

National Exams May 2015

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) The basis of calibrating an instrument is correlating the instrument response to measurement standards. What are standards?
- b) Why is the triple point of water a very good standard?
- c) What is instrument saturation?
- d) What defines the lowest detectable limit of a chemical sensor?
- e) Why should a calibration be repeated several times?
- f) How would hysteresis in a sensor be determined?
- g) Why do statistical methods not address the accuracy of a measurement?
- h) In many situations a single point calibration is used. What assumptions must be met for this to be an adequate calibration?
- i) If a calibration is not linear, where in the measurement range is the instrument most sensitive?
- j) Will a calibration detect drift errors?

**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.

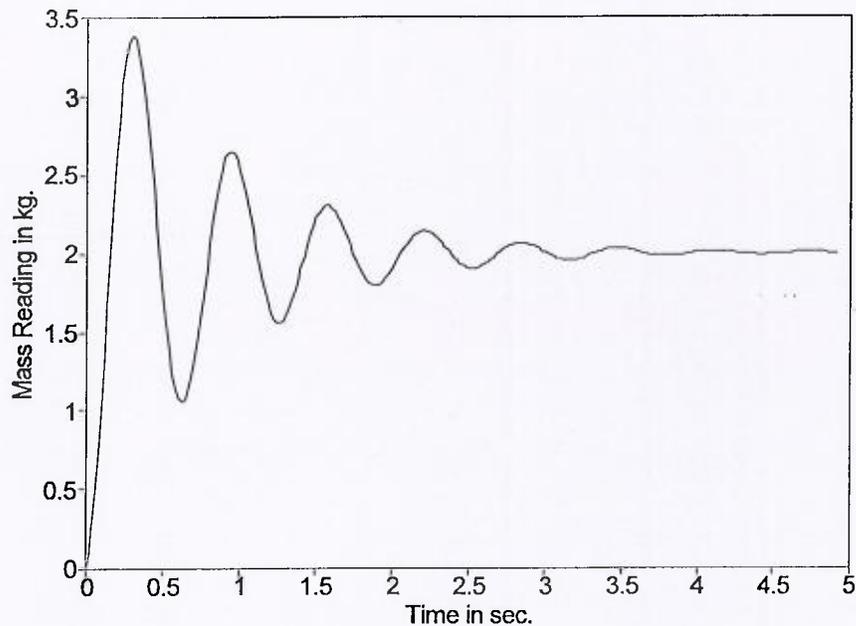
- a) What is the source of Johnson or thermal noise?
- b) Why must the input impedance of a voltmeter be as high as possible?
- c) What is common mode rejection and why is it important?
- d) What is the resolution of a 12 bit analog to digital converter expressed as a percentage?
- e) Why is the damping coefficient of a sensor system important?
- f) What is an anti-aliasing filter?
- g) What defines the minimum sampling rate for a digital data acquisition system?
- h) What is meant by a  $3\frac{1}{2}$  digit display?
- i) Why should the pre-amplifier for a sensor be located as close to the sensor as possible?
- j) Why is a shielded twisted pair cable commonly used in sensor systems?

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

Strain gauges are used to measure the deformation of metal members by changing their resistance as they deform with the metal. This resistance change with the elastic stress-strain relations provides a measure of the forces acting on the member. This requires a rigid attachment between the gauge and the member. This attachment is most often accomplished using a polymer type glue and backing material.

a)(8 marks) If the polymer used to bond the gauge to the metal member creeps (it slowly flows when it deforms), explain why this will appear as measurement hysteresis.

Consider the following response to a kg load placed on a horizontal beam. The sensor is calibrated to provide a mass measurement:



b)(5 marks) How long should the beam be allowed to settle before the mass reading is taken? What criterion did you use to determine this time?

c)(7 marks) Since the above curve depends on the mass, how would you determine the required settling time using a computer data acquisition system for different mass loads?

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

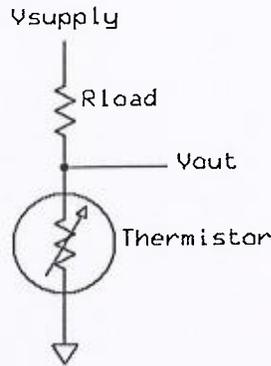
The moisture content is a very important parameter in agricultural products such as grain as it must be kept low to increase the storage life of the product however drying the product can be costly. To measure the moisture content of a product leaving a dryer on a continuous basis, the material can be placed between two insulated metal plates where it becomes the dielectric of a capacitor.

- a)(4 marks) Why is the electrical capacitance of a material a strong function of its moisture content?
- b)(2 marks) Capacitance moisture meters are usually calibrated against materials whose moisture content is determined by oven drying. If 21.46 grams of material are placed in an oven at  $110^{\circ}\text{C}$  for 1 hour and the final weight is 19.24 grams, what is the dry basis moisture content?
- c)(4 marks) If the balance used to weigh the samples in part c. was accurate to 0.02 grams, what error in the dry basis moisture content may result?
- d)(6 marks) A major difficulty in measuring the moisture content of a very large amount of a granular material is obtaining a small but representative sample. List several steps that can be taken to obtain a representative sample.
- e)(4 marks) Would measuring the relative humidity in the air leaving a dryer give a good value of the final moisture content of grain leaving the dryer?

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

Probably the most common measurement determines the temperature. Thermistors have the advantage of giving a large signal voltage and do not require cold junction compensation but they can only operate over a limited temperature range.

- a)(8 marks) In the measurement of temperature using a thermistor, its resistance may be converted to a voltage using a voltage divider as follows:



Write the voltage as a function of the resistances and show that the sensitivity at a particular thermistor operating resistance is at a maximum when the load resistor is equal to the thermistor operating resistance.

Thermocouples operate over a very wide range of temperature (with cryogenic to pyrometallurgical applications) but provide rather small signals and require cold junction compensation.

- b)(4 marks) Sketch a thermocouple measurement circuit.
- c)(4 marks) Explain what cold junction compensation is and why it is required.
- d)(4 marks) How would you build a cold junction compensation circuit without needing a supply of ice?

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

With the availability of cheap microcontrollers, data transmission is now mostly done digitally. Data is acquired, converted to a digital form and transmitted to a host computer for storage and processing. Some signal processing is, however, required at the data acquisition end.

- a)(3 marks) What are the important characteristics of an analog to digital converter?
- b)(3 marks) An integrating analog to digital converter integrates the input by charging a capacitor and then converts the charge to a digital value by timing the discharge at a constant current. If the integration is done over  $1/60^{\text{th}}$  of a second, why is this type of converter very interference immune in North America?
- c)(3 marks) A successive conversion analog to digital converter converts the input voltage by comparing it to digital to analog output voltages in a binary search. Why is a sample and hold stage required before this type of converter?
- d)(5 marks) Analog to digital conversion requires anti-aliasing filters. What is aliasing?
- e)(3 marks) The first element in a data acquisition system is a pre-amplifier. What are several functions performed by the preamplifier.
- f)(3 marks) What determines the required pre-amplifier gain?

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

There are a wide variety of optical sensors that detect light of various colours. These can be single units to detect the light intensity of a single beam or an array of detectors to generate pictures.

- a)(3 marks) Often, optical detectors must measure very low light intensities. Why does cooling the sensor increase its performance at low light levels?
- b)(3 marks) Semiconductor photo-diodes are common light detecting elements. These are reverse biased and the current measured. What allows a diode to conduct in the reverse direction and why is this light dependent?
- c)(7 marks) Spectrophotometers using an incandescent light source use either a grating or a prism to disperse the light into a spectrum. The beam colour is then chosen by allowing only a part of the spectrum to pass through the slit. Why should the slit be narrow? Why should it be wide? Explain this trade off.
- d)(7 marks) Fluorescence detection gives a more precise concentration measurement than an absorption spectrophotometer. Explain this briefly.