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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 B

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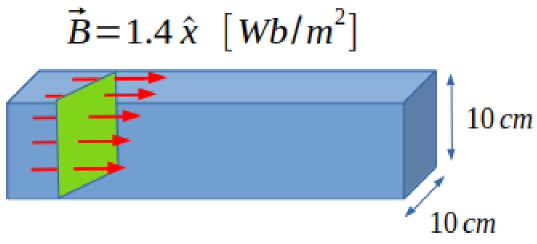
SECTION 1 – Multi-Choice Answer Questions

*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 = 0.014 [Wb]
c. flux = 0.14 [Wb]
d. flux = 1.4 [Wb]

[Correct answer: b]

Question 2.

Iron alloys used in transformers reach magnetic saturation when magnetic flux density reaches around

a. 0 – 0.005 T
b. 0.01 – 0.05 T
c. 0.1 – 0.5 T
d. 1.0 – 2.0 T

[Correct answer: d]

Question 3.

Consider an ideal generator. If the frequency of rotation increases by a factor of 2, what happens to the power output

a. remains the same
b. increases by a factor of 2
c. increases by a factor of 3
d. increases by a factor of 4

[Correct answer: d]

Question 4.

If a magnetic dipole moment is placed within a uniform magnetic field a torque will act on the magnetic dipole moment and will change its orientation. What will happen to the orientation of the magnetic dipole moment

a. Its orientation will be the same (parallel) as the orientation of the magnetic field.
b. Its orientation will be the anti-parallel to the orientation of the magnetic field.
c. Its orientation will be at the angle of the 90º (with respect to the right hand rule) to the orientation of the magnetic field.
d. Its orientation will be at the angle of the 270º (with respect to the right hand rule) to the orientation of the magnetic field.

[Correct answer: a]

Question 5.

What happens to the torque speed curve of an induction motor if the rotor resistance is increased?

a. the no-load speed increases and starting torque increases
b. the no-load speed decreases and starting torque decreases
c. the no-load speed is unchanged and starting torque increases
d. the no-load speed is unchanged and starting torque decreases
e. the no-load speed is decreases and starting torque is unchanged

[Correct answer: c]

Question 6.

A Y-connected three-phase 20 kW, 50 Hz 2-pole induction motor has a measured stator winding resistance of 4.3 Ω per phase and the following No-Load test measurements:

	Supply voltage (line-line)	Current (line current)	Input power
No-load test	400 V	4.6 A	2350 W

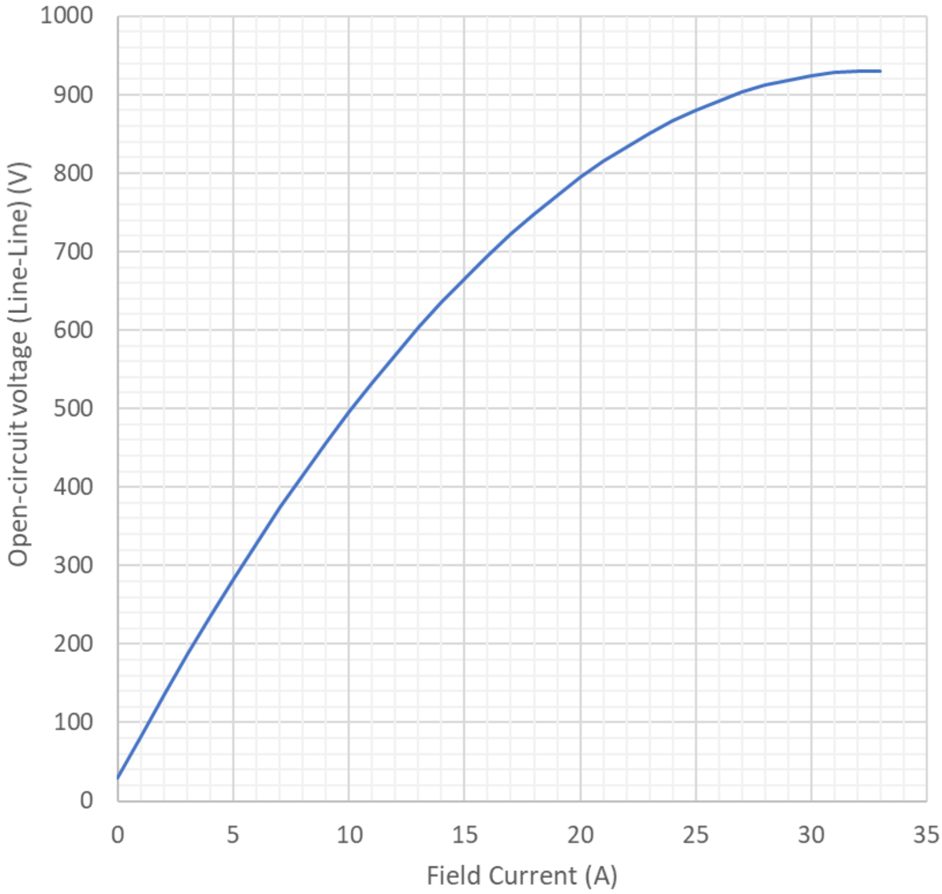
Determine the rotational loss P_{rot} for this motor:

a. 2259 W
b. 1531 W
c. 2077 W
d. 2441 W
e. 2623 W

[Correct answer: c]

Question 7.

A 415 V 50 Hz 3-phase Y-connected synchronous generator has open-circuit characteristics as shown below. The generator is producing an output of 40 kW. How much field current is required to produce the required per-phase induced stator winding emf $|E_f|$ of 520 V?



a. 5.5 A
b. 10.8 A
c. 26.8 A
d. It is not possible to tell without knowing the terminal voltage V_t

[Correct answer: c]

Question 8.

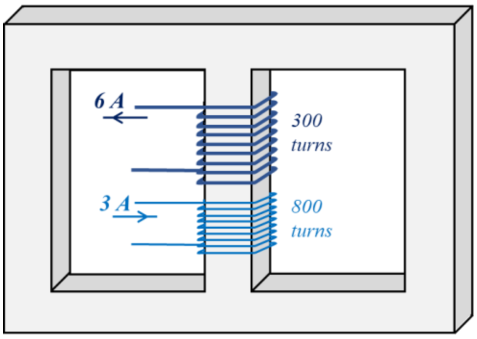
What is the most appropriate 3-phase induction motor to choose if you wish to operate a large pump at 390 rpm?

a. 10-pole, 50 Hz induction motor
b. 12-pole, 50 Hz induction motor
c. 14-pole, 50 Hz induction motor
d. 16-pole, 50 Hz induction motor
e. 18-pole, 50 Hz induction motor

[Correct answer: c]

Question 9.

A magnetic circuit has two windings as shown below. One winding consists of 300 turns and carries a current of 6 A, and the second winding has 800 turns and a current of 3 A.



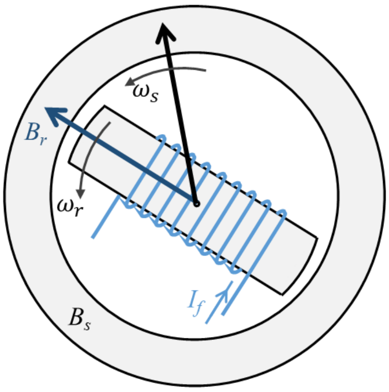
What is the net mmf produced by the two windings and what will be the direction of magnetic field in the central vertical section of the core?

a. 100 A-turns and magnetic field pointing downwards
b. 1800 A-turns and magnetic field pointing downwards
c. 2400 A-turns and magnetic field pointing upwards
d. 600 A-turns and magnetic field pointing downwards
e. 3400 A-turns and magnetic field pointing downwards
f. 600 A-turns and magnetic field pointing upwards

[Correct answer: f]

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: d (1 mark for answer b)]

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.

Saturation of magnetic material occurs when all magnetic dipole moments (domains or atoms) are ……. with the external magnetic field

[Answer: align]

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.

The full range of motor speeds at rated load is only possible for an induction motor if the supply .... is controlled.

[Answer: frequency]

Question 4.

The real power losses in a synchronous machine's iron core are a result of hysteresis and .... losses.

[Answer: eddy current]

Question 5.

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]

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.

State the Faraday law of induction and explain how it is useful for operation of generators.

[Correct answer: Faraday's law of induction states that the EMF is given by the rate of change of the magnetic flux. A generator contains elements that create a variable magnetic flux (for example a rotor), which in is used to generate the EMF.]

Question 2.

Consider a material that is placed inside a coil. You constantly are increasing a current and the magnetic flux intensity. After reaching the saturation magnetisation, the magnetisation of the material does not change. Explain why the magnetisation of the material remains constant.

[Correct answer: Magnetisation occurs because the magnetic domain align with the external field. A material is saturated When all the domains are aligned, at this point no further alignment is possible and hence magnetisation will not increase even though the magnetic flux intensity is still increasing.]

Question 3.

Describe carefully why a 3-phase power transformer is not usually Y-Y connected, for the case of real transformers where core saturation is present?

[Correct answer: Core saturation means that a non-sinusoidal exciting current waveform is need to ensure a sinusoidal flux and hence voltage waveform. The exciting current is required to contain a lot of 3rd harmonic component, with 3rd harmonics for each of the three phases being in phase with each other. But in any three-wire Y-connected system it is not possible for 3rd harmonics to be supplied (since $I_{a3} + I_{b3} + I_{c3} = 0$), and thus sinusoidal flux is not possible if both windings are Y-connected.]

Question 4.

Why is a synchronous motor generally unable to start a load? Describe briefly one method for starting synchronous motors.

[Correct answer: If the motor is energized when stationary, the rotating stator field and the stationary rotor field are not able to produce a consistent torque (the torque actually changes direction and magnitude – sinusoidally) that is able to act on the rotor and accelerate it up to speed. One method of starting is to use a separate smaller motor to accelerate the rotor approximately to the synchronous speed before then energising the rotor and connecting the mechanical load. Another method is to use a variable frequency drive, starting with a very low stator supply frequency (and hence slow stator field rotation) so that the rotor can be accelerated and synchronized and then gradually increasing supply frequency until the required speed is reached.]

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.

Consider a long solenoid (coil) with a core that is an iron alloy. The length of the coil is 80cm and the radius is 5cm. The number of turns is 200. The current is increased until the core is magnetised to saturation at about i = 2A and the saturated magnetic field is B = 1.5 T.

a). Calculate the amplitude of the magnetic flux intensity at the centre of the coil at the point when the core reaches saturation. [2 marks]

$H = N.i/L = 500$ [A/m]

b). Calculate the amplitude of the saturation magnetisation of this iron alloy. [5 marks]

$B = \mu_0 H + \mu_0 M \Rightarrow M = 1.19$ [MA/m]

c). The current is increased to i = 10A. Find the value of the flux passing through the coil and the value of the magnetic flux density. [5 marks]

$B = \mu_0 H + \mu_0 M_{sat} = 1.502$ [T]

$\phi = BA = 0.0118$ [Wb]

d). What is the relative permeability when i = 1A and when i = 10A? (for simplicity assume that the iron alloy is linear up until the point of saturation). [6 marks]

at i = 10 A (B = 1.502 T and H = 2500 A/m): $\mu_r = B/(\mu_0 H) = 478.3$

at i = 1 A is the same as i = 2A (B=1.5 T and H = 500 A/m): $\mu_r = 2387.3$

e). If we were to remove the iron-alloy core and attempt to obtain the same magnetic field of 1.5 T inside the solenoid, how much current would we need? Is this current of reasonable (practicable) amplitude? [2 marks]

$i \approx 4775$ A
no, its too large to be practicable

Question 2.

A 50 Hz, Δ-connected, 8-pole induction motor is supplied by a voltage (line-to-line) of 680 V. The motor can be represented by the Thevenin equivalent induction motor circuit, with Thevenin voltage Vth = 640 V and circuit parameters

R_{th} = 1.5 Ω, X_{th} = 2 Ω , R_2' = 0.5 Ω and X_2' = 1 Ω.

The motor is running at rated speed of 720 rpm..

a). Calculate the Thevenin equivalent circuit current I_2'? [6 marks]

Slip, s = 0.04 → R_{mech} = 12 Ω → Z_{tot} = 14 + j3 Ω → I_2' = 44.7∠-12.7° A

b). How much power is being supplied to the motor and at what power factor is it supplied? [4 marks]

S_{in} = 3 Vth. $I_2'^*$ = 83.9 + j18.0 kVA → P_{in} = 83.9 kW, PF = 0.978 lagging

c). What is the magnitude of line current being supplied to the Δ-connected motor? [4 marks]

|S| = sqrt(3).$|V_L|.|I_L|$ → $|I_L|$ = 72.9 A

d). If rotational losses (at normal operating speeds) are 3 kW, what is the motor efficiency? [6 marks]

$P_{mech} = 3.|I_2'|^2.R_{mech}$ = 71.9 kW → P_{out} = 68.9 kW {Or $P_{out} = P_{in} - P_{losses}$ }

Eff = P_{out}/P_{in} = 82.1%

Question 3.

A 3300/400 V single-phase 50 Hz transformer has the following open circuit and short circuit test measurements:

Open-circuit test (HV side open): V = 400 V, I = 21.0 A, P = 5250 W

Short-circuit test (LV side shorted): V = 313 V, I = 76 A, P = 7400 W

a). Determine the equivalent circuit parameters R_c and X_m (referred to the HV side)? [6 marks]

$R_{c(LV)} = 30.5\ \Omega \rightarrow R_{c(HV)} = 2074\ \Omega$, $X_{m(LV)} = 24.4\ \Omega \rightarrow X_{m(HV)} = 1661\ \Omega$

b). Determine the equivalent circuit parameters R_{eq} and X_{eq} (referred to the HV side)? [6 marks]

$R_{eq(HV)} = 1.28\ \Omega$, $X_{eq(HV)} = 3.91\ \Omega$

c). What should the transformer secondary current referred to the HV side, I_2', be for the transformer to operate at maximum efficiency? [4 marks]

Max when $P_C = P_{Cu} \rightarrow I_2' = V_2 / \mathrm{sqrt}(R_c.R_{eq}) = 64.0$ A {also, OK if answer gives current on LV side, $I_2 = 528$ A }

d). If the transformer supplies a load at 0.9 lagging power factor, what must the load be (in kW) if the transformer is operating at maximum efficiency? [4 marks]

$S_{2\ max}' = 211$ kVA $\rightarrow P_{max} = 190.1 - P_{Cu} = 184.8$ kW

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