MECHATRONICS WITH CONTROL

(22WSD912)

January 2023 2 Hours

Answer **ALL FOUR** questions.

Questions carry the marks shown.

Any University-approved calculator is permitted.

A range of formulae and tables likely to be of benefit in the solution of these questions is provided at the rear of the paper.

1.

a)

Describe the construction and operation of an optical incremental rotary shaft encoder. Include details of how to increase measurement resolution beyond the physical pulses, and detect direction. Illustrate your answer with appropriate diagrams for the encoder and its output signals. Include, giving reasons for your choice, two example applications where an incremental rotary shaft encoder would be a suitable sensing choice. [11 marks]

b) An incremental encoder is used with a tracking wheel to measure the linear displacement of a moving linear table with a maximum velocity of 1.5 ms-1. The wheel diameter is 52mm, and the code disc is 1024 PPR. The interface system uses quadrature decoding to record counts.

Determine:

i. The displacement per encoder pulse. [3 marks]

ii. The displacement after 7200 counts is recorded. [3 marks]

iii. Will a decoder circuit with a maximum input frequency of 10KHz is suitable for use with this encoder and wheel? [2 marks]

2.

a) Fully explain the operation of the analogue to digital converter (ADC) shown in Figure 2a. Start with the application of an unknown analogue voltage to the input and describe the conversion process to the output of an 8-bit binary code representing that unknown voltage. [8 marks]

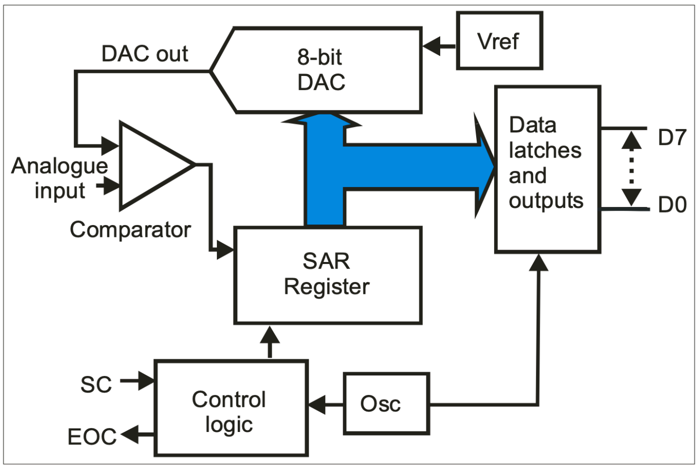

Figure 2a.

b) An ideal 8-bit unipolar ADC has a 5V reference. When supplied with an unknown at its input terminals, the output code is '11101101'. Find the unknown input voltage using the transfer function for an ideal ADC. [5 marks]

c) Calculate the LSB contribution for this ADC. [2 marks]

d) Draw a labelled block diagram showing all elements and interconnections for a system that reads signals from 4 analogue-output sensors into a computational system. The system should use a **single ADC** to read all signals with a four-channel multiplexer at the input. Include an indication of signal conditioning and anti-aliasing requirements. [8 marks]

 /continued

3.

a) Describe the construction, operation and characteristics of series wound and permanent magnet (PM) DC motors. Include labelled diagrams showing the motor's equivalent electrical circuit and speed vs torque graphs. Include discussion of the load/speed and starting torque characteristics for these motors. [16 marks]

b) A common way to control the direction of rotation of DC motors is through an H-Bridge arrangement. Draw a diagram of an H-Bridge circuit showing transistor status and current flow for forward rotation and draw a second diagram showing transistor status and current flow for reverse rotation. [6 marks]

c) Briefly describe two examples of methods of electronic speed control for permanent magnet DC motors connected to a computational system. Include a diagram with each. [10 marks]

4. A linear positioning system is designed around a horizontally orientated feed screw arrangement, as shown in figure Q4. The system must accelerate, travel at a maximum speed of 0.5m in 50s and then decelerate to stop. Assume the motor is operating at maximum torque when accelerating.

Referring to the data provided below, and showing all working and formulae used, determine the following:

i. Motor shaft speed in rpm. [6 marks]

ii. Torque reflected to the motor shaft at a constant speed. [6 marks]

iii. Acceleration of the leadscrew. [6 marks]

iv. Accelerating time. [4 marks]

v. Total distance travelled. [4 marks]

<u>Data</u>

Motor: maximum torque 7.8Nm, rotor inertia $3.883*10^{-4}$ kg m^2.

Gearbox: speed ratio 2:1, efficiency 86%, inertia $2.5*10^{-4}$ kg m^2.

Leadscrew: leadscrew and nut efficiency 36%, lead 2mm, mass of nut 0.06kg, mass of screw 0.625kg, screw effective diameter 0.01m.

Load: mass 5kg, coefficient of friction for linear bearings 0.002.

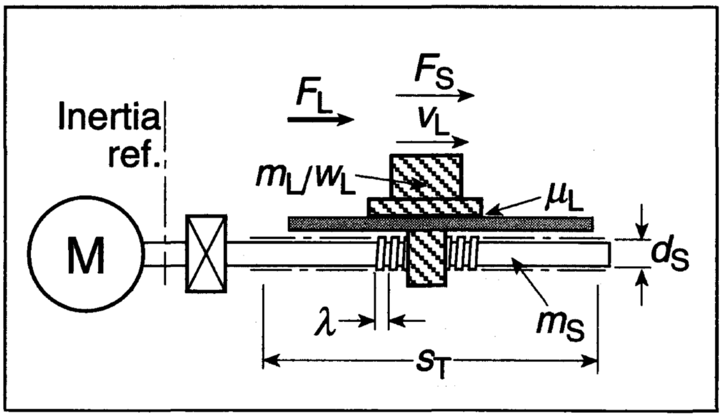

Figure Q4.

A Sutton

/continued

Useful formulae

Horizontal travel speed

$$VL := \frac{SL}{tL}$$

Lead screw speed

$$\varpi S := VL \cdot \frac{2 \cdot \pi}{\lambda}$$

rotational speed of motor shaft at maximum speed

$$\varpi M := \varpi S \cdot R$$

motor shaft speed

$$n := \frac{30 \cdot \varpi M}{\pi}$$

Linear accelerating force

$$FL := wL(\mu L \cdot Cos(A) + Sin(A))$$

Torque at the leadscrew at maximum speed

$$Ms := FL \cdot \left(\frac{\lambda}{2 \cdot \pi \cdot \eta s} \right)$$

torque reflected to motor shaft

$$Mo := Ms \cdot \frac{1}{R} \cdot \frac{1}{\eta G}$$

inertia of linear load

$$JL := (ML + MN) \cdot \left(\frac{\lambda}{2 \cdot \pi} \right)^2$$

inertia of feed screw

$$JS := 0.5 \cdot Ms \cdot \left(\frac{ds}{2} \right)^2$$

inertia of loaded machine reflected back to feed screw

$$JR := (JL + JS + JG) \cdot \left(\frac{1}{R^2} \right) \cdot \left(\frac{1}{\eta s} \right) \cdot \left(\frac{1}{\eta G} \right)$$

total inertia of the system

$$JT := JM + JR$$

acceleration of the motor

$$\alpha M := \frac{MM}{JT}$$

acceleration of the leadscrew

$$\alpha S := \frac{\alpha M}{R}$$

Accelerating time

$$tA := \frac{\varpi S}{\alpha S}$$

distance travelled during acceleration and deceleration, from accelerating time

$$SA := \frac{1}{2} \cdot \alpha S \cdot (2 \cdot tA)^2$$

total distance travelled in trapezoidal motion

$$ST := SA + SL$$