

# The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, SPRING SEMESTER 2016-2017

## **ELECTROMECHANICAL DEVICES**

Time allowed ONE Hour THIRTY Minutes

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*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)

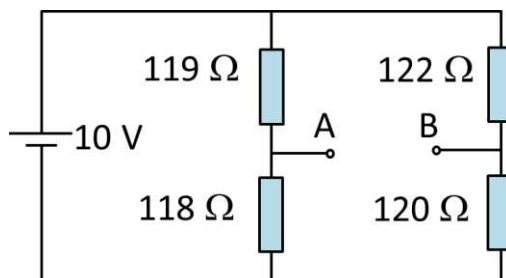
### **INFORMATION FOR INVIGILATOR:**

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. For the circuit shown in Fig. Q.1, calculate the voltage at point A measured with respect to point B.



[5 marks]

2. An electromagnetic actuator has an iron core with 1000 turns of wire carrying a current of 2A. The actuator has an air gap with a cross-sectional area of 200 mm<sup>2</sup> and a gap width of 5 mm when the actuator is at the start of its stroke. Assuming that the reluctance of the iron core is negligible and that the magnetic flux is uniform in the air gap, calculate the flux density and the actuator force.

[8 marks]

3. An induction motor is rated at 1500 W, 5.025 Nm, 415 V, 50 Hz, 2850 rev min<sup>-1</sup> when connected in star configuration. Using the simplified (linear) model of the motor's behaviour, find the speed at which it runs when producing a torque of 4 Nm when running from the rated power supply.

[4 marks]

4. Simplify the following Boolean algebra expressions (if possible), and draw the corresponding logic circuits.

(a)  $(A+B).(A+C)$  [2 marks]

(b)  $AB + A(B + C)$  [2 marks]

(c)  $(A+A+1).B.C$  [2 marks]

5. An analogue-to-digital converter is required to record a signal in the range 0-15 V with a resolution of finer than 0.001 V. How many binary digits (bits) will be required?

[3 marks]

6. Explain briefly what is meant by the constant  $\beta$  (also known as  $h_{FE}$ ) in the context of a bipolar junction transistor, and describe briefly how you would go about measuring this quantity (without the use of a meter with a setting for making this measurement directly).

[4 marks]

**SECTION B**  
**Answer ONE question**

7. (a) Given the existence of a rotating magnetic field within the stator of a three-phase squirrel-cage induction motor, explain the construction and purpose of the squirrel-cage rotor and the principles by which it fulfils this role. (You are not required to explain how the rotating magnetic field is produced in the stator and will gain no marks for explaining this). [10 marks]
- (b) A three-phase induction motor with two pairs of poles per phase is star-connected to a 400 V 50 Hz supply. The rotor of the motor has a resistance of  $4 \Omega$  and a standstill reactance of  $20 \Omega$  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.
- (i) What is the synchronous speed of the motor? [2 marks]
- (ii) What is the rms voltage across each winding (phase) of the motor's stator? [2 marks]
- (iii) What is the slip at the motor's rated speed, and hence what are the full-load torque and power? [10 marks]
- (c) Under full load, each phase of the motor draws a current of 3.8 A at a power factor of 0.7 lagging.
- (i) Find the phase angle of this current with respect to the phase voltage, and hence express the current in Cartesian and polar form. [5 marks]
- (ii) A capacitor of value  $30 \mu\text{F}$  is now placed between each line of the power supply and neutral in parallel with each motor winding. Calculate the phase current in Cartesian and polar form for this situation with the capacitors in place and hence the percentage reduction in current resulting from adding the capacitors. [6 marks]

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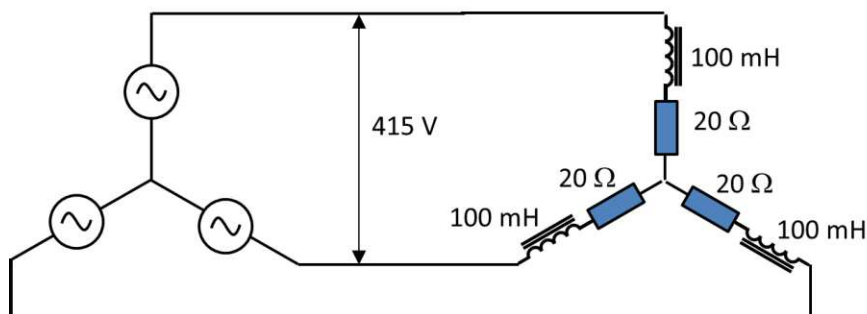


Fig. Q.8

8. A three phase load system (Fig. Q.8) consists of three identical loads, each consisting of a 100 mH inductor in series with a  $20\ \Omega$  resistor. The loads are connected in a star configuration. The load system is connected to a 50 Hz mains supply with line voltage 415 V (rms).
- Calculate the voltage across each phase of the load. [3 marks]
  - Calculate the impedance of one phase of the load (i.e. the resistor and inductor in series) expressed in both Cartesian and polar form. [6 marks]
  - Calculate the current flowing in each phase of the load, giving your answer in the form of magnitude and phase angle (relative to the phase voltage). [7 marks]
  - Calculate the power dissipated in each phase of the load and hence the total power dissipated. [7 marks]
  - Briefly explain, with the aid of a phasor diagram (for a single phase system) and mathematical expressions, the distinction between apparent power and active power and why this difference arises. Which units are used for these quantities? Note: no marks will be given for scalar illustrations or analogies. You do not need to present any mathematical proofs of the expressions you present. [10 marks]
  - Briefly explain why a power outage (power cut) might be seen to affect only a minority of houses along a street while others appear to be unaffected. [2 marks]

**SECTION C**  
**Answer ONE question**

9. (a) The circuit shown in Fig. Q.9(a) is initialised so that both outputs Q1 and Q2 are 1.

Work out the values of the outputs Q1 and Q2 when the clock line is pulsed six times.

[11 marks]

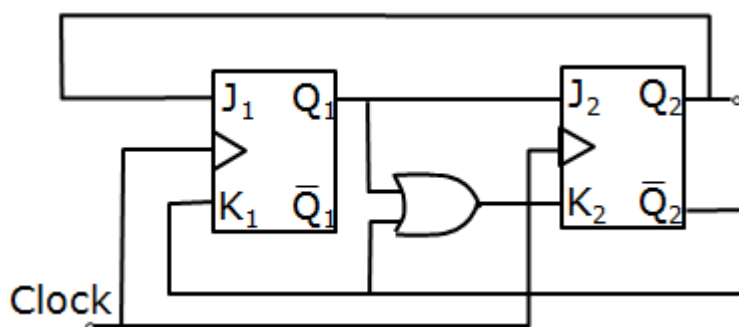


Fig. Q.9(a)

- (b) Design a digital logic circuit which takes five lines of digital input and gives a high output for all of these cases (and no other combinations): 10100, 10101, 10110, 10111.

[6 marks]

- (c) The circuit shown in Fig. Q.9(c) is used for operating an electromagnetic actuator A from a 12 V supply under the command of a 5V (TTL) logic signal. The particular application requires the actuator coil to be switched on and off very rapidly (at 25 kHz) and cleanly, i.e. ensuring that the actuator is either switched fully on or fully off for the relevant part of the switching cycle.

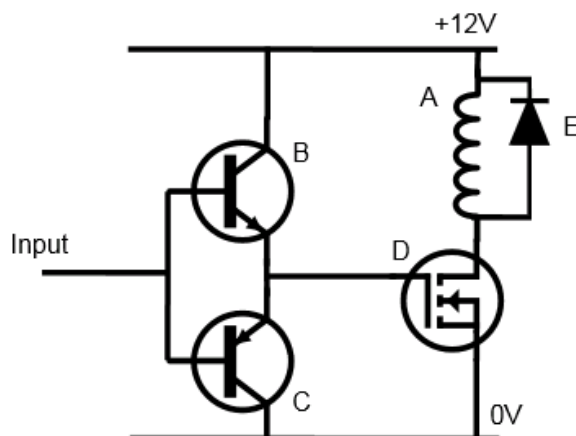


Fig. Q.9(c)

- (i) Give the full names for the components B, C, D and E.

[7 marks]

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- (ii) Explain what electrical property of component D would make it difficult to switch on and off rapidly and cleanly under the command of a low-current supply such as the logic signal. [3 marks]
- (iii) Hence explain how the use of components B and C overcome this problem. By what name is this configuration of components B and C known? [5 marks]
- (iv) What is the role of component E? [3 marks]

10. (a) Draw the full equivalent circuit of an operational amplifier (op-amp) in open-loop configuration, and explain how the output voltage is related to the voltages at the inverting and non-inverting inputs. Hence identify some assumptions which are typically made in order to simplify the analysis of op-amp circuits. [8 marks]
- (b) Using the principles and assumptions you have explained in part (a), derive the expression giving the closed-loop gain of the op-amp circuit shown in Fig. Q.10(b).

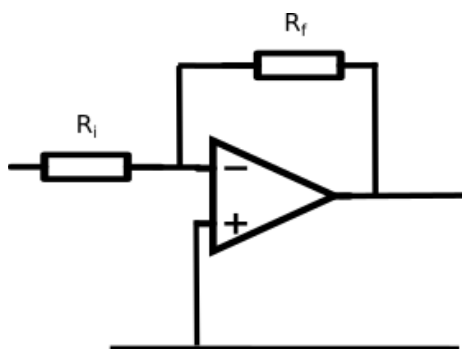


Fig. Q.10(b)

[10 marks]

- (c) Explain with the aid of one or more diagrams, how a piezoelectric accelerometer works, referring both to the physical principle of its operation and the op-amp circuit needed to obtain a useable output voltage proportional to acceleration. Draw a simple op-amp circuit to achieve this, and explain what such a circuit needs to achieve and why it is required. [10 marks]

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- (d) Fig. Q.10(d) shows the circuit for the instrumentation used to obtain a voltage output approximately proportional to the strain experienced by a strain gauge S.G. incorporated into a Wheatstone bridge. Part of the system is shown as a box labelled "Op-amp based circuit for strain gauge input". Explain briefly, what this circuit needs to achieve in terms of how its output voltage needs to relate to its inputs, and why this functionality is required. Write down the equation relating the input voltages to the output voltages, ensuring that you define any quantities in your equation on a sketch of the op-amp circuit. Note: You are NOT expected to derive the analysis of the operation of the circuit.

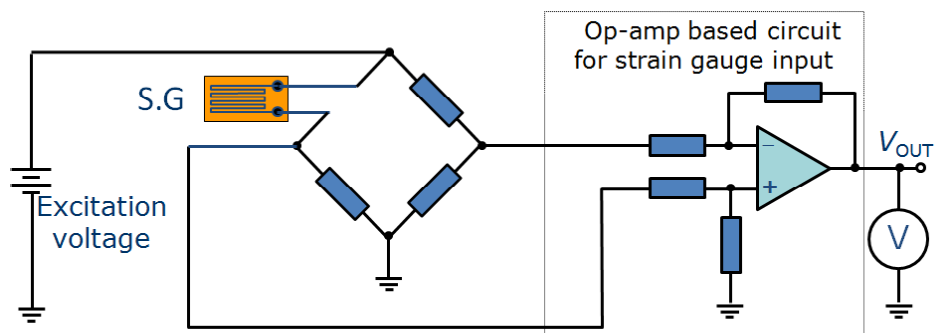


Fig. Q.10(d)

[7 marks]

**END**