UNIVERSITY OF SOUTHAMPTON ELEC2208W1

SEMESTER 2 EXAMINATIONS 2016-2017

POWER ELECTRONICS AND DRIVES

Duration 120 mins

This paper contains 6 questions

Answer **TWO** questions in **SECTION A** and **TWO** questions in **Section B.**

**Section A** carries 50% of the total marks for the exam paper

**Section B** carries 50% of the total marks for the exam paper

All numerical answers should be given to **5 significant figures**.

Only University approved calculators may be used.

A foreign language dictionary is permitted ONLY IF it is a paper version of a direct ‘Word to Word’ translation dictionary AND it contains no notes, additions or annotations.

**12 page examination paper (+ formula sheet)**

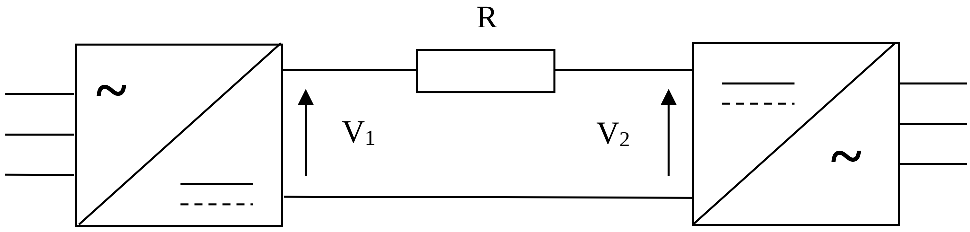
 

## SECTION A

### Answer *TWO* out of *THREE* questions

Question A1

(a) Describe and discuss the operation and features of the ac to ac power transmission system shown in Figure 1.




Bridge 1 Figure 1 Bridge 2

[4 marks]

(b) Calculate the voltages $V_1$ and $V_2$ for the transmission circuit shown in the figure with the firing advance angle of the inverter and the firing angle of the rectifier.
Calculate the system efficiency, ignoring any power loss in the two converters. The system specification is given below.

| | Bridge Converter 1 | Bridge Converter 2 |
|---|---|---|
| Type | 6-pulse fully controlled | 6-pulse fully controlled |
| Supply voltage | 415 V | 380 V |
| Frequency | 50 Hz | 60 Hz |
| Source inductance per phase | 0.011667 mH | 0.0125 mH |
| Mode | Rectifier | Inverter |
| Power | | 1.45 MW |
| dc current | | 10 kA |
| | | |
| The resistance, R is 0.002 Ω. | | |

**Question continues on the following page**

The mean output voltage of a p pulse converter, including overlap is given by: -

$$V_{mean} = p\frac{V_m}{\pi}\sin\frac{\pi}{p}\cos\alpha - \frac{pXI_L}{2\pi}$$

[10 marks]

(c)

A pulse of current, i, as a function of time, t, is observed in the gate of a power transistor that has the following relationship.

$$i = \frac{B}{t^2 - A} \qquad T_1 < t < T_2$$

where A and B are constants.
Determine an expression for the gate voltage, v, where the gate input capacitance is C.
Calculate the change in voltage between the times from $T_1$ to $T_2$, for the following parameter values.

| | | | |
|---|---|---|---|
| A | 2 $s^2$ | $T_1$ | 1 µs |
| B | 4 A | $T_2$ | 2 µs |
| C | 1 nF | | |

[6 marks]

Question A2

(a) (i) Draw and label a circuit diagram of a single phase to single phase cycloconverter. Identify each power electronic device in your circuit by numbering them in order. The supply and output frequencies are 50Hz and 16.667Hz respectively. The delay angles of the converter are all equal at $3\pi/4$ rad.

(ii) Draw voltage waveforms for the supply and output for one complete cycle of the output voltage. Also show which devices are conducting using the device numbers shown in your circuit diagram.

(iii) Explain the operation of this cycloconverter with a load consisting of an inductor and resistor in series over an output cycle.

[7 marks]

(b) The supply to a single phase to single phase cycloconverter is 120V and 60Hz. During an output half cycle the delay angles are 160, 124, 89, 46.635, 12, 12, 46.635, 89, 124 and 160 degrees.

(i) Calculate the average voltage over the positive half cycle of the output voltage.

(ii) Also calculate the average power dissipated in a resistive load of 0.49Ω.

[7 marks]

**Question continues on the following page**

(c) In a different converter, the voltage, v(t), across a load, over the time $-\pi < t < \pi$, is given by

$$v(t) = t^2 + t, \qquad -\pi < t < \pi$$

$$v(t) = v(t + 2\pi)$$

Sketch the voltage over the interval

$$-3\pi < t < 3\pi$$

Determine the Fourier series expansion for this voltage.
Express the series in terms of the $n^{th}$ harmonic.
Write in your answer book the first three terms of the series.

[6 marks]

Question A3

(a) Draw and label a circuit diagram for a dc-dc switch-mode and step-up (boost) converter using a power MOSFET as the main semiconductor switching device. Describe the operation of this circuit, when continuous current flows in the inductor. Include voltage and current waveforms for the inductor and circuit diagrams in your answer.

[7 marks]

(b) (i) Determine an expression from first principles relating the input voltage, E to the output voltage, $V_o$, as a function of the duty cycle, δ. Also from first principles, determine an expression for the inductance, L, in terms of the input and output voltages (E and $V_o$), duty cycle (δ), switching period (T) and mean current ($\bar{I}$).
State any assumptions made in deriving your expressions, by drawing and completing a table in your answer book which is similar to the one shown below.

| | Assumption |
|---|---|
| 1 | |
| 2 | |
| 3 | |

(ii) Calculate the following values if the maximum input power is 400W at a voltage of 120V. The output voltage is 1,000V when the switching frequency is 50kHz.

(a) The transistor on time.
(b) The average inductor current.
(c) The inductance.
(d) The peak inductor current.

[7 marks]

**Question continues on the following page**

(c) The drain-source voltage, $v_{DS}$, across a power MOSFET is given by the following equation where R is a constant.

$$v_{DS} = -\ \sinh(Rt)$$

Determine an expression for the energy lost in Y seconds.
Define all the symbols and constants used in your equations and make a list of them in your answer book.

[6 marks]

## SECTION B

### Answer *TWO* out of *THREE* questions

Question B1

A linear positioning system incorporates a high performance ballscrew with a lead (as defined in figure 2) of 0.01m, and is required to position the load to a resolution of $10^{-5}$m.

a) Determine the minimum pulses per revolution (PPR) of the incremental rotary position transducer that is used in this system, assuming the encoder is directly coupled to the ballscrew.

[5 marks]

b) If the maximum linear speed of the load is 5 m $sec^{-1}$, determine the encoder's maximum speed and maximum output pulse frequency.

[5 marks]

c) Provide a list of the most suitable encoder for this application, and compare advantages and disadvantages. Describe absolute encoders, semi absolute encoders and incremental encoders

[10 marks]

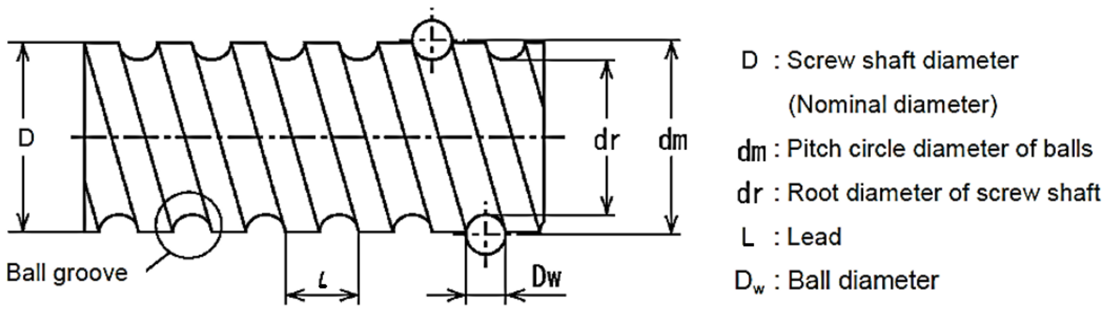



Figure 2: Ball screw schematic

Question B2

To test the component shown in Figure 3, it is spun at 5000 Rev.min$^{-1}$ around the Z-Z axis using a directly coupled permanent magnet brushed d.c. motor. Assuming that the component has a uniform density of 4000 kg.m$^{-3}$, determine:

a) The inertia of the component, around the axis of rotation, and hence the torque required to accelerate the component to 5000 rev min$^{-1}$ in 20 seconds.

[6 marks]

b) The stored energy in the rotating system at 5000 rev min$^{-1}$

[2 marks]

c) Based on the results from part (a), estimate the constant braking torque required to stop the motor from 5000 rev.min$^{-1}$ to 0 rev.min$^{-1}$ in 20s. Then, determine the associated regenerative current and the energy returned to the supply, assuming a constant regenerative current throughout.

[12 marks]

The motor's constants are $K_e$ = 0.6 Volt sec Rad$^{-1}$ and $K_t$ = 0.6 Nm Amp$^{-1}$. The motor's rotor resistance is 0.2 Ohm and its inertia is 0.15 kg.m$^2$

**Question continues on following page**

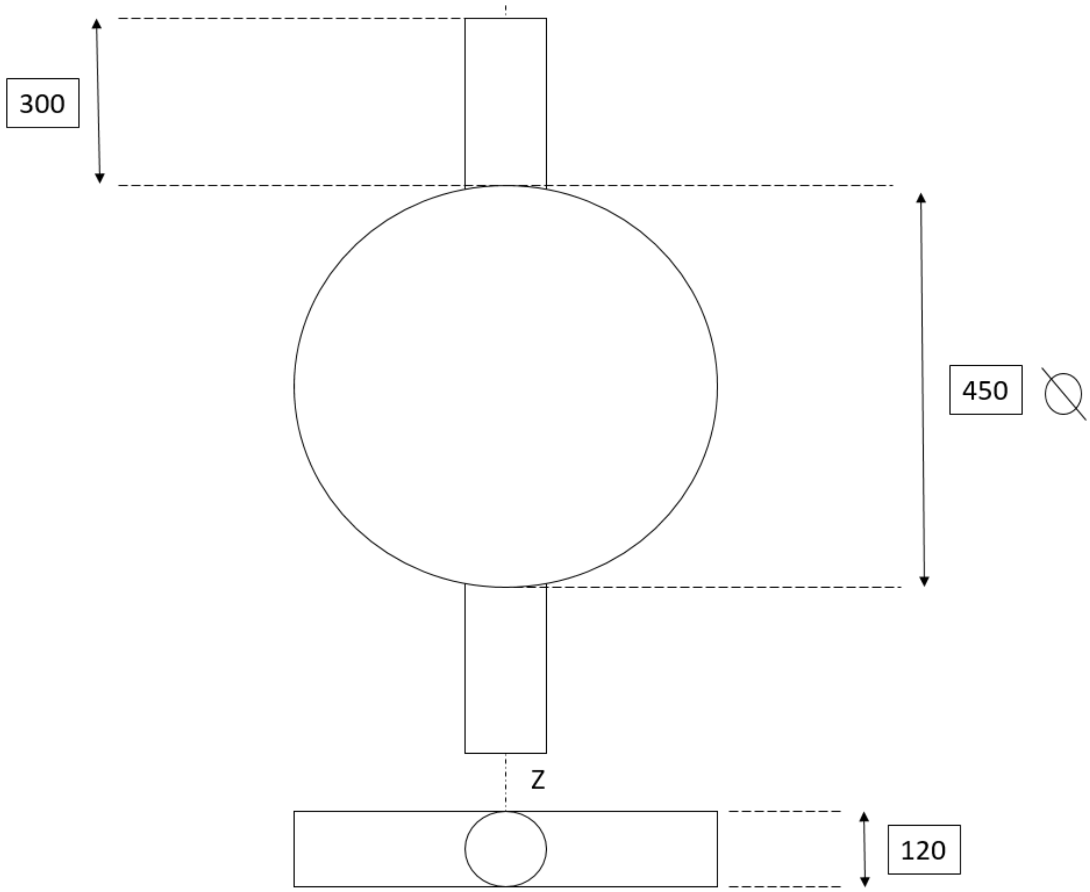



Figure 3: Components to be tested, all dimensions are in millimetres

Question B3

The speed of a 10 hp 300 V 1500 rpm separately excited DC motor is controlled by a three-phase full converter drive. The field current is controlled by a single-phase full converter supplied by one pair of lines from the three-phase supply, and is set to the maximum possible value. The AC input is a three-phase star-connected line-to-line 230 V 50 Hz supply. The armature and field resistances are 0.3 Ω and 125 Ω respectively, and the motor voltage constant is 1.0 V/(A-rad/s). The armature and field currents can be assumed to be continuous and ripple-free. The viscous/windage friction is negligible.

(a) Determine the delay angle of the armature converter $\alpha_a$ if the three-phase converter supplies a rated current and power to the motor operating at rated speed.

[12 marks]

(b) Determine the no-load speed if the delay angle is the same as in part (a) and the armature current at no-load is 20% of the rated value.

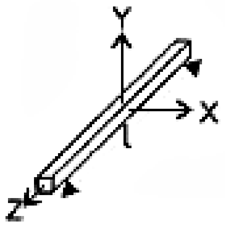
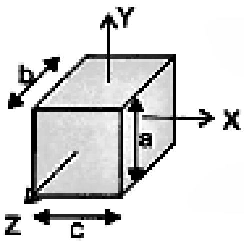
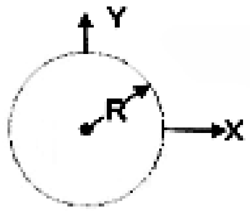
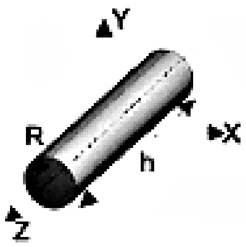
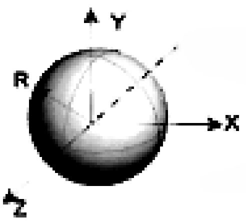
[5 marks]

(c) Determine the speed regulation at the no-load condition as in part (b).

[3 marks]

**END OF PAPER**

| Body | | $I_{xx}$ | $I_{yy}$ | $I_{zz}$ |
|---|---|---|---|---|
| Slender bar |  | $\frac{ml^2}{12}$ | $\frac{ml^2}{12}$ | – |
| Cuboid |  | $\frac{m}{12}(a^2 + b^2)$ | $\frac{m}{12}(b^2 + c^2)$ | $\frac{m}{12}(a^2 + c^2)$ |
| Thin disc* |  | $\frac{mR^2}{4}$ | $\frac{mR^2}{4}$ | $\frac{mR^2}{2}$ |
| Cylinder |  | $\frac{m}{12}(3R^2 + h^2)$ | $\frac{m}{12}(3R^2 + h^2)$ | $\frac{mR^2}{2}$ |
| Sphere |  | $\frac{2}{5}mR^2$ | $\frac{2}{5}mR^2$ | $\frac{2}{5}mR^2$ |

*A thin disc is considered a special case of a cylinder where h=0