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Faculty of Engineering

Department of
Mechanical Engineering

MCG 4136 / MCG 5184
MECHATRONICS

Final Examination (60%)
Dec 11, 2012
Prof. D. Necsulescu Duration: 3 h.

NOTE: Closed book exam. Calculators permitted. All ***12*** problems of equal value.

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1. A strain gauge with nominal resistance R =0.2 kΩ is installed in a branch of a Wheatstone bridge having for unstrained strain gauge $R_1 = R_2 = R_3 = R_4 = R$ and $V_i = 12$ V. The strain gauge is subject to a strain as a result of bending the beam on which it is cemented. A digital voltmeter with input resistance $R_m = 10$ MΩ gives a reading of $V_o = 20$ mV
Calculate the change of the resistance ΔR and the strain σ for gauge factor G = 2.00**.**

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2. A weighted-resistor Digital-to-Analog Converter has N = 8 bit, the reference voltage $v_R = 10$ V, the Most Significant Bit resistance R = 1 k Ω, and the feedback resistance of the operational amplifier $R_F = 5$ k Ω.
Calculate:

a) The output voltage v_0 corresponding to the Least Significant Bit;
b) The output voltage v_0 corresponding to the Most Significant Bit;
c) The maximum value of the output voltage v_0;
d) The nominal full-scale output voltage v_0;
e) The resolution
f) The output voltage v_0 corresponding to the binary input 10110011.

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3. An incremental encoder with 2^o slots evenly distributed along the circumference of 10 cm radius is installed on a shaft rotating at 1000 rpm.

Calculate the frequency in of the pulse output (in pulses per second) of the encoder before sampling.

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4. Assume a wire of diameter D, length L, cross section area A and resistivity ρ

a) Obtain the equation for the gauge factor G function of axial strain and Poisson ratio and resistivity ρ change with strain.

b) For a wire with 300 Ω nominal resistance, a Poisson ratio μ= 0.5 and an insignificantly low resistivity change with strain, calculate the change of the resistance of the wire when subject to an axial strain of 10^{-12} m/m.

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5. An accelerometer based o a strain gauge consist in a cantilever beam of length L = 5 mm, width w = 1.5 mm and thickness t =0.2 mm, fitted with a (seismic) mass M = 0.001 kg. The modulus of elasticity of the beam is E = 200 x 10^9 N/m^2. The strain gauge cemented at l = 5 mm, from the free end of the beam and having G = 2.0 is connected to a bridge which is interfaced to an ADC through an inverting amplifier. Assume nominal resistance of the strain gauge of R = 300 Ω and the supply voltage of the bridge V_i = 5 V.

The output voltage of the inverting operational amplifier is $V_o = [V_i R_o G\varepsilon/(2R)]$

a)Calculate the acceleration ***a*** which produces a voltage output V_o = 0.1 V when the resistance of the inverting amplifier is R_o =1 MΩ.

b) In case the ADC has only the range 0 to 10 V available, calculate a value for R_o which will give 5 V for V_o, for an acceleration value and all other factors being kept the same.

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6. The Gain – Bandwidth Product (GBP) of an operational amplifier is 10 MHz. The operational amplifier is an amplifier with a gain of 100 dB.

a) Calculate the bandwidth of the amplifier;

b) Can this amplifier be used for amplifying signals of 1000 Hz. If not, calculate the gain of the amplifier having the same GBP = 10 MHz

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7. Assume a positioning measuring potentiometer (with total resistance R = 35 k Ω , total length L=5 cm and input voltage V_i = 10 V) has the wiper at x= 2.5 cm . The voltage V_o of the potentiometer is measured with an analog voltmeter with input resistance R_o = 35 kΩ connected as load of a potentiometer.

a) Calculate the voltage V_o measured by the analog voltmeter;
b) Calculate the error in analog voltmeter measurement of V_o with regard to the V_o measured by a digital voltmeter with R_o = 2 MΩ.

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8. A tachometer has the tachometer constant K = 6 V/krpm (krpm= 1000 revolutions per minute) and is connected to a 8 bit ADC which has input voltage range from 0 to 10 V.

a) Calculate the maximum acceptable velocity that can be measured by the tachometer in this configuration.
c) Calculate the velocity measurement resolution of the tachometer with ADC.

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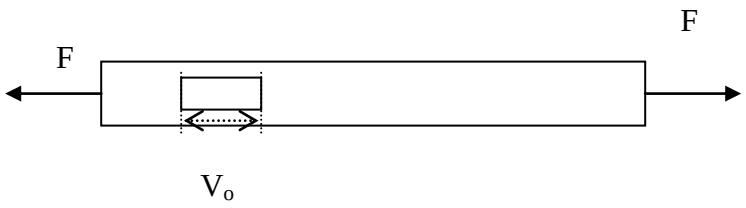
9. A strain gauge can be installed on a steel bar to measure the applied axial force, as shown



The bar has the Young elastic modulus 200 * 10^6 kN/m^2 and a cross section area 2 cm^2 is subject to an axial force F. For measuring this force, a strain gauge with a nominal resistance R= 300 Ω is cemented to the bar and connected in a branch of bridge with all other branches with resistances equal to 300 Ω and with the inverting amplifier output resistance of 1. 5 MΩ. The strain gauge factor is 2.0 and the voltage V_i = 12 V.
Calculate the force F given a measured voltage output 6 V.

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10. A PC based data acquisition system is considered for a J type thermocouple, having a Seebeck coefficient of 51 μV/ ^{0}C. Two limit designs will have to be evaluated.

Design A)

-a **8-bit A/D** converter which has input voltage ranges of 0 to 100 mV or 0 to 10 V selectable by software;

-a standard electronic reference junction block with a temperature uncertainty of +/– 0.3^0 C at 0^0 C;

-a standard thermocouple with +/–0.75^0 C error limit.

Design B)

-a **16-bit A/D** converter which has input voltage ranges of 0 to 10 V or 0 to 1 V selectable by software.

-a special electronic reference junction block with a temperature uncertainty of +/– 0.02^0 C

-a special thermocouple with +/– 0.025^0 C error limit 0^0 C

Compare the two designs.

a) calculate the resolution and determine the suitable input voltage range for the analog input voltage for A/D converter of **Design A and B**;

b) calculate the combined uncertainty (of A/D converter, Reference Junction and Thermocouple) regarding the temperature measurement. Which design is preferable?

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11. For a weighted resistors 4 bit Digital to Analog Converter:

a) Draw the equivalent circuit diagram

b) What is the ratio of the:
resistance for the Least Significant Bit / resistance for the Most Significant Bit.

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12. Consider a Stepper Motor with 2 phase stator and 6 teeth rotor.

a) Draw the diagram of the motor showing the stator phases and their electric Connections as well as the 6 teeth rotor.

b) Show the diagrams for four steps in full-stepping case.

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HINTS

$$F = \frac{2RAE}{V_i R_0 G} V_0$$

axial stress = 6 M***a***l / (w t^2).

$v_0 = \{2\, R_F\, v_R/R\}\{b_1\, /2 + b_2\, /(2^2) + \ldots\, b_N\, /(2^N)\}$