UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 3 Examination in Engineering: August 2018

Module Number: EE3303 **Module Name: Electric Machines**

[Three Hours]

[Answer **all questions**, each question carries **10 marks**]

Q1. a) i) State two disadvantages of using permanent magnets instead of electromagnets in electric machines.

ii) What is meant by 'remanaent flux density' and 'coercive force' in a magnetic hysteresis loop?

iii) Briefly explain two methods used to reduce the eddy current losses in a ferromagnetic core.

iv) Using Ampere's Law, derive an equation for the field intensity at a point r distance away from a long straight conductor carrying a current I.

[3.0 Marks]

b) The total core loss for a given magnetic core is found to be 3.4 kW at 50 Hz. Keeping flux density constant, the frequency of the supply is raised to 70 Hz. Calculate the eddy current loss and the hysteresis loss at 50 Hz and 70 Hz, if the total core loss increased to 5.2 kW at 70 Hz.

[2.5 Marks]

c) The transformer core shown in Figure Q1.a has its bottom section made of steel and rest made of iron. In the middle of the bottom section, there is an air gap with a distance of 0.1 cm. Its primary side winding has 500 turns and secondary side winding has 200 turns. Relative permeability of iron and steel are 1500 and 600 respectively. Take the permeability of free space as $4\pi \times 10^{-7}$ Wb/A.turns.m.

i) Calculate the total reluctance of the core.

ii) Determine flux density in the top section of the core, if the primary side current i_1 is 25 A.

iii) Draw the flux variation and the voltage variation at secondary side, if the current waveform shown in Figure Q1.b is applied to the primary winding.

[4.5 Marks]

Q2 a) i) Name two gasses used in gas filled dry type transformers.

ii) State two characteristics of an ideal transformer.

ii) Briefly explain the constructional differences between a core-type transformer and a shell-type transformer.

iii) Draw a conservator tank type oil immersed transformer and name the main components.

[4.0 Marks]

b) A 5 kVA, 200/400 V, 50 Hz single-phase step up transformer is tested to determine its equivalent circuit parameters. The results of the tests are given in Table Q2. For part (ii) and part (iii), assume the secondary side voltage and core loss of the transformer remains constant at 400 V and 150 W respectively.

i) Draw the approximated equivalent circuit of the transformer referred to the low voltage side.

ii) When delivering 3 kVA at rated voltage, the efficiency of the above transformer is 89%. Calculate the load impedance, the primary side voltage and the voltage regulation. Draw the corresponding phasor diagram.

iii) Determine the maximum possible efficiency and the corresponding kVA loading of the transformer for a load power factor of 0.8. Note that the maximum efficiency occurs when the copper loss equals to the core loss.

[6.0 Marks]

Q3. a) i) State two methods used in dc machines to reduce the effect of the armature reaction.

ii) Discuss why armature control of a dc motor cannot be used to achieve speeds above the rated speed.

iii) Briefly explain why a series dc motor should not be started on no-load.

iv) From the first principles, show that the electromagnetic torque T_m developed in a dc machine can be expressed by

$$T_m = \left(\frac{pz}{2\pi a}\right)\phi_f I_a$$

where notations have their usual meanings.

[4.0 Marks]

b) A shunt dc motor with an armature resistance of 0.5 Ω drives an elevator load which requires a constant torque of 300 Nm. The motor is connected to a 600 V supply and rotates at 1500 rpm. Assume brush contact drop is negligible.

i) Determine the armature current.

ii) Calculate the armature current and the speed of the motor, if the shunt field flux is reduced by 10%.

[3.5 Marks]

c) A 30 hp series dc motor connected to a 110 V dc supply draws a current of 150 A and operates at a reduced load of 19.5 hp. The armature resistance, the field resistance and the total core loss of the motor are 0.03 Ω, 0.02 Ω and 200 W respectively. The brushes used in the motor are metal graphite. Assume that the stray losses are 1% of the rated output power. Calculate

i) the induced back emf,
ii) the efficiency, and
iii) the rotational loss of the motor.

[2.5 Marks]

Q4 a)

i) State the parameters which can be used to control the speed of a three phase induction motor.
ii) State two advantages of wound rotor type induction motors over squirrel cage type induction motors?
iii) Briefly explain the three operating modes of a three phase induction machine using a torque speed characteristics curve.
iv) Explain how the dc test, the locked rotor test and the no-load test are conducted to determine the per-phase equivalent circuit parameters of a three phase induction machine.

[4.5 Marks]

b) A 208 V, 60 Hz, 1710 rpm, wye-connected, three-phase wound rotor type induction motor has following per-phase equivalent circuit parameters reffered to the stator side. Terms have their usual meanings. Assume the core losses and stray losses are negligible.

$R_S = 0.22\ \Omega$ $\quad R'_R = 0.3\ \Omega$ $\quad X_S = 0.43\ \Omega$ $\quad X'_R = 0.43\ \Omega$ $\quad X_M = 15.0\ \Omega$

i) Calculate the number of poles and the slip at rated speed.
ii) Calculate the starting torque and the pull out torque of the motor.
iii) Determine the input line current and the efficiency of the motor under rated load conditions, if the rotational loss is 200 W.
iv) How much additional resistance (reffered to the stator side) should be added to the rotor circuit in order to get the pull out torque of the motor at starting conditions?
v) Determine the starting current of the motor, before and after connecting the additional resistor in part (iv). Comment on your results.

[5.5 Marks]

Q5 a) i) Briefly explain why synchronous generators are preferred over induction generators in large power plants.

ii) Which synchronous machine type is typically used in coal power plants? Justify your answer.

iii) Briefly explain the operation of automatic voltage regulator (AVR).

iv) Draw a schematic diagram of an exciter arrangement that can be used in synchronous machines to make excitation completely independent of any external power source.

[3.5 Marks]

b) A 300 kVA, 480 V, 0.85 p.f. lagging, 60 Hz, two pole, wye-connected three-phase synchronous generator has an armature resistance of 0.04 Ω. The core loss, the stray loss and the rotational loss of the generator under rated conditions are 10 kW, 2 kW and 13 kW respectively. The open-circuit and short-circuit characteristics of the generator are shown in Figure Q5.

i) What is the synchronous reactance of the generator for a field current of 3 A?

ii) What is the synchronous reactance of the generator at rated armature current?

iii) Calculate the internal generated voltage and the voltage regulation of the generator at rated conditions. Assume that the synchronous reactance of the generator at rated conditions is equal to the reactance calculated in part (ii).

iv) Determine the efficiency and the input torque of the generator at rated conditions.

v) Calculate the maximum power the generator can deliver, if the field current is adjusted so that the generator supplies the rated current at rated voltage with 0.85 lagging p.f.

[3.5 Marks]

c) A 50 hp, 415 V, 0.8 p.f. lagging, wye-connected three-phase synchronous motor has an armature resistance of 0.03 Ω and a synchronous reactance of 2.0 Ω. Its efficiency at full load is 90%.

i) Determine the input power and the line current of the motor at rated conditions?

ii) Calculate the internal generated voltage, the consumed reactive power and the converted power of the motor at rated conditions.

iii) Calculate the new input power factor, if the internal generated voltage is decreased by 5%. Neglect the armature resistance and assume $E_A \sin(\delta)$ quantity remains the same where δ is the torque angle and E_A is the internal generated voltage.

[3.0 Marks]

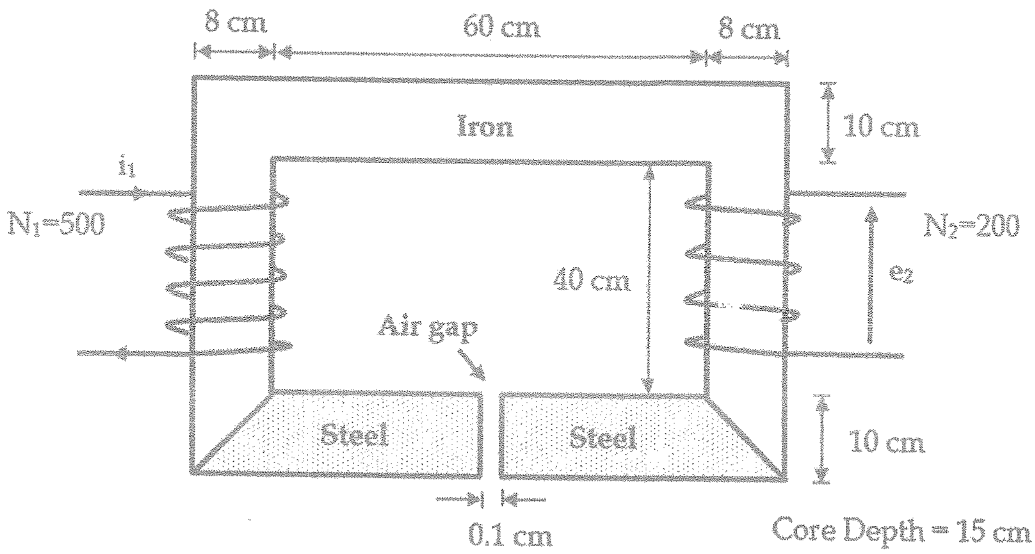


Figure Q1.a

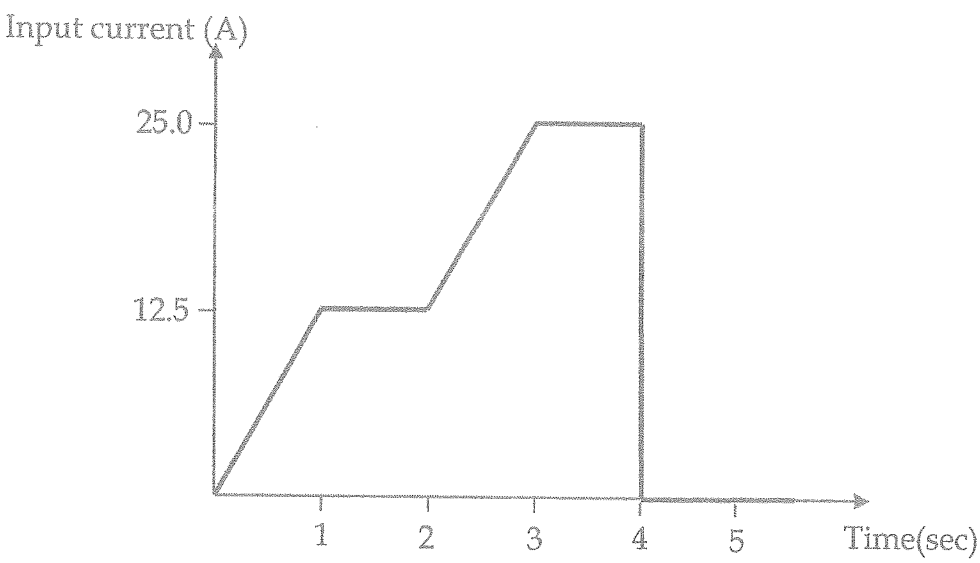
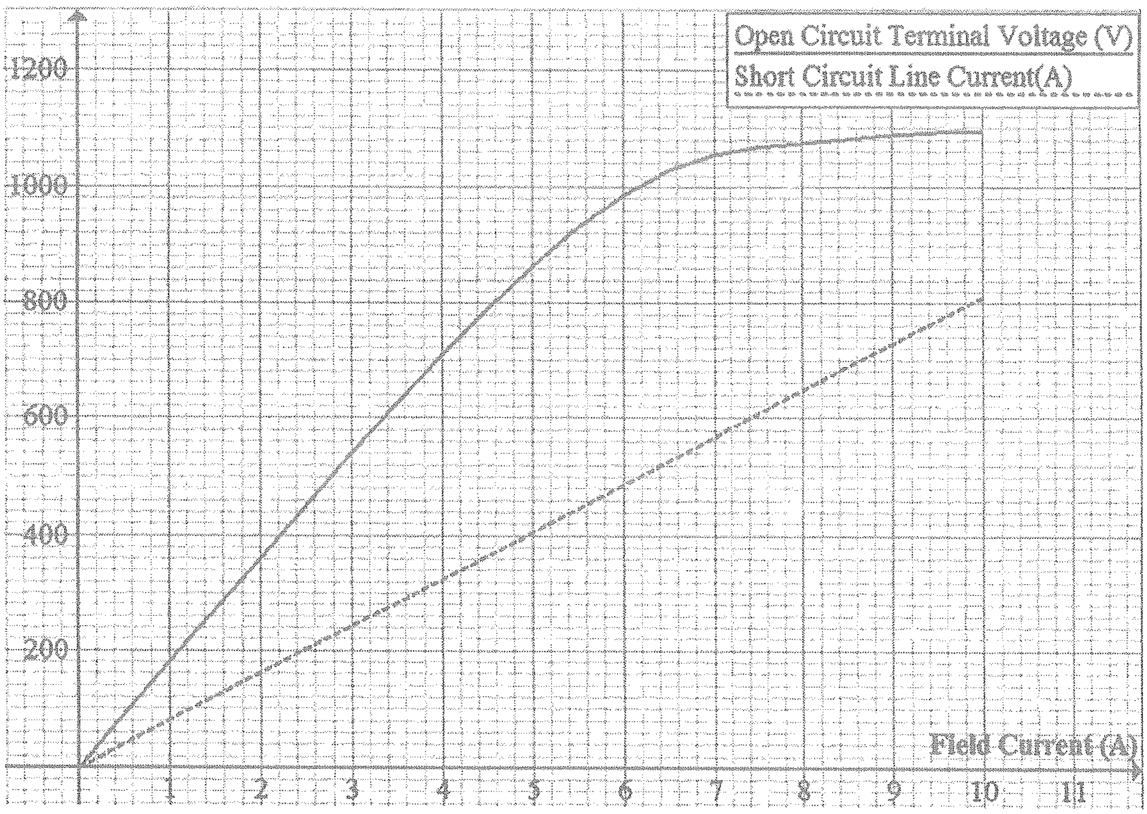


Figure Q1.b

Open-circuit Test	Short-Circuit Test
V_{OC} = 200 V I_{OC} = 1.25A P_{OC} = 150 W	V_{SC} = 20 V I_{SC} = 12.5 A P_{SC} = 175 W

Table Q2



Open Circuit Terminal Voltage (V)
Short Circuit Line Current(A)
1200
1000
800
600
400
200
Field Current (A)
1
2
3
4
5
6
7
8
9
10
11

Figure Q5