ME 552 Written Final Exam
Fall 2015

Name: Key

1) You need to determine the design-stage uncertainty for temperature measurements using a thermocouple. Measurements will be supplied to a high speed (i.e., 2 kHz) data acquistion system. Anticipated temperatures that the thermocouple will measure are near 700K. In your solution note: resolution uncertainty as (u_o) and instrument uncertainty as (u_c).

<u>The data acquisition system has the following specifications:</u>
Range: +/- 10 V, Accuracy 0.05% of reading, 12 bit memory

<u>Thermocouple:</u> 200
15 Range: 250 – ~~850~~ K, Sensitivity: 1.3 mV/K, Linearity: 0.2 K, Repeatability: 1 K, Resolution: 2 K

8 A. Solve for the uncertainty in the DAQ (mV). Solve symbollically before explicitly. and put boxes around both solutions

$\boxed{u_{DAQ} = \sqrt{u_o^2 + u_c^2}}$

$u_o = \frac{1}{2}$ resolution

$\boxed{= \frac{1}{2} \frac{\text{range}}{2^{\text{bits}}}}$

$u_o = \frac{1}{2} \frac{20V}{2^{12}}$

$u_o = 2.4mV$

$u_c = \sqrt{(\text{Accy} \cdot \text{reading})^2}$

$\boxed{u_c = \% \text{ accuracy} \cdot \text{reading}}$

$\%_{accy} \cdot (700K) \cdot \frac{1.3mV}{1K}$

$u_c \; (\%\text{accy}) \; (700)(1.3)$

$u_c = 0.455 mV$

$u_{DAQ} = \sqrt{2.4^2 + 0.2455}$

$\boxed{u_{DAQ} = 2.46 mV}$

5 15 B. Solve for the uncertainty in the thermocouple signal (mV) at the anticiapted temperature. Solve symbollically before explicitly.

$\boxed{u_c = \sqrt{u_{linearity}^2 + u_{repeatability}^2}}$

$u_{linearity} = \frac{.2K}{1.3} \cdot 1.3 \left(\frac{mV}{K}\right) = 0.26mV$

$u_{repeat} = 1(1.3) = 1.3mV$

$u_c = \sqrt{(0.26)^2 + (1.3)^2} = 1.33mV$

$u_{resolution} = \frac{1}{2} 2K$

$= 1 \cdot 1.3 = 1.3mV$

$u_d = \sqrt{u_o^2 + u_c^2}$

$u_d = \sqrt{(1.3)^2 + (1.3)^2} = \boxed{1.85mV}$

(3) (10)

at the anticipated temp

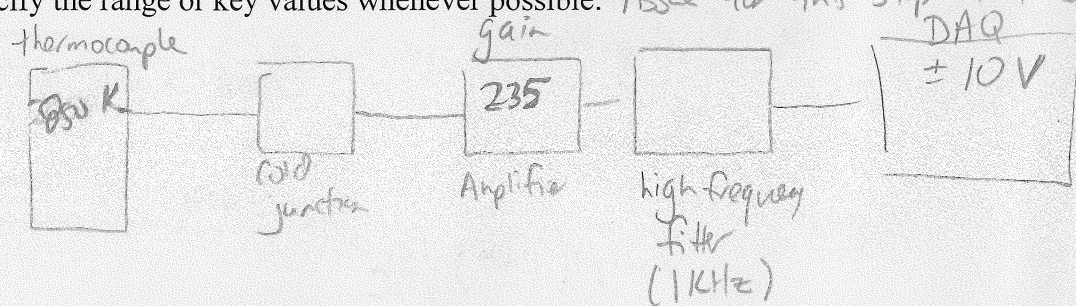
C. Solve for the total uncertainty (V). Solve symbollically before explicitly.

$$u_t = \sqrt{u_{DAQ}^2 + u_{thermocouple}^2}$$

$$\boxed{3.1\,mV} = \sqrt{2.46^2 + 1.85\,m^2}$$

(5) (25)

D. Outline the complete data acquistion system needed to take the voltage signal from the thermocouple to the A/D converter. You are interested in measureing the temperature at high frequencies. Note that there is more than just the thermocouple and the A/D board. Be sure to specify the range or key values whenever possible. Assume for this step that sensitivity is 0.05 mV/K



from thermocouple $850K \times 0.05\frac{mV}{K} = 42.5\,mV$

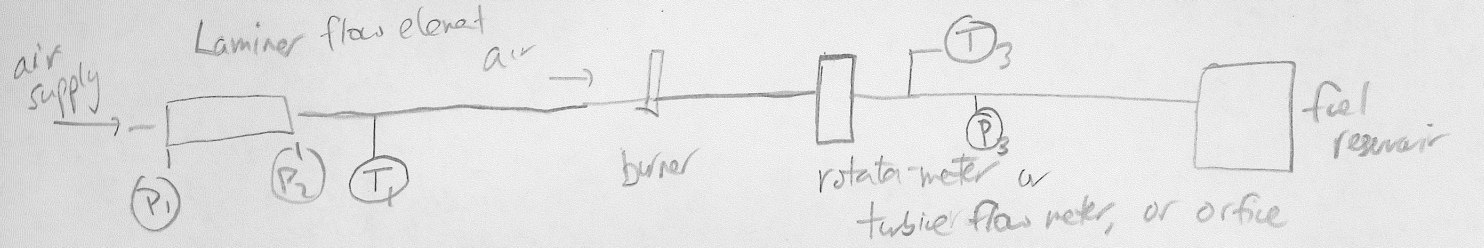
amplifier $\frac{10}{0.0425} = 235$ so a gain near 235 is needed

(20)

2) You are asked to set up a method for determining the uncertainty in the equivalance ratio for a combustion experiment. Recall that the equivalance ratio depends on the ratio of fuel and air mass flow rates. Follow the steps outlined below.

(6)

A) Sketch an experimental arrangment for measuring the air and fuel mass flow rates. Note that your budget is <u>not</u> sufficient to buy an instrument to directly mass flow rates (e.g., coriollis meter). Be sure to label all measurements (e.g., pressures) which need to be collected and where. You must use different sets of instruments for the fuel and air metering.



air supply: LFE provides Q and T_1 and P_2 are used to determine density. We need to verify that the flow through the LFE is laminar based on P_1 & P_2

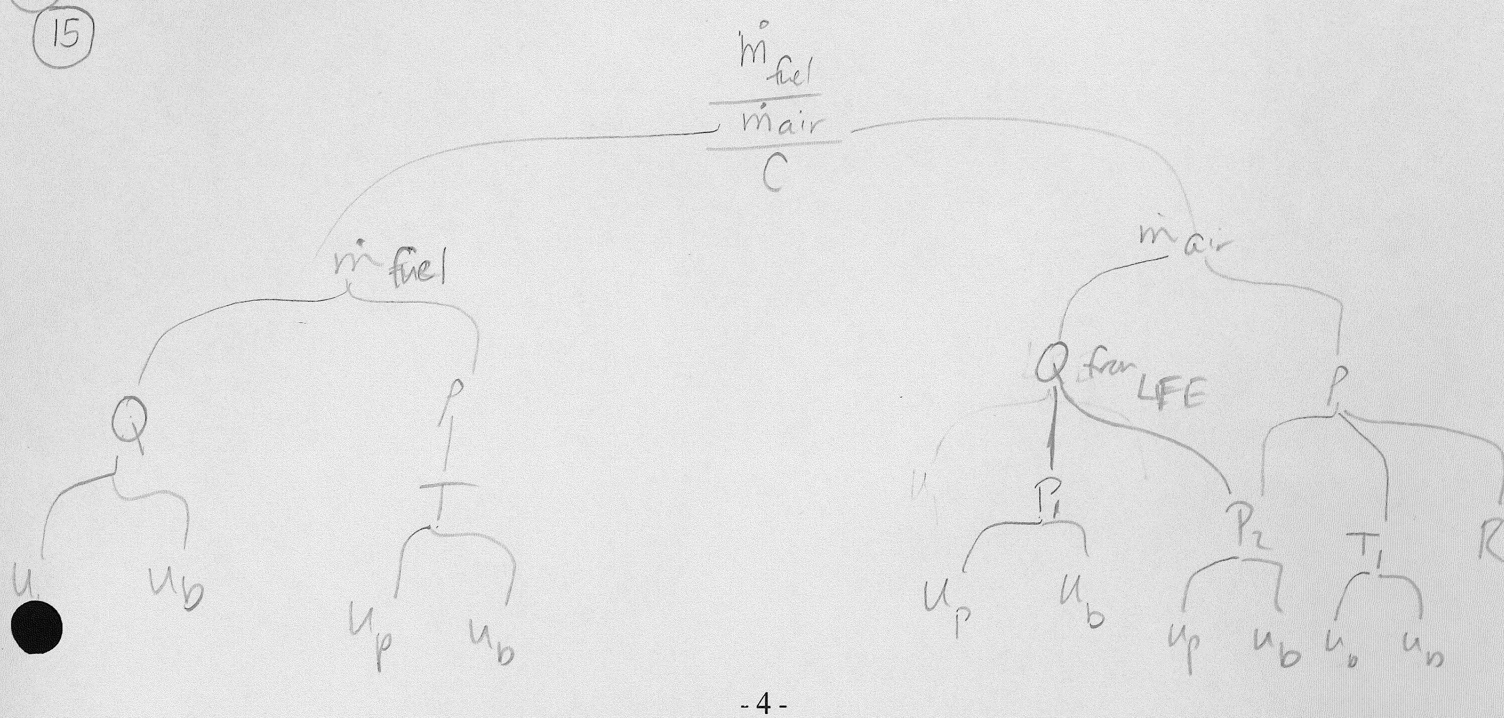
$$Q = f(\Delta P) \qquad \rho = \frac{P_2}{T_1 R}$$

$$\dot{m}_{air} = Q \cdot \rho$$

fuel: A rotameter is used to determine Q. We anticipate that the density is constant, but T_3 and P_3 can be used to determine density.

(4) (15)

B) Set up the uncertainty tree when determining the equivalance ratio for the system shown in part A. You may assume that this experiment is repeated multiple times.



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C) Now (just for part C) assume that the mass flowrate of air is determined from the relationship $\dot{m} = \frac{PV\pi D^2}{RT4}$, where P is the pressure, D is the diameter of a tube, T is the temperature, and V is measured directly (this is an assumption). Show symbolically the uncertainty for the mass flow rate assuming that the uncertainties of all of the measurements are known after using an uncertainty tree.

From Kline-McClintock

$$U_{\dot{m}} = \sqrt{\left(\frac{V\pi D^2}{RT4} U_P\right)^2 + \left(\frac{P\pi D^2}{RT4} U_V\right)^2 + \left(\frac{2PV\pi D}{RT4} U_D\right)^2 + \left(\frac{PV\pi D^2}{RT^2 4} U_T\right)^2}$$

D) If you divide that by the $\dot{m}$ what does it provide

3) As a general rule, why do you use amplifiers in data acquisition systems? Consider how an amplifier effects uncertainty.

3 5

It increases the signal and reduces the relative resolution error.