UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 3 Examination in Engineering: October 2019

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

[Three Hours]

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

Q1. a) i) Draw the hysteresis loop characteristic of a ferromagnetic material.

ii) Explain the importance of the hysteresis loop characteristic when selecting ferromagnetic materials for different applications giving two examples.

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

iv) The total core loss for a given magnetic core is found to be 4.2 kW at 50 Hz. Keeping flux density constant, the frequency of the supply is raised to 60 Hz. Calculate the eddy current loss and the hysteresis loss at 50 Hz and 60 Hz, if the total core loss increased to 5.4 kW at 60 Hz.

[5.0 Marks]

b) The transformer core shown in Figure Q1 has its bottom section made of iron and rest made of steel. Its primary side winding has 250 turns and secondary side winding has 50 turns. The width of the iron section is x. 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) Derive an expression for the total reluctance of the core in terms of x.

ii) Determine x, if the flux density in iron section is 0.75 T when primary current i_1 is 1.0 A.

iii) Draw the resulting flux $\Phi(t)$ and secondary side induced voltage $e_2(t)$ for 40 ms, if a primary current of $i_1(t) = 0.7 \sin(100\pi t)$ A is supplied where t is time in seconds. State any assumptions you make.

[5.0 Marks]

Q2 a) i) State two characteristics of an ideal transformer.

ii) Write three applications of transformers in a power system.

iii) Briefly discuss the functions of the conservator tank, dehydrating breather, Buchholz relay and radiator in a conservator tank type oil immersed transformer.

[3.5 Marks]

b) A 7.2 kVA, 1.2 kV/120 V, 50 Hz single-phase step-down transformer is tested to determine its equivalent circuit parameters. The results of the tests are given in Table Q2.

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

ii) Calculate the load impedance, voltage regulation and the efficiency of the transformer when it delivers 6 kVA at rated output voltage and 0.9 lagging power factor. 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 0.9 lagging. Assume the core loss in part ii remains the same. Note that the maximum efficiency occurs when the copper loss equals to the core loss.

[6.5 Marks]

Q3. a) i) Classify DC machines based on the field excitation.

ii) Briefly discuss the speed control of a DC motor using armature control and field control.

iii) Briefly explain why a shunt dc motor should not be started on a heavy load.

iv) A 4-pole DC machine has a field flux of 30 mWb per pole. The armature has 500 conductors connected as a wave winding. The DC machine runs at 750 rpm and it delivers a rated armature current of 65 A to a load connected to its terminals. Calculate the induced voltage and the electromagnetic torque of the DC machine.

[4.5 Marks]

b) A 15 hp, 220 V shunt motor takes a line current of 32 A. The armature and the field resistances are 0.3 Ω and 138 Ω respectively. The brushes used in the motor are metal graphite. The core and mechanical losses are 420 W. Assume that machine operates at a constant speed of 1200 rpm and armature reaction is negligible.

i) Calculate the induced back emf in the armature.

ii) Calculate the efficiency of the motor if the stray losses are 1% of the rated output power.

iii) Determine the rated current of the motor assuming the core and the mechanical losses remain the same.

[5.5 Marks]

Q4 a) i) State four advantages of induction machines over synchronous machines.

ii) Briefly discuss two starting methods used with three phase induction motors.

iii) Draw the typical torque speed characteristic curve of an induction motor.

iv) Test results taken on a 400 V, 60 Hz, 20 hp wye-connected, design class 'B' 3-phase induction motor for three tests are given in Table Q4. Determine the equivalent circuit parameters of the motor at the rated frequency.

[5.0 Marks]

b) A 415 V, 50 Hz, 960 rpm wye-connected wound-rotor 3-phase induction motor has following equivalent circuit parameters referred to the stator. Notations have their usual meanings.

$R_S = 0.2\ \Omega$ $\quad R'_R = 0.18\ \Omega$ $\quad X_S = 0.35\ \Omega$ $\quad X'_R = 0.35\ \Omega$ $\quad X_M = 22.4\ \Omega$

Take the rotational losses of the motor as 0.7 kW. The core losses and the stray losses are negligible. Calculate the following.

i) The slip at the rated speed
ii) The input line current and the developed torque at start
iii) The input line current, developed torque and the efficiency at the rated speed of the motor

[5.0 Marks]

Q5 a) i) Which synchronous machine type is typically used in hydro power plants? Justify your answer.
ii) Explain why excitation is important for synchronous machine operation and state two advantages of a brushless excitation system.
iii) Explain why synchronous motors are not inherently self-starting and how that is being overcome practically.
iv) Explain how the DC test, the open circuit test and the short circuit test are conducted to determine the per-phase equivalent circuit parameters of a three phase synchronous machine.

[5.0 Marks]

b) A 3-phase AC synchronous generator is rated at 10 MVA, 13.8 kV, 60 Hz and 0.8 lagging power factor. The stator with 2-pole per phase is wye-connected and has per-phase armature resistance of 1.5 Ω and per-phase synchronous reactance of 12 Ω. The generator is connected to an electric utility and operates at the rated conditions. Assume the friction and windage losses are 21 kW and core losses are 94 kW. Calculate the following parameters of the generator.

i) Internal armature induced voltage and the induced torque
ii) Real and reactive power output
iii) Drive shaft speed, power and torque
iv) Efficiency and voltage regulation
v) Torque angle if the stator is delta connected

[5.0 Marks]

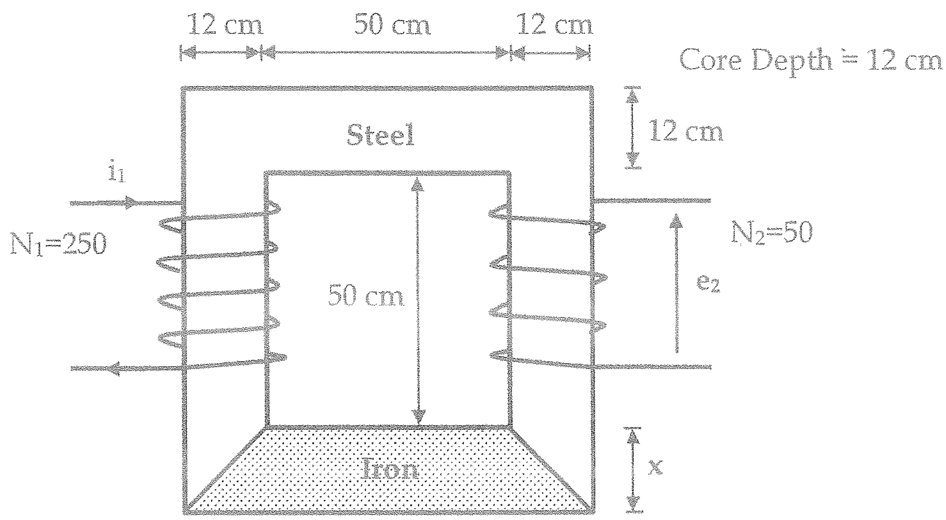

Figure Q1: Transformer core

Table Q2: Test results for the transformer

Open-circuit Test (Primary Open)	Short-Circuit Test (Secondary Shorted)
V_{OC} = 120 V I_{OC} = 1.2 A P_{OC} = 40 W	V_{SC} = 20 V I_{SC} = 6.0 A P_{SC} = 36 W

Table Q4: Test results for the 3-phase induction motor

DC Test	Blocked Rotor Test	No-load Test
V_{DC} = 20 V I_{DC} = 31.2 A	V_{BR} = 35.6 V P_{BR} = 0.8 kW I_{BR}= 24 A f_{test} = 15 Hz	V_{NL} = 400 V I_{NL} = 17.2 A f_{NL} = 60 Hz