Exercise walk-through

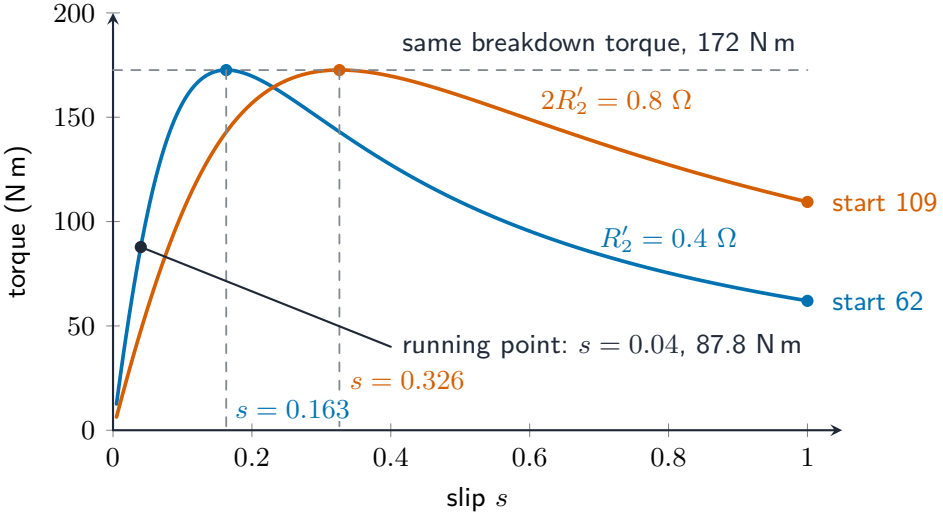
9.3
Induction machines

University Electrical Engineering

Induction machines: slip runs everything

1. **Speeds** 4-pole 50 Hz: $n_s = 1500$ rpm; at 1440 rpm **slip** is $60/1500 = 0.04$ and the rotor frequency is 2 Hz.
2. **Element** At $s = 0.04$ the slip-transformed resistance R_2/s is $25\times$ its locked-rotor value - a running motor is a different circuit from a starting one.
3. **Loss** Rotor **copper loss** is exactly s x air-gap power: 4% here - which is why big induction machines cluster near 1% slip.

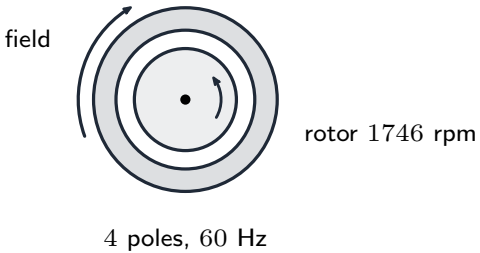
One curve, two addresses



Rotor resistance moves the breakdown peak toward start (62 to 109 N-m) and leaves the 172 N-m peak untouched.

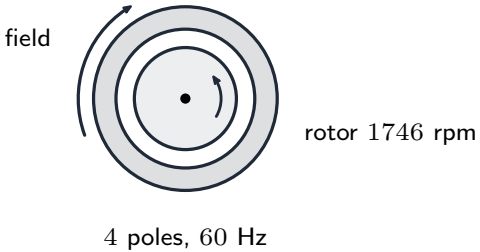
Exercise 2.1

2.1 The 4-pole, 60 Hz motor shown runs at 1746 rpm. Find the synchronous speed, the slip and the rotor frequency. [3]



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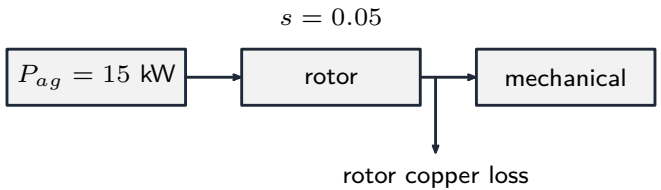


2.1

$$n_s = \frac{120 \times 60}{4} = \mathbf{1800\ rpm};\ s = \frac{54}{1800} = \mathbf{0.03};\ f_r = 0.03 \times 60 = \mathbf{1.8\ Hz}$$

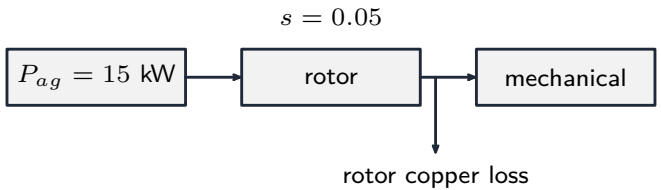
Exercise 2.2

2.2 A 4-pole, 50 Hz motor has an air-gap power of 15 kW at a slip of 0.05, as shown. Find the rotor copper loss, the mechanical power and the torque. [3]



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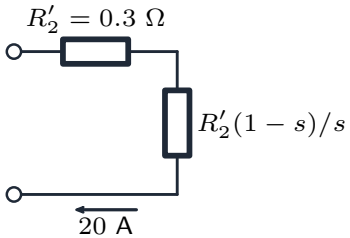


2.2

rotor copper loss $= 0.05 \times 15 =$ **0.75 kW**; mechanical $=$ **14.25 kW**; $T = \dfrac{15\,000}{157.1} =$ **95.5 N m**

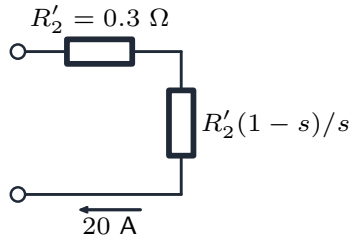
Exercise 2.3

2.3 The rotor branch shown has $R_2' = 0.3\ \Omega$ and carries $I_2' = 20$ A per phase at a slip of 0.03. Split R_2'/s into two parts. Find the rotor copper loss and the mechanical power for all three phases. [3]



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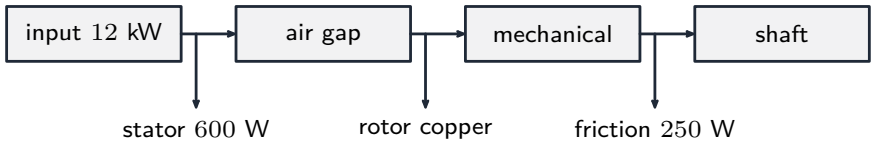


2.3

$\dfrac{0.3}{0.03} = 10\ \Omega = 0.3 + \mathbf{9.7}\ \Omega$; copper loss $= 3 \times 20^2 \times 0.3 = \mathbf{360\ W}$; mechanical $= 3 \times 20^2 \times 9.7 = \mathbf{11.6\ kW}$; check $\dfrac{360}{12\,000} = 0.03 = s$

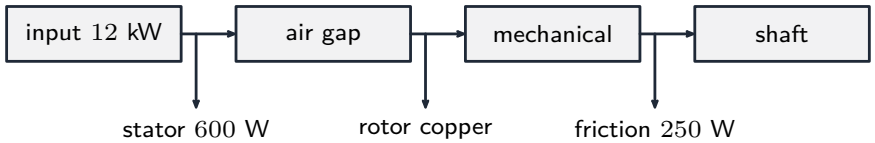
Exercise 2.4

2.4 A motor takes 12 kW from the supply, as shown. Its stator losses are 600 W, its slip is 0.04 and friction takes 250 W. Find the air-gap power, the shaft power and the efficiency. [3]



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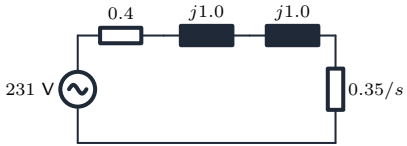
2.4

$P_{ag} = 12 - 0.6 = \mathbf{11.4\ kW}$; mechanical $= 0.96 \times 11.4 = 10.94$ kW, shaft $= 10.94 - 0.25 = \mathbf{10.69\ kW}$; $\eta = \dfrac{10.69}{12} = \mathbf{89.1}\%$

Exercise 3.1

3.1 A 400 V (line), star-connected, 4-pole, 50 Hz motor has the per-phase circuit shown: $R_1 = 0.4$, $X_1 = 1.0$, $R_2' = 0.35$, $X_2' = 1.0\ \Omega$. Ignore the magnetising branch.

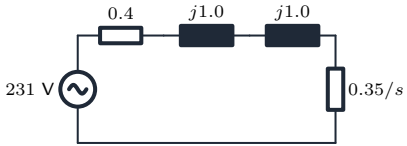
At $s = 0.035$, find R_2'/s, the current and the torque. Find the slip of maximum torque and the maximum torque. [5]



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3.1

$V = 231$ V per phase, $\omega_s = 157.1$ rad/s; $R_2'/s = \mathbf{10.0}\ \Omega$

$|Z| = \sqrt{10.4^2 + 2.0^2} = 10.59\ \Omega$, $I = \dfrac{231}{10.59} = \mathbf{21.8\ A}$

$$T = \frac{3 \times 21.8^2 \times 10}{157.1} = \mathbf{90.8\ N\ m}$$

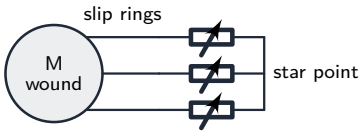
$$s_{max} = \frac{0.35}{\sqrt{0.4^2 + 2.0^2}} = \mathbf{0.172}$$

at s_{max}: $R_2'/s = 2.04\ \Omega$, $I = 73.2$ A, $T_{max} = \dfrac{3 \times 73.2^2 \times 2.04}{157.1} = \mathbf{209\ N\ m}$

Exercise 3.2

3.2 The motor of 3.1 is built with a **wound rotor** : external resistances can be added through slip rings, as shown. Its starting torque with no external resistance is 78 N m.

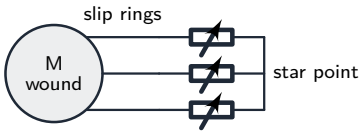
Find the external resistance (referred to the stator) that gives maximum torque at start, and that starting torque. If the resistance were left in, the motor would carry the 90.8 N m load at a slip of 0.204: find the share of the air-gap power lost in the rotor, and say what the operator should do. [5]



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3.2

for $s_{max} = 1$: $R'_2 + R_{ext} = \sqrt{0.4^2 + 2.0^2} = 2.04\ \Omega$, so $R_{ext} = \mathbf{1.69}\ \Omega$

starting torque $= T_{max} = \mathbf{209\ N\ m}$, almost three times 78 N m

rotor loss $= sP_{ag}$: **20**% of the air-gap power, against 3.5% without it

cut the resistance out in steps as the motor speeds up, so it runs at the low slip

Exercise 3.3 (a)

3.3 The workshop compressor is driven by the motor of 3.1. Its full-voltage (direct-on-line) starting current is 108 A and its starting torque 78 N m. The compressor needs 40 N m to break away. The supply company limits the starting line current to 60 A. Three starters are possible, as shown.

(a) Check the direct-on-line start against both limits. [2]



direct-on-line, star-delta, or 70% autotransformer

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(a) Check the direct-on-line start against both limits. [2]



direct-on-line, star-delta, or 70% autotransformer

(a) 78 N m is enough to break away; 108 A breaks the 60 A limit, so it fails

Exercise 3.3 (b)

3.3 The workshop compressor is driven by the motor of 3.1. Its full-voltage (direct-on-line) starting current is 108 A and its starting torque 78 N m. The compressor needs 40 N m to break away. The supply company limits the starting line current to 60 A. Three starters are possible, as shown.

(b) Find the starting line current and torque with star-delta, and check them. [2]

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(b) Find the starting line current and torque with star-delta, and check them. [2]

(b) $\frac{108}{3} = 36$ A, which passes; $\frac{78}{3} = \mathbf{26\ N\ m} < 40$ N m: the compressor does not start

Exercise 3.3 (c)

3.3 The workshop compressor is driven by the motor of 3.1. Its full-voltage (direct-on-line) starting current is 108 A and its starting torque 78 N m. The compressor needs 40 N m to break away. The supply company limits the starting line current to 60 A. Three starters are possible, as shown.

(c) Find the starting line current and torque with a 70% autotransformer, and check them. [2]

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(c) Find the starting line current and torque with a 70% autotransformer, and check them. [2]

(c) $0.7^2 = 0.49$: $0.49 \times 108 = \mathbf{53\ A}$, which passes; $0.49 \times 78 = \mathbf{38\ N\ m} < 40$: just fails

Exercise 3.3 (d)

3.3 The workshop compressor is driven by the motor of 3.1. Its full-voltage (direct-on-line) starting current is 108 A and its starting torque 78 N m. The compressor needs 40 N m to break away. The supply company limits the starting line current to 60 A. Three starters are possible, as shown.

(d) None of the three passes cleanly. What would you do, and why? [2]

Exercise 3.3 (d)

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(d) None of the three passes cleanly. What would you do, and why? [2]

(d) either unload the compressor at start (open its unloader valve) so it needs far less torque, then star-delta works; or use a variable-frequency drive, which gives full torque at about rated current; a start method must meet the current limit and the load torque at once