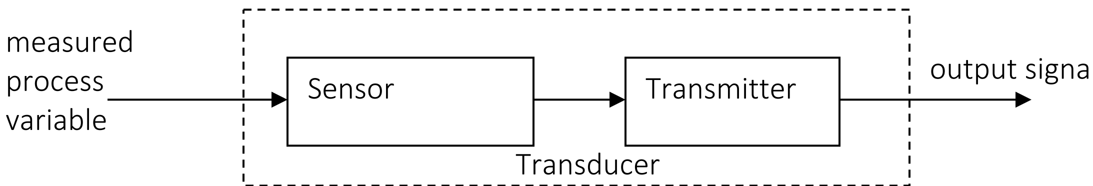
CHEN 479 UNIT OPERATIONS LABORATORY

INSTRUMENTATION AND SIGNAL PROCESSING WITH LABVIEW

Measurement Instrumentation

Rapid, on-line measurement of temperature, pressure, liquid level, flow rate, and composition is extremely important in the chemical process industry. Electronic communication of that information from the measurement sensors to a computer interface for data analysis and process control is also essential for safe and effective operation of processes. The two components of a process transducer to make and transmit properties are shown here:



Some common sensors are shown in the table below. Generally the process variable is not measured directly but obtained from a relationship between the measurable property and the desired process variable. For example, RTDs measure resistance but the resistance of the sensing element directly changes with temperature. Orifice and Venturi flow meters measure a pressure drop across an obstruction to obtain the velocity from the Bernoulli relation.

Temperature	Flow	Pressure	Level
Thermocouple	Orifice	Bourdon tube	Float
Thermister	Venturi	Diaphragm	Head device
Resistance	Rotameter	Bellows	Electrical conductivity
Temperature	Turbine	Strain gauge	
Detector (RTD)			
	Vortex-shedding	Piezoelectric	
	Thermal mass	Piezoresistive	

Most industrial analog sensors have a standard output range of 4 – 20 mA or 1 – 5 VDC. For example, the pressure sensor in this tutorial sends out a 4 – 20 mA signal. This particular pressure transducer was 1) designed to read a maximum of 1 MPa and 2) to have a linear response in its readings, so 4 mA corresponds to 0 MPa, 20 mA corresponds to 1 MPa, and pressures less than 1 MPa corresponds to a current between 4 and 20 mA. Again, the senor is sending a 4 – 20 mA signal—not information on the flowrate. The developer of the control system must tell the computer how to interpret the signal it receives, that is, the developer must program the system to recognize that 4 mA = 0 MPa, 20 mA = 1 MPa, 10 mA = 0.5 MPa, etc.

Control System

Controlling physical process requires taking in sensor data, interpreting it, and sending signals out to control devices such as pumps and valves. Many different vendors have created control systems for this purpose. The labs in the Chemical Engineering department at BYU mostly use a system from the company National Instruments called LabVIEW. With this system, individual electronic devices supply the signal to a PC through a *data acquisition* device (DAQ) and LabVIEW software interprets the incoming signals and sends outgoing control signals. This relationship is illustrated here:

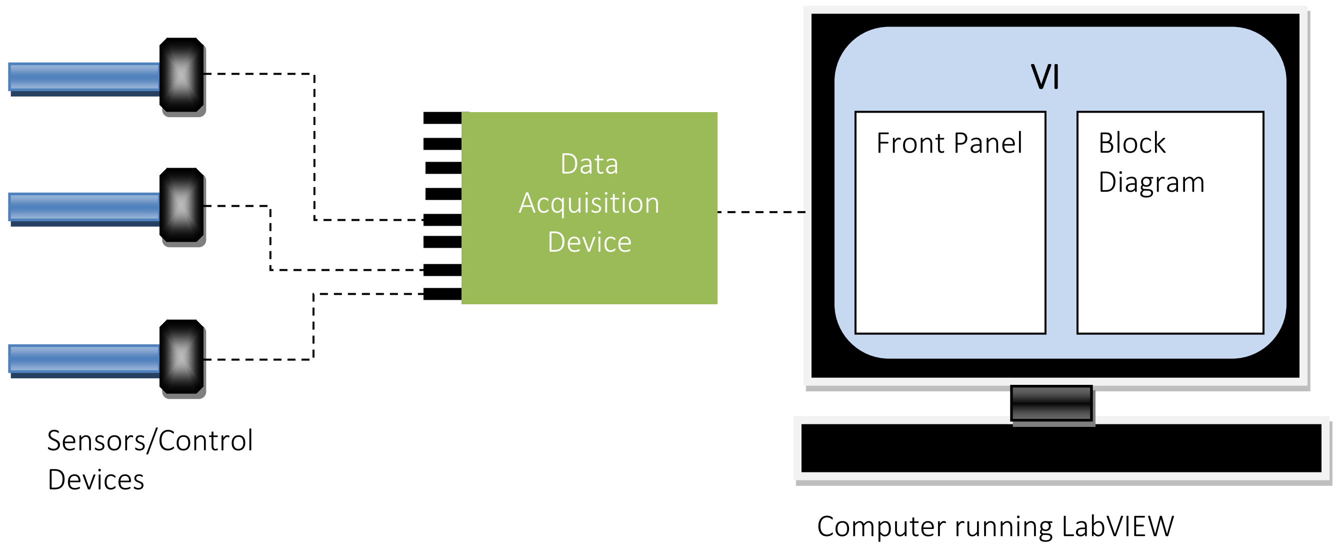


Figure 1 Components of a signal processing and control system.

In LabVIEW, measurements are set up as Virtual Instruments (VI). The user interface consists of a Block Diagram area and a Front Panel area. You create the user interface in the Front Panel window. This window will contain all the buttons, meters, output displays, controls, etc., to provide the user with the measured information from the process and control of the process. The GUI interface in the Front Panel is created by dropping control and display objects from tool palettes. As the GUI is created, icons of the controls and objects placed into the Front Panel are also displayed in the Block Diagram window. In addition to creating the user interface, you must also "tell" LabVIEW where to get signals, how to process them, and where to send that information in the objects available in the GUI you created. The Block Diagram allows you to make interconnections between the objects and to define how the signal is treated by the objects.

National Instruments has several data acquisition devices. The system used in this lab is picture in Figure 2. It consists of a *chassis* into which *modules* can be placed, a power supply, a power block, and a USB connection. This model of chassis has spaces for up to four modules. Only two modules have been installed in the chassis as pictured. The Digital Module on the left provides output signals to turn something on or off. A total of 8 possible on/off devices can be wired through this particular Digital Module. In technical jargon, this module has 8 *channels*. The

Analog Module has four channel that accept analog input. This particular module can accept both voltage and current. Other modules are available that accept only voltage, only current, and other types of signals.

The power supply depicted takes 110 V AC power from a typical wall socket and converts it to a 24 V DC power. The 24 V DC power is wired to the Power Block to allow several power connections for different devices. One connection is shown from the Power Block to the Chassis. The power for other sensors, such as the pressure transducer, will come from the Power Block.

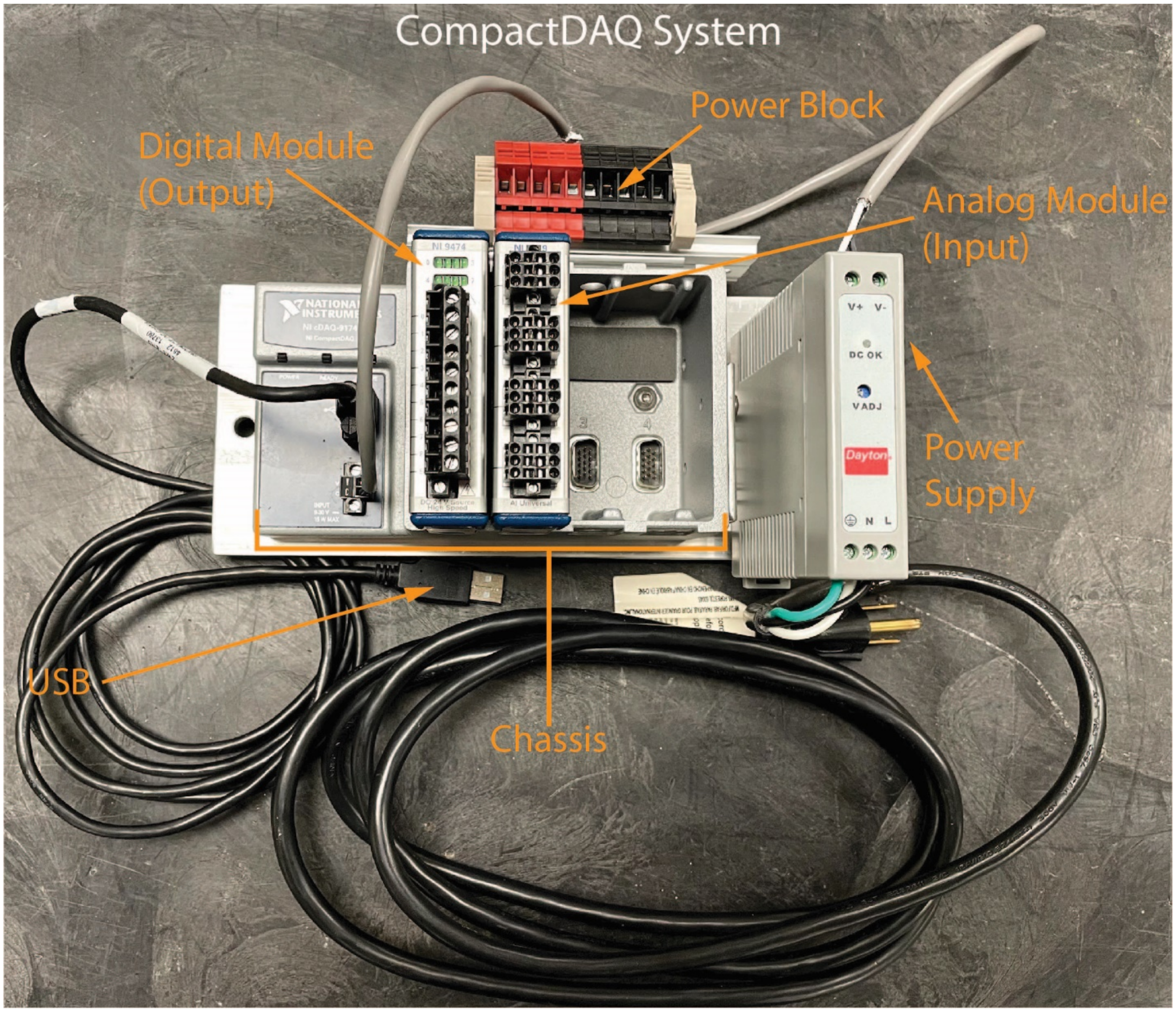


Figure 2 Data Acquisition System

The remainder of this document is a simple, introductory tutorial illustrating how one can use LabVIEW to connect three analog transducers for automated measurement of flowrate, pressure, and temperature in a pumped system. It shows the steps of creating the VI, setting up the Front Panel, and making connections in the Block Diagram. At the end of the tutorial, you will have a working interface to sample and visualize the flowrate, pressure and temperature measurements made in a system pumping water.

Apparatus

The water flow apparatus used in this tutorial is depicted in Figure 3. The system consists of a tank filled with water, a pump, and sensors. The water is pumped from the tank exit and through the sensors (flowrate, pressure, and temperature) before returning to the top of the tank. The pump is a peristaltic pump, and the flowrate can be controlled by a needle valve (not pictured).

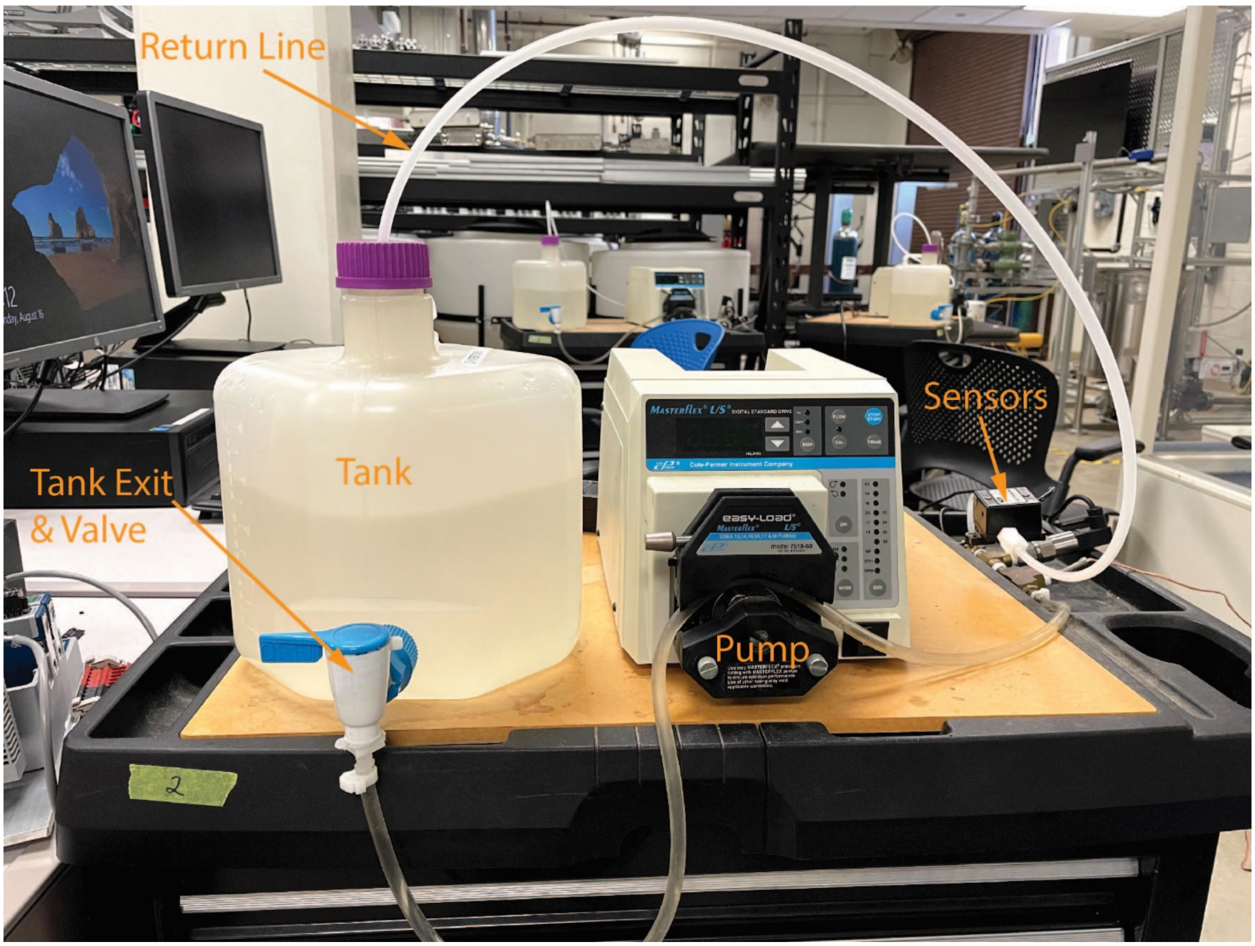


Figure 3 Flow system apparatus for LabVIEW tutorial.

The flowmeter and connections are pictured in Figure 4. The sensor is from the McMillan Co, and the specifications for this meter are discussed later. Power to the sensor is supplied through the two-pronged power plug which can be inserted in the outlets on a power strip connected to the side of the apparatus cart. The sensor leads, the wires that carry the signal from the sensor to the DAQ, are also pictured. Notice that the yellow wire is positive (+) and the white wire is negative (-). Instructions found later require connection of the sensor leads to the DAQ in a precise manner. The designation of which wire is positive and negative was supplied by the manufacturer. Though there are conventions[1] for which colors are positive vs negative, you should always check the manufacturer's documentation to confirm.

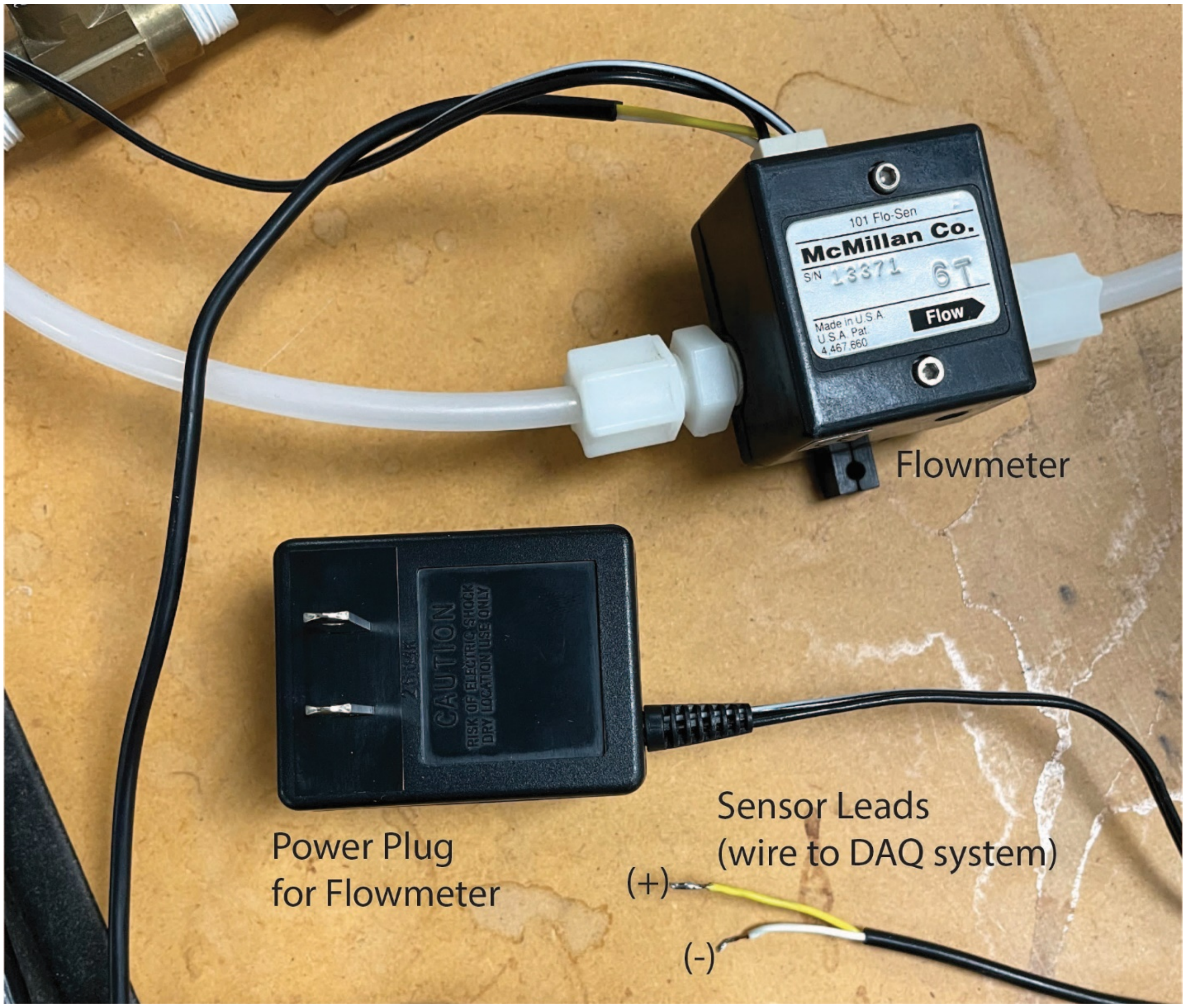


Figure 4 Flowmeter for the flow apparatus.

Figure 5 is a picture of the pressure transducer (sensor), thermocouple (temperature sensor) and needle valve used to control the flowrate of water through the system. The thermocouple is Type K (needed later), and the pressure sensor is model 7py6g9uith-01 from the HIlitand company. Turn the needle valve clockwise to close and counterclockwise to open.

[1] In the US, black or white wires are generally the negative (or ground) wire, and other colors are the positive wire. However, green is also commonly used for ground in residential applications, and the European standard uses other colors. The bottom line is you should always check the manufacturer's documentation to confirm the polarity.

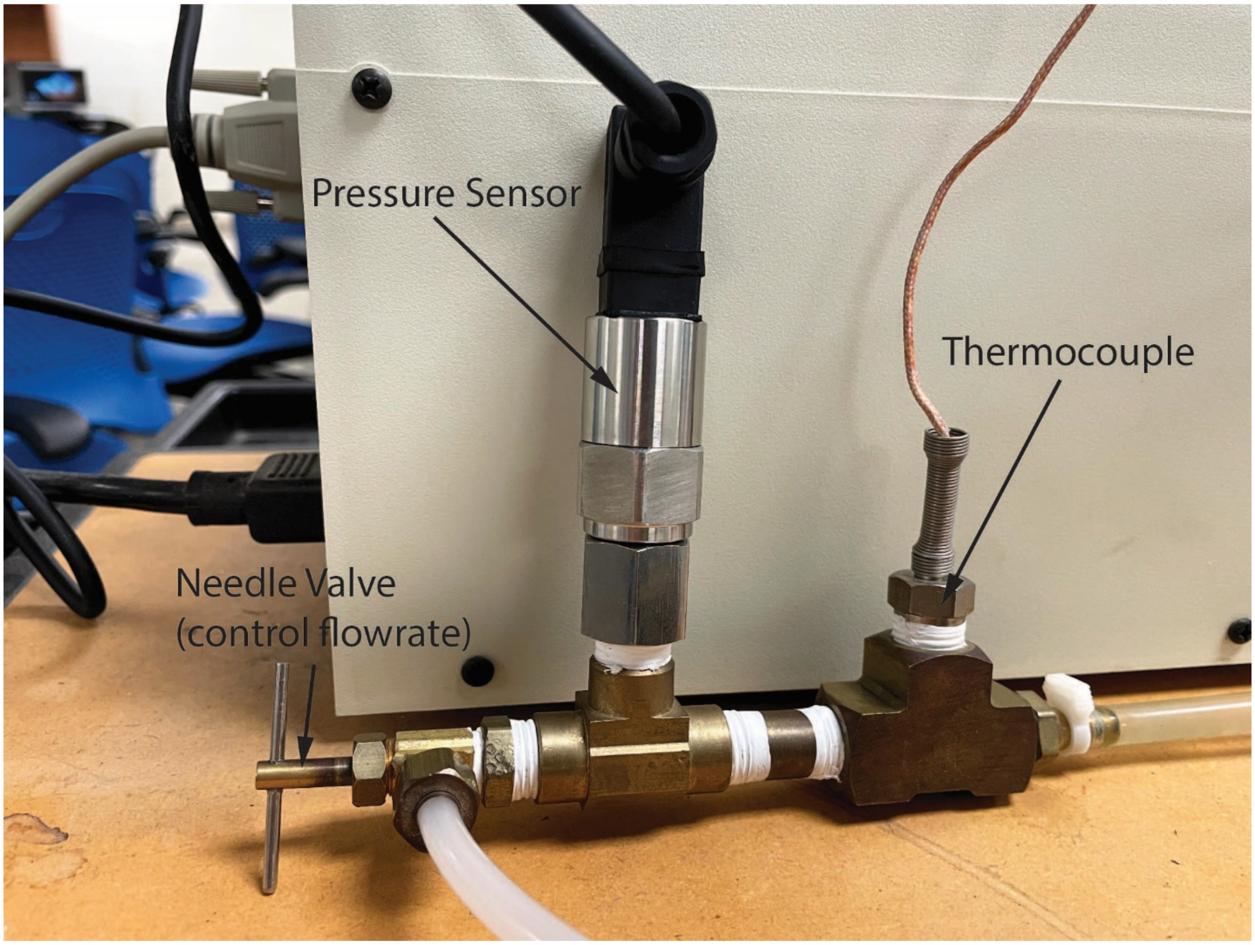


Figure 5 Needle valve, pressure sensor, and thermocouple for the flow apparatus.

The specifications for the pressure transducer are printed on the unit itself as depicted in Figure 6. The listed specifications are 1MPa and 4-20 mA. This means that the sensor has a maximum of 1 MPa and outputs a signal between 4 and 20 mA. Most sensors are designed to have a linear response, so in the absence of other documentation, 4 mA corresponds to 0 MPa, 20 mA to 1 MPa, and intermediate values are found by drawing a straight line through these two points. Also notice that the red lead is positive (+) and the black lead negative (-). As with the flowmeter, these wires will be connected to the DAQ later.

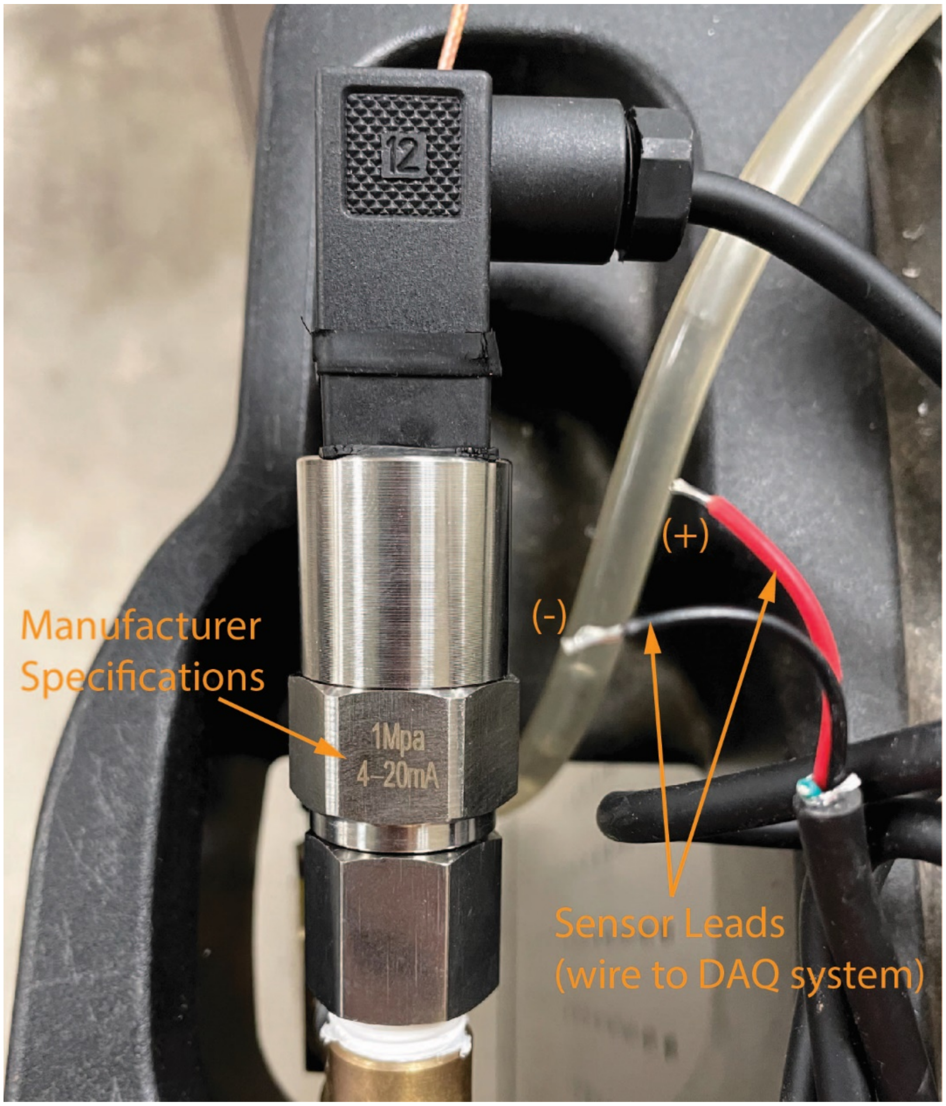


Figure 6 Close up of the pressure transducer showing the specifications and polarity of the leads.

Tutorial to Build the Control System

Connecting the DAQ and Starting LabVIEW

1. Obtain a CompactDAQ system (like one pictured in Figure 2) from the lab manager if one is not already supplied.
2. Close LabVIEW if it is open on the computer that will be used for the lab.
3. Plug the USB cord from the DAQ into the computer.
4. Plug the 3-prong power supply cord into one of the outlets on a surge protector strip near the computer.
    a. The computer may automatically bring up a window once it recognizes a DAQ has been connected.
    b. Close this window if it pops up.

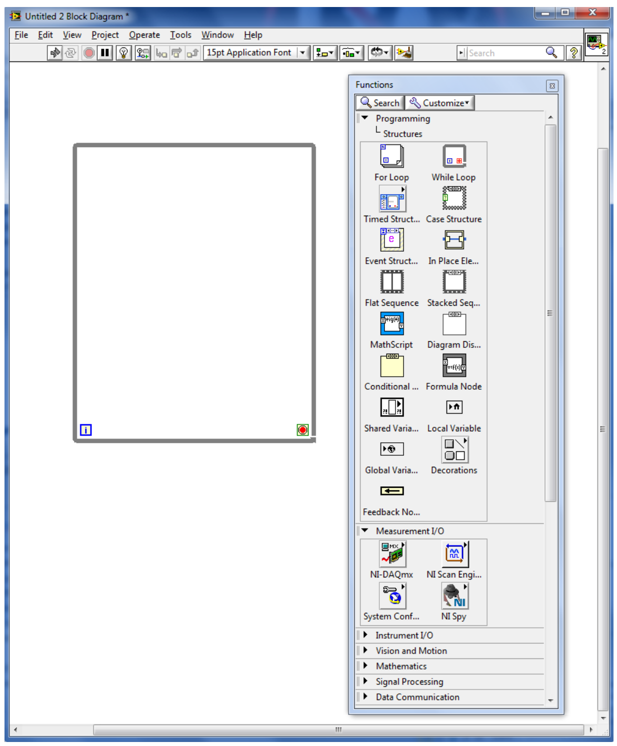
5. Open LabVIEW on the computer.
6. Create a "Blank VI" by selecting the appropriate option.

Configuring the Pressure and Flow Rate Sensors (Analog Inputs) in LabVIEW

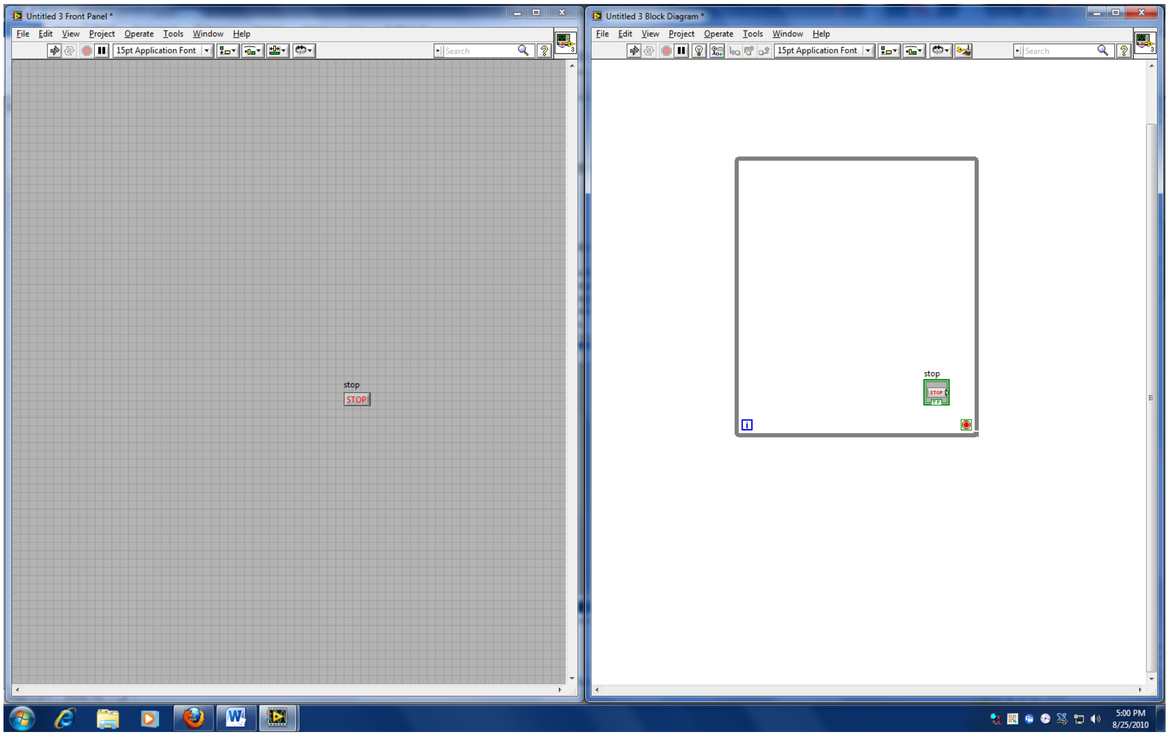
Set Up the Control Loop

LabVIEW allows you to create a graphical user interface that has switches, gauges, and other devices. You essentially create a program which begins to run when you start it and shut it down when you stop it. This is accomplished by putting everything in a *while loop*.

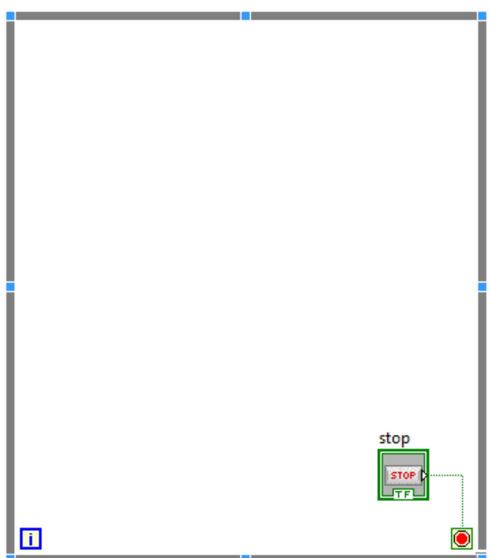
1. Separate the front panel and block diagram (control T).
2. Right-click on the **block diagram** and (if needed) expand the Functions window by clicking on the  to expand the box.
3. Navigate to Programming>>Structures and click on "While Loop."
4. Draw a loop (click and drag) on the block diagram. Your window should resemble the one shown here:



5. Add a stop button. You must tell the while loop when to stop.
   a. Right-click on the **Front Panel.**
   b. Click on "Boolean".
   c. Select the "Stop Button".
   d. Place the button somewhere on the **Front Panel**. It will also appear on the block diagram.
   e. Your window should now look like this:



f. Connect the Stop button on the **Block Diagram** to the red circle by placing the cursor on the center of the right side of the stop button and dragging a line to the red circle.
g. Once finished, your block diagram should look like this:



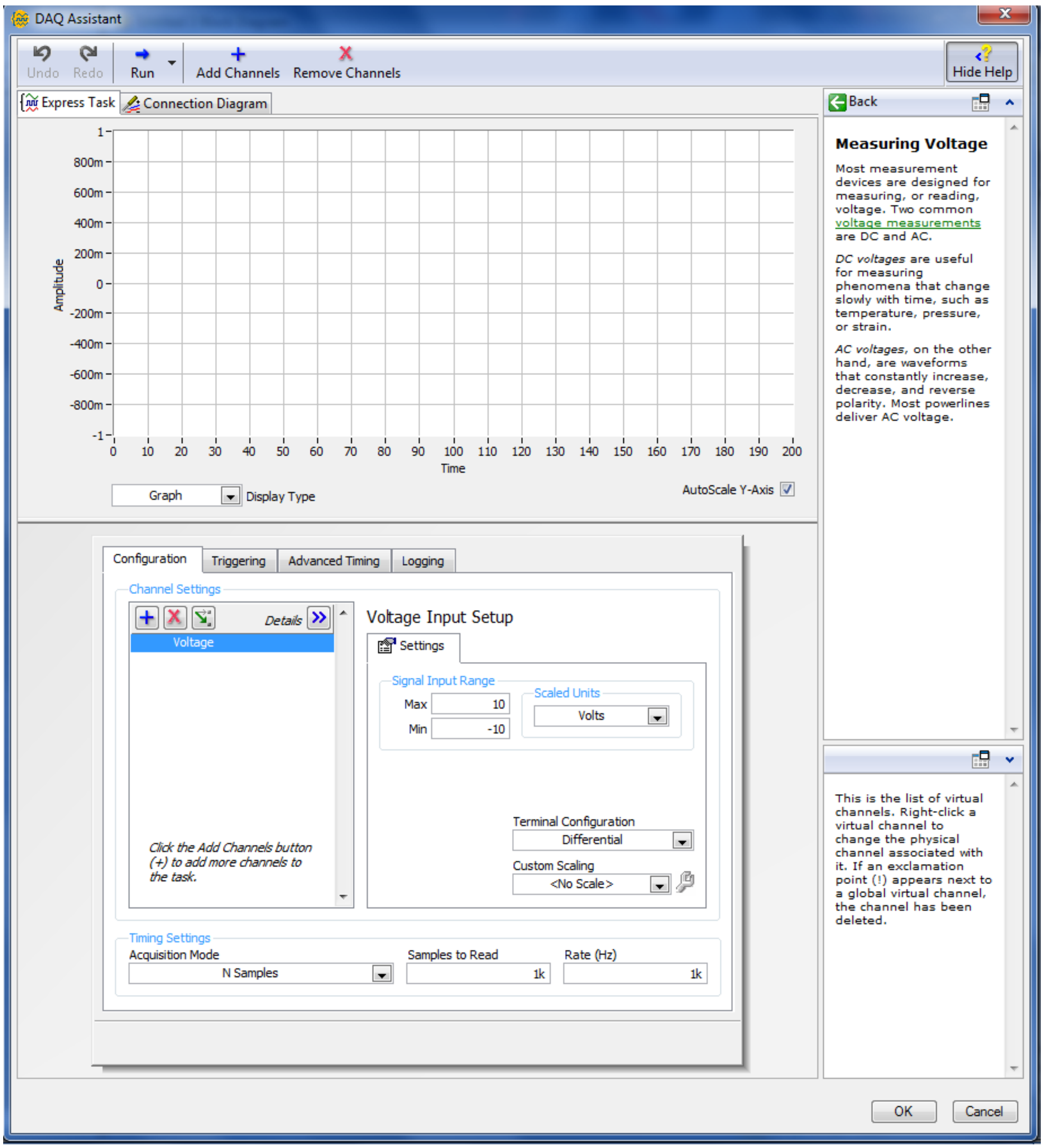
Configure the Flowrate Sensor

1. Right-click on the **Block Diagram** and navigate to Functions>>Express>>Input>>DAQ Assistant.
2. Place the DAQ Assistant inside the while loop on the block diagram, you will see a configuration box.
3. Choose Acquire Signals>>Analog Input>>Voltage.

a. You will then see a page with the DAQ devices capable of analog input listed.
b. Only one of your modules, NI 9219, has this capability so there should only be one device listed.

4. Choose channel ai0 and click “Finish.” (You may need to expand the list of channels under the device using the + (plus) sign.

5. You will now have a menu that looks like the following which allows you to configure the analog signal from channel ai0.



6. Change the name of the channel from "Voltage" to "Flowrate."
   a. Right-click on the word "Voltage" and select "Rename."
   b. Change the name to "Flowrate."
7. The flow meter is made by the McMillian Company (model 13157) which has provided the following calibration data (Also available at http://uolab.groups.et.byu.net/files/LabVIEW/labhints.htm). Notice that:

McMillan Company Certificate of Calibration

Model: 101-6T
Serial Number: 13157
Calibration Date: 08-02-2005
Next Calibration Due: 08-02-2006

CALIBRATION DATA...

Actual Flow	Output(VDC)	Error (F.S.)	Pulse (Hz)
1.0 L/min	5.00	+0.00%	323
0.5 L/min	2.50	+0.00%	160
0.2 L/min	0.99	-0.20%	62
0.1 L/min	0.50	-0.00%	31

Flow rates indicated are at STP.

Maximum allowable error (specification): ±3% F.S.

Calibrated For: H2O
Calibrated Using: H2O
Test Temperature: 20°C
Test Barometric Pressure: 740 mm Hg
Power Supply Voltage: 12.8 VDC

Techician: SOA

Figure 7 Calibration data for the flow meter.

   a. The flow meter outputs a voltage.
   b. At 5.0 volts, the flowrate is 1.0 L/min. At 0.50 volts, the flowrate is 0.1 L/min.

LabVIEW now needs to be told this information so that the output will read in L/min.

8. Under the "Custom Scaling" box, select "Create New."
   You have several options available to calibrate this signal.

a. Linear: Allows you to specify a slope and intercept (gain and offset). The calibration data shown in Figure 7 are fairly linear so they could be fit to a straight line (in Excel or Mathcad) and the resulting slope and intercept could be used.
b. Map Ranges: Allows you to input two points for the ranges of input and output. LabVIEW then assumes a straight-line model to obtain the intermediate points. Two of the points in Figure 7 could be used with this option.
c. Polynomial: Allows you to specify the coefficients in a polynomial. The coefficients are obtained by fitting calibration data provided from the manufactuer.
d. Table: If the calibration data don't seem to follow either a polynomial or a straight line, a table of data can be entered. LabVIEW will then interpolate linearly between the table points.

9. Select "Linear" and rename the calibration "Flowmeter – Linear."
    a. Figure 8 contains a linear fit of the calibration data found in Figure 7. Notice the slope is equal to 0.2 and the intercept is equal to 0.

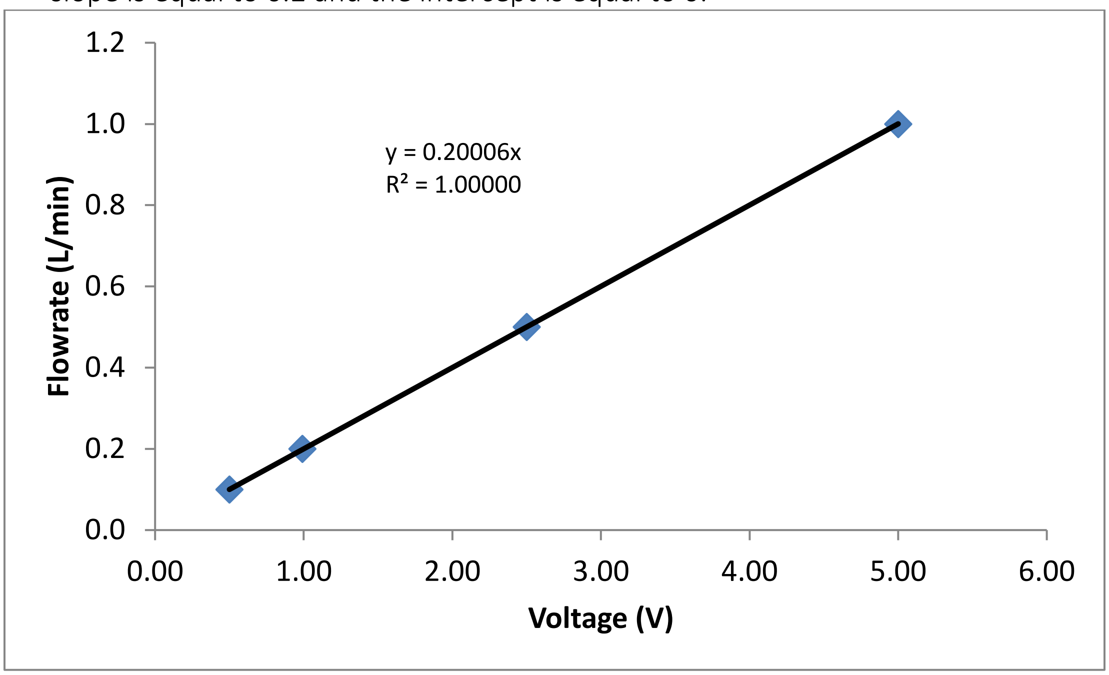
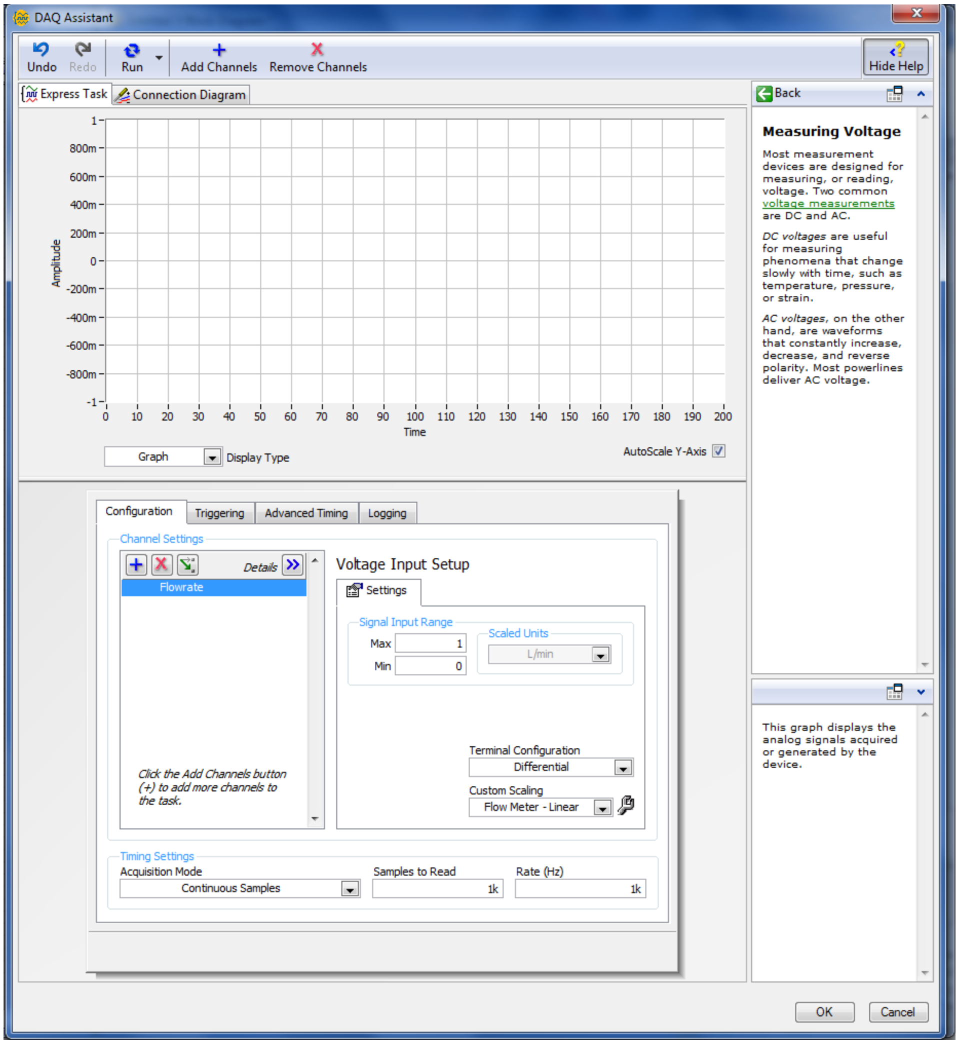


Figure 8 Fit of flowmeter calibration data to a straight line model.

10. In the "Scaling Parameters," change the slope to 0.20 and the intercept to 0.
11. Under the "Units" portion of the window, type "L/min" in the "Scaled" box.
12. Click OK. This will return you to DAQ configuration window.
13. Under "Settings" under the "Voltage Input Setup," change the "Signal Input Range" to correspond to the min and the max of the calibration curve for the "scaled" output (L/min).
    a. Change the Max to 1 and the Min to 0.
    b. Ensure that "L/min" is found in the "Scaled Units" box.
14. Select "Continuous Samples" from the "Acquisition Mode" box to set the timing settings. The timing settings affect how often LabVIEW the read the input from the channel.

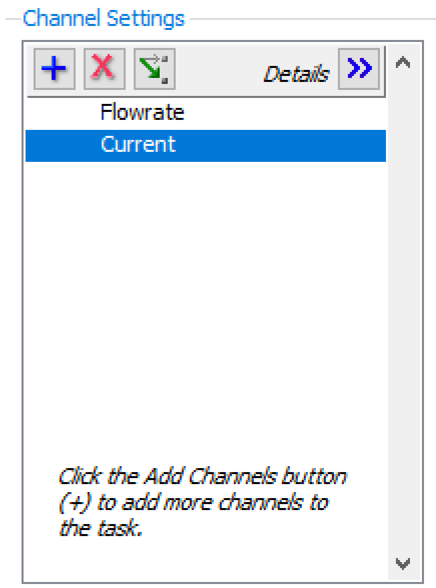
Once done, your window should look like this:



15. Click OK.
    a. The system will check to see if there are any problems with the configuration.
    b. You will be notified if there is a problem.
    c. Whether there is a problem or not, you will be returned to the Block Diagram.

Configure the Pressure Sensor

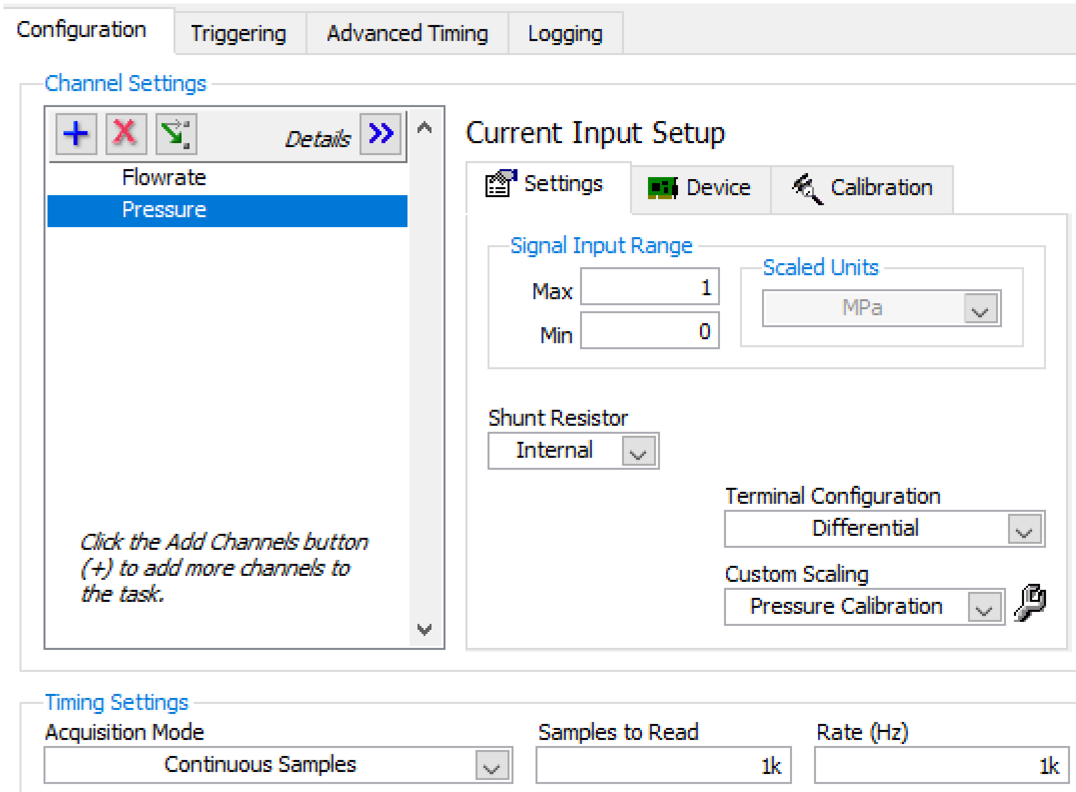
1. Double-click the DAQ Assistant icon on the Block Diagram if the DAQ window is not open.
2. Click on the  button under "Channel Settings" of the DAQ window and select "Current."
3. Select channel ai1 on the device and click OK. This will cause another channel to appear in the Channel Settings box.



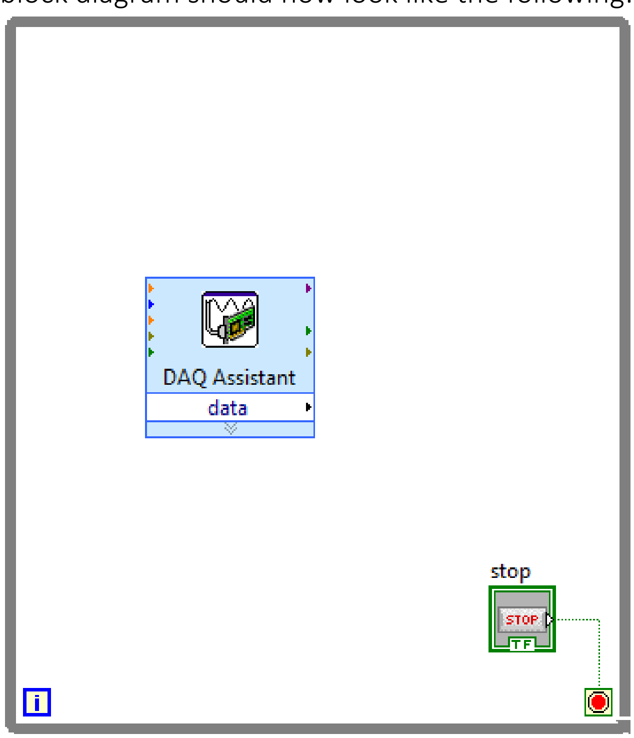
4. Rename this channel from “Current” to “Pressure.”

The pressure sensor is made by a company called Hilibrand. As explained above for Figure 6, the printing on the sensor indicates the current range to be 4 to 20 mA and the maximum pressure to be 1 MPa. This means that at 20 mA the pressure is 1 MPa, at 4 mA the pressure is 0 MPa, and that intermediate pressures are found by drawing a straight line through these two points.

5. Input the scaling into LabVIEW
    a. Select “Create New” under the “Custom Scaling” box.
    b. Select “Map Ranges”
        i. Name the scale “Pressure Calibration.”
        ii. Change the “Pre-Scaled” “Maximum” value to 0.02 and the “Minimum” value to 0.004.
        iii. Change the “Scaled Values” to 1 and 0 for the maximum and minimum respectively.
        iv. In the “Units,” type “MPa” in the “Scaled” box.
        v. Click OK which will return you to DAQ configuration window.
    c. Under “Settings,” change the “Signal Input Range” to correspond to the min (0) and the max (1) of the calibration curve for the “scaled” output (MPa).
    d. Set the timing settings by selecting “Continuous Samples” from the “Acquisition Mode” box.
6. Once done, your window should look like this.



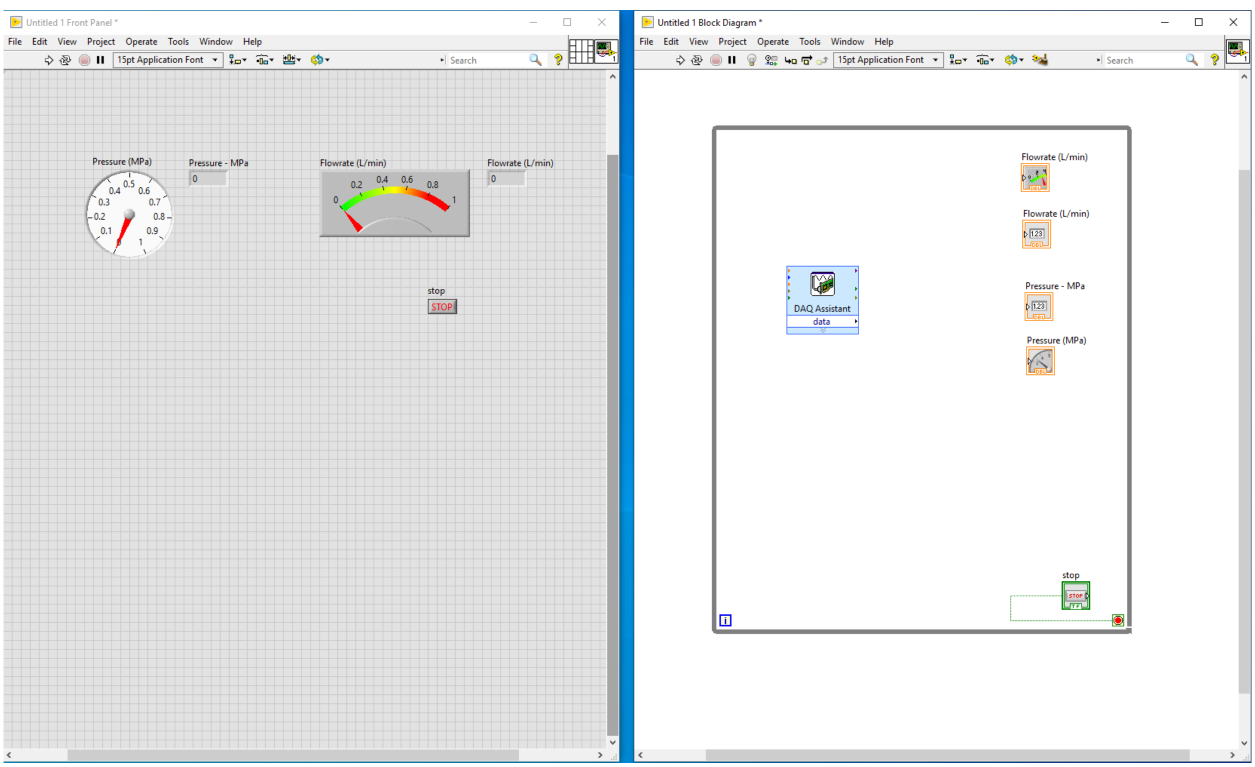
7. Click “OK” and your block diagram should now look like the following:



Add the Gauges to Display the Measured Pressure and Flow Rates

Now that LabVIEW knows how to interpret the signals sent to the board, you need to provide a convenient and useful display of the output results for the user in the GUI you are developing in the Front Panel window.

1. On the **Front Panel**, right-click and navigate to "Numeric."
2. Select "Gauge" and place the gauge on the front panel. (This gauge will be used to output the pressure.)
3. Right-click on the gauge and select "Properties."
4. On the "Appearance" tab, change the "Label" to "Pressure – MPa".
5. On the "Scale" tab, change the "Scale Range" minimum to 0 and the maximum to 1.
6. Click OK and rescale the gauge to the desired size by dragging on the Front Panel.
7. Using a similar procedure, add a digital output (Right-click>>Numeric>>Numeric Indicator) for the pressure. Rename as appropriate.
8. Using a similar procedure, add a "Meter" and a "Numeric Indicator" for the flowrate. (Don't forget to rename each gauge and change the range.)
9. Your window should now look like the following:

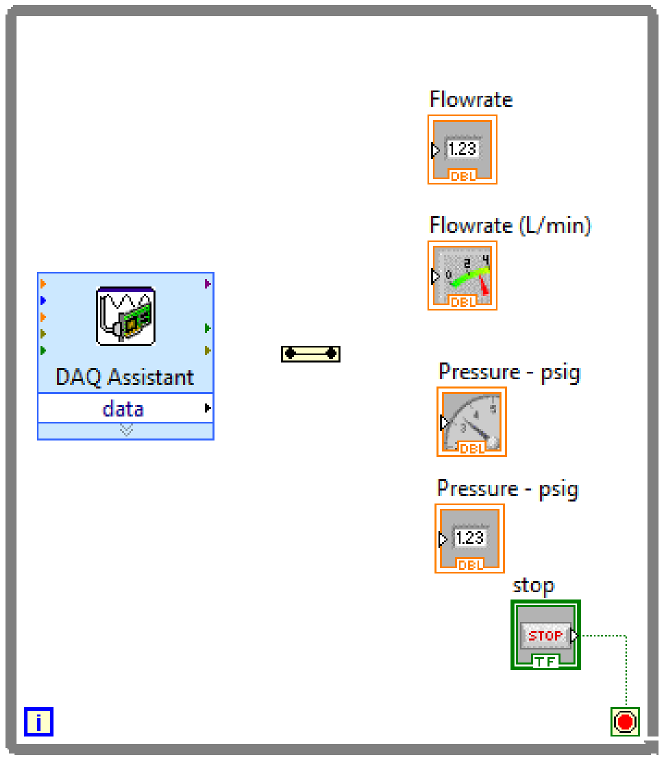


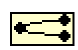
Connect the Gauges to the DAQ

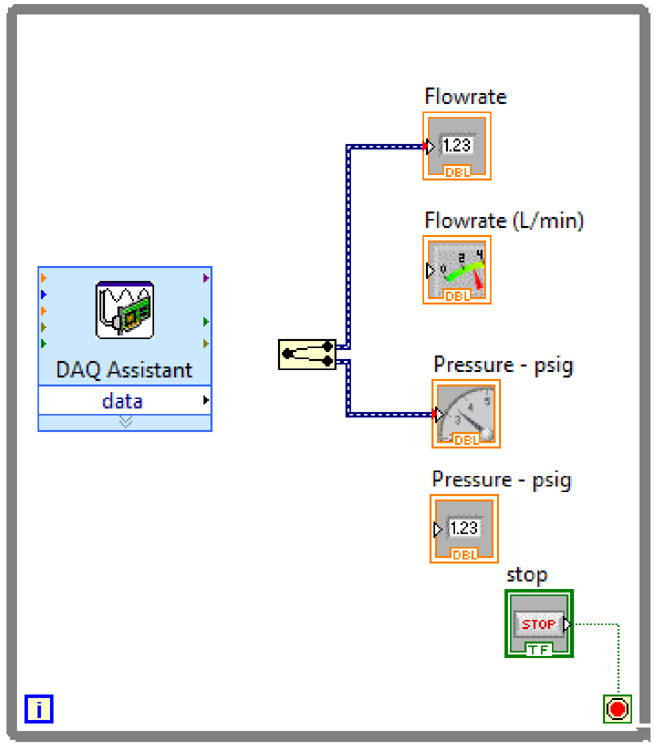
The next step is to connect the gauges to the DAQ and set up the interrelationships of the objects you have created in the user interface.

1.

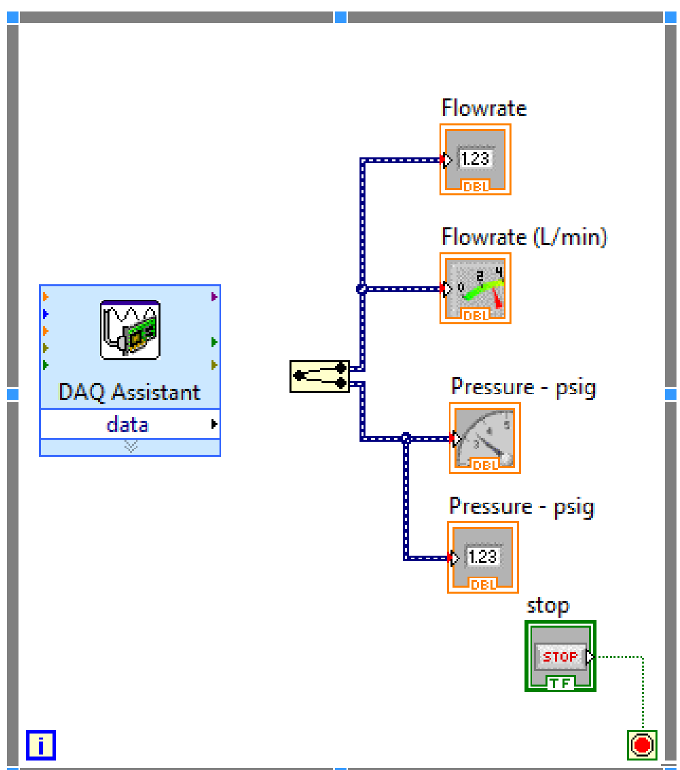
2. Drag the flowrate and pressure boxes to the right side of the block diagram as pictured below.
    a. To make things easier, make sure the two flowrate boxes are above the two pressure boxes.
3. Right-click on the block diagram and select "Express>>Sig Manip>>Split Signals."
4. Place the signal split icon on the block diagram as shown:



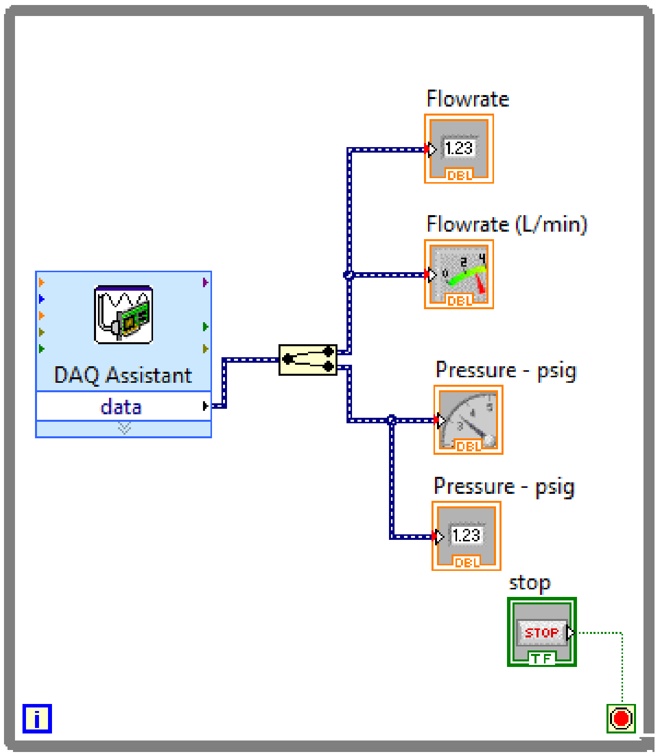
5. Drag the signal split down just enough to create two signals. 
6. Connect the top signal (ai0 - the analog input channels are numbered from ai0 down starting at the top of the icon) to *one* of the flowrate boxes.
7. Connect the bottom signal (ai1) to one of the pressure boxes.



8. Beginning at the unconnected flowrate box, drag a line to the middle of the line currently connecting the signal splitter and the first flowrate box.
9. Do the same thing for the unconnected pressure box.



10. Finally, connect the DAQ to the splitter by drawing a line from the arrow next to the word "data" to the signal splitter.



If your block diagram is somewhat unorganized and lines are hidden or blocked, you can clean the diagram up by dragging objects around to where you want them (and the lines will follow and change with the drag) or you can simply press CTRL+U, which will organize the Block Diagram for you.

Add an On/Off Switch to Power the Pressure Transducer

As will be explained below, the power for the pressure transducer is supplied through the same wire it uses to transfer the signal. The digital module of the DAQ (see Figure 2) imparts on/off capabilities to the control system. It has a total of 8 channels that can be used in this manner, but only one will be used in this tutorial.

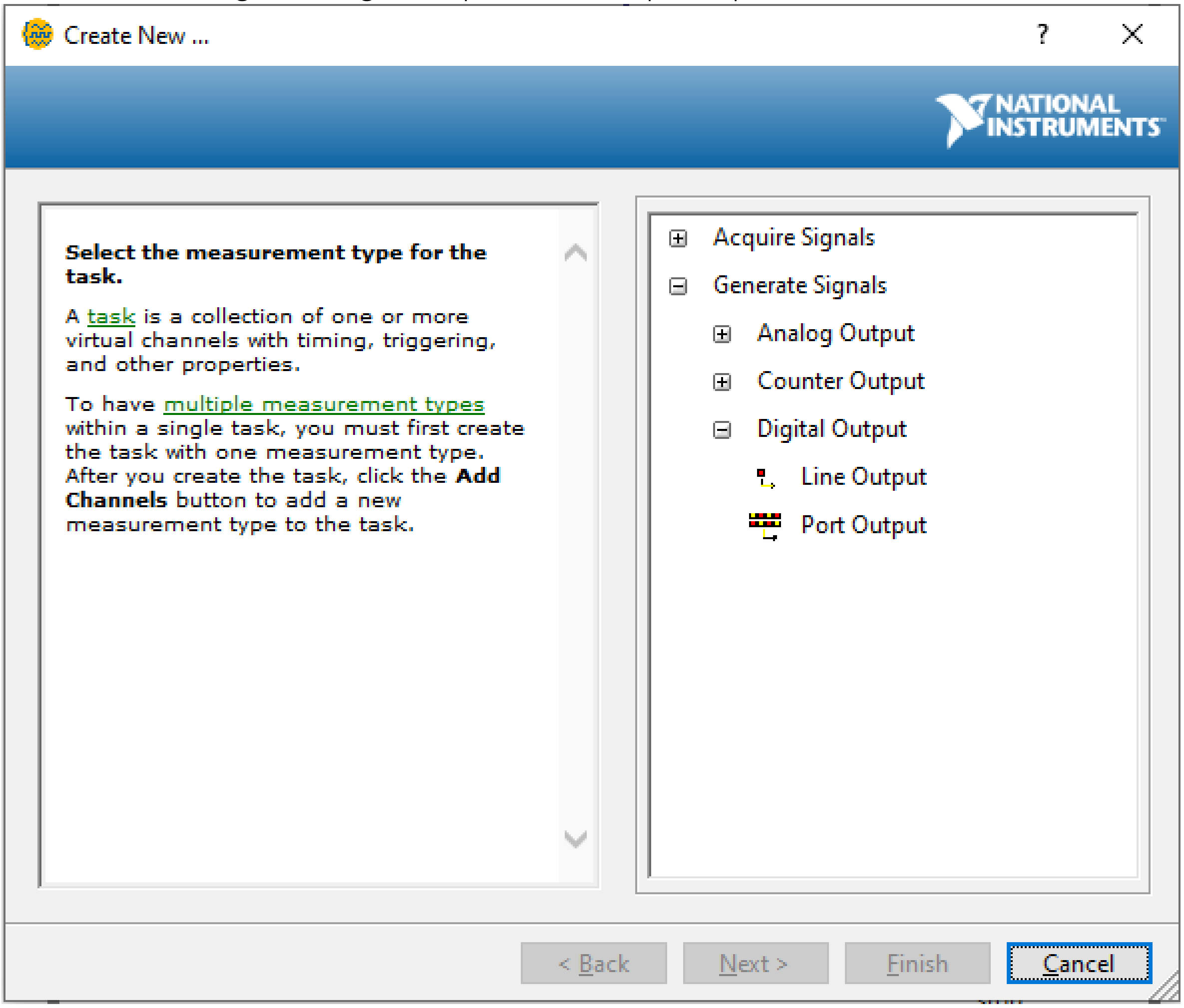
Add a button to turn on the power to the pressure sensor.

1. Right click on the Front Panel and select Boolean>>Push Button.
2. Place the button on the Front panel.
3. Rename the button from "Boolean" to "Pressure Sensor Power."

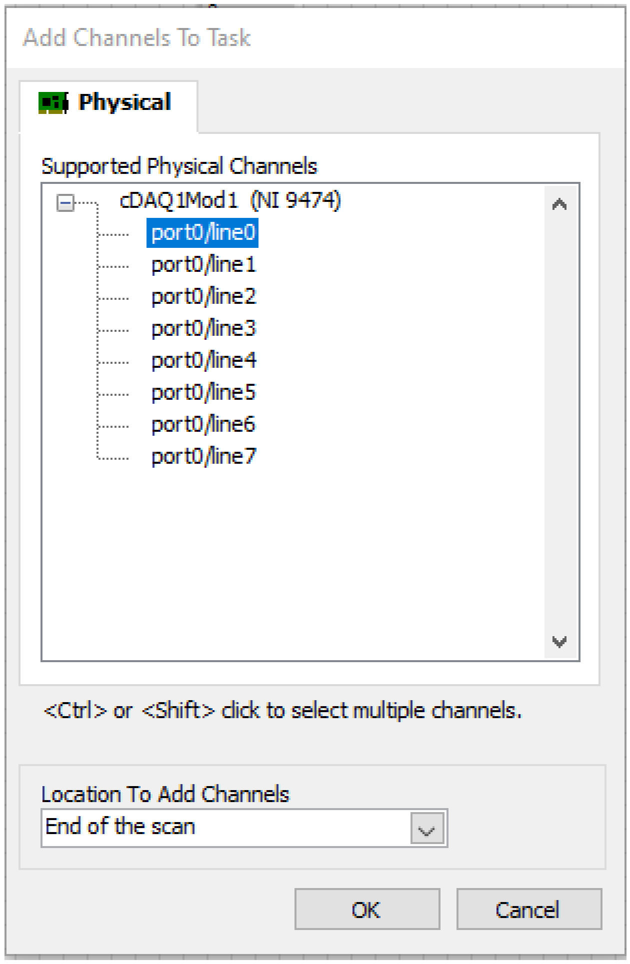
Program the Pressure Sensor Power Switch by doing the following.

1. Right click on the Block Diagram and select Express>>Output>>DAQ Assist. Place this on the clock diagram inside the while loop. A "Create New" window will pop up.

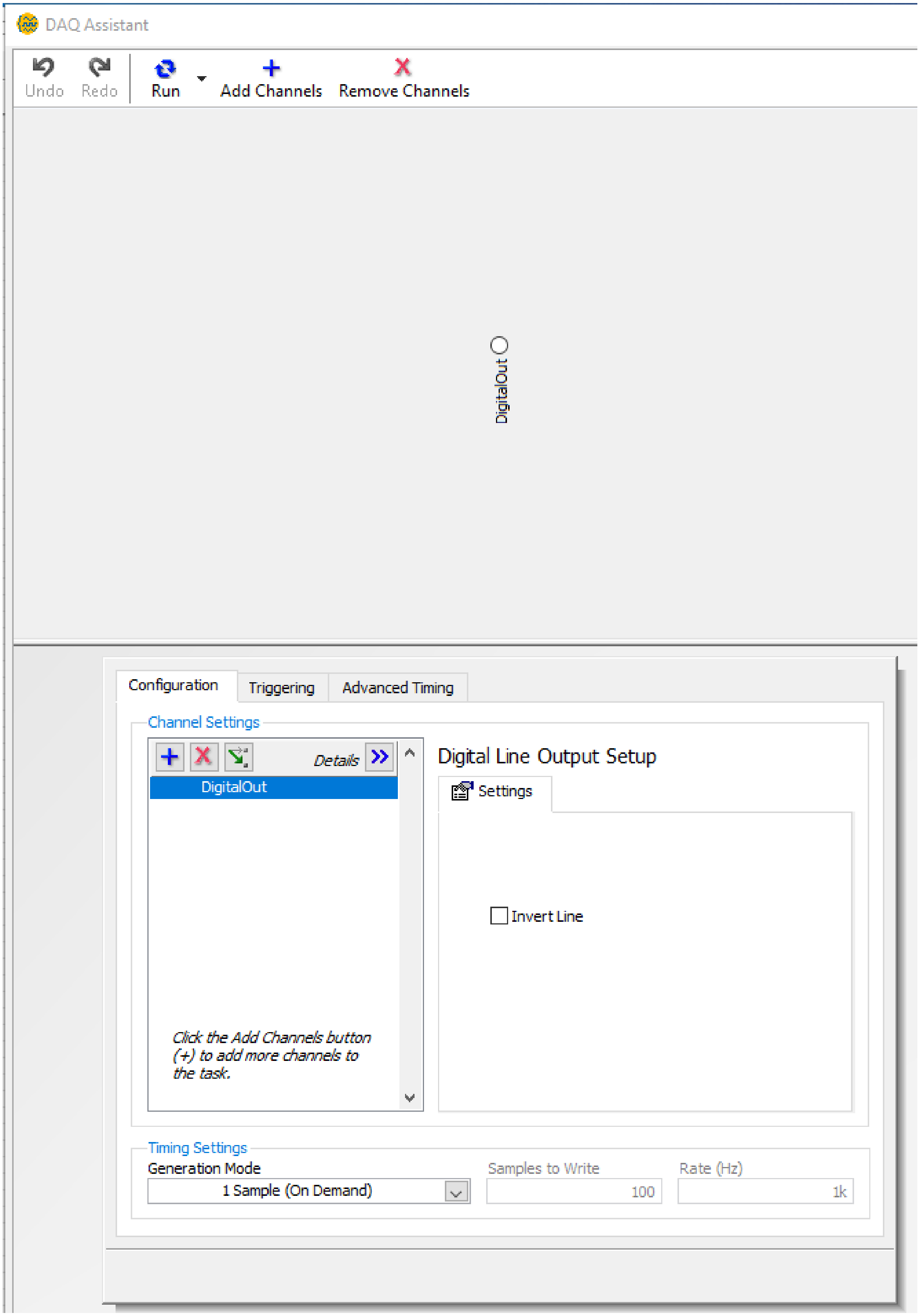
2. Select Generate Signals>>DigitalOutput>>Line Output as pictured below.



3. Select port0/line0 of CDAQ1Mod1 (NI 9474) as shown below.

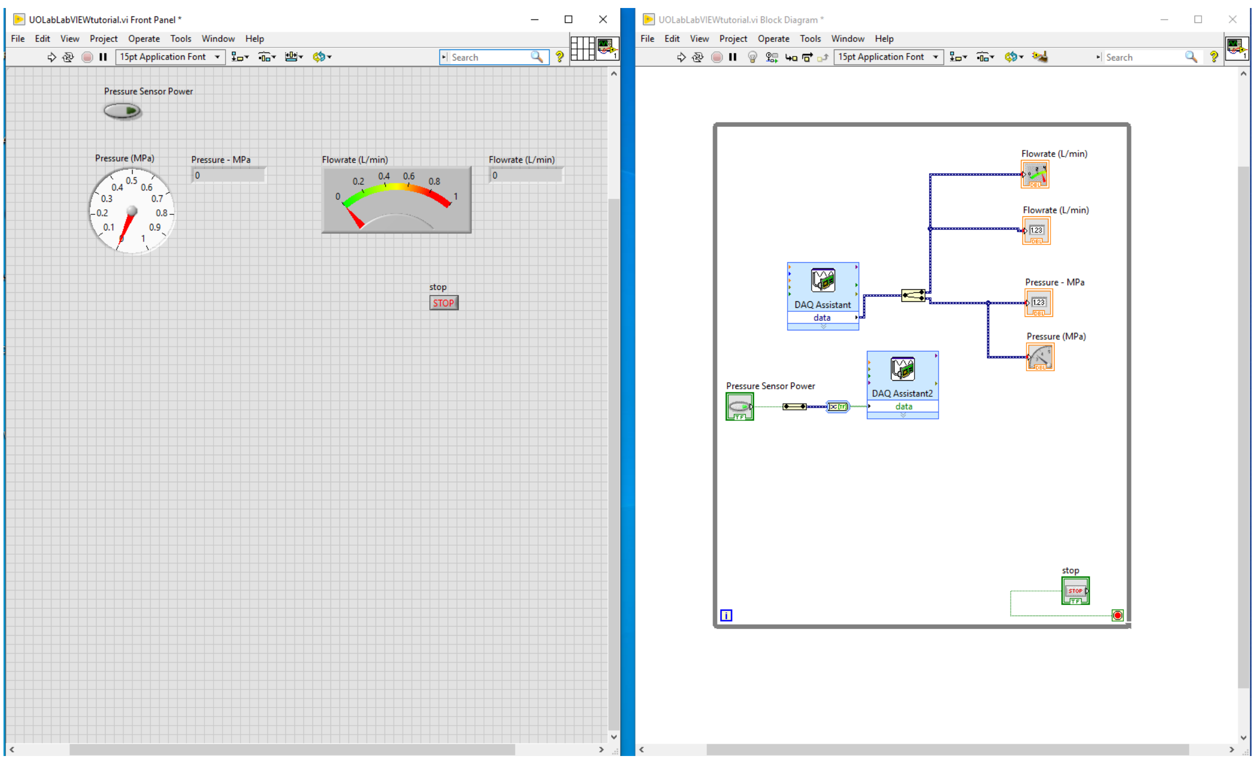


When finished, your DAQ Assistant should look like the following.


DAQ Assistant
Undo
Redo
Run
Add Channels
Remove Channels
DigitalOut
Configuration
Triggering
Advanced Timing
Channel Settings
Details
DigitalOut
Click the Add Channels button (+) to add more channels to the task.
Digital Line Output Setup
Settings
Invert Line
Timing Settings
Generation Mode
1 Sample (On Demand)
Samples to Write
100
Rate (Hz)
1k

4. Rename the channel from “DigitalOut” to “Pressure Sensor Power.”
5. Click “OK.”
6. Right click on the Block Diagram and select Express>>Sig Manip>>Merge Signals and place this on the Block Diagram between the Pressure Senor Power and the DAQ Assistant 2.
7. Resize the Merge Signal icon to have only one signal in and out by dragging from the bottom of the icon.
8. Connect the Pressure Sensor Power to the Merge Signal.
9. Connect the Merge Signal to the DAQ Assistant 2.

When complete, your system should look similar to the following.



Connect the Flowmeter to the DAQ

The flowmeter is easier than the pressure sensor to connect to the DAQ. This is because the power to the meter is supplied by a normal plug and not from the DAQ itself. You programmed the flowmeter on ai0 (the first channel) of the analog module. Thus, you need to connect the positive and negative leads of the flowmeter to the correct terminals of ai0 on this module. The steps below explain how to do this.

1. Right click on the DAQ in the Block Diagram and select Properties.
2. Select the “Connection Diagram” tab in the upper pane.
3. Select the Flow Rate channel.

LabVIEW will show the pin out for connecting the flow transducer to the DAQ. It should look something like the following.

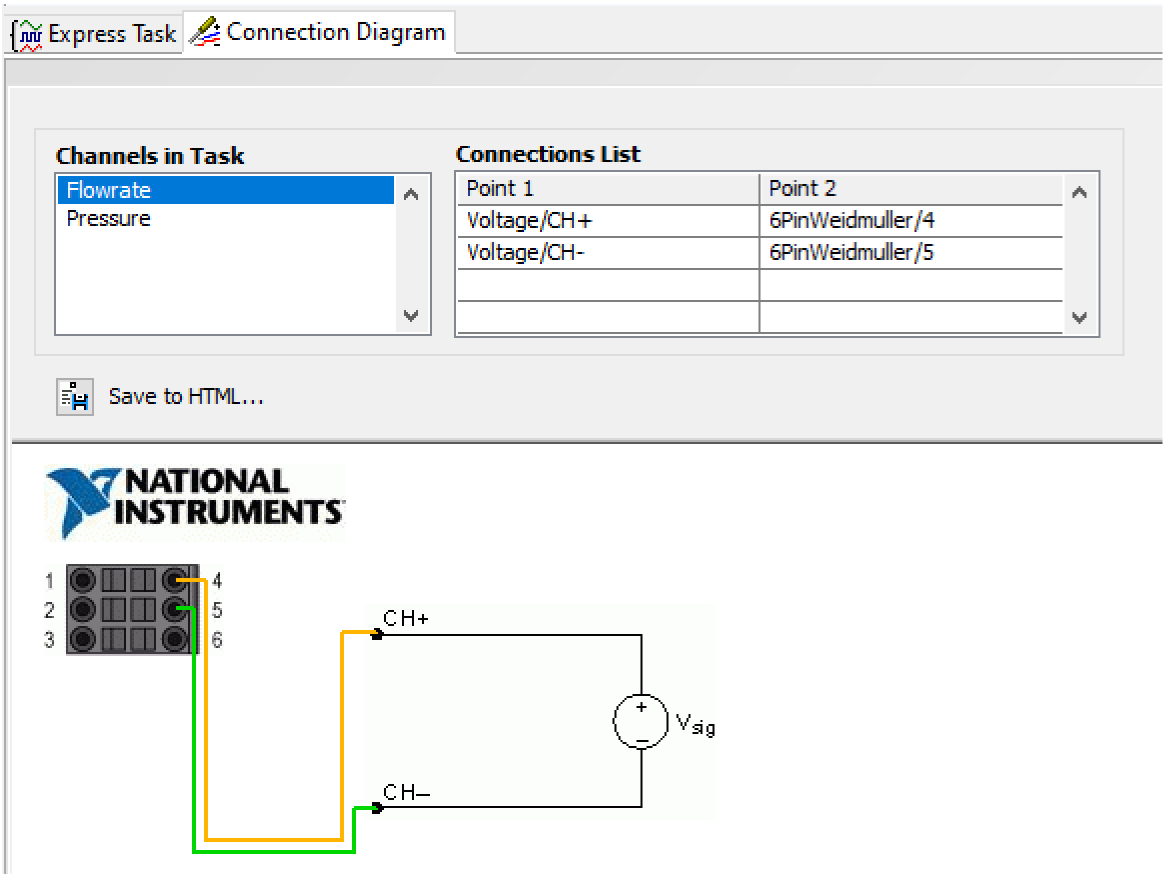


Figure 9 Connection diagram indicating the terminals and their polarities of Channel ai0 of the analog module to use when wiring the flowmeter to the DAQ.

This diagram means that the positive lead from the flowmeter (see Figure 4) should be connected to Terminal 4 of Channel ai0 and the negative lead to Terminal 5. Note that the colors on the diagram will not correspond to the wires on the meter. The colors on the diagram are simply to help you see where the wires should be connected.

1. Make a note of the connection diagram for the flowmeter. (Take a picture if needed.)
2. Click on the Pressure channel and note the connection diagram for the pressure sensor. (Take a picture if needed.)

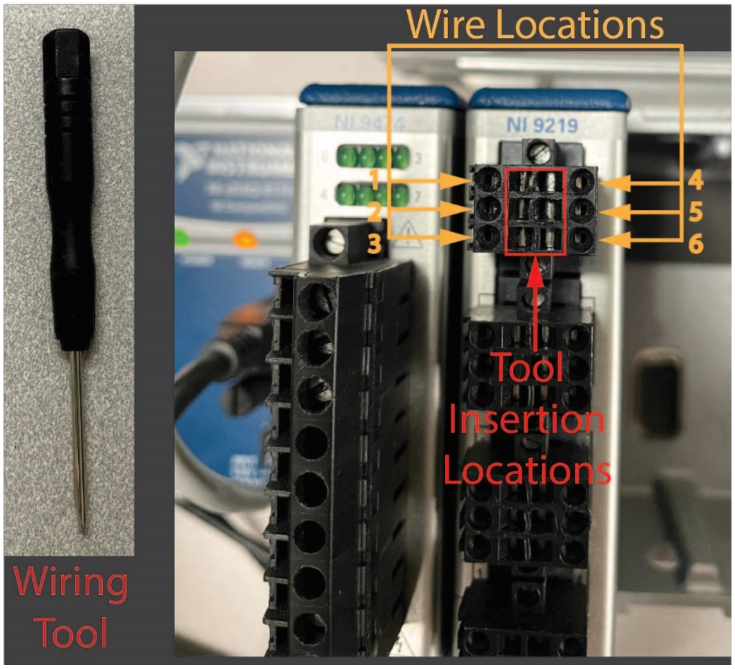


Figure 10 Analog module wiring explanation.

Figure 10 is an explanation of how to connect the wires to the analog module. The six terminals of Channel ai0 are highlighted. A red box identifies six openings on the channel, one for each terminal, where a tool is used for wiring. This tool is shown on the left. Follow the steps below to connect the positive lead from the flowmeter to Terminal 4. (Similar procedures are followed for other terminals).

1. Save your LabVIEW project to the J: drive.
2. Close LabVIEW.
3. ***Unplug*** **the DAQ system** from the power strip.
4. Ensure the positive lead from the flowmeter has about 1/8" exposed wire.
   a. Wind the metal strands between your finger and thumb if needed to remove fraying.
   b. Strip the wire back if needed.
5. Gently press the wiring tool into the square opening next to Terminal 4 until is stops. Hold the tool in this position while completing the next step. (This action pulls a clamp from the middle of Terminal 4 to the edge so that a wire can be inserted into the circular hole.)
6. Insert the exposed wire from the positive flowmeter lead into the circular terminal opening and hold in place.
7. Remove the tool from the square opening and let go of the flowmeter lead.

The wire will now be secured into the module. You should check the connection by lightly pulling on the wire. It should not come out.

Complete the wiring of the flowmeter to the DAQ.

1. Ensure the negative lead from the flowmeter has about 1/8” exposed wire. Strip and/or wind as needed.
2. Insert the negative lead from the flowmeter into Terminal 5 (as indicated in Figure 9) of Channel ai0 using the wiring tool.

Connect the Power to the Digital Module of the DAQ.

Recall that the digital module of the DAQ sends out signals. It requires power to do this, so you must wire power to the module. Notice, as pictured in the left panel of Figure 11, that there are a total of 10 terminals (labeled 0-9). The right panel shows that Terminal 9 is the common ground (negative). This is indicated with the label “COM” on the side of the module next to Terminal 9. Terminal 8 is the supply (positive) line. This indicated with the label “VSUP” on the side of the module next to Terminal 8.

Figure 11 Digital module of the DAQ system. Left: Font face showing a total of 10 terminals (labeled 0-9). Right: Side of module indicating the channel corresponding to each terminal.

The DAQ system is unplugged before performing these steps.

1. Obtain one short strand of black wire and one short strand of red wire.
2. Strip the wires if needed so that about 1/8” of metal is exposed on each end.
3. Connect one end *of the black wire* into one of the ports on the *black* portion of the power block. (See Figure 2.)

a. Use a small screwdriver to open the port by turning counter clockwise.
b. Insert the wire.
c. Secure the wire by turning the screwdriver clockwise.

4. Connect the other end of the *black wire* to Terminal 9 (COM) of the digital module using a screwdriver.
5. Connect one end *of the red wire* into one of the ports on the *red* portion of the power block. (See Figure 2.)
6. Connect the other end of the *red wire* to Terminal 8 (VSUP) of the digital module using a screwdriver.

Connect the Pressure Sensor to the DAQ

Connecting the pressure sensor to the DAQ is slightly more complicated than the flowmeter due to the manner in which it is powered. The flowmeter power was supplied through a typical 110 V plug (see Figure 4). The pressure transducer, however, doesn't have a plug. In this case, the power is supplied through the same wires on which the signal travels. This is called a 4-20 mA *two wire loop*.

The DAQ system is unplugged before performing these steps.

1. Read the information found at https://www.predig.com/indicatorpage/back-basics-fundamentals-4-20-ma-current-loops to understand the basics of 4-20 mA current loops.
    a. Figure 4 of this webpage is especially important.
    b. Make sure you identify which parts of the lab apparatus correspond to the following from Figure 4 of the webpage.
        i. Power Source
        ii. Transmitter
        iii. Receiver
    c. Pay special attention of the polarity connecting each part of the loop in Figure 4 of the webpage.
2. Connect the pressure sensor to the DAQ in a 4-20 mA two-wire loop configuration. Make sure to remember the following:
    a. Above, you created an on/off switch to *power* the pressure sensor using the digital modules of the DAQ.
        i. You selected port0/line0 for the button powering the pressure sensor. This is labelled DO0
        ii. The positive of this button goes to Channel 0.
        iii. The negative of this button should be connected to the black side of the power block (see Figure 2). (All the negatives for power are wired to the same common ground.)
    b. Above, you set Channel ai1 of the *analog* module to *receive* the pressure sensor signal.
    c. You can double click on the DAQ of the Block Diagram and select the Connection Diagram tab to view which terminals (and their polarities) of Channel ai1 to use when wiring the pressure sensor. (You should have a picture of this.)
    d. The polarity of the pressure sensor leads (wires) is depicted in Figure 6.

Run the System and Do the LabVIEW Homework Assignment

1. Pass off the wiring of your system with the lab or assistant lab manager.
2. Plug the DAQ into a power strip once the wiring is passed off.
3. Ensure the USB connection from the DAQ is connected to the computer. Connect if needed.
4. Open LabVIEW on the computer and load the VI you created in this tutorial.
5. Press the Play button on in the tool bar of either the Block Diagram or Front Panel to start the control system. Troubleshoot any problems.
6. Open the exit valve on the water tank (see Figure 3).
7. Open the needle valve on the system (see Figure 5).
8. Place the plastic tubing into the pump and close the clamp.
    a. Ensure the tubing is placed between the black housing and the metal roller assembly.
    b. Ensure the tubing at the inlet and outlet of the pump is aligned on the "V"-shaped grooves of the black housing.
9. Plug the power strip on the side of the apparatus cart into an outlet.
10. Plug the pump into the strip on the side of the apparatus.
11. Plug the flowmeter into the strip on the side of the apparatus.
12. Turn on the pump.
    a. The switch is on the side.
    b. The speed can be changed using the up and down arrows.
13. Complete the LabVIEW Homework Assignment once your system is running properly.