

The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, SPRING SEMESTER 2015-2016

ELECTROMECHANICAL DEVICES

Time allowed ONE Hour THIRTY Minutes

Candidates may complete the front cover of their answer book and sign their desk card but must NOT write anything else until the start of the examination period is announced.

Answer ALL of Section A, ONE question in Section B and ONE question in Section C

Only silent, self contained calculators with a Single-Line Display, or Dual-Line Display are permitted in this examination.

Dictionaries are not allowed with one exception. Those whose first language is not English may use a dictionary to translate between that language and English provided that neither language is the subject of this examination.

No electronic devices capable of storing and retrieving text, including electronic dictionaries, may be used.

DO NOT turn examination paper over until instructed to do so

In this examination candidates are required to answer ALL questions in Section A, ONE out of TWO questions in Section B and ONE out of TWO questions in Section C. If a candidate answers more than the required number of questions, all questions will be marked and the highest marks will be used in the final examination mark.

ADDITIONAL MATERIAL: Formula sheet (3 pages)

INFORMATION FOR INVIGILATOR:

Question papers should be collected in at the end of the exam – do not allow candidates to take copies from the exam room.

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SECTION A
Answer ALL the questions

1. Calculate the equivalent capacitance across the battery for the circuit shown in Fig. Q.1 and hence the charge stored by the circuit.

[3 marks]

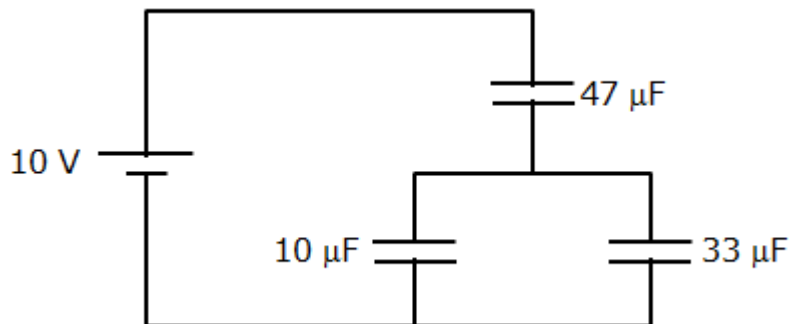


Fig. Q.1

2. A load consisting of a 30 mH inductor and a 15Ω resistor are placed in series across a 20V 50 Hz ac supply (Fig. Q.2). Calculate the current supplied to the load and the voltage across the resistor, expressing all your answers both in Cartesian and polar form.

[6 marks]

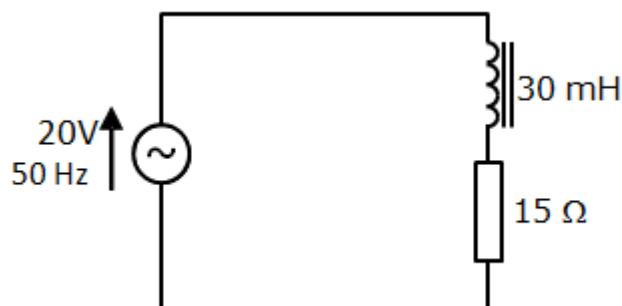


Fig. Q.2

3. A loudspeaker has an impedance of $(7 + j3) \Omega$ at a particular frequency. If the loudspeaker is to be driven from a signal generator via a transformer with a turns ratio of $3:1$ as shown in Fig. Q.3, what will be the impedance of the loudspeaker referred to the primary of the transformer, measured at that frequency? Express your answer in Cartesian form, and hence state the magnitude of the impedance. Assume that the transformer acts as an ideal transformer.

[3 marks]

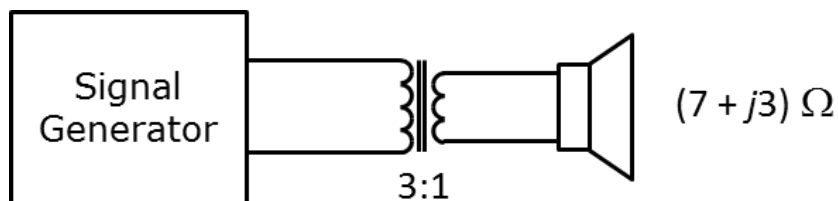


Fig. Q.3

4. Simplify the following Boolean algebra expressions (if possible), and draw the corresponding logic circuits.
- (a) $(A+B).(C+D)$ [2 marks]
- (b) $(A+1).D.C$ [2 marks]
- (c) $(A+A+A).B.C$ [2 marks]
5. Sketch a typical open circuit gain curve of an op-amp, label all axis and use a realistic scale. Then explain, in no more than 30 words, why you would never use an op-amp without feedback resistors. [8 marks]
6. If you wanted to design a circuit to count from 0 to 4×10^{12} , how many bits would the circuit need to represent the digital data? [4 marks]

Turn over

SECTION B
Answer ONE question

7. A three-phase induction motor with two pole-pairs is star-connected to a 415 V 50 Hz supply. The rotor of the motor has a resistance of 4Ω and a standstill reactance of 20Ω referred to the stator windings. The motor's full-load (rated) speed is $1445 \text{ rev min}^{-1}$. Use the theoretical model of the induction motor which is based on its electrical characteristics rather than the linearised empirical model.
- (a) What is the synchronous speed of the motor? [2 marks]
- (b) What is the rms voltage across each winding (phase) of the motor's stator? [2 marks]
- (c) What is the slip at the motor's rated speed, and hence what are the full-load torque and power? [8 marks]
- (d) What is the starting torque i.e. the torque when the rotor is completely stalled and not rotating? Is this answer likely to be correct for a commercial squirrel-cage motor? Illustrate your answer with a simple sketch of a practical torque-speed curve. [9 marks]
- (e) When it is supplied at the rated frequency and voltage and is running at its rated speed, the motor draws a phase (or line) current of 3.25A at a power factor of 0.68 lagging. What power is being drawn from the power supply, and hence what is the motor's efficiency? [5 marks]
- (f) Explain the physical principle of a three phase squirrel-cage induction motor, including a description of the roles of the three-phase supply and the squirrel-cage. You are encouraged to illustrate your explanation with sketches but you do not need to quote any equations. [9 marks]

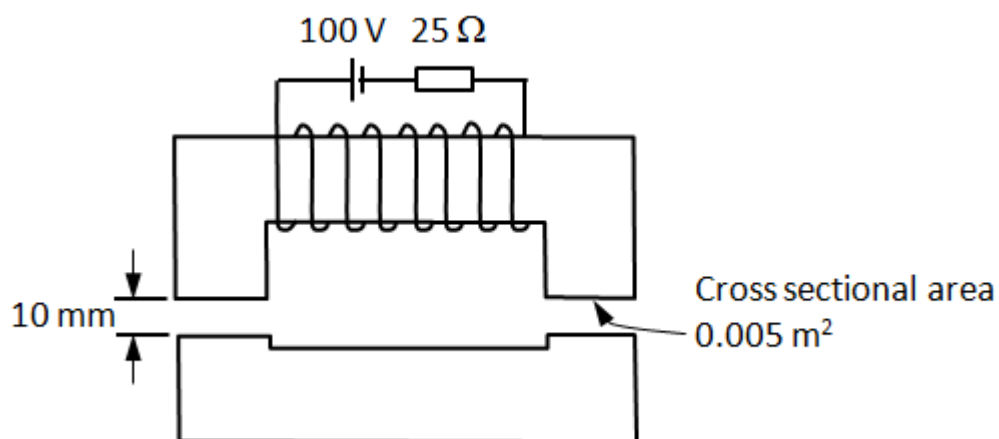


Fig. Q.8(a)

8. The lifting electromagnet magnet shown in Fig. Q.8(a) has 800 turns of wire with a resistance of 25Ω and is fed from a 100 V dc supply. The iron core is in two parts which can be separated (leaving an air gap); the upper part of the electromagnet is attached to a crane and the lower part is attached to the item the crane is intended to lift. The cross-sectional area of the core is assumed to be constant at 0.005 m^2 ; each pole face also has this area.

(a) Calculate the current in the windings and hence the magnetomotive force.

[4 marks]

(b) For the situation where the two parts of the core are separated by 10 mm air gaps as shown in Fig. Q.8(a), calculate the flux carried by the core and hence the lifting force available from the electromagnet. State any assumptions you make.

[14 marks]

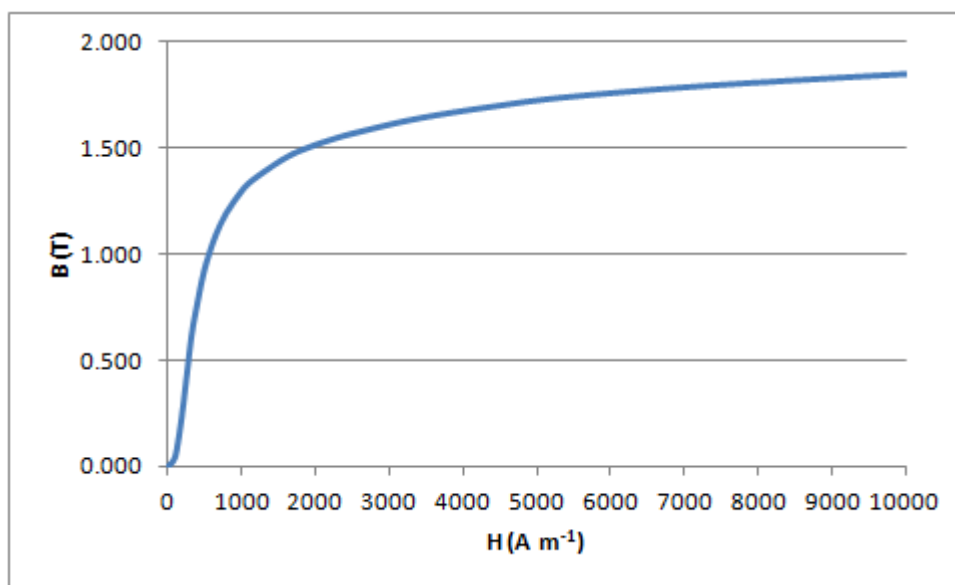


Fig. Q.8(b)

(c) The air gap is now assumed to have closed to a negligible distance as the magnet is used for lifting a heavy item attached to the lower part of the core. The iron used for making all the parts of core has a B-H curve as shown in Fig. Q.8(b), and the length of the closed magnetic path through the iron core is 0.4 m. Calculate the total flux in the core and force with which the electromagnet can hold the bottom part of the core onto the top part. Again, state any assumptions you make.

[10 marks]

(d) While the above actuator can provide relatively large forces over relatively small distances of travel it would not be suitable as a means of causing large movements with large forces. Choose a different actuator which could provide (for example) 1000 N of force over a travel of 500 mm, completing the movement in 1 second or less, and explain how it could be operated under the command of a logic signal, for example from a microprocessor. Identify any ancillary equipment needed but you are not expected to draw any circuit diagrams.

[7 marks]

Turn over

SECTION C
Answer ONE question

9. This question relates to digital electronics:

(a) For your 4th year project, you are designing a speed camera to catch people speeding on campus. The speed camera consists of a digital camera, and a radar speed detector. It is your job to design a glue logic circuit to make the camera take a picture when a car is detected travelling above 40 km/h. The speed detector outputs a three bit binary number, representing the speed of the passing cars. An output of binary one, represents a car travelling at 10 km/h, an output of binary 2 represents a car travelling at 20 km/h and so on. If no car is detected the speed detector will output binary 0 and if the speed is higher than 70 km/h, the device simply outputs binary 7. The camera will take a single picture when a 1 is placed on its input.

- Draw a truth table of a circuit that could be used to connect the camera and the speed detector, so that the camera would only fire when a car travels above 40 km/h.
- Now draw the circuit diagram for this circuit.
- Write the Boolean expression for this truth table.

[10 marks]

(b) Using timing diagrams and an example circuit explain what race times are and why it is important to be aware of them when designing digital systems.

[5 marks]

(c) Draw the equivalent circuit for an operational amplifier, then write down its:

- Input impedance
- Output impedance
- The equation relating the input terminals to the output voltage.

[5 marks]

(d) Now consider the non-inverting operational amplifier:

- Draw the non-inverting op-amp circuit.
- Derive the closed loop gain expression for this circuit. (State what assumptions you are making during the derivation).
- Design a circuit to give a closed loop gain of 10 (choose sensible values of resistors).

[7 marks]

(e) What advantages does the flash converter have over the one based on the R2R ladder and why? Draw the circuit diagram of a flash converter.

[5 marks]

(f) You are designing a 5 bit digital to analog converter. If the maximum output voltage of the converter is 20 volts what is its resolution?

[3 marks]

10. This question relates to switching high power loads on and off:

- (a) Draw a circuit diagram of a relay (including the internal components); list the advantages and disadvantages of using a relay.

[5 marks]

- (b) Draw a diagram of a MOSFET in its on and off states and explain how it works. Explain why they are slow to turn on and off. What advantages does a BJT have over a MOSFET? Using a circuit diagram explain what can be done to speed up the turning on and off a MOSFET.

[5 marks]

- (c) Draw a diagram of full wave single phase AC->DC converter that would produce almost perfectly smoothed DC. Using a diagram, show how current flows in the circuit when the supply voltage is both negative and positive.

[10 marks]

- (d) You are designing a power supply circuit to run off the UK mains supply, to give a ripple voltage of 0.1 V at 100 mA. What value of capacitance would you use to achieve this? What other component would you use to make sure you got even smoother DC?

[5 marks]

- (e) Draw a 4 bit R2R ladder. What voltage will appear on the output when a voltage of 1V is applied to the pin closest to the output? Prove this with diagrams and simple equations.

[10 marks]

END