National Exams May 2016

04-Agric-A5, Principles of Instrumentation

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM.
Any non-communicating calculator is permitted.

3. Questions 1, 2 and any other three (3) questions constitute a complete exam paper. Only questions 1, 2 and the first three (3) other questions as they appear in your answer book will be marked.

4. All questions are of equal value.

Question 1. (20 marks)(You must answer this question. Each part is worth 2 marks.)

Answer the following short answer questions very briefly. Point form, graphs or sketches may be used as appropriate.

a)(2 marks) Why is the RMS error of a calibration more useful than the R^2 value?

b)(2 marks) What is the mathematical definition of noise?

c)(2 marks) What is meant by the terms 'zero' and 'span'?

d)(2 marks) When is a three point calibration required?

e)(2 marks) What is a blank and why should its measurement be repeated several times?

f)(2 marks) A highly sensitive instrument has an increased response to interferences. What are interferences?

g)(2 marks) Why does taking the derivative of a signal increase the noise in the result?

h)(2 marks) What is meant by a 'representative' sample?

i)(2 marks) What defines the 'lowest detectable limit' of a measurement?

j)(2 marks) What type of standards can be used in calibrating an instrument?

Question 2. (20 marks)(You must answer this question. Each part is worth 2 marks.)

Answer the following short answer questions very briefly. Point form, graphs or sketches may be used as appropriate.

a)(2 marks) What steps in a calibration procedure should be carried out to determine the dynamic response of an instrument?

b)(2 marks) How fast should a varying signal be sampled?

c)(2 marks) What is the difference between noise and electrical interference?

d)(2 marks) What is common mode rejection in a differential amplifier?

e)(2 marks) What must be done so that a measurement does not affect the system being measured?

f)(2 marks) Why are digital data transmission systems more reliable than analog systems?

g)(2 marks) How does grounding a cable shield only at one end reduce the interference induced in a cable?

h)(2 marks) Why should a sensor preamplifier be located very close to the sensor?

i)(2 marks) Explain why thermocouples, which produce small signals, are relatively immune to electrical interference.

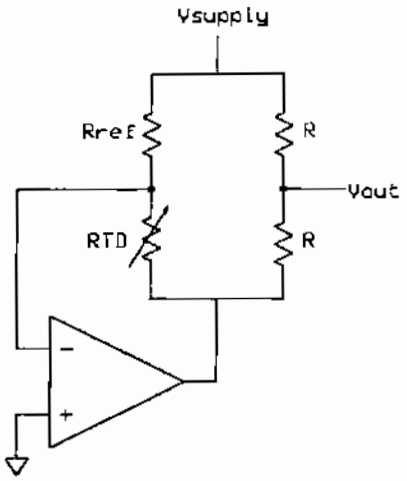
j)(2 marks) How would you choose the number of bits required in digitizing an analog signal?

Question 3. (20 marks)(You only have to do three questions from questions 3 to 7.)

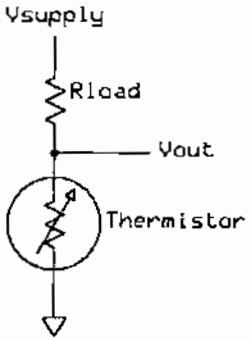
An RTD (Resistor, Temperature Dependent) is a temperature sensor made of platinum wire wound around a ceramic bobbin. An RTD with a resistance of 100 Ω at 0^{O} C gives a resistance change of approximately 2 Ω / 5^{O} C. Measurements of very small temperature changes are often required.

a)(3 marks) Why are Wheatstone bridges used for sensitive resistance measurements?

b)(7 marks) Show that the following circuit gives an output voltage (Vout) that linearly follows the resistance of the RTD.



Thermistors are similar to RTD sensors but they give a much larger non-linear resistance change with temperature. The resistance change is large enough that a simple voltage divider is sufficient to provide the measurement.



c)(3 marks) Why should the load resistor be chosen to equal the resistance of the thermistor in the middle of the expected temperature measurement range?

Question 3 (continued)

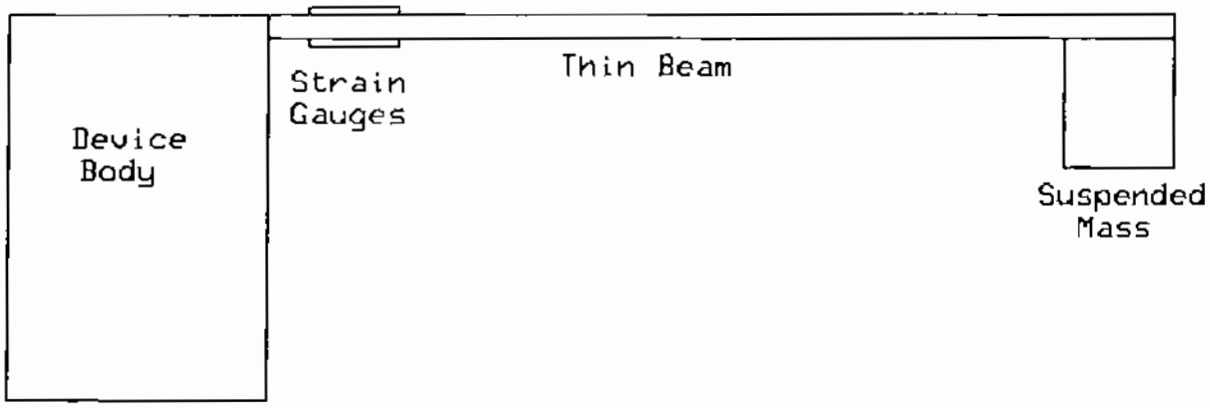
d)(3 marks) Both the RTD and thermistors give larger signals as the supply voltage is increased. Explain why the supply voltage should be kept low.

RTD sensors with the platinum wire wound around a ceramic bobbin are larger and heavier than thermocouples.

e)(4 marks) Why do thermistors give a faster response to temperature changes?

Question 4. (20 marks)(You only have to do three questions from questions 3 to 7.)

Some accelerometers are made of a thin beam fixed at one end with a mass attached to the free end. The beam bends due to the weight of the mass and the deflection is measured by strain gauges near the fixed end:



a)(4 marks) Why is the weight of the mass at the end of the beam a vector quantity?

b)(8 marks) The beam is very sensitive to accelerations in the principal axis but also slightly sensitive to accelerations in the other two axes. If you have three accelerometers, how would you compensate for the slight sensitivities?

c)(8 marks) If one accelerometer is to be used as a tilt sensor, in what orientation should the accelerometer be mounted -- with the beam aligned vertically or horizontally with respect to gravity?

Question 5. (20 marks)(You only have to do three questions from questions 3 to 7.)

To measure the velocity of air in buildings or outdoors, a variety of anemometer types may be used. These include Pitot tubes, rotary anemometers and thermal sensors.

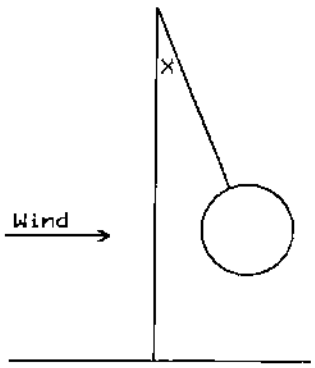
a)(4 marks) Describe the operation of a Pitot tube and give the equation relating its output to the air velocity.

b)(4 marks) The Pitot tube equation often has a coefficient which accounts for non-ideal behaviour. What non-ideal behaviour does this coefficient include?

c)(4 marks) A thermal anemometer measures wind speed through a heat transfer process. Explain how this instrument works.

d)(4 marks) Cup anemometers are the main instrument used by meteorologists to measure wind speed. The spin rate is proportional to the wind speed. What factors are important in the design of this type of instrument?

e)(4 marks) One simple anemometer may be made by hanging a weighted ping pong ball by a thread. Develop an equation relating the wind speed to the angle X shown in the diagram.



Question 6. (20 marks)(You only have to do three questions from questions 3 to 7.)

Electrical filters are used to remove unwanted frequency components from a signal.

a)(2 marks) How is a signal broken into its frequency components mathematically?

b)(2 marks) What is the most used filter type in instrument applications?

c)(2 marks) What is an anti-aliasing filter?

d)(4 marks) A second order low pass filter has a cutoff frequency of 30 Hz. How much is a 120 Hz interference signal reduced?

e)(4 marks) The operation of a low pass filter is analogous to taking a running average. What is the problem that occurs when averaging the signal from a non-linear sensor?

f)(6 marks) How would you build a low pass filter for an air flow measurement without using electrical components?

Question 7. (20 marks)(You only have to do three questions from questions 3 to 7.)

In fitting a calibration curve, a model of the sensor is required. This model is an equation relating the sensor output to the quantity being measured. A general purpose model is a polynomial of the form $x = a + by + cy^2 + dy^3$ where x is the sensor output and y is the quantity being measured. This can be fitted using a linear least squares method.

a)(3 marks) Why is this a general purpose model?

b)(3 marks) Where is the error term assumed to be in the least squares fitting procedure?

In fitting an equation of the form $y = ax^b$ a logarithmic transformation is often used to linearize the equation so that a linear least squares fit can be used. The result is $\log(y) = \log(a) + b \log(x)$.

c)(5 marks) If the error is independent of x, that is $\varepsilon+y = ax^b$, is this transform valid? Explain.

d)(5 marks) If the error is increases with y, that is $\varepsilon y = ax^b$, is this transform valid? Explain.

c)(4 marks) Why would an RMS error value be appropriate for reporting the error in case c) above, while a signal to noise ratio be appropriate for case d) above?