National Examinations – December 2019

16-Mec-A5, Electrical & Electronics Engineering

Mechanical Engineering

3 hours duration

Name [print]:   **Signature:**

Notes:

[1] If doubt exists as to the interpretation of any question, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.

[2] Candidates may use one of two calculators, the Casio or Sharp approved models. This is a closed book examination.

[3] This examination consists of the front page and 8 numbered pages.

[4] Any five (5) questions constitute a complete paper. Only the first five questions as they appear in the answer book will be marked.

[5] Each question is of equal value.

[6] Clarity and organization of the answers are important.

[7] The candidate is required to sign this examination paper and submit it with the solution booklets.

[8] $\pi = 3.14159$
     1 hp = 746 W
     $\mu_0 = 4\pi \times 10^{-7} \, H \, m^{-1}$

Front Page

QUESTION 1

Consider the amplifier circuit shown in Figure 1. Assume an average DC current gain β =100 for the npn transistor.

[a] Determine the values of R_E and R_C required for an operating point of $I_C = 2$ mA and $V_{CE} = 6V$.

[b] Sketch the I_C vs V_{CE} characteristic and draw the dc load line.

[c] For $R_L = 3k\Omega$, draw the ac load line and estimate the output voltage v_O for an input current $i_b = 10 \sin \omega t$ μA.
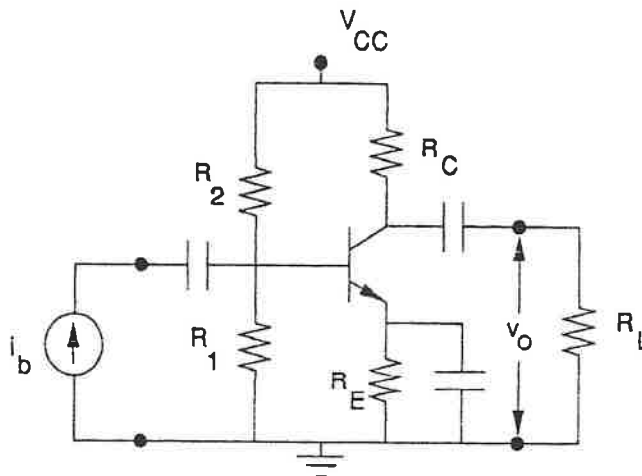

Figure 1   Transistor Circuit

Component List			
$R_1 = 10\ k\Omega$	$R_2 = 30\ k\Omega$	$V_{cc} = 15$ V	

QUESTION 2

This question consists of two parts which are not necessarily related.

Part I: Design
Develop the truth table for a 2-input exclusive or gate and write the Boolean algebra expression for the output Y as a function of the inputs A,B.

You are provided with a quantity six 2-input NOR gates. Design the gate array to implement the 2-input exclusive or function.

Part II: Analysis
A combinational logic circuit is shown in Figure 2.

[a]   Write a Boolean algebra expression for the output C as a function of the inputs A, B, K_0 and K_1.

[b]   Apply DeMorgan's theorems and simplify the expression obtained in [a].

[c]   For each of the 4 possible combinations of K_0, K_1, reduce the expression for C to its simplest form.
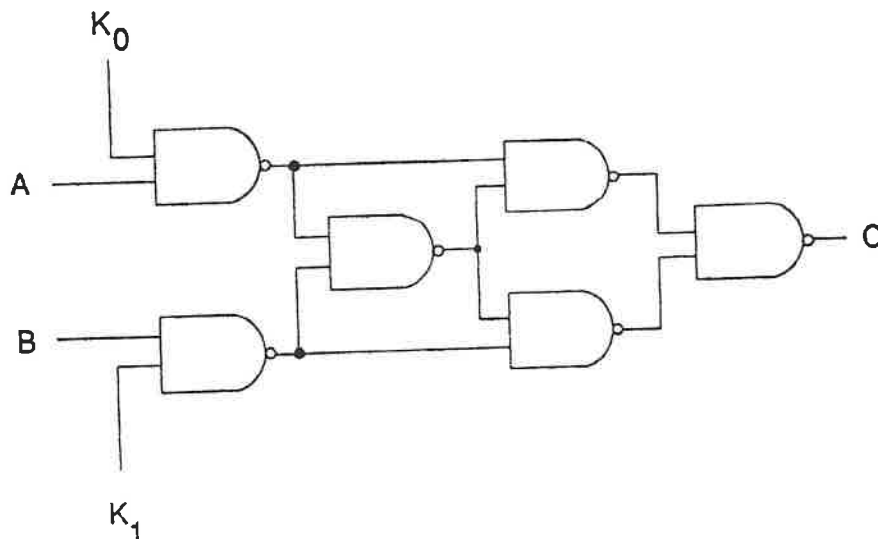

Figure 2   Circuit Schematic

QUESTION 3

A novel type of DC machine is designed using a disc type rotor of effective outer and inner diameters D and d respectively, as shown in Figure 3. A current I_2 is fed radially through the rotor via two ring shaped carbon brushes. The rotor lies in the horizontal plane and is situated in a vertical magnetic field of uniform density, B Tesla. The rotor spins at an angular speed ω rad/s.

[a]   Find the magnitude of the emf e generated between the brushes.

[b]   Determine the torque that the rotor will be subjected to and find the output horsepower of the machine.

HINT: As a starting point, consider an elemental annulus of radius **r** and radial length **dr**.
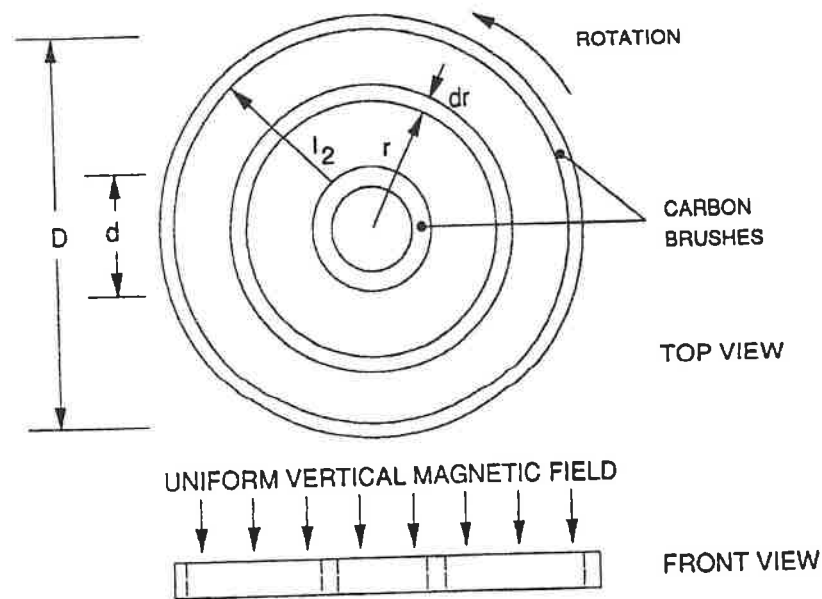

Figure 3 dc Machine

QUESTION 4

Consider the magnetic circuit of a transformer shown in Figure 4. Infinite permeability can be assumed for the iron core. The following specifications apply.

d_1=3.77 x 10^{-2} m A_1=0.02 m^2 N_1 (primary) = 200 turns
d_2=7.54 x 10^{-2} m A_2=0.02 m^2 N_2 (secondary) = 20 turns

When a dc voltage equal to 10 mV is applied to the primary winding, the measured primary current is 100 mA. When a dc voltage of 0.1 mV is applied to the secondary winding, the measured secondary current is 100 mA.

Assume that the leakage inductances, and eddy current and hysteresis losses are negligible; consider an operating frequency of 1000 Hz.

[a]   Draw the equivalent circuit for the transformer referred to the primary and calculate component values.

[b]   A transducer with an impedance of 0.078Ω is connected across the secondary of the transformer; an amplifier is connected to the primary. Calculate the output impedance of the amplifier to give maximum power transfer to the load.
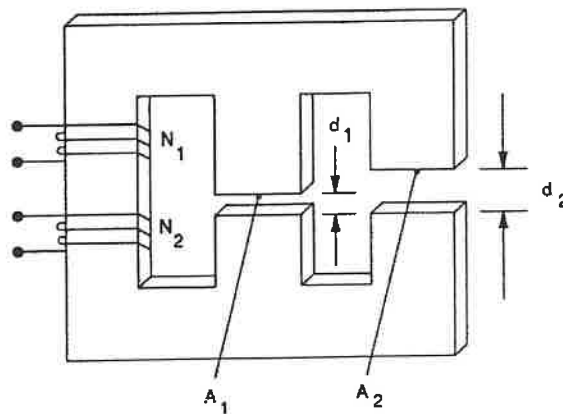

Figure 4 Transformer

QUESTION 5

Consider the circuit shown in Figure 5. Assume an ideal operational amplifier with infinite bandwidth and infinite open loop gain.

[a]   Use the straight line approximation technique to sketch a plot of the magnitude of V_O / V_I in dB versus $\log_{10}$ of frequency for a frequency range of 0.001 Hz to 10 MHz. Clearly indicate all gain levels, corner frequencies and unity gain points. Show calculations of the data used to plot your graph.

A signal generator is connected to the input of the circuit.

[b]   A sine wave of frequency 0.01 Hz is selected for input to the circuit. What is the function of the circuit at this frequency? Write an expression for the transfer function of the circuit in the time domain.

[c]   A sine wave of frequency 1000 Hz is selected for input to the circuit. What is the function of the circuit at this frequency? Write an expression for the transfer function of the circuit in the time domain.

[d]   A sine wave of frequency 1 MHz is selected for input to the circuit. What is the function of the circuit at this frequency? Write an expression for the transfer function of the circuit in the time domain.
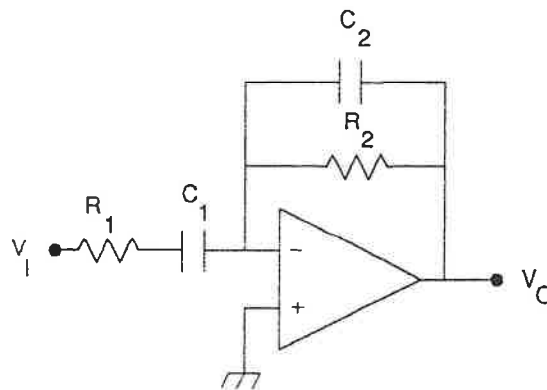

Figure 5 Circuit Schematic

Resistors		Capacitors	
R_1	160 kohm	C_1	1.0 µF
R_2	16 Mohm	C_2	1 pF
Component List			

QUESTION 6

This question consists of two parts which are not necessarily related.

Part I

A 3 phase, 300 hp, 12 pole wound rotor induction motor is operated from a 60 Hz source. The per phase rotor resistance r_2 was measured and found to be 0.04Ω. At full load, the speed of the motor is 582 rpm. At full load, determine the following.

[a]   The speed of the magnetic field in revolutions per minute.

[b]   The slip of the rotor.

[c]   The frequency of the rotor currents.

[d]   The angular velocity of the stator field with respect to the stator.

[e]   The angular velocity of the stator field with respect to the rotor.

[f]   The angular velocity of the rotor field with respect to the rotor.

[g]   The angular velocity of the rotor field with respect to the stator.

Part II

In the normal operating region of an induction motor, torque is a linear function of the slip. A test was performed on a 3 phase, 8 pole squirrel cage induction motor which is operated from a 60Hz source and it was found that it developed a torque of 3 N.m at a speed of 810 rpm.

The induction motor is used to drive a load which requires a torque which is a linear function of speed. In another test, it was found that the torque required by the load was 0.5 N.m at a speed of 435 rpm.

[a]   Sketch the speed-torque characteristics for the motor and load.

[b]   Calculate the operating point for the motor-load system.

QUESTION 7

Consider the RC circuit shown in Figure 7. The switch S_1 is closed at time t=0, connecting the dc supply V_I to the network.

[a]   Derive an expression for the voltage drop across the capacitor C_1 as a function of time.

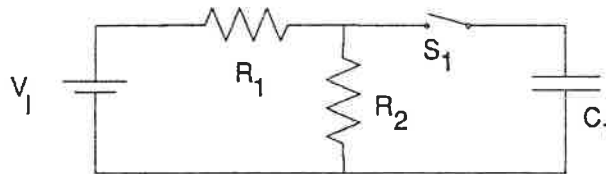[b]   Derive an expression for the current delivered to the capacitor C_1 as a function of time.

Figure 7 RC Circuit

COMPONENT LIST			
$R_1 = 30 \ k\Omega$	$R_2 = 30 \ k\Omega$	$V_I = 10 \ V$	$C_1 = 3 \ \mu F$

QUESTION 8

Part I

Consider the circuit shown in Figure 8a. A one volt (rms) ac voltage source, given by $V = \angle 0°$ is connected to a parallel R-L network. The resistor R has a value of 1Ω; the impedance of the inductor is $j1\Omega$.

Calculate: [a] the current I_1 through R; [b] the current I_2 through L; [c] the total current I_T into the network; [d] the real power delivered to the load; [e] the system power factor. Note: The currents for parts [a] to [c] should be expressed as phasor quantities of the form $I \angle \varphi°$.

Part II

A capacitor is added in parallel to the inductor as shown in Figure 8b. The impedance of the capacitor is $-j1\Omega$.

Calculate: [a] the current I_1 through R; [b] the current I_2 through L; [c] the current I_3 through C; [d] the total current I_T into the network; [e] the real power delivered to the load; [f] the system power factor. Note: The currents in parts [a] to [d] should be expressed as phasor quantities of the form $I \angle \varphi°$.
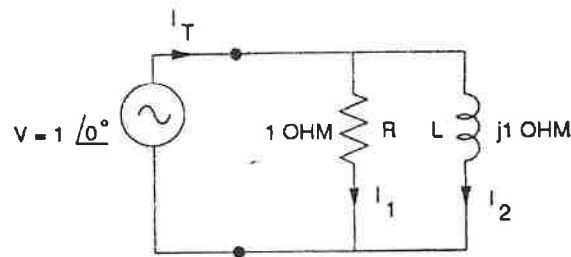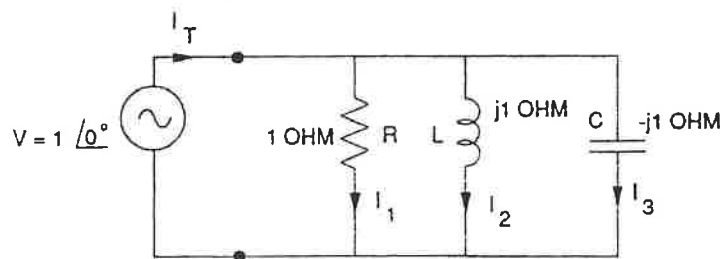

Figure 8a Circuit for Part I

Figure 8b Circuit for Part II