The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, SPRING SEMESTER 2019-2020

ELECTROMECHANICAL DEVICES

Time allowed AS PER SUBMISSION DEADLINE PUBLISHED ON MOODLE

Open-book take-home examination

Answer ALL questions

You must submit a single pdf document, produced in accordance with the guidelines provided on take-home examinations, that contains all of the work that you wish to have marked for this open-book examination. Your submission file should be named in the format '[Student ID]_[Module Code].pdf'*.*

Write your student ID number at the top of each page of your answers.

This work must be carried out and submitted as described on the Moodle page for this module. All work should have been submitted via Moodle by the due date.
Work submitted after the deadline will be subject to penalty.

No teaching enquiries will be answered by staff during the assessment period Monday 18th May to Friday 12th June 2020 and no questions should be raised by students. If you believe there is a misprint note it in your submission but answer the question as written. Contact SS-Programmes-UPE@exmail.nottingham.ac.uk *for any support.*

Plagiarism, false authorship and collusion are serious academic offences *as defined in the University's Academic Misconduct Policy and will be dealt with in accordance with the University's Academic Misconduct Procedures. The work submitted by students must be their own and you must declare that you understand the meaning of academic misconduct and have not engaged in it during the production of your work.*

ADDITIONAL MATERIAL: Formula sheet

SECTION A [34 marks]

1. Calculate the equivalent resistance of the resistance network shown in Fig. Q.1 and the power dissipated in the network. [4]

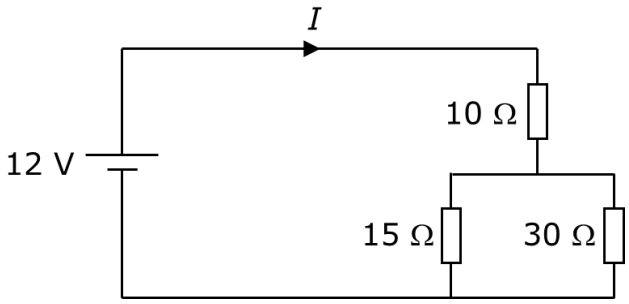

Fig. Q.1

2. A 100 Ω resistor and a 20 μF capacitor are connected in series across a 100 V (rms) 50 Hz supply (Fig. Q.2). Calculate the current in Cartesian and polar form, and explicitly state its magnitude and phase angle. [6]

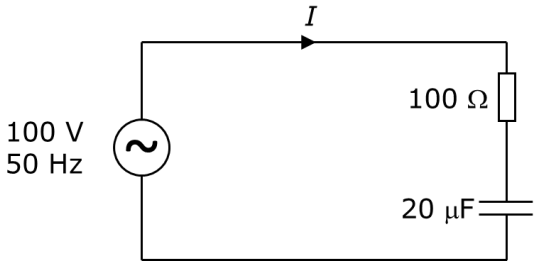

Fig. Q.2

3. The electromagnetic actuator shown in Figure Q.3 has a winding with 2000 turns through which a current of 0.5 A flows. One of the pole pieces slides in order to form a variable air gap. The cross-section of the pole pieces is 200 mm^2. If the reluctance of the core is neglected and there is assumed to be no significant air gap between the sliding components, calculate the force provided by the actuator when the air gap between the pole pieces is 5 mm. [6]

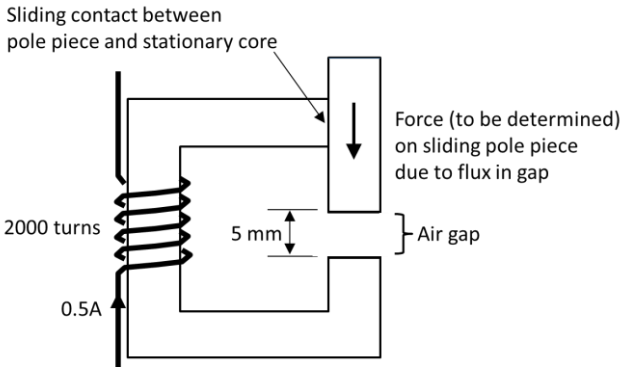

Fig. Q.3

4. (a) Explain, with a diagram, what ripple is in the context of power supply design. [4]

(b) Explain what happens to the electrical energy within the ripple when a voltage regulator is used. [2]

Your explanation for each part of this question should not be more than 30 words.

[6 marks total for Q.4]

5. Minimize the following Boolean expressions showing full working (every step must be written out in full).

(a) $(A+B)(A+C)$ [3]

(b) $(\bar{A}+B)(\bar{A}(B+A))$ [3]

[6 marks total for Q.5]

6. Draw the Boolean expression $ABC + A\bar{B}C + A\bar{B}\bar{C}$ as a circuit and write out its truth table in full, making no assumptions or minimizations. [6]

SECTION B [66 marks]

7. A three-phase AC, star-connected squirrel-cage induction motor with 4 poles per phase runs from a 380V (rms, line-to-line) 50 Hz supply. Its power and speed under rated (full-load) conditions are 25 kW, 1445 rev min^{-1}.

(a) Assuming the motor is connected to the above power supply, calculate:

i) the line-to-neutral (phase) voltage [1]
ii) the motor's rated torque [3]
iii) the motor's synchronous speed. [2]

(b) Using the simple, linear empirical model of induction motor characteristics, calculate the speed (in rev min^{-1}) at which it will run when the torque is 100 Nm and the voltage and frequency remain at their rated values. [5]

(c) Additionally it is known that the rotor resistance is 10.2 Ω and the rotor standstill reactance is 1 Ω (referred to the stator windings).

i) Calculate the per-unit slip when the motor is running at 1275 rev min^{-1} from its rated voltage and frequency. Hence use the theoretically-based model to determine calculate the torque provided by the motor when it is running at this speed. [8]

ii) State in no more than 40 words why it would not be appropriate to perform the calculation in part (c)i) using the empirical model you used in part (b). (You should NOT attempt to use the empirical model in this case and will get no marks for doing so) [3]

iii) State in no more than 20 words why it would not be sensible to use this motor to run at this speed (and providing the torque you calculated in part (c)i)) for significant lengths of time. [3]

(d) When the motor is producing 25 kW of mechanical power at its rated voltage and current, the motor draws a line current of 58 A at a power factor of 0.7. Calculate the electrical power drawn and hence calculate the efficiency of the motor. [6]

[31 marks total for Q.7]

8. (a) You are an electronic engineer working on developing a new airplane. Part of the project requires you to design a noise cancelling system for the interior of the aircraft to reduce internal noise. For this task you have decided to use an inverting operational amplifier circuit.

i) An operational amplifier has an output and input resistance; what can we usually assume these values to be? Write down the full equation linking the input voltage to the output voltage for the inverting amplifier circuit, and then simplify this equation. What assumption is made in this simplification? [5]

ii) Draw a diagram of the open loop gain of an operational amplifier as a function of frequency. Label both of the axes with reasonable numbers, and on the same graph draw the response of a non-inverting operation amplifier with a feedback resistor of 1000 Ω and an input resistor of 100 Ω. [5]

iii) What is output clipping in the context of the behaviour of an operational amplifier? Explain this with a diagram and no more than 40 words of text. [5]

iv) Why might you not want a very low value of input impedance for an operational amplifier circuit? Answer in no more than 30 words of text. [5]

(b) Next, you are tasked with developing a system to deploy the landing gear of the aircraft. For this circuit you must connect a signal form a microprocessor to a solenoid which releases the landing gear.

i) For this task you decided to use a push-pull pair connected to a MOSFET, which in turn will activate the solenoid. Explain in no more than 40 words why a MOSFET can be slow to operate, and why using a push-pull pair will speed up its operation. [5]

ii) The solenoid is rather large, and you are worried about back EMF when it is turned off. Identify a component which must be added to the circuit to protect the MOSFET from this back EMF. Draw the full circuit consisting of the push-pull pair, the MOSFET, the solenoid and the extra protective component. How does this component protect the MOSFET? You answer should be no more than 20 words. [5]

(c) Finally, you are designing a sensing circuit to detect if the aircraft undercarriage has been deployed. As part of this sensing circuit you decided to use an R2R ladder within an analog-to-digital converter (ADC) circuit. Each input of the R2R ladder runs on two volts (2 V) and the R2R ladder takes five bits of digital input. What is the maximum output of the R2R ladder and what is the voltage resolution of the voltage steps it can produce? In no more than 20 words of text, explain why you might you choose to use a R2R ladder based ADC rather than a flash converter (flash ADC) in a consumer product. [5]

[35 marks total for Q.8]