Department of Mechanical and Aerospace Engineering
MAE 334 - Introduction to Instrumentation and Computers
Laboratory 3 - Conversion of Work into Heat

Objective:

To measure the temperature rise in a calorimeter caused by conversion of mechanical work (friction) into heat, and to determine whether this temperature rise can be modeled as a first order process.

Background:

In this experiment, you will use the imbedded thermistor to measure the change in temperature of an aluminum calorimeter. The temperature rise is produced by conversion of mechanical work into heat. The mechanical work is produced by turning the calorimeter cylinder. A 5 kg mass is suspended from a cord which is wrapped around the drum. If the cord is wrapped approximately 4 to 6 turns, the frictional force will be just sufficient to lift the weight and the opposite end of the cord will become slack. Then, the total amount of mechanical work will be the product of the force and the distance traveled. The force will equal the weight, since the suspended mass is not accelerating. The distance will be equal to the circumference of the drum times the number of turns of the cylinder. The latter can be calculated from the mechanical counter mounted on the apparatus. If W is the mechanical work, m is the suspended mass, g the acceleration of gravity, d the diameter of the drum and n the number of turns,

$$W = (mg)(\pi d n) \tag{1}$$

The rate of work done, or power

$$P = \frac{dW}{dt} = (mg)\left(\pi d \frac{dn}{dt}\right) = \text{Force x Distance per unit time} \tag{2}$$

If the apparatus were perfectly insulated, all of the mechanical work would go into heating the cylinder. Actually, some heat is continually lost to the surroundings. If Q is the rate of heat loss to the surroundings and dE/dt the rate of energy gain by the calorimeter, the first law of thermodynamics gives:

$$\frac{dE}{dt} = P - Q \tag{3}$$

The rate of energy gain is related to the rate of temperature rise by

$$\frac{dE}{dt} = C\frac{dT}{dt} \tag{4}$$

where T is the temperature and C is the heat capacity of the calorimeter. The rate of heat loss can then be found from:

$$Q = P - C\frac{dT}{dt} \tag{5}$$

The rate of heat loss from the calorimeter to the surroundings can be calculated from

$$Q = H(T(t) - T_{lab}) \tag{6}$$

where H is the product of the convective heat transfer coefficient and the surface area of the calorimeter and T_{lab} is the surrounding lab air temperature. Equation (5) then becomes

$$P - C\frac{dT}{dt} = H(T(t) - T_{lab}) \tag{7}$$

which can be rewritten:

$$\tau\frac{dT}{dt} + T(t) = P/H + T_{lab} \tag{8}$$

where $\tau = C/H$. For a constant P, equation (8) has the solution:

$$\frac{T(t) - T_f}{T_{lab} - T_f} = e^{-t/\tau} \tag{9}$$

where $T_{lab} - T_f = -P/H$. For the cooling process which follows the cessation of power input, $P = 0$ and the solution becomes

$$\frac{T(t) - T_{lab}}{T_i - T_{lab}} = e^{-t/\tau} \tag{10}$$

where T_i is the temperature at the start of the cooling process (which is T_f in equation (9)) and T_{lab} is again the room temperature. Both Equations (9) and (10) can be linearized by taking the natural log of both sides as in Experiment 2. If the heat transfer from the calorimeter to the lab air, $H(T(t) - T_{lab})$, is small compared to P, Equation (7) can be reduced to

$$\frac{dT}{dt} = \frac{P}{C} \tag{11}$$

For constant P/C, the temperature, $T(t)$, is a linear function of time. The following data for the calorimeter can be used to calculate P/C:

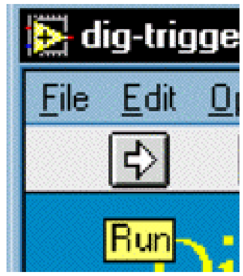
m = 5 kg
g = 9.81 m s^{-2} C = 184 J/oK
diameter = .0465 m 1 J = 1 N m = 1 kg m^{2} s^{-2}

Procedures: Lab Setup

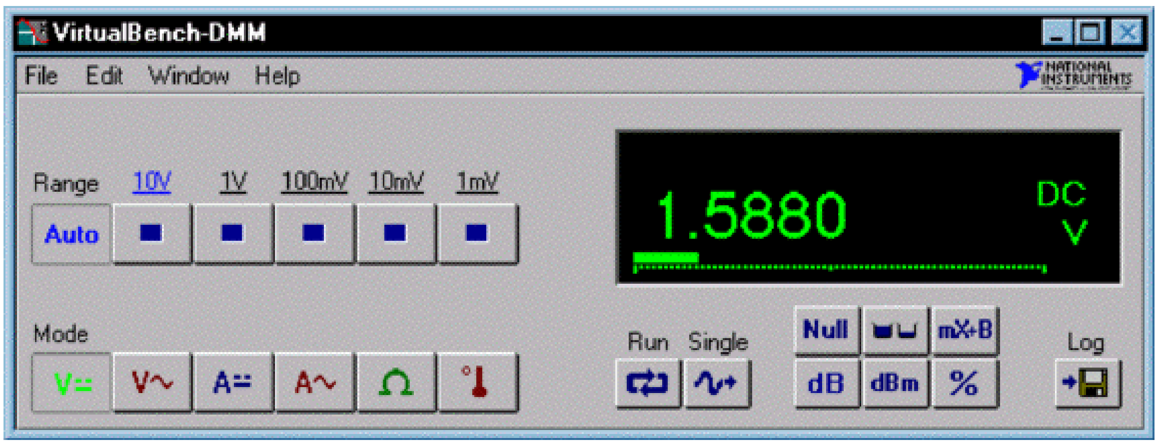
1. The programs used for this experiment will be the Digital Trigger, Virtual Bench Digital Multi Meter and Virtual Bench Data Logger.

- First invoke the digital trigger, which can be found in the "mae334 L4-5" folder on the desk top. This turns a the 5 volt output used to power the thermistor.

1. Activate the program by setting the toggle button ON and pressing the Run button (right arrow button under the drop down menu EDIT) to turn on a 5 volts DC supply to energize the thermistor.



2. Next invoke the Virtual Bench Digital Multi Meter and record the average voltage on channel 0. The multi-meter should read between 1-3 volts depending on the temperature. If it does not have your TA check the connections to make sure your station is properly set up.

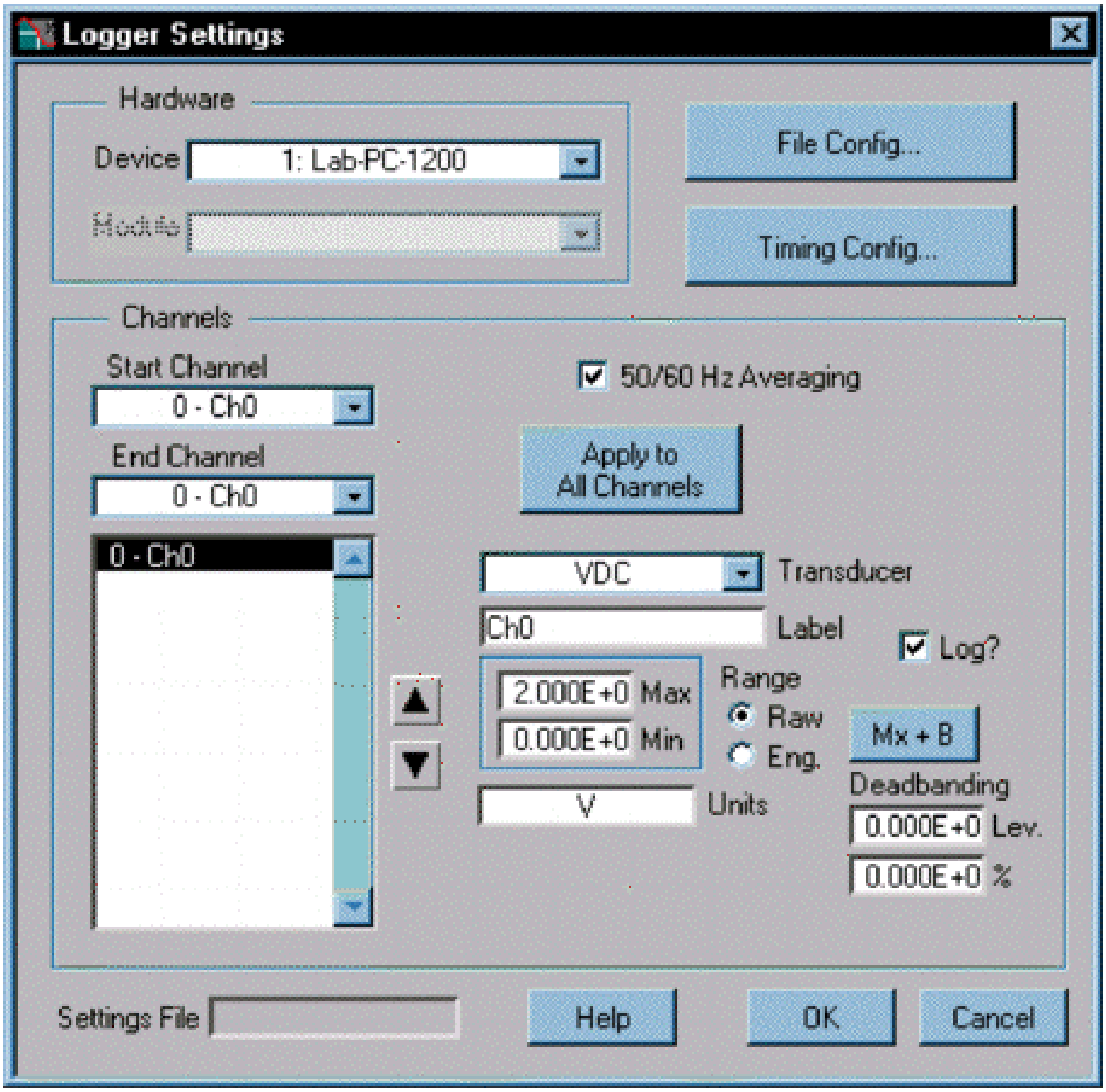


- Exit the Digital Trigger program by pressing the X at the top right corner of the digital trigger virtual instrument. Close the Virtual Bench Digital Multi Meter.
    - NOTE: It is important to exit the digital trigger program with the sequence described above to retain the 5 volts across the thermistor circuit but prevent cross talk with the data logger which may introduce noise in the collected data.
- Invoke the Virtual Bench Data logger as shown below.
    - To measure the voltage, go to the EDIT - SETTINGS menu and change the TRANSDUCER to VDC and RANGE to RAW. (as shown below)

To convert the voltage values you have collected to temperature in degrees Celsius you will need to use the following calibration equation:

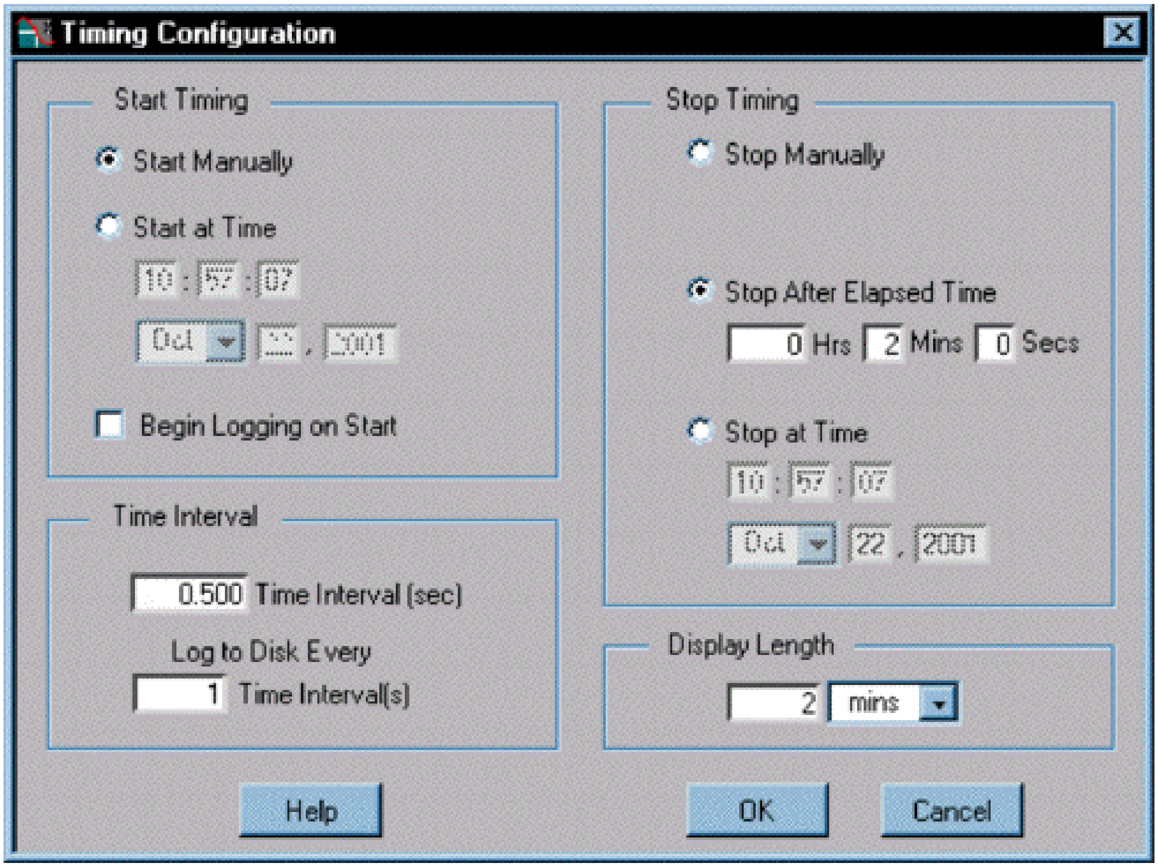
$$T(^{0}C) = -40.53*V(volts) + 93.43$$

Using this equation with a typical starting voltage of 1.7 will give a room temperature of $T(^oC) = -40.53*(1.7 \text{ volts}) + 93.43 = 24.5\ ^oC$. Adjustments can be made to the offset value, 93.43, if your thermistor has drifted since the calibration was performed. The absolute temperature is not important for this lab as all the calculations use a relative temperature, like ($T_{lab} - T_f$) or dT/dt.

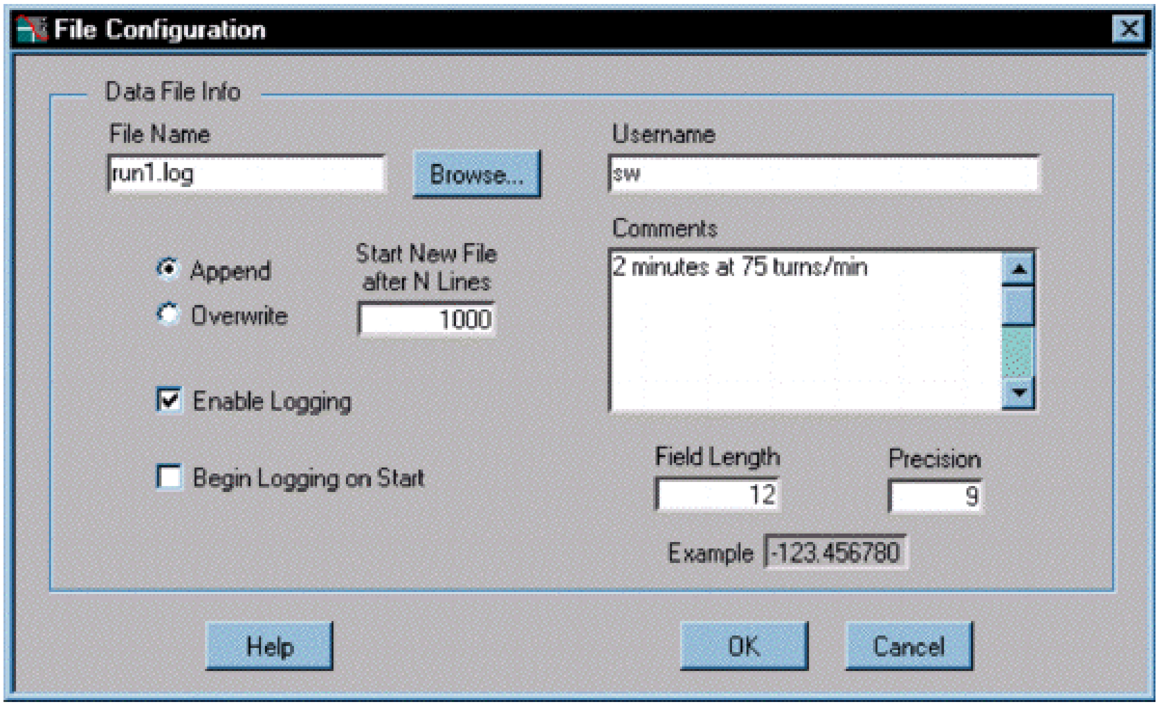


- Change the transducer to VDC
- Change the input voltage Range to a Max of **3** volts and the Min to 0 (Zero). **Not like the picture which has a 0-2 volt range!**
- Set Start Channel and End Channel to 0-Ch0
- Check the 50/60 Hz averaging check box to eliminate line noise from the signal.

For the first part of the experiment, the data logger will be set to collect data every half second for 2 minutes.



- Set the Time Interval to 0.50 seconds.
- Set the display length to 2 minutes.
- Set the Stop After Elapsed Time to 2 minutes.



- Be certain to Enable Logging in the File Configuration menu ***and*** the logger Setting Menu

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Procedures: Data Collection

1. Use the data logger program to sample a 2 minute temperature data records.

    - Set the counter mechanical rotation counter to 0
    - Enable logging
    - Start sampling temperature
    - Turn the drum at a constant rate of rotation of approximately 75 turns per minute for two minutes. (until data collection stops)
    - This will produce a temperature rise of about 5 degrees K, sufficient to accurately determine dT/dt.
    - It is important that you turn at a constant rotation rate or in other words your power input is constant.
    - ***Remember to change file names between data collection runs to avoid overwriting previously collected data)***

Note that the voltage drops as the temperature increases!

2. After you have saved a data file open it in Excel and plot it. This has a two fold purpose. Firstly to insure you actually recorded the data correctly and secondly to allow the calorimeter drum to cool down. The hotter your drum the worse your data will be. Be patient! Right click on your data plot and fit a trend line to the data. Record the equation in your lab notebook. Save and close the data file (but not Excel).

3. Repeat Step 1 **AND 2** for four different rates of work (e.g., 75, 90, 105 and 120 RPM), by turning the drum at different speeds.

4. Do this whole process 2 more times. You should have a total of 12 data records (and 12 slope and intercepts logged in your notebook). This will be used to check the precision of your measurements. REMEMBER: The heat loss will increase as the calorimeter is heated above room temperature, allow the cylinder to cool for a while between runs. You can monitor the cooling process by collecting data and watching the temperature on the screen. Remember to reset the counter prior to the next run. Save each set of data to the disk.

5. In order to estimate the rate of heat loss, collect data during the cooling process until the temperature returns to within a few degrees of the lab air temperature. This will require approximately 45 minutes. Do this for your highest work load of about 120 RPM. For this part of the lab **reconfigure the Timing Configuration** to the following parameters:

- Stop After Elapsed Time = 45 min.
- Display Length = 45 min.
- Timing Interval = 5.0 sec

Data Analysis and Result Presentation

a. First perform a regression on the data obtained during the cooling process (step 5), using the linearized form of Equation (10) to determine the time constant, τ, and from it the value of H. (τ = C/H)

$$\ln\left[\frac{T(t)-T_{lab}}{T_i-T_{lab}}\right]=\frac{-t}{\tau}$$

b. Using this H, calculate the temperature T_f in Equation (9).
c. Perform a regression on the linearized form of Equation (9) for the data obtained while the drum was turned.

$$\ln\left[\frac{T(t)-T_f}{T_{lab}-T_f}\right]=\frac{-t}{\tau}$$

d. Determine the 95% confidence interval for each regression and plot the linearized data, the regression line and its confidence limits (see Example 4.6, 1st Ed., 4.9 2nd & 3rd Ed.).
e. Perform a linear regression on temperature vs. time during the turning of the drum, and compare the value of dT/dt predicted by Equation (11) with the measured value.

Report

The report should follow the prescribed format.

The Results section include graphs and/or tables showing your results each with a caption thoroughly explaining the content and what is learned from the data.

Conclusions: Does the theory adequately describe the data? What was the effect of cylinder speed on the results? Did the successive trials at a given cylinder speed agree within expected precision? Under what circumstances is the heat transfer negligible? What result would you expect if you continued turning the cylinder for longer periods of time? What difficulties did you have? What errors were present? Comment on the design of the experiment. How could it be improved?

Note:

Your report should contain at least 4 graphs, one at each work input rate (75, 90, 105, 120 RPM) heating process vs. time and one graph of the cooling process (linearized) vs. time and one table listing of all the heating run results. The graphs should include a regression line as well as 95% confidence limits. The table should include (run number; Turns/min; dT/dt from regression; 95% confidence interval size; P/C; and % difference between dT/dt from P/C).

Look at spreadsheets from the last lab, http://www.eng.buffalo.edu/Courses/mae334/labs/lab2/LINEST-ArrayFunction2.xls and http://www.eng.buffalo.edu/Courses/mae334/labs/lab2/Lab2-StaticCalibrationComplete.xls for help with the regression analysis and confidence interval determination.

See the LINEST function help screen for more information. A 2 column by 5 row area must be selected for the LINEST array output prior to entering the formula. The formula is then entered in the first row and column and CTRL + SHIFT + ENTER are pressed after the formula is typed in to indicate that it is an array function. To modify the array function the same procedure must be followed.