); SC test (95 V, rated current, 510 W).

Compute the rated currents both sides. Determine the core loss and the full-load copper loss from the tests (state which test gives which). Compute the full-load efficiency at unity pf and at 0.8 pf – explain why one is lower using the loss structure. Compute the all-day efficiency if the transformer is at full load 8 h, half load 8 h, and energised-but-no-load 8 h. [8]

3.2 A 100 kVA transformer has core loss 500 W and full-load copper loss 1200 W.

Derive the load fraction (in kVA, at unity pf) at which efficiency is MAXIMUM (where variable loss = constant loss), and compute that maximum efficiency. Verify by computing the efficiency at load fractions 0.5 and 0.9 – both should be lower. State why the maximum condition equates the two loss families. [7]