Exam Drive Technology Retake

Neighbours

Lecturer: Daniel T. McGuiness, Ph.D

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SEMESTER: WS 2024
DATE: 09.05.2025
TIME: 08:30-10:00 am

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First and Last Name

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Student Registration Number

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Grading Scheme	$\geq 90\%$	1
	$\leq 80\%$ and $\geq 90\%$	2
	$\leq 70\%$ and $\geq 80\%$	3
	$\leq 60\%$ and $\geq 70\%$	4
	$\leq 60\%$	5

Result:

___/ max. 100 points

Grade:

Student Cohort	BA-MECH-22
Study Programme	B.Sc Mechatronics, Design and Innovation
Permitted Tools	Non-programmable calculators are allowed.

Important Notes

Unnecessary Items

Place all items not relevant to the test (including mobile phones, smartwatches, etc.) out of your reach.

Identification (ID)

Lay your student ID or an official ID visibly on the table in front of you.

Examination Sheets

Use only the provided examination sheets and label each sheet with your name and your student registration number. The sheets be labelled on the front. Do not tear up the examination sheets.

Writing materials

Do not use a pencil or red pen and write legibly.

Good Luck!

Please read the following instructions carefully.

- You have **90 minutes** to complete this exam. This question booklet contains 3 question(s), 7 pages (including the cover) for the total of 100 points.
- Check to see if any pages are missing.
- All the questions are **compulsory** and all the notations used in the questions have their usual meaning taught at the lectures and done in practice.
- **Read the instructions for individual questions carefully** before answering the questions.

Question	Maximum Point	Result
3-Phase Induction Machine	40	
Calculating the Capacitor for a Single-Phase IM	20	
To work with Electric Machines	40	
Sum	100	

[Q1] 3-Phase Induction Machine 40

A three-phase Y-connected 220-V (line-to-line) 7.5-kW 50-Hz 4-pole squirrel-cage IM has the following parameter values in Ω/phase *referred to the stator.*

$$R_s = 0.2 \quad \Omega, \quad R_r' = 0.21 \quad \Omega, \quad X_s = 0.283 \quad \Omega, \quad X_r' = 0.359 \quad \Omega, \quad X_m = 10.25 \quad \Omega.$$

The total friction, windage, and core losses (P_{rot}) may be **assumed to be constant** at 233 W, independent of load.

a. Draw the equivalent circuit for this machine and show the relevant parameters on the circuit . (9)

For a slip value of s=0.015 and given circuit parameters in the question, determine:

b. The stator current and the power factor, (6)

c. The synchronous speed and the rotor speed for this drive , (5)

d. The torque generated , (5)

e. The input power for this operating condition , (5)

f. The efficiency when operated at rated voltage and frequency , (5)

g. Considering the design of this motor, state if it is possible to start this drive with a slip ring starter. Give reasons to justify your answer . (5)

[Q2] Calculating the Capacitor for a Single-Phase IM 20

A 2.5-kW 120-V 50-Hz capacitor-start motor has the following impedances for the main (Z_{main}) and auxiliary (Z_{aux}) windings (at starting):

$$Z_{\text{main}} = 3.2 + \mathbf{j}\,3.0\,\Omega,$$
$$Z_{\text{aux}} = 8.3 + \mathbf{j}\,3.9\,\Omega.$$

Find the value of starting capacitance which will place the main and auxiliary winding currents in quadrature at starting.

[Q3] To work with Electric Machines 40

Please answer the following questions briefly in a few sentences.

a. For an application which requires high inertial load and where power generation is the main goal, which electrical machine would be applicable ? Please justify your reasons. (8)

b. You are requested with a machine design where torque pulsation is required to be as small as possible as the drive will be used in scientific instrumentation. Which drive would be suitable for this scenario ? (8)

c. Due to recent budget cuts, your customer requests you to come up with a drive for use in Trams but there will be minimal budget for control design. Under these requirements which drive(s) is/are suitable? (8)

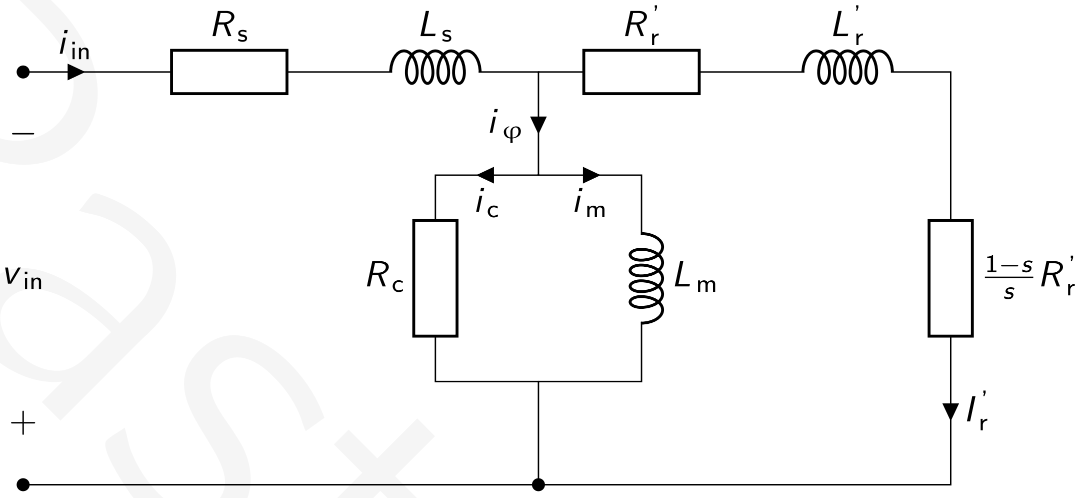
d. What is slip and for which kind of machine is it important? In addition, please describe the speed relations of rotor and stator with regards to slip (8)

e. You are required to build a machine for use in hard to reach environments? Which drive(s) is/are usable under these requirements? Please justify your reasons (8)

Answers

[A1] 3-Phase Induction Machine 40

a. The equivalent circuit of an induction machine with relevant parameters are as follows: (9)



b. Let the impedance Z_f represent the per-phase impedance presented to the stator by the magnetising reactance and the rotor. Therefore we can bulk collect the reactance on the rotor size as:

$$Z_f = R_f + \mathbf{j}X_f = \left(\frac{R_r'}{s} + \mathbf{j}X_r'\right) \quad \text{in parallel with} \quad \mathbf{j}X_m$$

Substitution of numerical values gives, for $s = 0.015$,

$$Z_f = R_f + \mathbf{j}X_f = (4.77 + 6.64j)\,\Omega$$

The stator input impedance can now be calculated as:

$$Z_{in} = R_s + \mathbf{j}X_s + Z_f = (4.97 + 6.92j)\,\Omega$$

The line-to-neutral terminal voltage is equal to:

$$V_{in} = \frac{220}{\sqrt{3}} = 127.02\,\text{V}$$

and hence the stator current can be calculated as:

$$\hat{I}_{in} = \frac{V_{in}}{Z_{in}} = \frac{127.02}{(4.97 + 6.92j)} = (8.69 - 12.11j)\,\text{A}$$

The stator current (I_{in}) is thus 14.91 A and the power factor is equal to $\cos(-54.33) =$ 0.58 **lagging**. (6)

c. The synchronous speed (n_s) can be found as:

$$n_s = \left(\frac{120}{\text{poles}}\right) f_e = \left(\frac{120}{4}\right) \times 50 = 1500.0\,\text{rpm}$$

or the angular stator speed (ω_s) can be calculated to be:

$$\omega_s = \frac{4\pi f_e}{\text{poles}} = 157.08\,\text{rad}\,\text{s}^{-1}$$

The rotor speed (n_r) is:

$$n_r = (1 - s)\, n_s = (0.985) \times 1500.0 = 1477.5\,\text{rpm}$$

or in the angular speed form: (5)

$$\omega_r = (1 - s)\, \omega_s = (0.985)) \times 157.08 = 154.72\,\text{rad}\,\text{s}^{-1}$$

d. The air-gap power (P_{gap}) is calculated to be:

$$P_{gap} = n_{ph} I_2^2 \left(\frac{R_r'}{s}\right) \text{W}$$

> The only resistance included in Z_f is R_r'/s.

The power dissipated in Z_f is equal to the power dissipated in R_r'/s and hence we can write:

$$P_{gap} = n_{ph} I_1^2 R_f = 3\,(14.91)^2\,(5) = 3179.51\,\text{W}$$

We can now calculate P_{mech} and the shaft output (P_{shaft}) power as:

$$\begin{aligned} P_{shaft} &= P_{max} - P_{rot} = (1 - s)\, P_{gap} - P_{rot}, \\ &= (0.985) \times 3179.51 - 233 = 3131.81\,\text{W} \end{aligned}$$

and the shaft output torque (T_{shaft}) can be found as : (5)

$$T_{shaft} = \frac{P_{shaft}}{\omega_r} = \frac{2898.81}{154.72} = 18.74\,\text{N}\,\text{m}^{-1}$$

e. The efficiency (η) is calculated as the ratio of shaft output power to stator input power.

The input power is given by (5)

$$\begin{aligned} P_{in} &= n_{ph} \text{Re}\,[V_{in} I_{in}] \\ &= 3312.9\,\text{W} \end{aligned}$$

f. Thus the efficiency (η) is equal to: (5)

$$\eta = \frac{P_{out}}{P_{in}} = \frac{2898.81}{3312.9} = 0.88 \approx 88.0\% \quad \blacksquare$$

g. The method of using a slip starter requires direct access to the rotor structure which is not possible with a squirrel cage rotor as the rotor is a closed circuit with no possible connections . (5)

[A2] Calculating the Capacitor for a Single-Phase IM 20

The currents $\hat{I}_{\text{main}}$ and $\hat{I}_{\text{aux}}$ are the currents which flow into Z_{main} and Z_{aux} respectively. The impedance angle of the main winding (ϕ_{main}) is:

$$\phi_{\text{main}} = \tan^{-1}\left(\frac{3.2}{3.0}\right) = 43.152^{\circ}$$

To produce currents in time quadrature with the main winding (i.e., to create the necessary phase difference), the impedance angle of the auxiliary winding circuit (including the starting capacitor) must be (in degrees):

$$\phi = 43.152 - 90.0 = -46.848$$

The combined impedance of the auxiliary winding and starting capacitor is equal to

$$Z_{\text{total}} = Z_{\text{aux}} + \mathbf{j}X_{\text{c}} = 8.3 + \mathbf{j}\,(3.9 + X_{\text{c}})\ \Omega$$

where $X_{\text{c}} = -\frac{1}{\omega_{\text{c}}}$ is the reactance of the capacitor and $\omega = 2\pi\,50 \approx 314.159\,\text{rad}\,\text{s}^{-1}$. Therefore

$$\tan^{-1}\left(\frac{3.9 + X_{\text{c}}}{8.3}\right) = -46.848^{\circ}$$

$$\frac{3.9 + X_{\text{c}}}{8.3} = \tan(-46.848) = -1.067$$

and hence

$$X_{\text{c}} = -1.067 \times 8.3 - 3.9 = -12.756\,\Omega$$

The capacitance C is then

$$C = \frac{-1}{\omega X_{\text{c}}} = \frac{-1}{314.159 \times -12.756} = 249.538\,\text{ţF} \quad \blacksquare$$

[A3] To Work with Electric Machines 40

a. An environment where a high inertial load would mean a force carrying significant weight. An idea which would be high inertial load would be water. As the requrement is for power generation the ideal choice would be **Synchronous Machine** with a **Salient Pole** design as the high inertial load would allow a bigger rotor design and to generate the required grid frequency, it needs significant poles to operate. (8)

Ideal Answer: Synchronous Machine with Salient Pole.

Unfortunately choosing an induction motor would be not the best as the frequency control would not be ideal and is generally not preferred for massive scale operations.

b. This requirement requires some elaboration. A scientific instrument requires precision and the machine should also be chosen as to minimise distubances. This in turn limits the choices one could have. The ideal choice is **PMSM** as while being more expensive than **BLDC** has better toque output. (8)

   Ideal Answer: PMSM.

   Unfortunately choosing switched reluctance motor, classic dc motor or induction would not be preferred.

c. Limitations in budget cuts would require some thinking on choosing a machine which can internally handle load variation with good tolerance. As an application of tram means the load will have high fluctuation as passengers depart and board means we require a machine with constant speed per torque operation. (8)

   Ideal Answers: DC Drives or Synchronous Motor

d. Slip is defined as the difference between the stator and the rotor and is only apparent in machine where synchronicity is not its primary operation. This concept only applies to induction machines. The relation between the rotor and stator is as follows: (8)

$$(1 - s)\, n_{\mathrm{s}} = n_{\mathrm{r}}$$

   where s is slip, n_{s} is the rotation speed of stator in rpm and n_{r} is the rotation speed of the rotor in rpm.

e. The environment with hard to reach environments require a machine with **minimal** maintenance. This limits the applications of DC drives as their carbon brushes would cause problems. In addition synchronous machines without PMs are also liable as they also need brushes to conduct electricity to the rotor. (8)

   Ideal Answers: Induction, PMSM, BLDC, Stepper, SRM