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UNIVERSITY OF TASMANIA

EXAMINATIONS FOR DEGREES

ENJ231 Electric Machines and Transformers

Example Paper A

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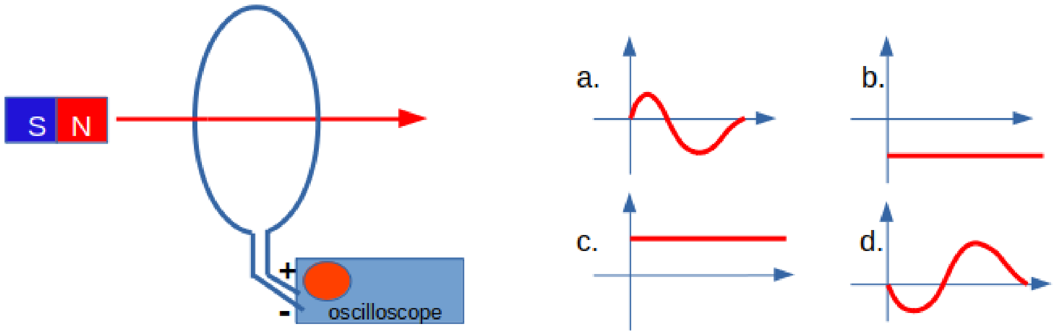
SECTION 1 – Multi-Choice Answer Questions

*Answer **all** TEN (10) Questions. Each question is worth 2 marks. This section is worth 20 marks, or 20% of the examination.*

Question 1.

A magnet is moving across a wire loop (from left to right) as shown on a figure below. Use Lenz's law to determine which of the following figures (a, b, c, or d) shows the correct reading for the induced current.



Hint: if current flows in the anticlockwise direction (as seen from the left) then the voltage is positive; if current flows in the clockwise direction (as seen from the left) then the voltage is negative.

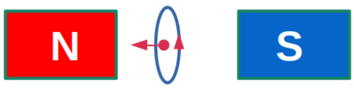
a: up and down
b: negative flat
c: positive flat
d: down and up

[Correct answer: a]

Question 2.

A magnetic dipole moment is placed within a uniform magnetic field. Initially, the dipole is not aligned with the magnetic field, but it soon realigns. Which figure correctly represents the final orientation of the magnetic dipole moment?

A.



B.

C.

D.

[Correct answer: C]

Continued...

Question 3.

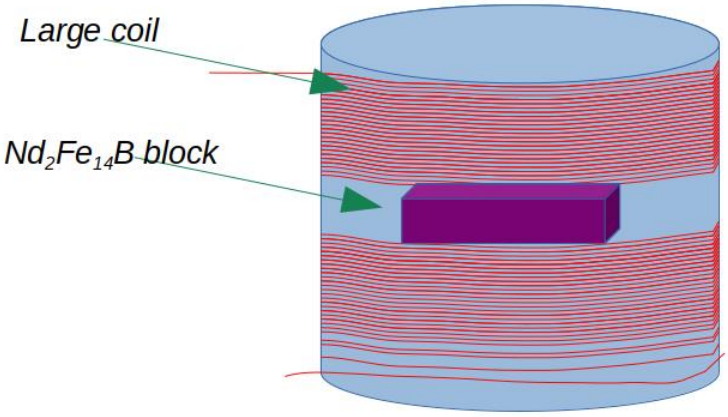
Magnetic flux intensity describes the component of the magnetic field that:

a: is induced by the electric current
b: is induced both by the electric current and magnetisation
c: is induced by magnetisation

[Correct answer: a]

Question 4.

An unmagnetised neodymium block is placed inside a large coil.



Which of the statements below is correct:

A) As you increase the electric current flowing through the coil, the magnetisation of the neodymium block increases.
B) If the current is too large, the magenetisation does not increase even if the current increases.
C) If the current is too large, the relative permeability decreases even if the current increases.
D) All of the above.

[Correct answer: D]

Question 5.

The starting torque for an induction machine can be increased if:

a. the rotor flux leakage reactance is increased
b. the stator resistance is increased
c. the rotor resistance is decreased
d. the rotor resistance is increased

[Correct answer: d]

Question 6.

A single-phase 3300 V / 400 V, 90 kVA, 50 Hz transformer has the following open-circuit test measurements:

	Supply voltage	Current	Input power
Open-circuit test (HV side open)	400 V	5.5 A	1950 W

Determine the value of R_c referred to the HV side (don't forget to refer to the HV side):

a. 5585 Ω
b. 4388 Ω
c. 82 Ω
d. 1.2 Ω
e. 64 Ω

[Correct answer: a]

Question 7.

A single-phase 3300 V / 400 V, 90 kVA, 50 Hz transformer has the following short-circuit test measurements:

	Supply voltage	Current	Input power
Short-circuit test (LV side shorted)	267 V	27.3 A	3200 W

Determine the value of R_{eq} referred to the HV side:

a. 292 Ω
b. 22.3 Ω
c. 0.33 Ω
d. 4.29 Ω
e. 1516 Ω

[Correct answer: d]

Question 8.

What speed will a 50 Hz, 3-phase, 8-pole Y-connected synchronous generator operate at?

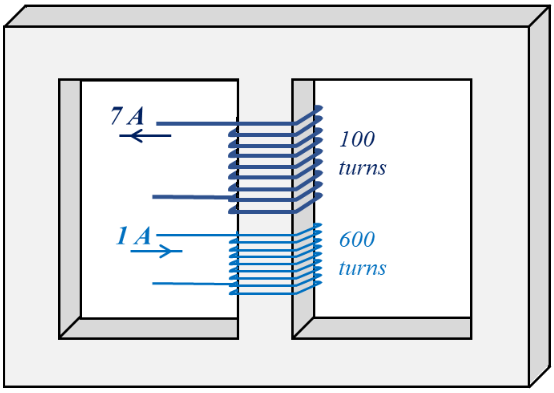
a. 1500 rpm
b. 3000 rpm
c. 375 rpm
d. 900 rpm
e. 750 rpm

[Correct answer: e]

Continued…

Question 9.

A magnetic circuit has two windings as shown below. One winding consists of 100 turns and carries a current of 7 A, and the second winding has 600 turns and a current of 1 A.



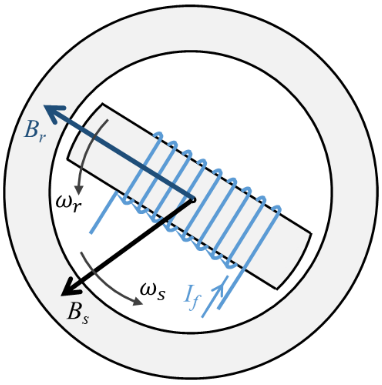
What is the net mmf produced by the two windings and what will be the direction of magnetic field in the central vertical section of the core?

a. 1300 A-turns and magnetic field pointing upwards
b. 100 A-turns and magnetic field pointing downwards
c. 100 A-turns and magnetic field pointing upwards
d. 1300 A-turns and magnetic field pointing downwards
e. 700 A-turns and magnetic field pointing downwards

[Correct answer: b]

Question 10.

An AC machine is represented by the figure below, which shows the rotor and stator fields and their direction of rotation. The machine is operating at steady state.



Which of the following is true for the operation of this machine?

a. An external counter-torque is applied in the ***opposite*** direction to rotation and the machine is operating as a ***motor***
b. An external counter-torque is applied in the ***opposite*** direction to rotation and the machine is operating as a ***generator***
c. An external counter-torque is applied in the ***same*** direction to rotation and the machine is operating as a ***motor***
d. An external counter-torque is applied in the ***same*** direction to rotation and the machine is operating as a ***generator***

[Correct answer: a (1 mark for answer c)]

SECTION 2 – Fill-In The Blank Questions

*Answer **all** FIVE (5) Questions. Each question is worth 2 marks. This section is worth 10 marks, or 10% of the examination.*

Question 1.

A wire carrying current produces a magnetic field. The static magnetic field is

produced by ………………….. ………………… .

[Answer: steady current]

Question 2.

Faraday's law of induction states that a ……………………………………………………… produces an electromotive force.

[Answer: time-varying magnetic flux or rate of change of magnetic flux]

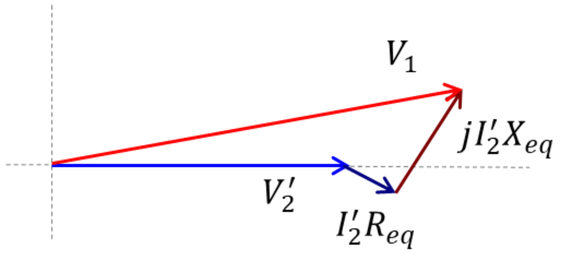
Question 3.

A DC machine requires a commutator so that the ………………………………… is able to be reversed as the machine rotates.

[Answer: direction of current in the armature (or rotor) conductors (or windings)]

Question 4.

The phasor diagram for a transformer supplying power to a load is shown below.



The load is …………….. reactive power and the transformer output voltage is ……..….. than its input voltage.

[Answer: consuming or absorbing or using AND smaller or lower or less]

Question 5.

In the transformer equivalent circuit, the components R_{eq} and X_{eq} represent ………………………………………………………..

[Answer: winding resistance and winding leakage flux of both windings]

Continued...

SECTION 3 – Short Answer Questions

*Answer **all** FOUR (4) Questions. Each question is worth 2.5 marks. This section is worth 10 marks, or 10% of the examination.*

Question 1.

A wire loop (same as in **Section 1 Question 3** above) is placed in the uniform magnetic field. What will happen to the orientation of the wire loop if you periodically change the direction of the current? In your answer provide the explanation to what happens.

[Correct answer: The loop will periodically rotate. Reversing the direction of the current changes the orientation of the magnetic dipole moment. Subsequently, torque acting on the loop will make it flip so that the orientation of the magnetic dipole moment is aligned with the magnetic field.]

Question 2.

Name a few effects that impact effectiveness of a real transformer:

[Correct answer: Eddy currents losses, hysteresis losses, flux leakage]

Question 3.

A typical B vs H curve for real magnetic material, indicating on it the two non-ideal behaviours. What are the main impacts of real iron cores on the exciting current that is required to ensure a sinusoidal flux

[Correct answer: Sketch of B-H curve with saturation and hysteresis; Impact is non-sinusoidal exciting current and/or exciting current that contains 3^{rd} harmonics]

Question 4.

Sketch a torque-speed curve for a typical induction motor, indicating on your sketch the normal range of operation, starting torque and synchronous speed.

[Correct answer: well-labelled T-s curve of IM, with synch speed, starting torque, pull-out torque and normal operating range clearly shown]

SECTION 4 – Calculation Questions

*Answer **all** THREE (3) Questions. Each question is worth 20 marks. This section is worth 60 marks, or 60% of the examination.*

Question 1.

You have a 15cm long coil with 300 turns of wire carrying a current of 0.75 A. The radius of the coil is 8cm. The coil is shown in the Figure below.

a). Initially the coil is empty. What is the magnetic flux intensity inside the coil?

[4 marks]

$H = N\ i\ /l = 300\ .\ 0.75\ [A]\ /\ 0.15\ [m] = 1500\ [A/m]$

b). What is the inductance of the coil?

[4 marks]

$L = \lambda/i = N\ .\ H\ .\ \mu_0\ .\ 4\ .\ \pi\ .\ r^2\ /i = 0.061\ [H]$

c). You then put a steel core inside the coil. The steel core has the same dimensions as the coil and it has relative permeability of $\mu_r = 850$. What is the magnetic flux density inside the coil?

[4 marks]

$B = H\ .\ \mu_0\ .\ \mu_r = 1.6\ [T]$

d). The saturation magnetisation of the steel core is 1.5 MA/m. You now increased the current to 16 A. What is the magnetic flux density inside the coil?

[8 marks]

Magnetic flux intensity: $H = N\ i\ /l = 32000\ [A/m]$

Expected magentisation at $i = 16A$ $M = (\mu_r - 1)\ H = 27.17$ MA/m which is much larger than the saturation magnetisation, thus

$B = \mu_0\ .\ (H + Ms) = \mu_0\ .\ (\ 32000\ A/m + 1500000\ A/m) = 1.925\ [T]$

Question 2.

A 2-pole three-phase wound-rotor induction motor which is connected in Δ-configuration to a 400 V RMS line-line 50 Hz supply, is required to drive a constant torque load (required load torque doesn't vary with speed) at a speed of 2800 rpm. The rotational losses are negligible (P_{rot} = 0), and the motor has the following per-phase IEEE equivalent circuit parameters:

$$R_1 = 2\ \Omega,\ \ X_1 = 2\ \Omega,\ \ R_2' = 1\ \Omega,\ \ X_2' = 2\ \Omega,\ \ X_m = 100\ \Omega.$$

a). Draw the per-phase Thevenin equivalent circuit for the induction motor and determine the Thevenin equivalent circuit parameters V_{th}, R_{th} and X_{th}.

[4 marks]

Answers: V_{th} = 392.1 V , R_{th} = 1.92 Ω, X_{th} = 2.00 Ω

c) How much torque is the motor producing at the required operating speed?

[5 marks]

Answers: slip = 0.0667 → T = 72.8 Nm

d) Calculate the power output, power losses and hence efficiency of the motor?

[7 marks]

Answers: R_{mech} = 14 Ω, P_{mech} = 21356 W → $|I_2'|$ = 22.55 A → P_{loss} = 4457 W → Eff = 82.7%

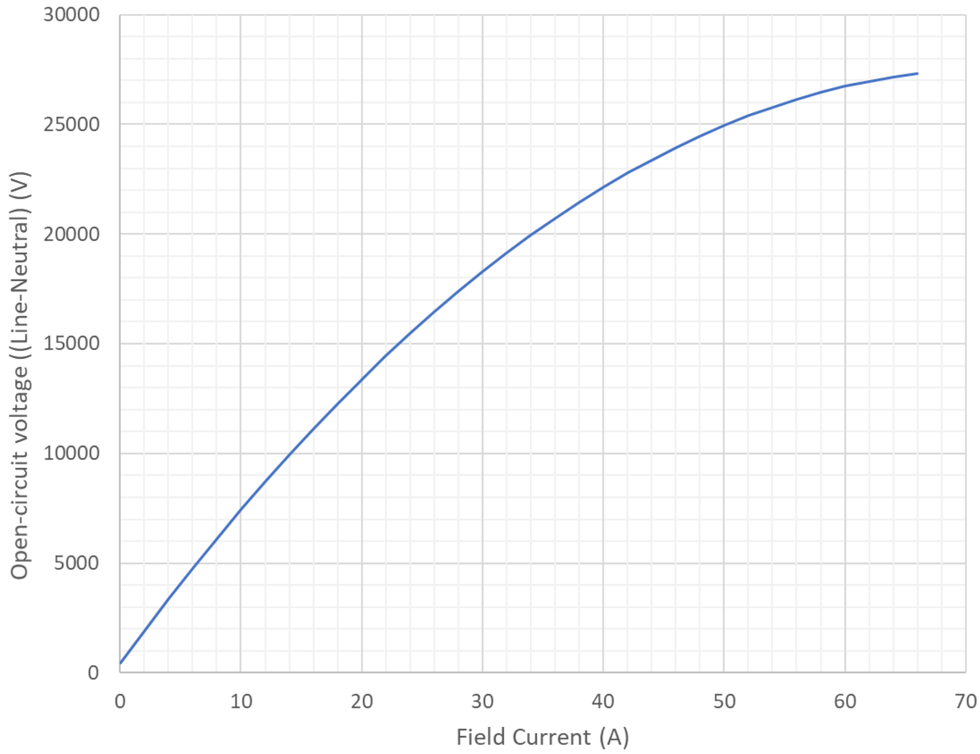
e) Calculate the starting torque that this motor can produce? Will it be able to start the load?

[4 marks]

Answers: at slip = 1, T = 59.9 Nm → since constant torque load of 72.8 Nm required, this motor cannot start the load.

Question 3.

A 50 Hz, 3-phase, 8-pole Y-connected synchronous generator, which has open-circuit characteristics shown in the Figure below, has armature resistance $R_a = 0.1\ \Omega$ and a synchronous reactance $X_s = 1\ \Omega$. The terminal voltage of the generator is 33 kV (line to line), and the generator is producing an output of 300 MVA at 0.8 lagging power factor.



a) Using the terminal phase voltage as the reference (i.e. use phase angle of V_t as 0°) calculate the magnitude of the armature current, I_a?

[6 marks]

Answers: $|V_t|$ = 19.05 kV → $|I_a|$ = 5249 A

b) Determine the induced emf, E_f, in each stator winding owing to the field flux, and the field winding current, I_f, which must be supplied to achieve this operating point?

[6 marks]

Answers: $|E_f|$ = 22.95 kV → I_f = 42.5 A

c) If the rotational losses for this machine are 4 MW, what must the externally applied input torque (from the prime mover) be?

[8 marks]

Answers: P_{out} = 240 MW, P_{loss} = 12.3 MW → P_{in} = 227.7 MW → T_{in} = 2.90 x 10^6 Nm

Formula Sheet

Constants

$\mu_0 = 4\pi \times 10^{-7}$ H/m

Magnetic Fields and Circuits

Electromotive force, emf $\varepsilon = \oint \vec{E} \cdot d\vec{l}$

Motional emf $\varepsilon = \oint (\vec{v} \times \vec{B}) \cdot d\vec{l}$

Ampere's Law $\oint \vec{H} \cdot d\vec{l} = i_{enc}$

Faraday's Law: emf, $\varepsilon = -\frac{d\phi}{dt}$

Lorentz force

Flux density $B = \mu H = \mu_0(H + M) = \frac{\phi}{A}$

Permeability $\mu = \mu_r \mu_0$

Magnetomotive force: MMF, $F = Ni = Hl$

Reluctance $\mathcal{R} = \frac{l}{\mu A}$

Flux $\phi = \frac{F}{\mathcal{R}}$

Induced emf $e = N\frac{d\phi}{dt}$

Flux linkage $\lambda = N\phi$

Faraday's Law for coil $\varepsilon = -\frac{d\lambda}{dt} = -N\frac{d\phi}{dt}$

Inductance $L = \frac{\lambda}{i}$

Stored energy $E = \frac{1}{2}Li^2$

Induced rms voltage $e_{rms} = 4.44 N_1 \phi_m f$

Transformers

Turns ratio $a = \frac{N_1}{N_2}$

$\frac{Z_1}{Z_2} = \left(\frac{N_1}{N_2}\right)^2$

Voltage Regulation $= \frac{|V_2|_{NL} - |V_2|_L}{|V_2|_L} \times 100\%$

$\eta = \frac{output\ power}{input\ power} = \frac{P_{out}}{P_{out} + losses} = \frac{P_{out}}{P_{out} + P_c + P_{cu}}$

DC Machines

Armature emf $E_a = K_a \Phi \omega_m$

Developed torque $T_m = K_a \Phi I_a$

$\Phi = K_f I_f$ (for unsaturated)

Separately excited: $T = \frac{K_a \Phi V_t}{R_a} - \frac{(K_a \Phi)^2}{R_a}\omega_m$

Shunt: $T = \frac{K_a K_f V_t^2}{R_a R_{fw}}\left(1 - \frac{K_a K_f}{R_{fw}}\omega_m\right)$

Series: $T = \frac{K_{sr} {V_t}^2}{\left(R_a + R_{ae} + R_{fw} + K_{sr}\omega_m\right)^2}$, $K_{sr} = K_a K_f$

Synchronous Machines

$n_s = \frac{120f}{P}$ rpm

$E_f = V_t + I_a R_a + I_a jX_s = |E_f|\angle\delta$

$P_{in} = T_{applied} \times \omega_m$

Power (3-phase) $P = \frac{3|V_t||E_f|}{|X_s|}\sin\delta$

Reactive power (3-phase) $Q = \frac{3|V_t||E_f|}{|X_s|}\cos\delta - \frac{3|V_t|^2}{|X_s|}$

Induction Machines

$n_s = \frac{120f}{P}$ rpm

$slip = s = \frac{(n_s - n_m)}{n_s} = \frac{\omega_s - \omega_m}{\omega_s}$

Rotor frequency $f_2 = sf_1$

Stator copper loss $P_1 = 3I_1^2 R_1$

Rotor copper loss $P_2 = 3I_2^2 R_2 = sP_{ag}$

$P_{mech} = P_{ag}(1 - s)$

Output Torque $T = \frac{P}{\omega_m}$

Thevenin equivalent $V_{th} = \frac{V_1}{\sqrt{R_1^2 + (X_1 + X_m)^2}} \times X_m$

$$Z_{th} = \frac{jX_m(R_1 + jX_1)}{R_1 + j(X_1 + X_m)} = R_{th} + jX_{th}$$

Torque equation

$$T_{mech} = \frac{3}{\omega_s}\frac{V_{th}^2}{\left(R_{th} + \frac{R_2'}{s}\right)^2 + (X_{th} + X_2')^2}\frac{R_2'}{s}$$

Slip at max torque $s_{T_{max}} = \frac{R_2'}{\sqrt{R_{th}^2 + (X_{th} + X_2')^2}}$

Max torque $T_{max} = \frac{3}{2\omega_s}\frac{V_{th}^2}{R_{th} + \sqrt{R_{th}^2 + (X_{th} + X_2')^2}}$