Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2013-14 (2.0 hours)

EEE6022 Motion Control and Servo Drives 6

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. a. Fig. 1 shows the schematic of a servo drive system in which the payload mass m, supported by the guide, is coupled to the motor with inertia J_m via a pulley and belt transmission. Assuming that friction and inertia of the pulley and belt are negligible, determine the optimal radius of the pulley r that minimises the motor torque. **(8)**

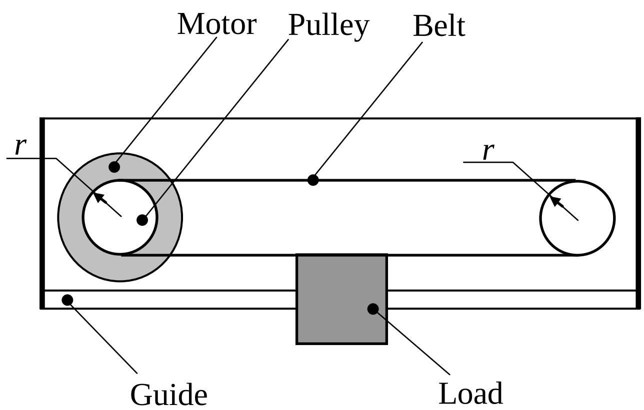

Fig. 1

b. The motor in Fig. 1 with inertia of 0.002 kgm^2 is required to move the purely inertial load of 0.2 kg through a distance of 0.4m in 0.1s using a trapezoidal velocity profile and the optimal transmission arrangement. Determine the peak torque and speed rating of the motor. Would the motor overheat if such a movement were executed repeatedly given that the rms torque rating of the motor is 6.0 Nm? **(8)**

c. If the same movement is to be performed using a triangular velocity profile, calculate the rms torque and maximum output power of the motor. **(4)**

2. A permanent magnet dc servomotor with the following parameters

rated torque = 10Nm
rated current = 20A
armature resistance $R_a = 0.37\Omega$
armature inductance $L_a = 1.5$ mH
moment of inertia $J = 4.0\text{x}10^{-2}$ kgm^2

is connected to a 200V dc supply via the H-bridge which operates in the bipolar mode at 10 kHz switching frequency, as shown in Fig. 2

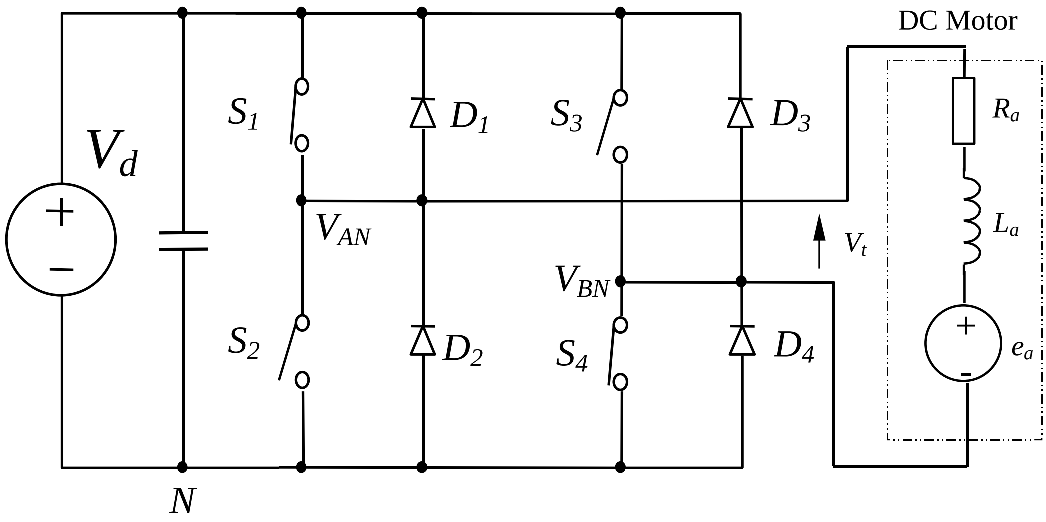

Fig. 2

a. Describe, with the aid of appropriate waveforms, the bipolar operation of the converter, assuming that the switches and diodes are ideal devices. **(6)**

b. Derive an expression for the output voltage, V_t, as a function of duty ratio and for the 'gain of the converter' defined as the ratio of the output voltage to the control input. **(3)**

c. Given the peak value of a triangular carrier V_{tp} = 10V, sketch the transfer function block diagram between the control input of the H-bridge, $V_c(s)$, and the motor speed, $\omega(s)$, specify the parameters of each block, and calculate the electrical and mechanical time constants of the drive system. **(5)**

d. Design a proportional plus integral (PI) current controller to yield a first order closed-loop response with a time constant of 1.0 millisecond. **(6)**

3. **a.** The transformation matrix from a stationary ($\alpha\beta$) system to a 3-phase (abc) system is given by:

$$C_{abc\leftarrow\alpha\beta} = \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix}$$

Show that electromagnetic torque of a sinusoidal waveform motor is given by:

$$T_{em} = \frac{3}{2} p\left(\Psi_\alpha i_\beta - \Psi_\beta i_\alpha\right)$$

where p is the number of pole-pairs, and Ψ_α, Ψ_β, i_α and i_β are the α and β axis components of the motor flux-linkage and current, respectively. **(6)**

b. A sinusoidal waveform permanent magnet servomotor has the following parameters

Number of pole pairs = 2
Phase resistance = 4.2 Ω
Phase inductance = 4.8 mH
Voltage constant (the ratio of rms phase voltage induced to the speed of rotation) = 25 V/krpm
Moment of inertia = 0.005kgm^2

Calculate the no-load peak flux linkage of a phase winding, and the torque constant of the motor. **(2)**

c. Sketch the d-q axis transfer function block diagram of the motor, and specify parameters of each block. **(4)**

d. Design d-q axis current controllers with an appropriate structure to yield a first order response with a time constant of 1.0 millisecond. **(8)**

4. **a.** In space vector modulation, a voltage space vector is defined as:

$$V_s = \frac{2}{3}\left(v_{an} + \alpha v_{bn} + \alpha^2 v_{cn}\right)$$

where $\alpha = e^{j\frac{2\pi}{3}}$, $j = \sqrt{-1}$. If the three phase voltages, v_{an}, v_{bn}, and v_{cn} are given by:

$$\begin{aligned} v_{an} &= V_m \sin \omega t \\ v_{bn} &= V_m \sin(\omega t - 2\pi / 3) \\ v_{cn} &= V_m \sin(\omega t + 2\pi / 3) \end{aligned}$$

show that the resultant voltage space vector is a rotating vector of constant magnitude V_m and the speed of rotation is ω.

Note: The following trigonometric identities may be used.

$$\sin A + \sin B = 2\sin\left(\frac{A+B}{2}\right)\cos\left(\frac{A-B}{2}\right)$$

$$\sin A - \sin B = 2\sin\left(\frac{A-B}{2}\right)\cos\left(\frac{A+B}{2}\right)$$

(8)

b. A three-phase, 4-pole star-connected induction motor has a rated speed of 1450 rpm, when operating from a 415V, 50Hz supply. The machine has the following parameters measured at 50Hz and referred to the stator:

Magnetising reactance	= 48.6 Ω
Stator resistance	= 0.35 Ω
Rotor resistance	= 0.55 Ω
Stator leakage reactance	= 1.20 Ω
Rotor leakage reactance	= 0.95 Ω

(i) If the motor operates at 50% rated torque, calculate the rotor speed, stator current, power factor, air-gap flux linkage, and efficiency. **(8)**

(ii) If the motor is fed by a three-phase variable frequency inverter and operates at 1000 rpm and rated torque, estimate the output phase voltage (rms) and frequency of the inverter. **(4)**

JBW