Power Engineering 3

Induction Motor Tutorial Solutions

①

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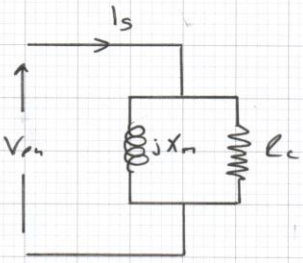
Subject: INDUCTION MOTOR TUTORIAL Date: THU 10th MAR

Q1 NO LOAD TEST



$$P_{in} = \frac{V_{ph}^2}{R_c}$$

$$\Rightarrow R_c = \frac{V_{ph}^2}{P_{in}} = \frac{400^2}{100} = \underline{\underline{1600\,\Omega}}$$

$$Q_{in}^2 = S_{in}^2 - P_{in}^2 = (V_{ph} I_s)^2 - P_{in}^2$$

$$\Rightarrow Q_{in}^2 = (400 \times 1)^2 - 100^2 = 150000$$

$$\Rightarrow Q_{in} = 387\ \text{VAr}$$

$$Q_{in} = \frac{V_{ph}^2}{X_m}$$

$$\Rightarrow X_m = \frac{V_{ph}^2}{Q_{in}} = \frac{400^2}{387} = \underline{\underline{413\,\Omega}}$$

Department of Electronics & Electrical Engineering, University of Glasgow, Rankine Building, Oakfield Avenue, Glasgow G12 8LT, UK

Tel: +44 (0)141 330 3157 Fax: +44(0)141 330 3158 Email: saffron@elec.gla.ac.uk Web: www.speedlab.co.uk

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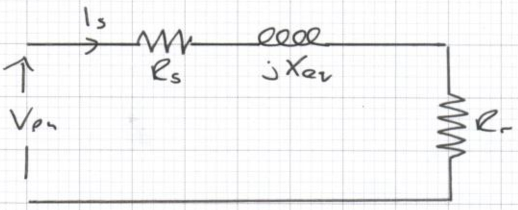
127500

LOCKED ROTOR TEST:



$$P_{in} = I_s^2 (R_s + R_r)$$

$$\Rightarrow (R_s + R_r) = \frac{P_{in}}{I_s^2} = \frac{350}{5^2} = 14\,\Omega$$

$$R_s = 6\,\Omega \quad \Rightarrow \quad \underline{\underline{R_r = 8\,\Omega}}$$

$$Q_{in}^2 = S_{in}^2 - P_{in}^2 = (V_{ph} I_s)^2 - P_{in}^2$$

$$\Rightarrow Q_{in}^2 = (100 \times 5)^2 - 350^2 = 127500$$

$$\Rightarrow Q_{in} = 357 \text{ VAr}$$

$$Q_{in} = I_s^2 X_{eq}$$

$$\Rightarrow X_{eq} = \frac{Q_{in}}{I_s^2} = \frac{357}{5^2} = \underline{\underline{14.3\,\Omega}}$$

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x

vi) $$\text{EFFICIENCY} = \frac{\text{OUTPUT POWER}}{\text{INPUT POWER}} \times 100\%$$

$$= \frac{30671}{33000} \times 100\%$$

$$= \underline{\underline{92.9\%}}$$

Q3 i) $$N_s = \frac{120 \times f_s}{p} = \frac{120 \times 50}{4}$$

$$\Rightarrow N_s = 1500 \text{ rpm}$$

$$\text{SLIP } (s) = \frac{N_s - N_r}{N_s} = \frac{1500 - 1350}{1500}$$

$$\Rightarrow \text{SLIP } (s) = \underline{\underline{0.1}}$$

ii) Need to draw the Equivalent Circuit and determine I_r

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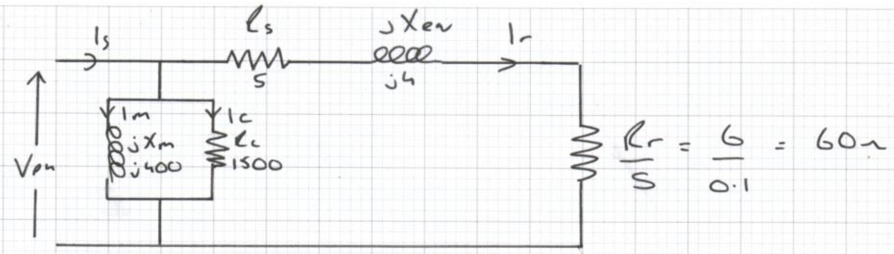
Subject: NOTE : 400V IS LINE VOLTAGE   Date:



$\frac{400}{\sqrt{3}} = 231V$

$$Z_T = R_s + jX_{eq} + \frac{R_r}{s} = 5 + j4 + 60$$

$$\Rightarrow Z_T = 65 + j4 = 65.1\angle 3.5^\circ$$

$$\Rightarrow I_r = \frac{V_{ph}}{Z_T} = \frac{231\angle 0^\circ}{65.1\angle 3.5^\circ} = \underline{\underline{3.55\angle -3.5^\circ}}$$

AIRGAP POWER $P_{GAP} = \frac{3 I_r^2 R_r}{s}$

$$= \frac{3 \times 3.55^2 \times 6}{0.1}$$

$$= \underline{\underline{2268W}}$$

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iii) MECH POWER $= P_{GAP}(1-S)$

$\Rightarrow P_{mech} = 2268(1-0.1)$

$\Rightarrow P_{mech} = \underline{\underline{2041\,W}}$

iv) $TORQUE = \dfrac{P_{mech}}{SPEED} = \dfrac{2041}{\frac{1350}{60} \times 2\pi} = \underline{\underline{14.4\,Nm}}$

v) IRON LOSS $= \dfrac{3V_{PH}^2}{R_C} = \dfrac{231^2 \times 3}{1500} = 35.5\,W \times 3$

$= \underline{\underline{107\,W}}$

STATOR COPPER LOSS $= 3I_r^2 R_S = 3 \times 3.55^2 \times 5$

$= \underline{\underline{189\,W}}$

ROTOR COPPER LOSS $= 3I_r^2 R_r = 3 \times 3.55^2 \times 6$

$= \underline{\underline{227\,W}}$

TOTAL POWER LOSS $= \underline{\underline{523\,W}}$

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vi) INPUT POWER = OUTPUT POWER + LOSSES

$\Rightarrow$ INPUT POWER = 2041 + 523 = $\underline{\underline{2564 \text{ W}}}$

vii) EFFICIENCY = $\frac{\text{OUTPUT POWER}}{\text{INPUT POWER}} \times 100\%$

$\Rightarrow$ EFFICIENCY = $\frac{2041}{2564} \times 100\% = \underline{\underline{79.6\%}}$

viii) FROM THE EQUIVALENT CIRCUIT:

$$\bar{I}_s = \bar{I}_m + \bar{I}_c + \bar{I}_R$$

So need to determine I_m, I_c + I_R in Cartesian Co-ordinates:

$$\bar{I}_m = \frac{\bar{V}_{ph}}{jX_m} = \frac{231\angle 0°}{400\angle 90°} = 0.58\angle -90°$$

$$\Rightarrow \bar{I}_m = -j0.58$$

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$$\bar{I}_c = \frac{\bar{V}_{ph}}{R_c} = \frac{231\angle 0^\circ}{1500\angle 0^\circ} = 0.15$$

$$\bar{I}_R = 3.55\angle -3.5^\circ \equiv 3.54 - j\,0.22$$

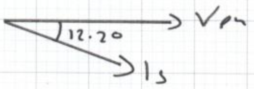
$$\Rightarrow \bar{I}_s = \bar{I}_m + \bar{I}_c + \bar{I}_R$$

$$\Rightarrow \bar{I}_s = -j\,0.58 + 0.15 + 3.54 - j\,0.22$$

$$\Rightarrow \bar{I}_s = 3.69 - j\,0.8$$

$$\Rightarrow \bar{I}_s = \underline{\underline{3.78\angle -12.2^\circ}}$$

Angle Between $\bar{V}_{ph}$ & $\bar{I}_s$ is 12.2°



$$\Rightarrow \text{Power Factor} = \cos 12.2^\circ = \underline{\underline{0.977}}$$

(NOTE $3 V_{ph} I_s \cos\phi$ SHOULD EQUAL INPUT POWER!)

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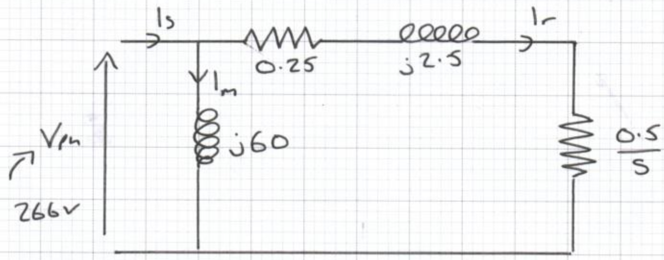
Q4 SIMPLIFIED EQUIVALENT CIRCUIT:



$\frac{460}{\sqrt{3}} = 266\text{V}$

(No Iron Loss so R_c not included)

FIRST OF ALL CALCULATE I_m (this value is the same for both Standstill and Rated Speed Operation)

$$\bar{I}_m = \frac{\bar{V}_{ph}}{jX_m} = \frac{266\angle 0^\circ}{60\angle 90^\circ} = \underline{\underline{4.43\angle -90^\circ}}$$

STANDSTILL (S = 1)

$$\frac{R_r}{S} = \frac{0.5}{1} = 0.5$$

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$$Z_T = 0.25 + j2.5 + 0.5$$

$$\Rightarrow Z_T = 0.75 + j2.5 \equiv 2.61 \angle 73.3^\circ$$

$$\Rightarrow \bar{I}_r = \frac{\bar{V}_{ph}}{\bar{Z}_T} = \frac{266 \angle 0^\circ}{2.61 \angle 73.3^\circ} = 102 \angle -73.3^\circ$$

$$\Rightarrow \bar{I}_r \equiv 29.3 - j97.7$$

$$\bar{I}_s = \bar{I}_m + \bar{I}_r = -j4.43 + 29.3 - j97.7$$

$$\Rightarrow \bar{I}_s = 29.3 - j102.1 \equiv \underline{\underline{106 \angle -74^\circ}}$$

<u>AT RATED SPEED (1764 rpm)</u>

$$N_s = \frac{120 \times f_s}{p} = \frac{120 \times 60}{4} = 1800 \text{ rpm}$$

$$\Rightarrow S = \frac{N_s - N_r}{N_s} = \frac{1800 - 1764}{1800} = 0.02$$

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$$\Rightarrow \frac{R_r}{S} = \frac{0.5}{0.02} = \underline{\underline{25\,\Omega}}$$

$$\Rightarrow Z_T = 0.25 + j2.5 + 25 = 25.25 + j2.5$$

$$\Rightarrow Z_T = 25.4\angle 5.65^\circ$$

$$\Rightarrow \bar{I}_r = \frac{\bar{V}_{ph}}{Z_T} = \frac{266\angle 0^\circ}{25.4\angle 5.65^\circ} = \underline{\underline{10.5\angle -5.6^\circ}}$$

$$\Rightarrow \bar{I}_r = 10.4 - j1.03$$

$$I_s = \bar{I}_m + \bar{I}_r = -j4.43 + 10.4 - j1.03$$

$$\Rightarrow I_s = 10.4 - j5.5 = \underline{\underline{11.76\angle -27.9^\circ}}$$

RATIO: $\frac{\text{STARTING CURRENT}}{\text{FULL LOAD CURRENT}} = \frac{106}{11.76} = \underline{\underline{9.01}}$

FULL LOAD POWER FACTOR $= \cos(-27.9) = \underline{\underline{0.88}}$ LAGGING

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