

## 9.3 Induction machines

Name: \_\_\_\_\_ Class: \_\_\_\_\_ Date: \_\_\_\_\_

Total: 25 marks

KEY WORDS slip • rotating field

### Objective

Use slip, the per-phase equivalent circuit and the air-gap power to find current, torque and loss in a three-phase induction machine – every answer closed by the power balance.

### 1 Key knowledge and worked examples

#### ■ Synchronous speed and slip

$n_s = 120f/p$  (rpm);  $s = (n_s - n)/n_s$ ; rotor frequency  $f_r = s \cdot f$ . The rotor resistance appears as  $R'_2/s$  – slip turns the machine's behaviour into one element.

#### ■ Air-gap power and torque

The air-gap power  $P_{ag} = 3I^2 R'_2/s$  gives the torque  $T = P_{ag}/\omega_s$  (with  $\omega_s = 2\pi n_s/60$ ), and  $P_{mech} = (1 - s)P_{ag}$ ; the rotor copper loss is exactly  $s \cdot P_{ag}$  and the stator copper loss is  $3I^2 R_1$ . The balance  $P_{in} = P_{mech} + s \cdot P_{ag} + 3I^2 R_1$  must close.

#### ■ Worked example: maximum torque on demand

Neglecting stator impedance, peak torque comes at  $s_{max} = R'_2/X$  – so a wound rotor that adds external resistance moves the peak toward start. With  $R'_2 = 0.3\Omega$  and total reactance  $X = 2.0\Omega$ , adding  $R_{ext} = 1.7\Omega$  puts the peak at  $s = 1$ : starting torque rises from 48.9 N · m to 176.8 N · m – bought with higher slip (and rotor loss) when running.

### 2 Practice

**2.1** A 6-pole, 50 Hz motor runs at 970 rpm. Compute the synchronous speed, the slip and the rotor frequency. [3]

**2.2** A rotor has  $R'_2 = 0.5\Omega$ . Compute  $R'_2/s$  at  $s = 0.03$  and state how many times larger this is than  $R'_2$ . [3]

**2.3** At  $s = 0.05$  a 4-pole 50 Hz machine draws rotor-referred current  $I = 20$  A with  $R'_2 = 0.4\Omega$ . Compute the air-gap power, the torque and the mechanical power. [3]

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### 3 Exam-style questions

**3.1** A 400 V (line), 4-pole, 50 Hz induction motor has, per phase,  $R_1 = 0.4\Omega$ ,  $X_1 = 0.8\Omega$ ,  $R'_2 = 0.3\Omega$ ,  $X'_2 = 0.8\Omega$  (magnetising branch neglected), and runs at  $s = 0.04$ .

Compute the total series impedance and the stator current. Find the air-gap power, the electromagnetic torque and the mechanical power. Find both copper losses and verify the power balance. State why the rotor frequency allows a lightly laminated rotor iron. [8]

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**3.2** The motor above is rebuilt as a wound-rotor machine. The total series reactance is  $X = 2.0\Omega$  and  $R'_2 = 0.3\Omega$ .

Derive the condition on  $R'_2/s$  for maximum torque (stator resistance neglected), and hence the external rotor resistance that places maximum torque at starting ( $s = 1$ ). Compute the starting torque without and with the added resistance. Explain the running penalty of leaving that resistance in circuit. [8]

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