Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (2.0 hours)

EEE217 Avionic Systems

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.** Summarise the main advantages of a Fly-By-Wire flight control system, and sketch a figure illustrating its essential features.

(5)

b. The true airspeed of a certain aircraft flying in the troposphere region is V_T= 560 km/h, the static air temperature is T_S = -34.5 ^{o}C and the static pressure is P_s=37.65 kPa:

i. Calculate the Mach number M , and the altitude of the aircraft.
ii. Calculate the air density ρ .
iii. Calculate the calibrated airspeed V_C .

(9)

c. When the aircraft is flying at a higher altitude H=15240m (50000ft), the static pressure is P_s=11.1 kPa, and the true airspeed is V_T= 1200 km/h:

i. Calculate the speed of sound A .
ii. Calculate the total pressure P_T.

(6)

<u>The following may be assumed:</u>

Gas constant for unit mass of dry air : R_a *=287.0529 J/^{o}K .kg*

$$\textit{Impact pressure} = P_0\left(\left(1+\frac{(\gamma-1)(V_c/A_0)^2}{2}\right)^{\gamma/(\gamma-1)}-1\right) \textit{ when } V_c < A_0$$

$$\frac{P_T}{P_s} = \left(1+\frac{(\gamma-1)}{2}M^2\right)^{\frac{\gamma}{(\gamma-1)}} \textit{for subsonic flight ;}$$

$$\frac{P_T}{P_s} = \frac{\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{(\gamma-1)}} M^{\frac{2\gamma}{(\gamma-1)}}}{\left(\frac{2\gamma}{(\gamma+1)}M^2-\frac{(\gamma-1)}{(\gamma+1)}\right)^{\frac{1}{(\gamma-1)}}} \textit{ for supersonic flight.}$$

$$\gamma = \frac{\text{specific heat of air at constant pressure}}{\text{specific heat of air at constant volume}} \textit{ and } P_T \textit{ is the total pressure.}$$

<u>At sea level:</u> the static pressure P_0 *=101.325 kPa, the absolute static air temperature is* T_0 *=288.15^{o}K, the air density* ρ_0 *=1.225 kg/m^3 and the speed of sound* $A_0 = 340.3$ *m/s.*

2. **a.** If n is the number of independent channels of a redundant configuration, explain how adaptive majority voting can realise a 2-out-of-n system for $n \geq 3$. What would be the minimum number of functioning channels, if non-adaptive majority voting is adopted? **(4)**

b. The dominant failure mechanism of a certain integrated circuit (IC) is electromigration with an effective activation energy $\frac{E_a}{n}$=0.7 eV. When operating at 80^{o}C, the mean time to failure (*MTTF)* was found to be 30000 hours. Assuming that the failure process behaves as a chemical process with a reaction rate $Q(T) = Q_o\, e^{\left(-\frac{E_a}{kT}\right)}$ and that the drift in parameters is proportional to $t^n\, Q(T)$ where k, T and t are the Boltzman's constant, the absolute temperature and time respectively:

i. Show that the $MTTF = t_o\, e^{\left(\frac{E_a}{nkT}\right)}$.

ii. Calculate the *MTTF* of the IC when operated at 30^{o}C .

(6)

c A certain aircraft requires 10 kW of electrical power in order to supply the essential services, such as flight instruments, communications systems etc., and 30 kW in order to supply all the services. Such aircraft could be equipped with a single 30 kW generator (option 1), two identical 15 kW generators (option 2) or three identical 10 kW generators (option 3). For options 2 and 3 the generators share the electrical power generation. Furthermore, it is assumed that the three types of generator have a constant failure rate λ = 1.0 × 10^{-4}/hour. For a 10-hour flight:

i. Calculate the probability of losing the capability of generating 30 kW of electrical power, when options 1, 2, and 3 are adopted.

ii. Calculate the probability of losing the capability of generating 20 kW of electrical power, when options 2 and 3 are adopted.

iii. Show that for a 2-out-of-3 active system, the mean time to failure $MTTF = \frac{5}{6\lambda}$.

(10)

<u>*The following may be assumed:*</u>

Boltzman's constant $k = 8.6 \times 10^{-5}\, eV/^o K$

Reliability function for <u>m-out-of-n system (active):</u> $R(t) = \sum_{k=m}^{n} \frac{n!}{k!(n-k)!}\left[e^{-\lambda kt}\right]\left[1-e^{-\lambda t}\right]^{n-k}$

Reliability function for <u>m-out-of-n system (passive):</u> $R(t) = e^{-\lambda mt} \sum_{k=m}^{n} \frac{(m\lambda t)^{k-m}}{(k-m)!}$

$$MTTF = \int_0^{\infty} R(t)\,dt$$

3. a. An electromechanical actuator consisting of a servo motor, a nut and a screw with a pitch length $\lambda = 10$ mm, figure 3.1, is driving a load with a mass m =35000 kg. The motor has a back-emf constant $k = 0.16$ V.s/rad, an armature resistance R =20 mΩ, and a rotor inertia $J_m = 1.5\times10^{-3}$ kg.m^2. Furthermore, the gear ratio between the nut and the motor is 10:1. Assume the mechanical transmission to be lossless.

i. Calculate the armature current and the copper loss P_c of the motor, when producing an electromagnetic torque T_m =15Nm.

ii. When friction is neglected and only the copper loss is considered, show that the efficiency of the motor is given by $\eta = \dfrac{1}{1+\dfrac{R}{k^2}\dfrac{T_m}{\Omega_m}}$, where Ω_m is the speed of the motor.

iii. When a constant friction torque T_f is also considered, show that the efficiency is then given by $\eta = \dfrac{\left(1-\dfrac{T_f}{T_m}\right)}{\left(1-\dfrac{T_f}{T_m}\right)+\dfrac{R}{k^2}\dfrac{T_m}{\Omega_m}}$.

(11)

b. The electromechanical actuator is now controlled so as to drive the load for a distance of 25 mm:

i. Calculate the load inertia J_r referred to the shaft of the servo motor.

ii. Calculate the time T required to travel the distance when following a parabolic velocity profile, and the motor torque is limited to $T_p = 20$ Nm.

iii. Calculate the time T required to travel the distance when following a triangular velocity profile, and the motor torque is limited to $T_p = 20$ Nm.

iv. Calculate the energy lost in the winding of the motor, when the load travels the distance following a triangular velocity profile.

(9)

<u>The following may be assumed:</u>

$T_p = (J_m + J_r)\dfrac{\theta_m}{\tau(T-\tau)}$ *and* $T_p = 6\,(J_m + J_r)\dfrac{\theta_m}{T^2}$ *for a trapezoidal and a parabolic velocity profile, respectively.* θ_m *is the angle covered by the shaft of brushless servo motor, and* τ *is the duration of acceleration and deceleration phases.*

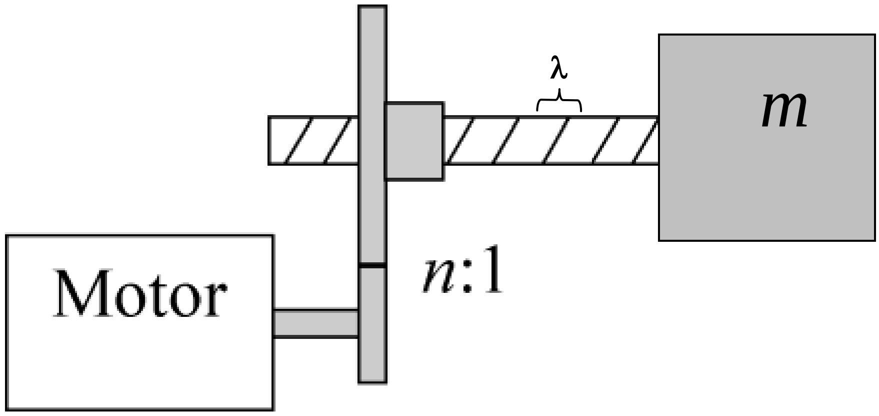

Figure 3.1 Schematic of electromechanical actuator.

4. a. A potentiometer used to measure angular position θ of an actuator, can measure a maximum angle of 160^o, has a resistance R_p =10kΩ and its output is converted to digital format using an n-bit analogue-to digital-converter (ADC).

i. Show that the error is given by $Error(\%) = \dfrac{a(1-a)\dfrac{R_p}{R_m}}{1+a(1-a)\dfrac{R_p}{R_m}} \times 100$;

where $a = \theta/\theta_{\max}$.

ii. Calculate the error, when the potentiometer is loaded by a recorder with an input resistance $R_m = 100\,k\Omega$.

iii. What should be the minimum sampling frequency f_s of the ADC if the actuator follows the periodic position profile

$$\theta(t) = \theta_0 \sin(2t) + \frac{\theta_0}{3}\sin(4t) + \frac{\theta_0}{5}\sin(6t).$$

(8)

b. The output of the potentiometer is now converted to digital format using a 4-bit ($b_3 b_2 b_1 b_0$) analogue-to-digital converter (ADC), which drives a logic circuit, controlling red, green and yellow LEDs, figure 4.1. The logic circuit was designed in order to ensure that:

- the red LED is ON when $\theta < 10^o$ or $\theta \geq 150^o$.
- the yellow LED is ON when $10^o \leq \theta < 70^o$ or $90^o \leq \theta < 150^o$.
- the green LED is ON when $60^o \leq \theta < 100^o$.

i. Construct the truth table of the logic circuit.

ii. Obtain the Sum-Of-Products (SOP) expressions of the logic functions Green and Red and show that the logic function Green is independent of the least significant bit b_0 of the ADC.

iii. Obtain the Product-Of-Sums (POS) expression of the logic function Yellow.

(12)

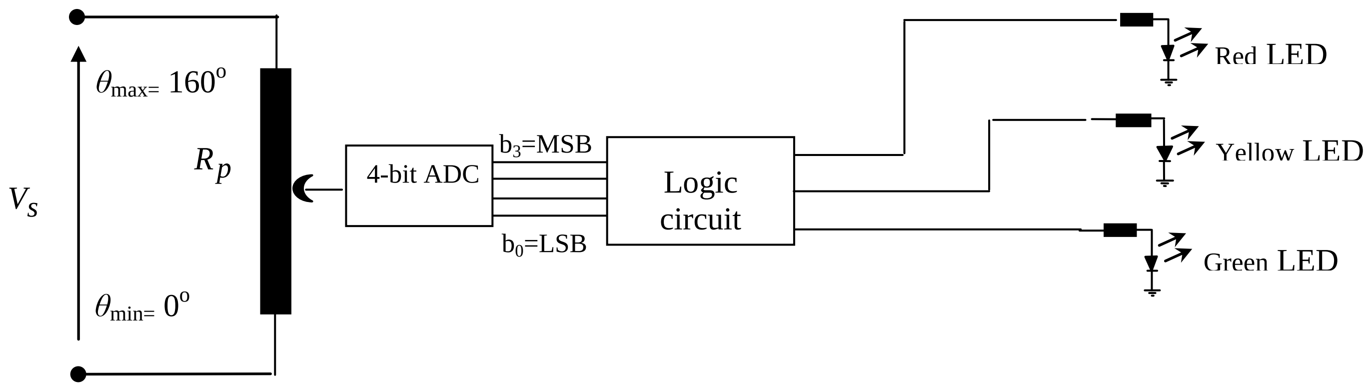

Figure 4.1 Potentiometer

KA/JBW