# PROFESSIONAL ENGINEERS ONTARIO

## National Examinations - May 2003

## 98-Mec-A6, Electrical and Electronics Engineering

## Mechanical Engineering

3 hours duration

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NAME [print]: SIGNATURE:

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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] Any five questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.

[4] All questions are of equal value.

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

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

## QUESTION 1

Consider the amplifier circuit shown in Figure 1. Assume an average DC current gain $\beta = 100$ 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 $V_{CE} = 6$ V.

[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 $i_b = 10 \sin \omega t$ $\mu$A.

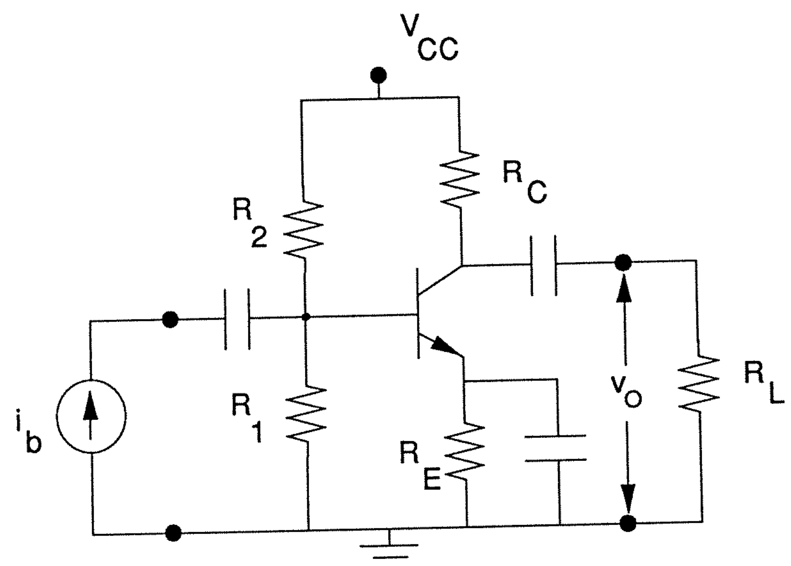


**Figure 1 Transistor Circuit**

| Component List | | | |
|---|---|---|---|
| $R_1 = 10$ kΩ | $R_2 = 30$ kΩ | $V_{CC} = 15$ V | |

## QUESTION 2

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 2. 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 T. 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**.

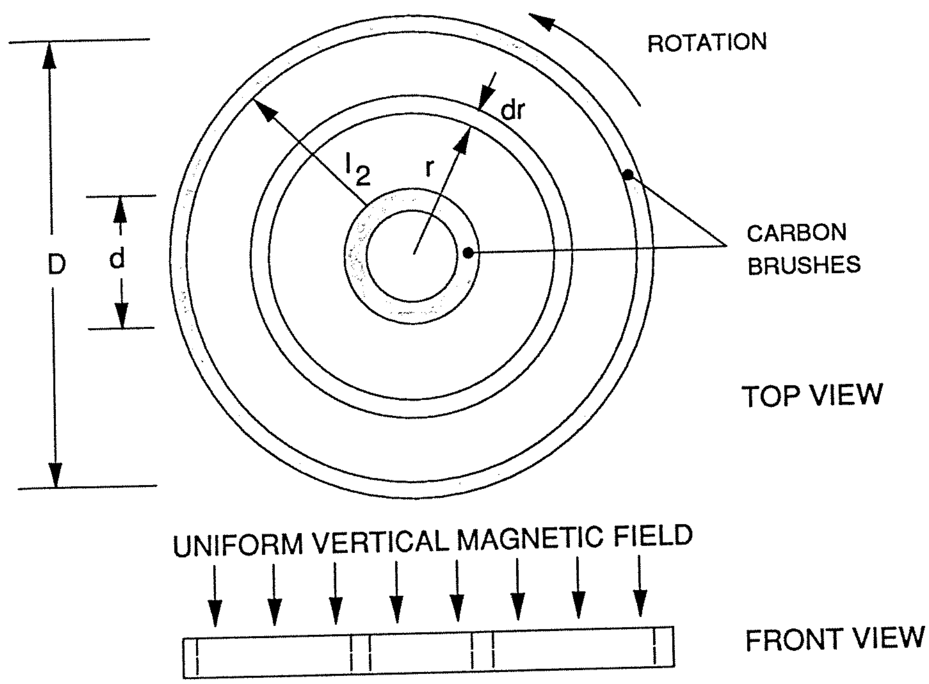


**Figure 2 dc Machine**

## QUESTION 3

Consider the RC circuit shown in Figure 3[a]. 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 transfer function of the circuit, $V_o/V_I$, in the time domain.

[b] Sketch the transfer function for a time interval of 5 time constants.

The RC circuit is reconfigured as shown in Figure 3[b]. An ac voltage source of variable frequency, $v_i$, is connected to the input.

[c] Derive an expression for the transfer function of the circuit, $v_o/v_i$, in the frequency domain.

[d] Sketch the magnitude of the transfer function for a frequency range of 4 decades, centered at the corner frequency of the circuit.

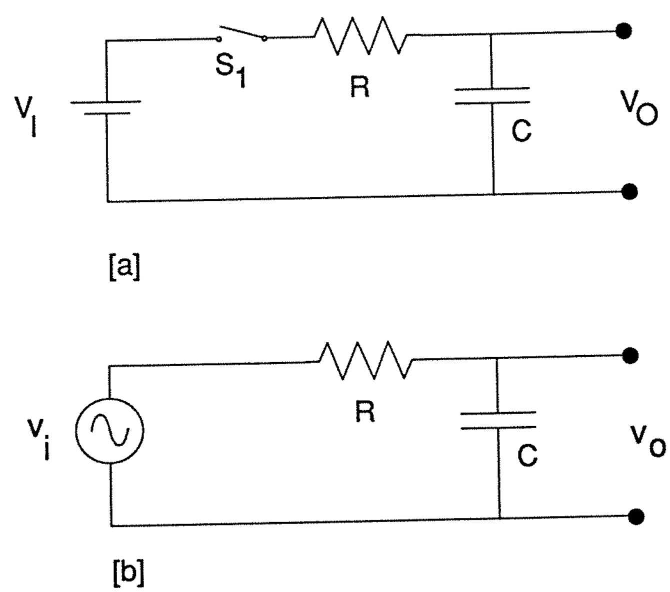


**Figure 3 RC Circuit: [a] dc test; [b] ac test**

## QUESTION 4

Consider the magnetic circuit shown in Figure 4. An ac voltage source $v_1(t)$ is applied to the primary winding, with $N_1$ turns, which results in a primary current $i_1(t)$. A voltmeter is used to measure the voltage induced in the secondary winding, $v_2(t)$. The magnetic circuit has a mean length of L m, a cross sectional area of A $m^2$ and a relative permeability of $\mu_R$. The primary current is given by:

$$i_1(t) = I_P \sin \omega t$$

where $I_P$ is the peak value of the primary current and $\omega$ is the radian frequency of the supply voltage source. Neglect the resistance of the windings, leakage inductances and other losses.

[a] Develop expressions for the primary voltage, $v_1(t)$, and the secondary voltage, $v_2(t)$, as a function of the current $i_1(t)$.

[b] Develop an expression for the impedance of this circuit as viewed from the primary.

[c] Sketch waveforms for the primary voltage, $v_{AB}$, and the secondary voltage, $v_{XY}$, showing the magnitudes and phase relations with respect to the primary current $i_1(t)$.

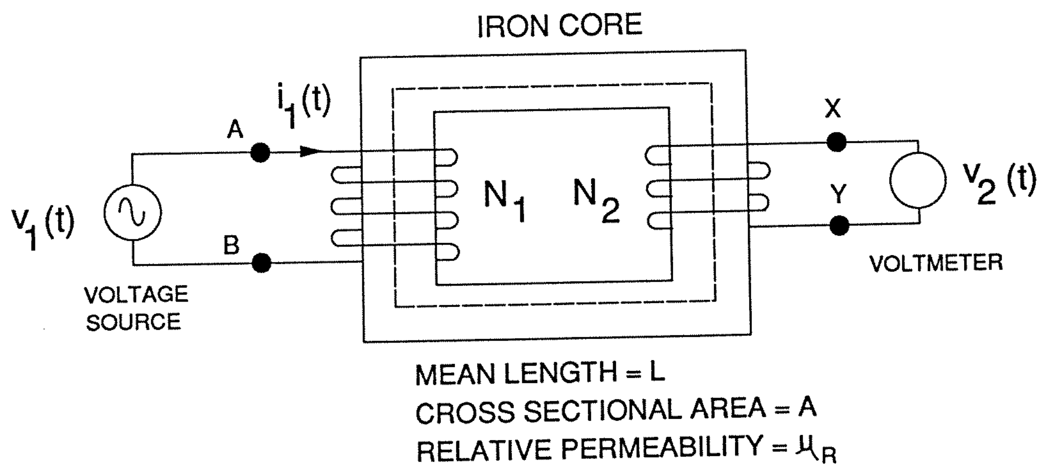


**Figure 4 Magnetic Circuit**

# QUESTION 5

Design a combinational logic circuit to meet the following specifications:

Input:
3-bit binary number, CBA
[ C = MSB; A = LSB ]

Outputs:
X; to be logic 1 for all even number inputs [0,2,4,6]
[ zero is to be considered an even number]
Y; to be logic 1 for all odd number inputs [1,3,5,7]

A block diagram of the logic circuit is shown in Figure 5.

[a] Develop the truth table for the logic circuit.

[b] Write Boolean algebra expressions for the outputs as a function of the inputs and simplify where possible.

[c] Design the gate array to implement your design.
**Only 2-input NOR gates are available.**

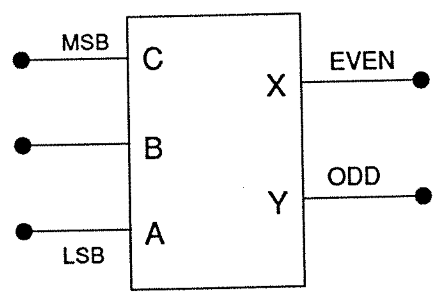


**Figure 5 Block Diagram of Combinational Logic Circuit**

# QUESTION 6

## Part I

A dc test is performed on a 208-V, six-pole, delta connected, 60Hz induction motor, as shown in Figure 6.

[a] If $V_{DC} = 3.32$ V and $I_{DC} = 3.1$ A, calculate the per phase stator resistance, $r_1$.

Three phase excitation is applied to the motor which runs with a slip of 3.5%. Find:

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

[c] The speed of the rotor in revolutions per minute.

[d] The electrical frequency of the rotor current.

The load on the motor is now doubled. Calculate:

[e] The speed of the rotor in revolutions per minute.

## Part II

You are provided with a graph of the speed-torque characteristic of a three phase wound rotor induction motor. The torque required to drive a pump is $T = K_P n^2$ ( $K_P$ is a constant; n is speed in revolutions/second). The induction motor is to be used to drive the pump. Show how you would determine the operating point speed of the system.

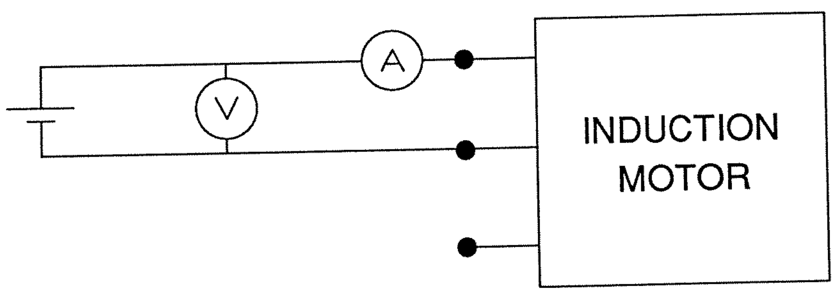


**Figure 6 dc Test on Induction Motor**

## QUESTION 7

Consider the circuit shown in Figure 7, which has been designed using ideal operational amplifiers, ( $U_1$ to $U_3$ ), with infinite bandwidth and infinite open loop gain. In the schematic, A, B and C are constants.

In the derivation of the transfer function for such circuits, one can assume:

[i] zero differential voltage between the input terminals of the operational amplifier, and

[ii] zero current flows into either terminal of the operational amplifier.

Applying the principle of superposition, derive an expression for the transfer function of the total circuit [ $E_O$ as a function of $E_1$, $E_2$ ]. It can be assumed that the transfer functions for an inverting amplifier and a non-inverting amplifier are known.

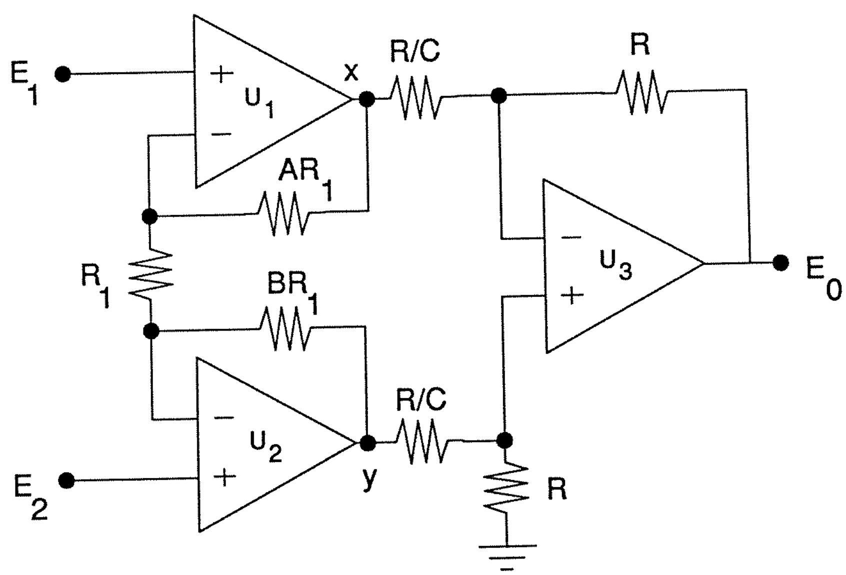


**Figure 7 Circuit Schematic**

# QUESTION 8

A 120-V shunt dc motor has, at rated speed of 900 RPM, an armature current of 175 A. The armature resistance is $R_A = 0.026$ ohm.

[a] What is the no-load speed of the motor, in RPM?

[b] Calculate the torque developed by the motor at rated speed.

[c] Calculate the speed regulation of the motor.

[d] What resistance must be inserted in the armature circuit in order that the motor will develop half of the rated torque at 700 RPM? The field flux can be assumed to be constant.