

National Exams December 2009

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. Any non-communicating calculator is permitted. This is an Open Book examination. Note to candidates you must indicate the type of calculator being used. ie. write the name and model designation of the calculator on the first inside left hand sheet of the exam work book.
3. Questions 1, 2 and any other three (3) questions constitute a complete paper. Only Questions 1, 2 and the first three other questions as they appear in your answer book will be marked.
4. All questions are of equal value.

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

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

- a) Why do statistical methods improve the precision but not the accuracy of a measurement system?
- b) Why are digital data transmission methods more reliable than analog data transmission methods?
- c) What is the dynamic response of a sensor?
- d) Why can noise never be completely eliminated from a measurement system?
- e) Why are sensitivity and selectivity often conflicting goals in the design of a measurement system?
- f) What is the common mode rejection ratio of a differential amplifier?
- g) How can aliasing errors be avoided?
- h) Why are industrial signals often transmitted as 4 to 20 milliampere currents rather than as 0 to 10 volt signals?
- i) What determines the smallest value that can be reliably measured by an instrument?
- j) What must be considered so that a measuring instrument will not affect the quantity being measured?

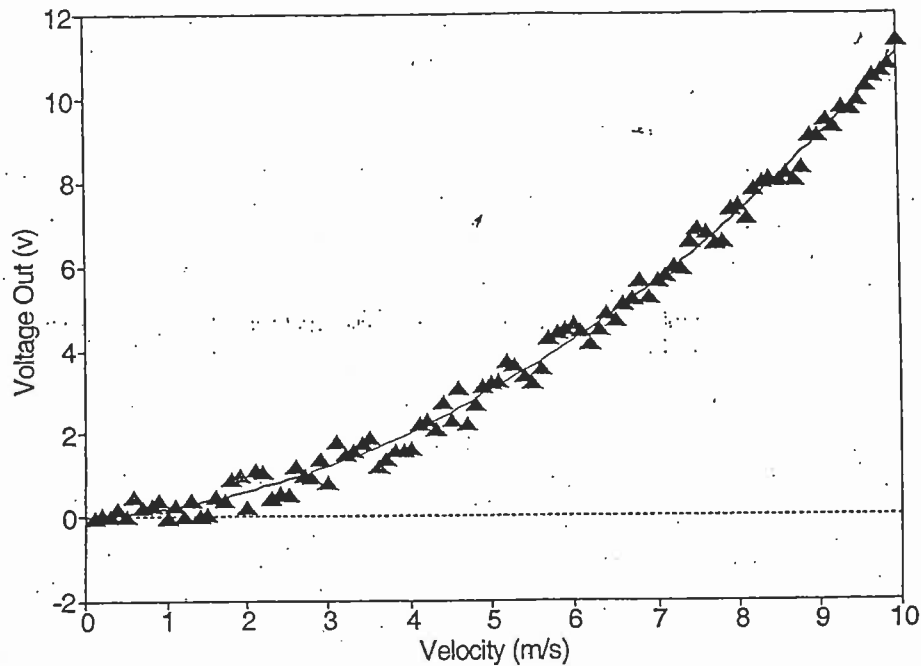
Question 2. (You must answer this question. Each is worth 2 marks.)

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

- a) Why does a quartz pressure sensor require a very high impedance preamplifier?
- b) Why are Wheatstone bridge circuits used to measure small resistance changes in such sensors as strain gages or RTD thermometers?
- c) What precautions must be taken when a thermocouple is used to measure the temperature of a high temperature oven?
- d) Why is the measurement of capacitance well suited to the determination of the moisture content of grain?
- e) What factors affect the calibration of gas flow sensors?
- f) What is a self heating error when a thermistor is used to measure temperature?
- g) Why are piezoelectric pressure sensors not well suited to measure static pressures?
- h) How can monochromatic light be produced from the output of an incandescent light source?
- i) What effects do temperature changes have on strain gage systems?
- j) How can the cold junction compensation of a thermocouple be accomplished without using ice?

Question 3.

The following is a calibration curve of a hypothetical velocity sensor.



a)(4 marks) The independent calibration variable here is the velocity. In general, how would you get good values of an independent variable for calibration.

b)(7 marks) The calibration fit obtained was:

$$\text{Voltage} = 0.09933 \text{ Velocity}^2 + 0.1136 \text{ Velocity} + 0.009774$$

Rearrange this equation to get Velocity as a function of Voltage. Why is this rearrangement necessary?

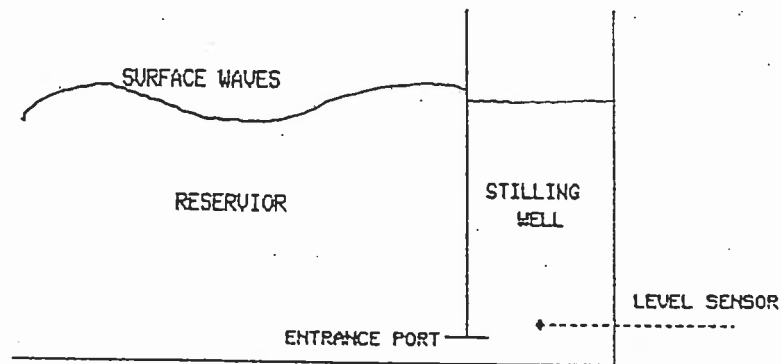
c)(4 marks) The above fit gave an R^2 value of 0.9937 and an estimated standard error of the dependent variable of 0.267 volts. What do these statistics mean and which is the more useful?

d)(5 marks) In fitting an equation of the form $Y = aX^b$, a logarithmic transformation is often used inappropriately. Under what circumstances is this transformation not appropriate? If you don't know that a transformation is appropriate before you do a regression, how can you show it is appropriate after the regression is done?

Question 4.

A pneumatic level sensor behaves as a first order system with a time constant of 2 seconds.

- a)(6 marks) If this sensor is placed in a liquid, how long would you have to wait before the sensor output may be considered valid? Explain the criteria you used in specifying this wait time.
- b)(5 marks) If the sensor is placed in a large reservoir where surface waves are present, what is the maximum wave frequency that can be detected? Explain the criteria you used in specifying this frequency.
- c)(4 marks) If an average of the level is required, how would you obtain it if your measuring and data presentation system had no computing capability?
- d)(5 marks) A stilling well, shown in the figure, may be used to damp the wave amplitude over the sensor. The inertia of the fluid in the well may, however, make the system behave as a second order resonant system. What parameters determine the resonance? Is resonance a problem in the measurement system?



Question 5.

The response of a spectrophotometer follows Beer-Lambert's law:

$$-\log T = \epsilon Cl$$

where T is the fraction of light transmitted through the sample, ϵ is an absorption coefficient which depends on the wavelength of the light and the sample material, C is the concentration of the absorbing substance and l is the optical path length through the sample. The measurement output is a voltage directly proportional to the fraction of light transmitted:

$$v = kT$$

where v is the output voltage and k is the electrical equipment gain.

- a)(6 marks) Sketch the curve relating the output voltage to the concentration of the absorbing substance in the sample. Indicate where in the concentration range the output is most sensitive to changes in the concentration and where the concentration data is most affected by electrical measurement noise.
- b)(4 marks) What determines the lowest concentration that can be measured by a device of this type?
- c)(2 marks) What determines the wavelength of light generated by a light emitting diode?
- d)(4 marks) The light used in measuring the concentration must be monochromatic. Why is light with a wider wavelength band not suitable for this measurement?
- e)(4 marks) Coloured objects reflect light at many wavelengths. How can the colour of an object be described quantitatively?

Question 6.

Noise and interference are often severe problems in a data acquisition system.

- a)(6 marks) Noise is often generated in the measuring system itself.
What is the most important characteristics of noise?
Describe two sources of broadband (white) noise in a measuring system.
Why can noise never be completely eliminated from a measurement?
- b)(6 marks) Shielded twisted pair cables are often used to convey analog signals over fairly long distances.
How does this cable reduce external interference?
What kind of receiving electronics should be used with this type of cable?
Why should the shield be connected only at one end?
- c)(4 marks) Data can be transmitted digitally over a serial link.
What error detection techniques might be applied to make the data transmission more robust?
- d)(4 marks) Describe how digital data can be transmitted over a radio link.

Question 7.

Electrical filters are used to remove unwanted frequency components of a signal. These can occur due to resonances in mechanical measurement systems or from interference such as that from 60 Hz. power wiring.

- a)(5 marks) A low pass filter removes high frequency components such as vibrations in a weigh scale, but it also slows the measurement process. How would you optimize the cutoff frequency and filter order for a particular problem?
- b)(5 marks) Averaging is often used to reduce the error due to noise or high frequency interference in a measurement. Why does this work? How would you determine the number of data points or the averaging time required to reduce the noise to some acceptable value?
- c)(4 marks) What is an anti-aliasing filter and where is it used in an instrumentation system?
- d)(4 marks) A second order low pass filter has a cutoff frequency of 30 Hz. How much is a 120 Hz. noise signal reduced?
- e)(2 marks) Why are active filters preferred over passive units?