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UNIVERSITY OF TASMANIA / SHANDONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

EXAMINATIONS FOR DEGREES

Autumn Semester 2020

ENJ231 Electric Machines and Transformers

Examination Paper A

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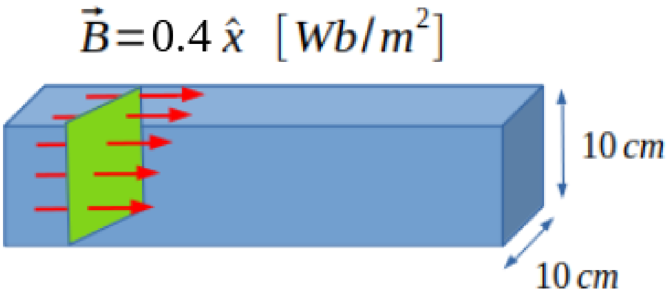
SECTION 1 – Multi-Choice Answer Questions

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

Question 1.

The magnetic flux passing through the green surface is

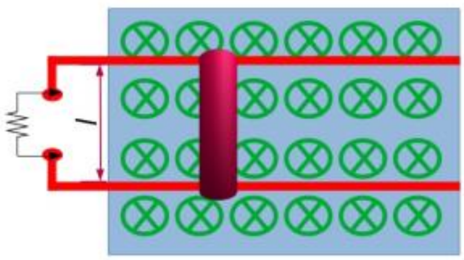


a. flux = 0 [Wb]
b. flux = 0.004 [Wb]
c. flux = 0.04 [Wb]
d. flux = 0.4 [Wb]

[Correct answer: b]

Question 2.

A metal rod of length l is placed on conducting rails (distance between the rails is also l) in a uniform magnetic filed B. The rod is cylindrical and can roll over the rails. The magnetic flux density points into the page. What is direction of the current to make to rod roll in the right direction?



a. Anticlockwise
b. Clockwise
c. it does not matter, the flow of the current will result in the movement of the rod
d. it does not matter, the flow of the current will not result in the movment of the rod

[Correct answer: b]

Question 3.

The saturation magnetisation is:

- **a.** The maximum value of magnetisation
- **b.** Is the critical value of magnetisation beyond which the increase of magnetisation is nonlinear
- **c.** Is the magnetisation of saturn alloys

[Correct answer: a]

Question 4.

Dielectric breakdown:

a. is measure of polarisation of the bound charges
b. occurs when the external field is so large that it breaks bound charges apart
c. is the strength of the electric field inside the dielectric

[Correct answer: b]

Question 5.

A single-phase 2200 V / 230 V, 50 kVA, 50 Hz transformer has the following open-circuit test measurements:

	Supply voltage	Current	Input power
Open-circuit test (LV side open)	2200 V	0.95 A	1620 W

Determine the value of R_c referred to the HV side:

a. 316 Ω
b. 1810 Ω
c. 277 kΩ
d. 3025 Ω
e. 28.9 kΩ

[Correct answer: d]

Question 6.

A single-phase 2200 V / 230 V, 60 kVA, 50 Hz transformer has the following short-circuit test measurements:

	Supply voltage	Current	Input power
Short-circuit test (LV side shorted)	253 V	17.8 A	2100 W

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

a. 6.63 Ω
b. 72.4 mΩ
c. 14.2 Ω
d. 63.29 Ω
e. 0.693 Ω

[Correct answer: a]

Question 7.

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

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

[Correct answer: b]

Question 8.

A 2-pole, 50 Hz Δ-connected squirrel-cage induction machine has the per-phase Thevenin equivalent circuit parameters shown below. The motor is running at a slip of 4%, and rotational losses can be ignored.

$$V_{th} = 400\text{ V} \quad R_{th} = 2\ \Omega \quad X_{th} = 3\ \Omega \quad R_2' = 1\ \Omega \quad X_2' = 1\ \Omega$$

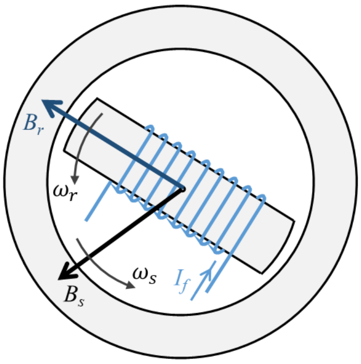
What is the output torque of the motor?

a. 51 Nm
b. 61 Nm
c. 103 Nm
d. 72 Nm

[Correct answer: a]

Question 9.

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 ***generator***
b. An external counter-torque is applied in the ***same*** direction to rotation and the machine is operating as a ***motor***
c. An external counter-torque is applied in the ***opposite*** 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: c (1 mark for answer b)]

Question 10.

A Δ-connected three-phase 600 kW, 50 Hz 2-pole induction motor has a measured stator winding resistance of 3.2 Ω per phase and the following No-Load test measurements:

	Supply voltage (line-line)	Current (line current)	Input power
No-load test	3300 V	28.5 A	32.4 kW

Determine the rotational loss P_{rot} for this motor:

a. 25.2 kW
b. 34.2 kW
c. 29.8 kW
d. 40.2 kW
e. 24.6 kW

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

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.

Magnetic susceptibility describes how well materials can get ….. by the external magnetic field.

[Answer: magnetised]

Question 2.

A non-linear nature of ferromagnetic materials, means that close to saturation, the value of ...... is not linearly proportional to the magnetic flux intensity.

[Answer: magnetisation]

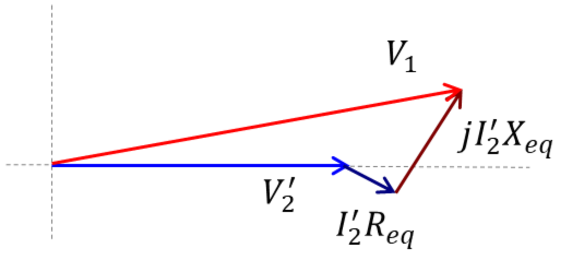
Question 3.

In a synchronous machine, the angle δ is the physical angle between the ………………………..……

[Answer: rotor magnetic field (or rotor axis) and the net rotating magnetic field in the machine]

Question 4.

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



The transformer is supplying a ……….. power factor load, and the magnitude of the transformer input voltage is ……..….. than the voltage supplied to the load.

[Answer: lagging AND higher, or larger, or greater]

Question 5.

The rated voltage of a transformer is usually limited because .... puts an upper limit on the value of peak flux in the core.

[Answer: saturation]

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.

Consider an empty coil that induces a magnetic field. What will happen to the magnetic flux inside the coil if you placed a ferromagnetic material inside the coil?

[Correct answer: The magnetic flux increase. This is because the ferromagnetic material will become magnetised and the total magnetic filed will increase due to magnetisation. The total field will be the sum of the magnetic flux intensity produced by the coil and magnetisation produced by the ferromagnetic core.]

Question 2.

Which material is the most optimal to for a core of the transformer? Is it a hard ferromagnetic material or a soft ferromagnetic material? Explain your answer.

[Correct answer: the most optimal to for a core of the transformer is a soft ferromagnetic material. This is because for soft ferromagnetic material the magnetisation changes quickly with the change of the magnetic flux intensity. Hard material does not change its magnetic properties easily and so it not the most optimal to material to form a core of the transformer.]

Question 3.

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: Answer should have a well-labelled Torque-speed curve of an induction motor, with typical shape of curve included, and with synchronous speed, starting torque, pull-out torque and also normal operating range clearly shown and labelled]

Question 4.

Transformer are normally designed so that the iron core is in saturation when operated normally. Describe what this means for the time-varying magnetic flux in the core and for the magnetising current that must be supplied to the transformer?

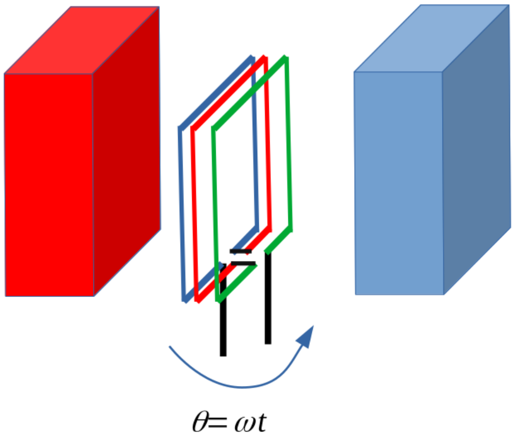
[Correct answer: The time-varying flux is sinusoidal, since voltage is sinusoidal, but magnetizing current is therefore non-sinusoidal because of saturation effects. This means that the magnetising (or exciting) current that is supplied to the transformer will not be sinusoidal, in fact it especially needs to contain a significant 3rd harmonic component]

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.

Three (3) identical wire frames are connected in a series. The frames rotate within a uniform magnetic field 100 times per second. The dimensions of a single frame is 20cm x 20cm. The magnetic flux density is B = 1.2 T.



a). Calculate the angular frequency, ω (measured in radians per second). [1 mark]

ω = 628.3 [rad/s]

b). Calculate the form of magnetic flux passing through a single frame, as well as the value of the peak flux (maximum flux) passing through a single frame [3 marks]

flux through 1 frame: ϕ = 0.048 . cos (628.3 . t) [Wb]

peak flux through 1 frame: ϕ = 0.048 [Wb]

c). Calculate the EMF and peak EMF generated by a single frame. [3 marks]

EMF by 1 frame: E = 30.16 . sin (628.3 . t) [V]

peak EMF by 1 frame: E = 30.16 [V]

d). Calculate the effective (rms) EMF generated by this generator [3 marks]

rms EMF by 3 frames: EMF RMS = 63.98 [V] e). If the load is 2 Ω, calculate the average power generated by this generator [4 marks]

average power: p = 2046.6 [W]

f). If the frequency of rotation doubles (i.e. increases to 200 rotations per second) how does the average power generated by this generator changes? [3 marks]

average power: p = 8186.2 [W]

g). If the number of frames doubles (i.e. increases to N = 6) how does the average power generated by this generator changes (assume the frames rotate 100 times per second)? [3 marks]

average power: p = 8186.2 [W]

Question 2.

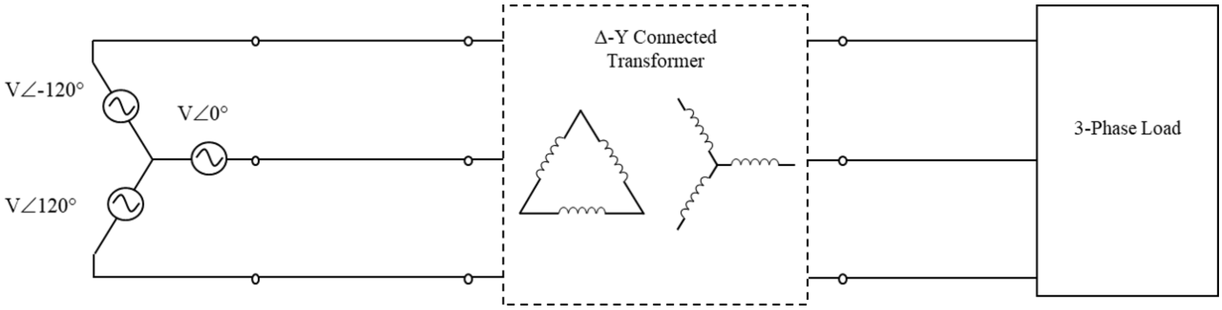
A Δ-Y connected 3-phase transformer is made up of three single-phase 40 kVA 2200/300 V transformers, each with the following equivalent circuit parameters:

R_1 = 1.2 Ω, X_2 = 3.5 Ω , R_2 = 20 mΩ, X_2 = 60 mΩ, R_{c1} = 4000 Ω, and X_{m1} = 2000 Ω

(R_{c1} and X_{m1} are quantities specified on the HV or primary side)

The transformer supplies a 3-phase load of 100 kW at 0.9 lagging power factor, at a load voltage of 500 V.

You should use the *approximate equivalent circuit* to answer this question.



a). Calculate the magnitude of the secondary winding current (per phase) for the transformer? [6 marks]

|S| = sqrt(3).$|V_L|.|I_L|$ → $|I_2| = |I_L|$ = 128.3 A

b). Determine R_{eq} and X_{eq} referred to the primary side? [3 marks]

$R_{eq} = R_1 + a^2R_2'$ = 2.28 Ω, X_{eq} = 6.73 Ω

c). Determine the transformer input (primary) line-to-line voltage (using the secondary winding voltage as reference, that is having an angle of 0)? [6 marks]

$V_1 = V_2' + I_2'(R_{eq} + jX_{eq})$ = 2206∠2.3° V (is line-to-line since delta-connected primary)

d). Calculate the transformer's open-circuit or no-load voltage (line-to-line)? [5 marks]

$V_{2oc} = V_1/a$ = 300.8 V → $V_{2oc\ (line\text{-}line)}$ = 521 V

Question 3.

A Y-connected 3-phase, 2-pole, 50 Hz synchronous generator with per-phase resistance R_a = 0.3 Ω and synchronous reactance X_S = 3 Ω is producing an output of 20 MW real power and is consuming 5 MVAr reactive power, at a terminal voltage of 12,000 V (line-to-line). Rotational losses are negligible.

a). Calculate the armature current (using the per-phase terminal voltage as the reference voltage, that is having angle of 0)? [4 marks]

$S = 3\, V_t.\, I_a^*$ → $I_a = 992 \angle 14°$ A

b). Calculate the per-phase induced emf in the stator windings owing to rotor field flux, $|E_f|$? [6 marks]

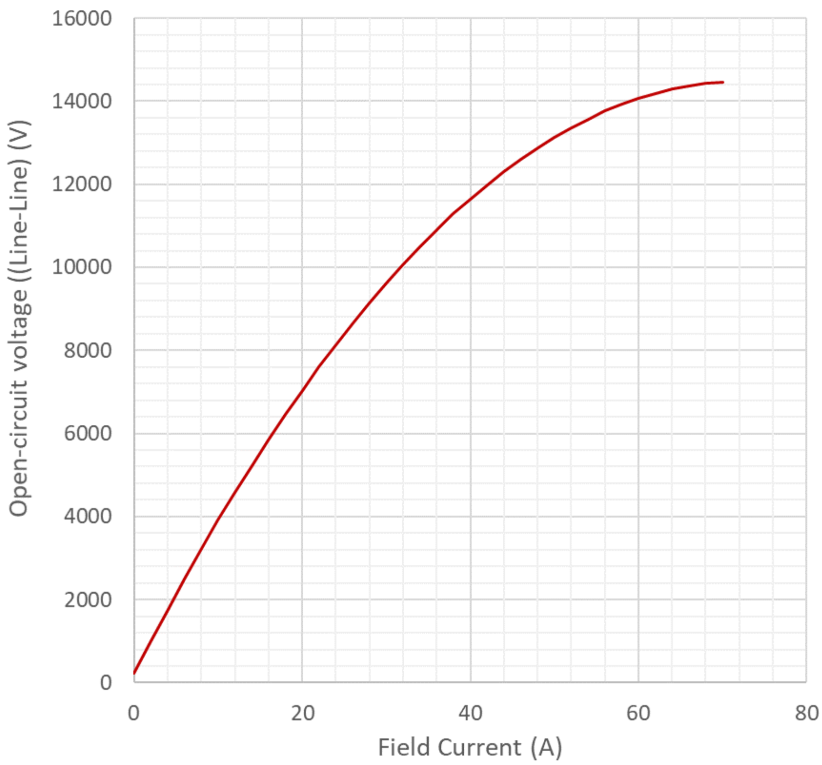
$E_f = V_t + I_a(R_a + jX_S)$ → $E_f = 7137 \angle 24.5°$ V → $|E_f| = 7137$ V

c). Determine the rotor angle for this operating point? [4 marks]

$\delta = 24.5°$

d). The OCC curve for the machine is shown below. Determine the field current that is required at the current operating point? [6 marks]

$|E_f| = 7137$ V → open-circuit line-line voltage = 12360 V → $I_f = 44$ A



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

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

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