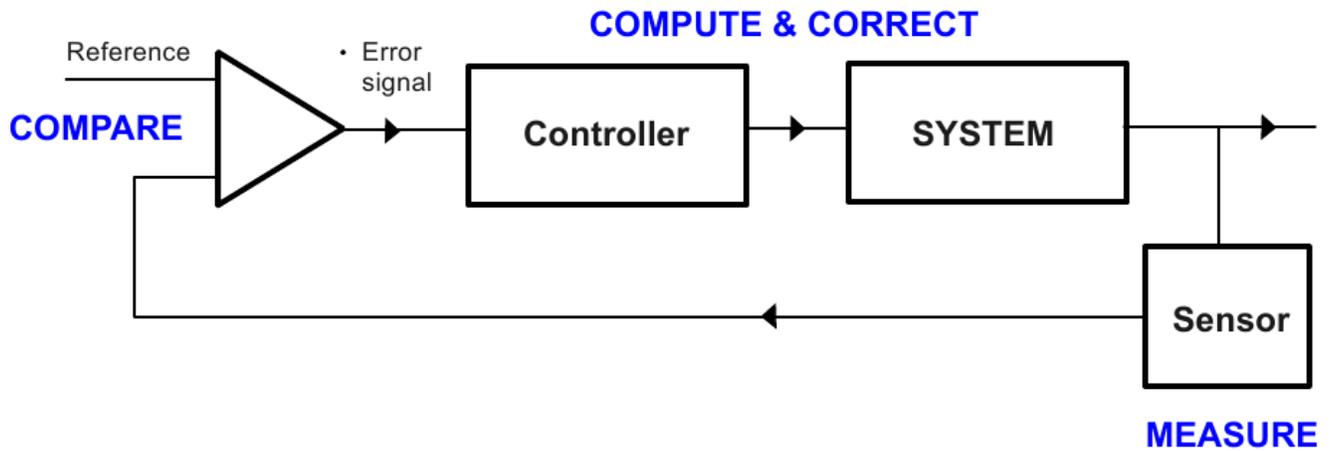


# PHYC 500: Introduction to LabView

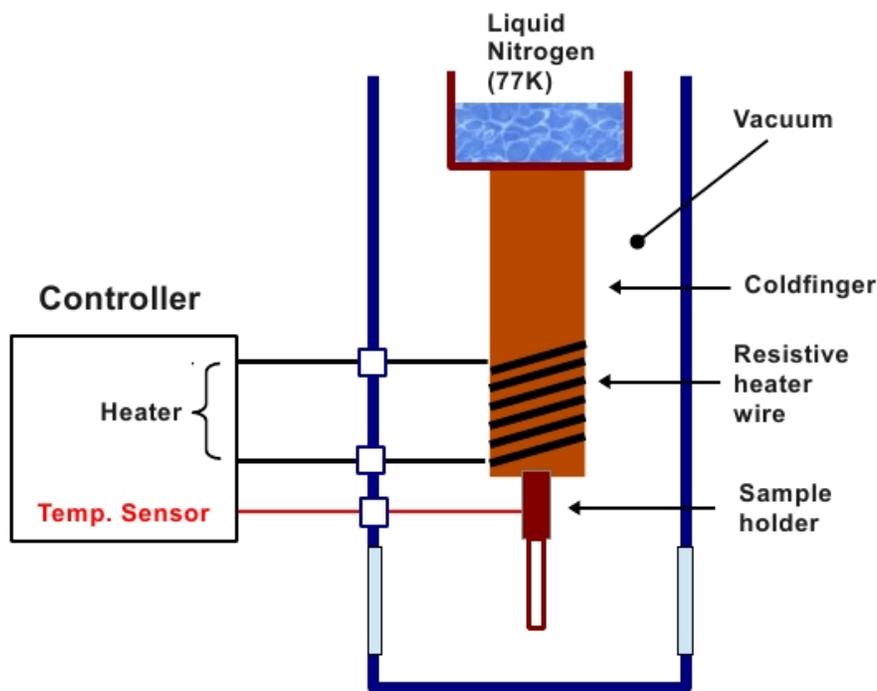
M.P. Hasselbeck, University of New Mexico

## Exercise 6 (v 1.3) Process control

This exercise simulates the action of a closed-loop controller. Its operation is illustrated in this system diagram:



In this LabView simulation, the SYSTEM is an optical cryostat:



Referring to the above figure, a liquid nitrogen reservoir at 77 K is thermally linked to a sample holder via a conductive copper shaft called a coldfinger. The liquid nitrogen reservoir, coldfinger, and sample are insulated from room temperature laboratory air by a vacuum enclosure. A sensor reads the temperature of the sample, which is adjusted by supplying current to a resistive heater wire that is wound around the coldfinger. Flat windows on the enclosure allow optical access to the sample for experiments.

Temperature control can be understood as a balance between conductive heat removal by the liquid nitrogen reservoir (modeled by Fourier's Law) and Joule heating in the resistive wire (described by Ohm's Law):

$$\frac{dT}{dt} = -\beta\Delta T + \alpha I^2 R$$

In this differential equation,  $I$  is DC current,  $R$  is the resistance of the heater wire, and  $\alpha$  and  $\beta$  are constants. This system can be setup and analyzed in LabView using discrete time-steps  $\Delta t$ :

$$T_{i+1} - T_i = [-\beta(T_i - 77\text{K}) + \alpha I^2 R] \Delta t$$

Create a While Loop and add a control button to the conditional stop. The time-behavior of the cryostat is modeled with a SubVI called heater.vi found on the class homepage. Save it to your computer. Right-click inside the While Loop and highlight "Select a VI...". Browse to the location of heater.vi and select it. You can also drag it directly into the Block Diagram.

The While Loop should execute at 1 Hz. Right-click and select Timing: Wait (ms). Create a 1000 ms constant and wire it to the left terminal of the Wait function. This sets the time step  $\Delta t$ . Connect this to the **dt** input terminal of the SubVI. Place a Shift Register on the While Loop by right-clicking on it and selecting "Add Shift Register". This is used to pass the temperature between loop iterations. Connect the Shift Register output terminal (right-side arrow) to **Tout** on the SubVI. Connect **Tin** to the Shift Register input terminal. Create a constant 77 on its input (left-side arrow) to initialize the Shift Register. Wire the 77 constant to the **Tamb** terminal of the SubVI.

Right-click on the current input terminal and create a control. Double-click on the icon to find this control on the Front panel. Right-click on the control and Replace: Numeric: Vertical Pointer Slide. Right-click on the slider, select Properties, select the Scale tab, and change Maximum to 1 on the Scale Range. Right-click on the Front Panel and select Graph; Waveform Chart. Right-click on the Plot Legend and choose the common plot depicting individual points. Go back to the Block Diagram and wire the Waveform Chart

to the SubVI output terminal labeled **Tout**. Right-click on the **Tout** terminal and create a numerical indicator. The sample temperature will be shown on this indicator and displayed graphically on the chart.

Go to the Front Panel, set the current control to zero, and run the VI. After a few seconds, increase the current to 0.5. When the temperature gets above ~ 100K, reduce the current to zero and observe the slow decay back towards 77K. Stop the VI and save it.

## **PID controller**

A PID controller is the most widely-used method for precisely maintaining the set point of a process. It uses an time-varying error signal  $\varepsilon(t)$ , which is the difference between the reference point (set point) and the measured value as shown in the system diagram above. The control signal is composed of three terms: P, I, and D. The P term is directly proportional to the error signal. The I and D terms are related to the time integral and time derivative of the error signal, respectively. The relative contribution of each component to the control signal is weighted by the corresponding constant coefficients ( $K_P$ ,  $K_I$ ,  $K_D$ ). The control signal is defined as:

$$K_P \varepsilon(t) + K_I \int_0^t \varepsilon(\tau) d\tau + K_D \frac{d\varepsilon(t)}{dt}$$

On the Front Panel, remove the manual heater control. Create a new numerical control and label it “Setpoint (K)”. Go to the Block Diagram and verify that its icon is inside the While Loop.

**Note:** The following instructions require LabView 2015.

Right-click in the Block Diagram, select Control & Simulation: PID: PID.vi and place it in the While Loop. Connect the Setpoint control to the corresponding terminal and the input temperature (left terminal of Shift Register) to the **process variable** terminal. The **output** is the heater current; wire it to the corresponding terminal on heater.vi. Right-click on the **dt (s)** input terminal of PID.vi and create a 1 second constant, consistent with the execution period of the While Loop.

The control signal for heater.vi is the output of the PID structure. This signal replaces the manual control slider on the Front Panel. In its present configuration, the PID controller can generate a very large positive or negative control signal. The simulation must account for the physical limitations of the cryogenic control system. There are two important considerations. First, the controller cannot supply an arbitrarily large current to the resistive heater. Second, it is meaningless to have a negative current – the resistor



readings stored in memory. More complicated controller action is attained here by simply changing the gain coefficients of PID.vi to configure it as PI, PD, or PID depending on the requirements of the application. In this noise-free simulation, a P-controller is adequate.