

1. Overview

Harvard Apparatus is pleased to introduce the PHD ULTRA™ CP (Constant Pressure) Syringe Pump. This ingenious system uses the world-renowned Harvard Apparatus PHD ULTRA™ syringe pump technology enhanced to allow pressure controlled flow.

The PHD ULTRA™ Syringe Pump series is a family of high-accuracy, microliter- and milliliter-compatible pumps designed for versatile technical use including mass spectroscopy, calibration, drug and nutritional infusions, microdialysis, dispensing, chromatography and LC/HPLC.

PHD ULTRA™ CP allows the user to set pressures in units of mmHg, kPa and psi. This grants the system the ability to satisfy a myriad of constant pressure applications from low-pressure physiologic infusions to high-pressure reactor injections.

Using the PHD ULTRA™ CP syringe pump and software-controlled pressure monitoring, along with the appropriate sensor and amplifier the system is able to maintain a user defined pressure accuracy of $\pm 2\%$ once the steady state pressure has been achieved. The response of the PHD ULTRA™ CP to changes in the infusion backpressure will depend on the "PID" settings discussed in this addendum.

These instructions will guide you through the PHD ULTRA™ CP setup process to get you started.

2. System Concept

The PHD ULTRA™ CP employs a manually set PID (proportional-integral-derivative) controller. A PID controller is a closed loop system that calculates an error value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

The PID controller algorithm involves three separate constant PID parameters, the proportional (P), the integral (I) and derivative (D) values. Explaining the PID values in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change.

A PID controller relies only on the measured process variable, not on knowledge of the underlying application, making it a useful controller for low to high-pressure applications. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific experiments.

Included with the PHD ULTRA™ CP is a Windows PC software application that allows you to monitor, control, and log the pump data to your PC via USB. This application is not necessary to run the constant pressure capability. However, it is a useful tool to help monitor the operation of the PHD ULTRA™ CP. Harvard Apparatus recommends using the application to assist in your constant pressure setup. Once familiar with the system settings and operation, the constant pressure experiment can run without a PC.

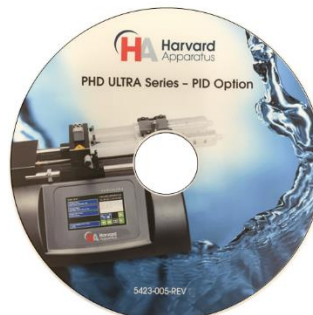
You will need to provide a pressure sensor and amplifier capable of a linear output scalable within 0-10V. For example, a linear voltage output of 0-5V will work as long as the amplifier scaling is setup correctly.

Harvard Apparatus offers several transducers and amplifiers for physiological experiments. Please contact Harvard Apparatus for available options. A sample hardware setup is shown later in this document.

3. Windows PC Software Installation Package

The PHD ULTRA™ CP syringe pump ships with a CD that contains the following items:

- Harvard Bioscience USB Drivers
- PHD Ultra Family User Manuals and PID Setup Instructions
- USB Serial Driver (Virtual COM Port)
- USB Bulk Driver (Flash Update – used only when upgrading pump firmware)
- PID Pump Data Log Application



PHD ULTRA™ CP (PID Option) CD

4. USB Serial Communication Driver Installation

The Virtual COM Port driver supplied with the PHD ULTRA pump allows PC applications to connect to the PHD ULTRA™ pump as though a serial COM Port. Connect the PHD ULTRA™ CP to a PC using the standard USB cable supplied with the unit.



PHD ULTRA™ CP USB Connection

When you connect the powered on PHD ULTRA™ Syringe Pump to a computer USB port, Windows will prompt you to search for the necessary software. Browse to the Pump Drivers folder on the supplied CD, and allow Windows to install the USB serial port for PHD ULTRA™ Syringe Pump. Depending on your version of Windows and driver install preferences, you may need to open the Windows Device Manager to install the driver.

In this case, when viewing connecting hardware through the Device Manager in your Windows operating system, please note that on Windows XP, the pump will appear under Ports (COM & LPT) and on Windows 7, the pump will appear under Other Devices. Right-click on the connected item and select Update Driver Software. You will then need to browse to the Pump Drivers folder on the provided CD and click through the installation windows until the Virtual COM Port driver installation is completed. Before closing Device Manager, note the COM port number that Windows assigned to the port.

5. PID Pump Data Log Application Installation

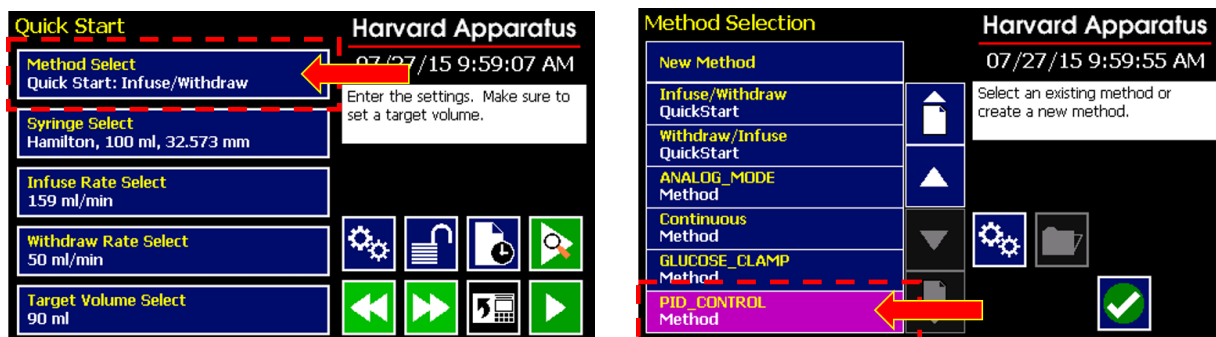
Included with the PHD ULTRA™ CP is a Windows PC software application that allows you to monitor, control, and log the pump data to your PC via USB. This application is not necessary to run the constant pressure capability. However, it is a useful tool to help monitor the operation of the PHD ULTRA™ CP. Harvard Apparatus recommends using the application to assist in your constant pressure setup. Once familiar with the system settings and operation, the constant pressure experiment can run without a PC.

6. PID Pump Setup

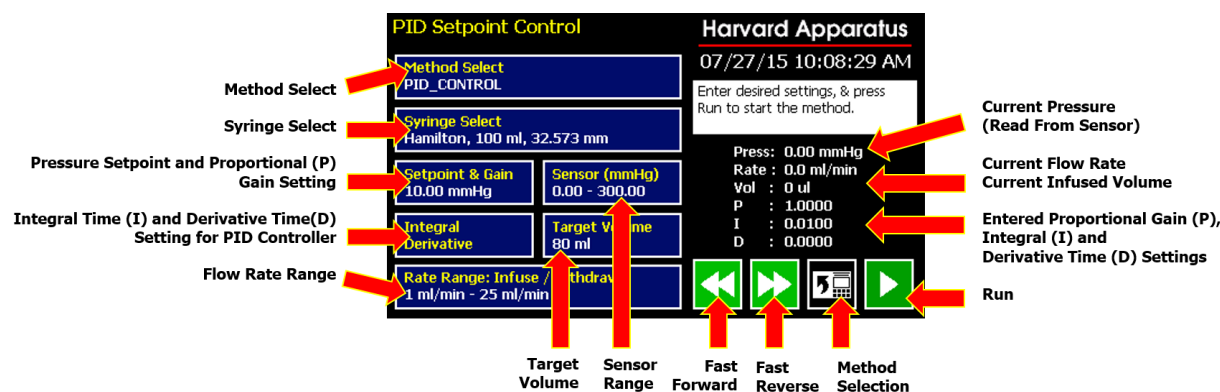
Setting up the Pump in PID Control mode requires setting up a few parameters on the pump before you can start using it with the remote PC application. The example given in section 8 will use the following parameters.

Power on the PHD ULTRA™ CP syringe pump. Please refer to the PHD ULTRA™ manual for additional information on power connections. The manuals are located in the User Manual folder provided on the included PID Option CD.

- Method Select:** The PHD ULTRA™ CP syringe pump will power up in the mode it was last used. Select the **Method Select** section of the touchscreen and choose the method titled "PID_CONTROL" to open the PID Setpoint control setup screen.



PHD ULTRA™ CP PID_CONTROL Method Selection



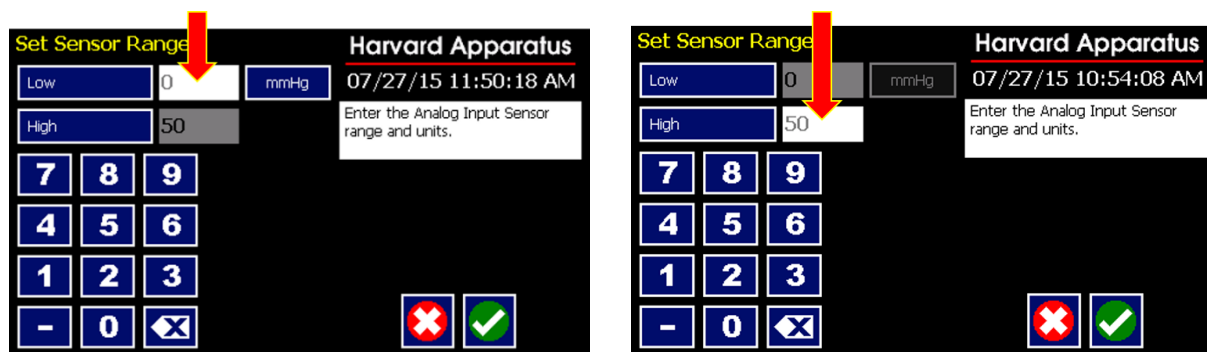
PHD ULTRA™ CP PID Setpoint Control Method Setup Screen

We will now setup the remaining parameters on the PID Setpoint control setup screen.

- b. **Syringe Select:** Select the **Syringe Select** section of the touch screen to choose the required syringe type. Please refer to the PHD ULTRA™ manual for additional information on selecting the proper syringe type along with loading and securing the syringe onto the PHD ULTRA™ CP syringe pump.
- c. **Sensor Setup:** Select the Sensor section of the PID Setpoint Control setup screen. The PHD ULTRA™ CP PID Control feature is compatible with various linear amplifier / sensor combinations for low to high-pressure applications. The **Sensor Range** must be set to correspond to the amplifier settings and pressure sensor that will be connected to the PHD ULTRA™ CP analog input connector.
Set the LOW value to correspond to the sensor reading at 0.0 volts. Set the HIGH value to correspond to the sensor reading at +10.0 volts. Set the sensor unit to correspond to the sensor pressure units.

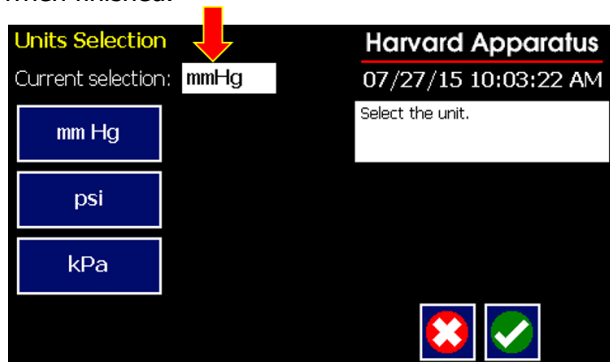
For example, the Harvard Apparatus APT 300 Perfusion Transducer has a capable range of – 300 to 300 mm/Hg. If we have an experiment that requires constant pressure infusion at 10 mmHG, then we want an acceptable pressure range that is within the sensor capability and gives enough resolution for an accurate measurement. In this case, we would choose 0-50 mmHG. This range is well within the capabilities of the APT 300 sensor. This will also give us good resolution when we see a graph of the measurement by using the PID Pump Data Log application later in these instructions.

Select the Sensor Range setup on the PID Setpoint Control Method Setup Screen. On the Set Sensor Range screen select Low and then High to enter the sensor measurement range. In this case, we entered "0" for the Low reading and "50" for the High reading.



PHD ULTRA™ CP PID Set Sensor Range Low & High Setup Screens

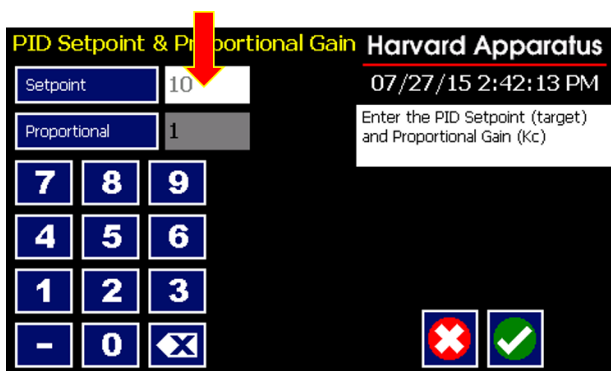
Select the unit icon to choose the required units. Choose from mmHg, kPa and PSI. Press the green check mark when finished.



PHD ULTRA™ CP PID Sensor Units Selection Setup Screen

The sensor setup and amplifier calibration method will depend on the equipment used with the PHD ULTRA™ CP. Please refer to the sensor and amplifier user manuals for additional setup information. To assist with your constant pressure setup, we show a basic block diagram of the hardware requirements along with an example using a Harvard Apparatus TAM-D amplifier and APT 300 Perfusion Transducer in section 7, Example Setup & PID Data Log Application.

Select the Setpoint & Gain section of the PID Setpoint Control setup screen.



PHD ULTRA™ CP PID Setpoint & Proportional Gain Setup Screen (Enter Setpoint)

The Setpoint is the pressure level that you want to achieve in your experiment. In this case, the setpoint is 10; the engineering units chosen in the previous section were mmHG. Therefore, the Setpoint pressure is 10 mmHG.

- d. PID Settings: As mentioned in the System concept section, The PHD ULTRA™ CP employs a manually set PID (proportional-integral-derivative) controller. A PID controller is a closed loop system that calculates an error value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

The PID controller algorithm involves three separate constant PID parameters, the proportional (P), the integral (I) and derivative (D) values. Explaining the PID values in terms of time: P

depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The PID controller is named after its three correcting terms (Proportional “P”, Integral “I” and Derivative “D”) tuning parameters. These parameters sum to calculate the output of the PID controller.

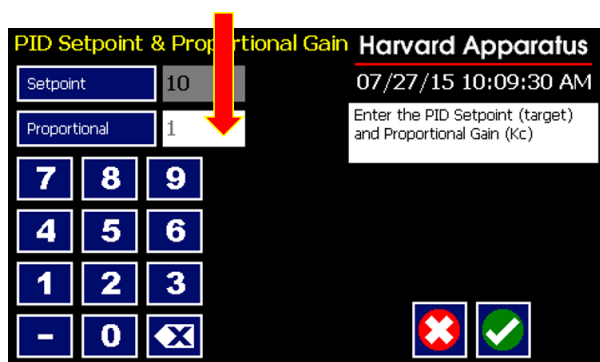
A PID controller relies only on the measured process variable, not on knowledge of the underlying application, making it a useful controller for low to high-pressure applications. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific experiments.

The desired tuned result of the controller depends on the response of the PID controller to an error, the degree to which the controller overshoots the setpoint, and the degree of system oscillation.

The Proportional selection on the PID Setpoint & Proportional Gain Setup Screen is the “P” part of the PID Control method. This is the first of three PID controller-tuning parameters we will discuss.

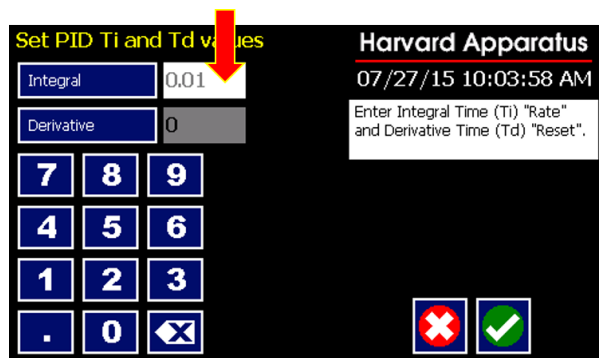
The **Proportional Gain** term produces an output value that is proportional to the current error value. The proportional response adjusts by multiplying the PID error by a constant, called the proportional gain constant. This constant is entered into the Proportional selection on the Setpoint & Proportional Gain Setup Screen.

A high **Proportional Gain** results in a large output change for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and PID practice indicate that the proportional term should contribute the bulk of the output change. We recommended that the starting Proportional Gain parameter be set to 1 and adjusted as needed.



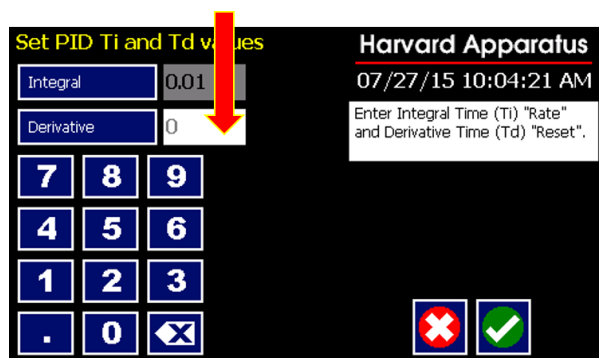
PHD ULTRA™ CP PID Setpoint & Proportional Gain Setup Screen (Enter Proportional)

Integral Time: The Integral time "I" term accelerates the output pressure towards the entered setpoint and helps mathematically eliminate the error that can occur in the PID controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the setpoint value. Adjusting the Integral time will help to mitigate overshoot. We recommended that the starting Integral parameter be set to 0.01 and adjusted as needed.



PHD ULTRA™ CP PID Set PID Integral & Derivative Times (Integral Setting)

Derivative Time: The Derivative "D" term predicts system behavior and thus improves settling time and stability of the system. An estimated 25% of controllers use a Derivative time setting. The lower use of this term is due to its variable impact on system stability in real-world applications. It is for this reason that we generally set the Derivative term set for zero in most applications.



PHD ULTRA™ CP PID Set PID Integral & Derivative Times (Derivative Setting)

- e. **PID Tuning:** The response of the PID controller will vary based on the output pressure application. The standard PID settings of P-1, I = 0.010 and D = 0 may not produce the output pressure response that the application requires. This section provides guidance to help the user tune the PID controller to achieve the desired response for the experiment at hand. When unsure of what PID parameters to use, try the following tuning method.

This method requires the PID Data Log PC application to monitor the chart recording output pressure response. First, set the Integral "I" and Derivative "D" time values to zero and the Proportional "P" to 1. Increase the Proportional "P" until the output pressure graph oscillates.

Once the pressure is oscillating, take the set "P" value and decrease it by ½. This produces a "quarter amplitude decay" type response, which reduces the system error quickly. A fast PID loop

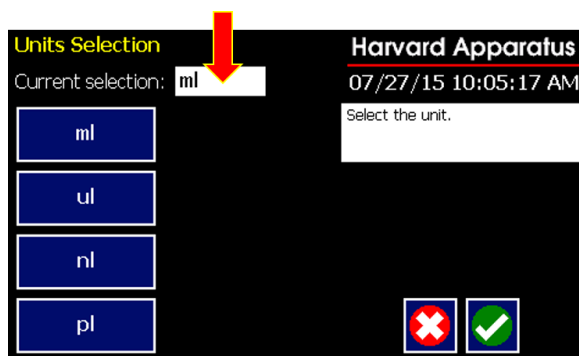
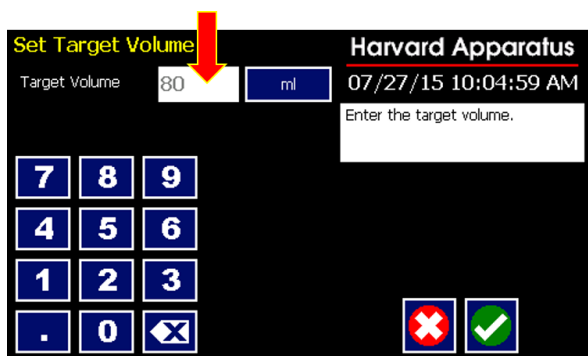
tuning usually overshoots slightly to reach the setpoint more quickly; however, some applications cannot accept overshoot, in which case an over-damped closed-loop system is required, which will require a Proportional setting significantly less than half that of the Proportional setting that was causing oscillation.

The next step is to increase the Integral time to correct any offset in sufficient time for the application. However, too large of an increase in Integral time will cause instability. Finally, increase the Derivative time, if required, until the loop response is fast enough to recover from a drastic change in pressure. However, too much Derivative time will cause excessive response and overshoot. It is normal to leave the Derivative time set at zero. The following chart gives guidance on the impact of increasing any one PID parameter independently. Please see section 7, Example Setup & PID Data Log Application for graphical examples of the impact from changing PID settings.

Impact on Controller Performance When Increasing "P", "I" or "D" Independently					
Parameter	Rise time	Overshoot	Settling time	Error	Stability
Proportional	Decrease	Increase	Small change	Decrease	Degrade
Integral Time	Decrease	Increase	Increase	Eliminate	Degrade
Derivative Time	Minor change	Decrease	Decrease	No effect in theory	Improve if small

Chart Listing Impact on Controller Performance When Increasing "P", "I" or "D" Independently

- f. Target Volume: The Target volume sets the total volume of fluid required for the infusion experiment. The maximum volume is equal to the size of the installed syringe. Enter the Target Volume with the keypad. Selecting the volume units allows the volume units to be set in terms of ml, ul, nl & pl.



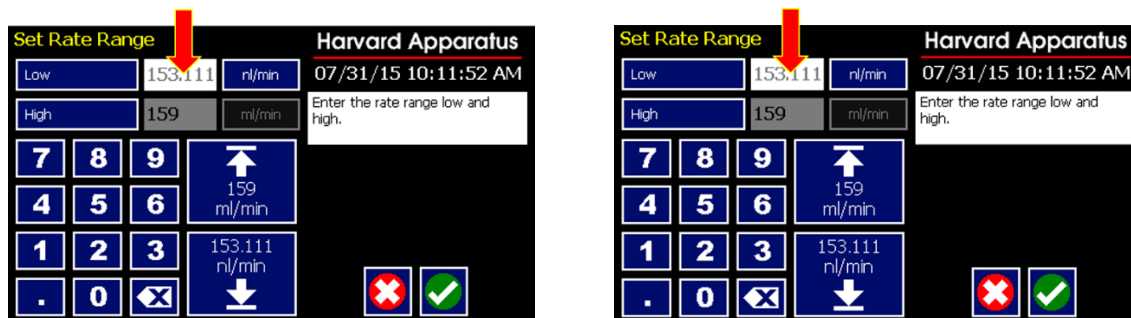
PHD ULTRA™ CP PID Set Target Volume Screens

- g. Flow Rate Range: The Flow Rate Range Output Limiting ensures that the pump operates within a safe range for your system and can help when tuning the PID gain parameters.

The HIGH rate limit is the maximum rate that the pump will operate when the PID control is running. This value must be less than or equal to the maximum flow rate for the selected syringe, and greater than the LOW rate limit.

The LOW rate limit is the minimum rate that the pump will operate when the PID control is running. This value must be greater than or equal to the minimum flow rate for the selected syringe, and less than the HIGH rate limit. In the event that a flow rate range is not entered, the

PHD ULTRA™ CP will default to the minimum and maximum flow rate range for the installed syringe.

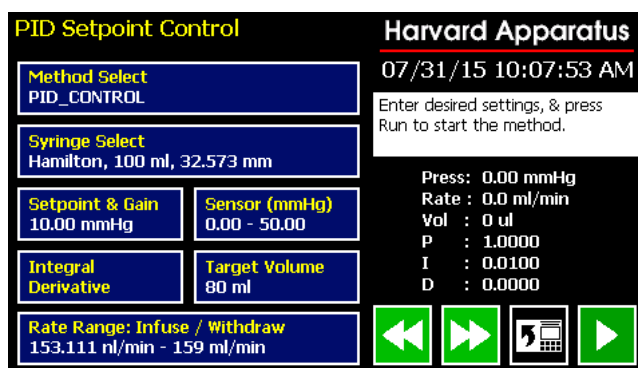


PHD ULTRA™ CP PID Set Flow Rate Range Screens

NOTE: While the pump is running, the minimum flow rate is not zero. The pump must remain energized to maintain pressure when the flow rate drops to zero, however, the pump will continue to move at a very slow rate. In most applications, the system pressure will bleed off while the system is running and the pump will maintain the pressure at the target setpoint. When running in a closed system. However, the pump movement will eventually cause the system to over pressurize when running for a long period of time.

For closed systems, the pump has a Reverse Enable setting accessible via the PID Pump Data Log PC application that allows the pump to switch directions when running the PID control algorithm. By default, the PID control runs in Infuse Only mode. Setting Reverse Enable allows the pump to operate in both the Infuse Withdraw directions. Please be sure to follow the Syringe Loading instructions in the Pump User's Guide.

- h. Run Screen: Once all parameters are set the Run screen will look like the example below.



PHD ULTRA™ CP PID Run Screen

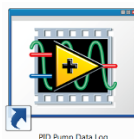
7. PID Pump Data log Application

a. Installing PID Pump Data Log Application

- i. To install the PID Pump Data Log application, launch the PID Pump Data Log setup.exe application located in the Pump Applications/PID Pump Data Log Installer folder on the included PID Option CD.

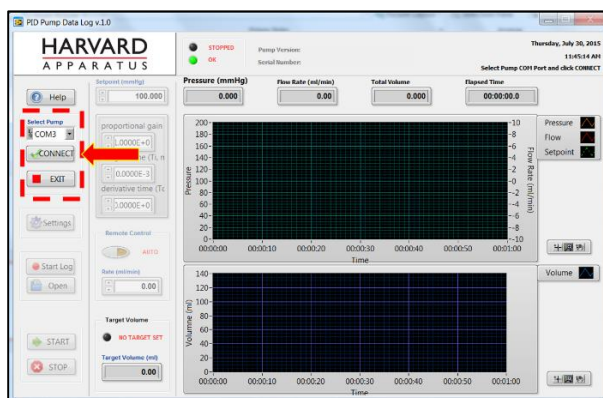
This program uses the National Instruments LabVIEW platform. You will be prompted to install programs on your PC from National Instruments (NI) files that are required for the application to run. Confirm the installation destination directories, and accept the National Instruments (NI) license agreement notifications, and click Next >> to start installation.

The installation program will install the PID Pump Data Log application along with various support files. Allow the installer to complete, and restart if prompted to do so. When the application installation is complete, the PID Pump Data Log shortcut shown below will appear on your Windows desktop.



PHD ULTRA™ CP PID Pump Data Log Application Shortcut

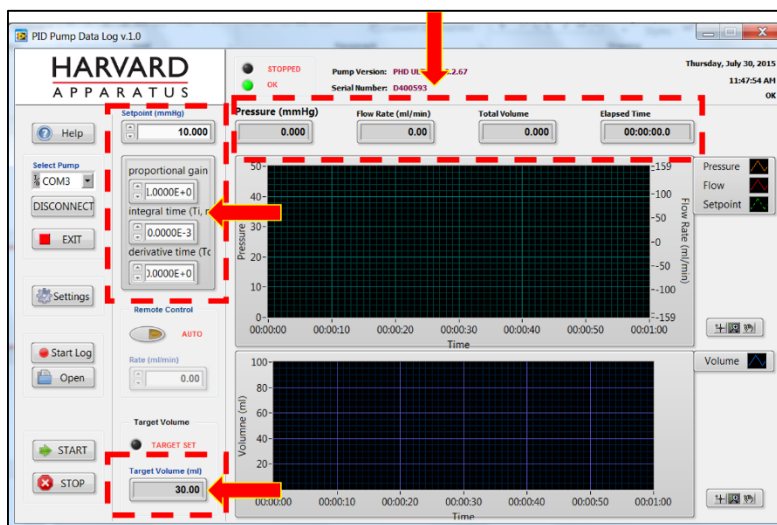
- ii. Please refer to section 4 and load the USB Serial Communication Driver before proceeding. Connect the pump to the computer using a USB cable, and turn on the pump.
- iii. Connect the sensor output to the pump Analog Input connector.
- iv. Launch the PID Pump Data Log program from the Windows desktop shortcut or from the Program Menu. The PID Pump Data Log application will open.
- v. Select the COM port the PC has assigned to the pump connection from the Select Pump pulldown menu. The COM port is the one assigned in section 4. Then select the CONNECT icon to connect establish a connection to the PHD ULTRA™ CP Pump.



Select Pump COM Port & Select Connect

b. Graphical User Interface PID Pump Data Log Application

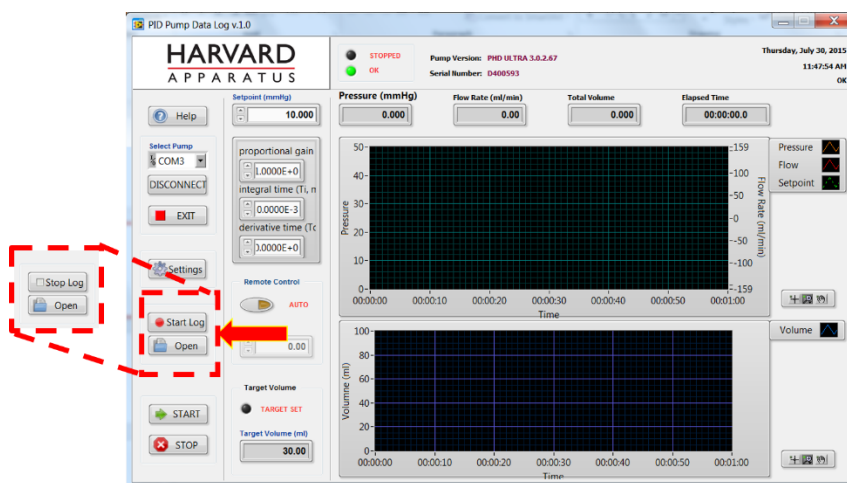
- i. Once connected, the Setpoint, PID Tuning and Volume parameters set on the PHD ULTRA™ CP will update on the PID Pump Data Log application. The PID tuning parameters can be changed here on the PC Data Log application interface.



PID Data Log PC Application

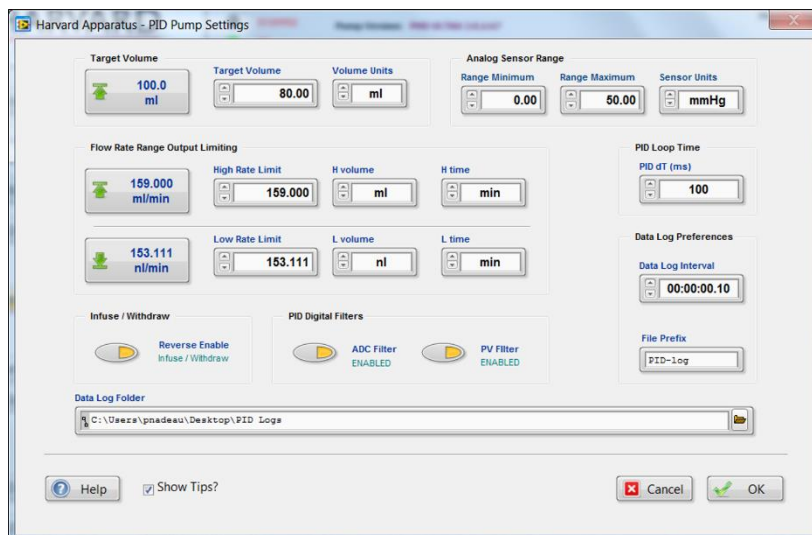
The Pressure, Flow Rate, Total Volume and Elapsed time readings are from the pump. They will update during the experiment.

- ii. The PID Pump Data Log PC application has the ability to save sampled data to a .CSV (comma-separated value) file. Select the Start Log button before running the pump. The datalog file saves to a folder on the PC desktop named "PID Logs". The next section shows how to change this default location.



PID Data Log PC Application Start/Stop Data Log

- iii. The Settings button brings up a more detailed settings screen.



PID Data Log PC Application Settings Screen

The application reads all of the PID Pump settings and displays the PID Pump settings editor window. The PID Pump Settings window allows you to view and edit the following settings.

Target Volume: The set target volume of the experiment.

Analog Sensor Range: The set analog sensor range, changing this will require the user to recalibrate the sensor amplifier combination. Please see section 8 for an example of calibrating a sensor and amplifier with the PHD ULTRA™ CP.

Flow Rate Range Output limiting: This setting is the minimum and maximum flow rate range of the experiment.

PID Loop Time: The rate at which the application calculates the PID loop. The setting of 100 mS is appropriate for most applications. Only advanced PID users should change this setting.

Infuse/Withdraw Reverse Enable: This setting allows the pump to engage into the withdraw mode to help adjust to changes in the infusion pressure.

PID Digital Filters: Provide PID loop anti-aliasing. Only advanced PID users should change this setting.

Data Log file Prefix, and Data Log Folder: Allows the naming and location of the PID datalog folder and file.

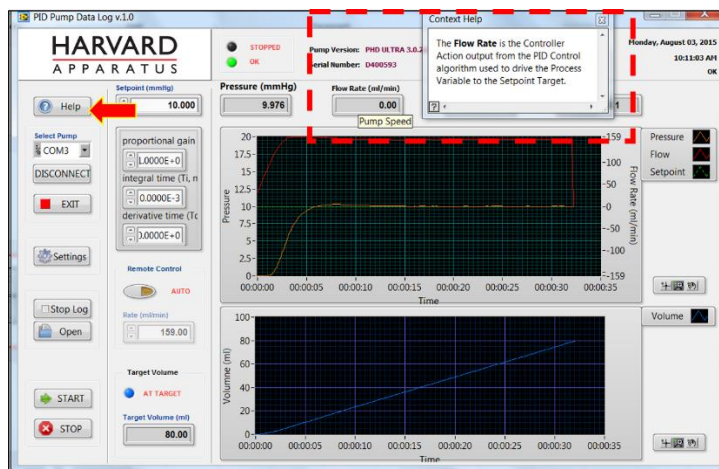
Data Log Interval: Sets the sample rate of the data log to .CSV file.

The Target Setpoint, PID gains, and Manual Control can be modified while the PID Control is running.

The Target Volume, Analog Sensor Range, Flow Rate Range, PID Loop Time, Reverse Enable, PID filters, and datalog settings can only be edited while the pump is stopped.

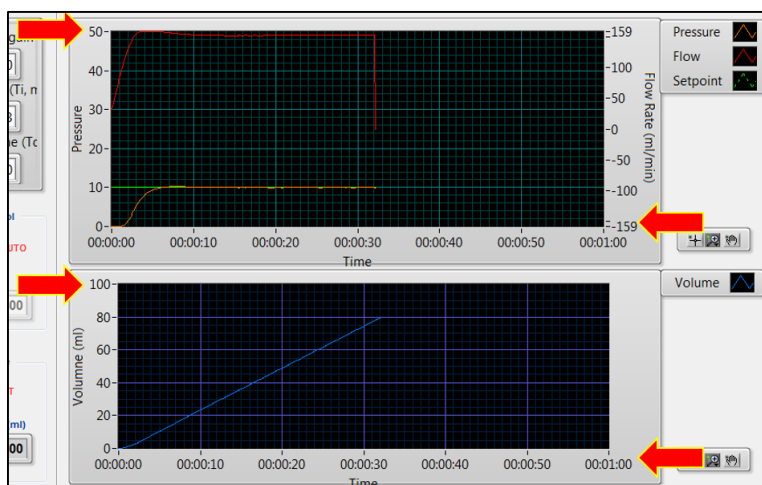
Note: the pump can be started and stopped from both the application and pump touch screen. The PID Data Log program will detect the pump telemetry over the USB, update the display and log the data to disk (if enabled).

- iv. Click the Help button to toggle the pop-up Context Help Window. Click the cursor over the item of interest and the Context Help for that item will appear.

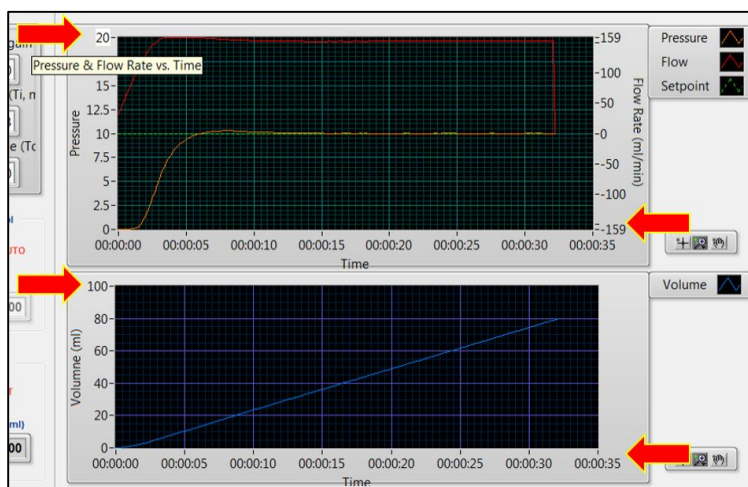


Context Help

- v. The X/Y axis parameters are adjustable in real time for both the Pressure / Flow rate vs. Time and Volume vs. Time data chart (plot) recordings. This does not change the settings on the PHD ULTRA™ CP syringe pump; it simply changes the scaling on the viewable chart. Simply select the parameter to change and enter the new parameter. The new parameter must be with the range of the set sensor.

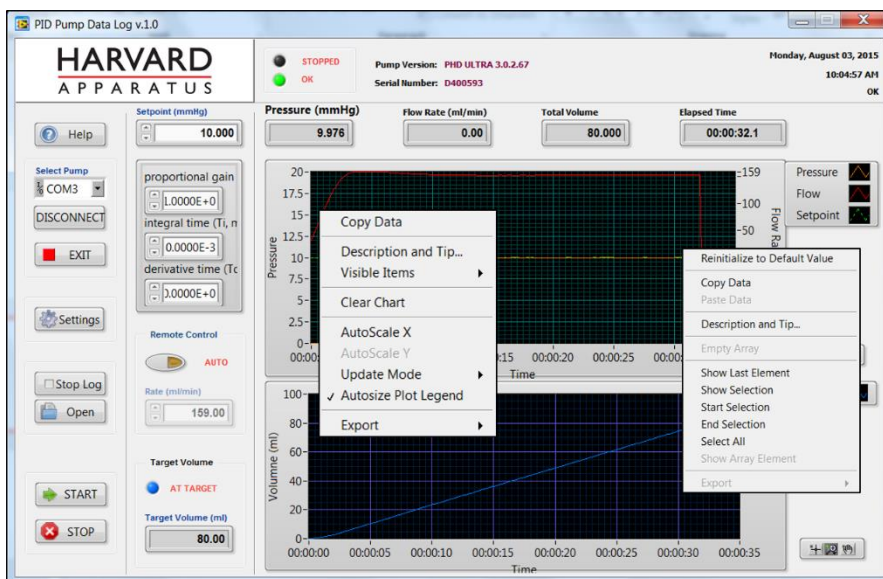


X/Y Parameters Based on Pump Settings



X/Y Parameters Adjusted in PID Pump Data Log PC Application GUI

- vi. Placing the cursor over any functional area of the GUI (graphical user interface) and performing a right click will allow access to various chart-formatting features. As with the X & Y parameters, changing these settings will only change the view of the data on the GUI of the PC application. The general "right click" functions include the following.



"Rick Click" Chart (Plot) and Plot Legend Functions

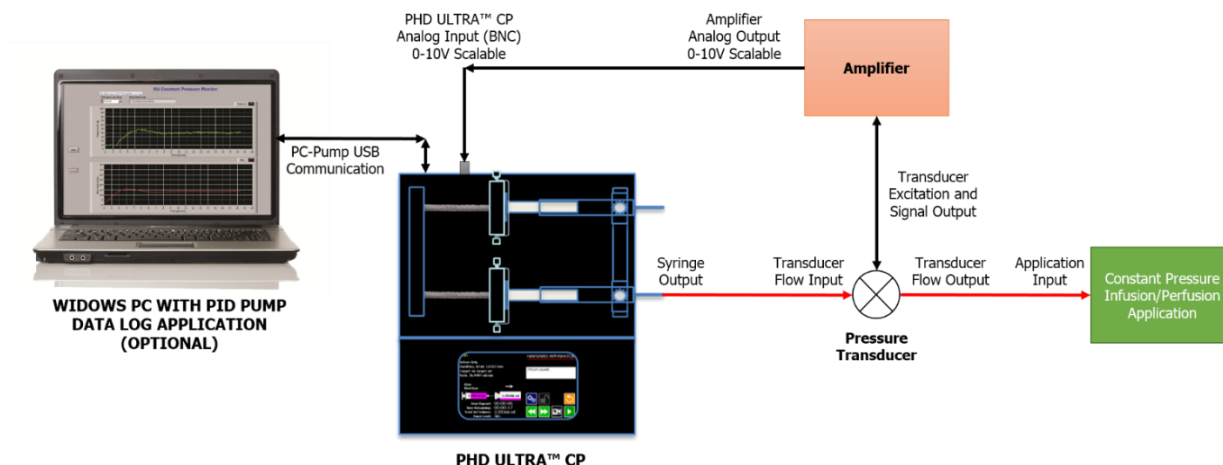
- Copy Data: Creates a snapshot picture of the chart and places it in the clipboard. This can then be pasted into another program such as Word, Excel or PowerPoint.
- Description and Tips: Place the cursor over any functional area of the GUI (graphical user interface) to see a brief description of the function.

- Visible Items: Depending on where the placement of the cursor is on the chart section of the GUI, the ability to enable/disable any plotted parameter.
- Clear Chart: Clears all data on the chart.
- Autoscale X / AutoScale Y: Automatically scales the X or Y-axis on any chart.
- Update Mode: Changes the data update mode on the chart when the chart is running.
- Autosize Plot Legend: Automatically sizes the chart based
- Export: Similar to the copy feature. Sends a picture of the chart to either Excel, computer clipboard or saves a picture of the file to a user specified location.
- Plot Legend: The user has the ability to adjust the plot legend and the look of each individual chart (color, line thickness...etc.).
- Elements and Selections: Allows the manipulation of the plot legend.

8. Example Setup

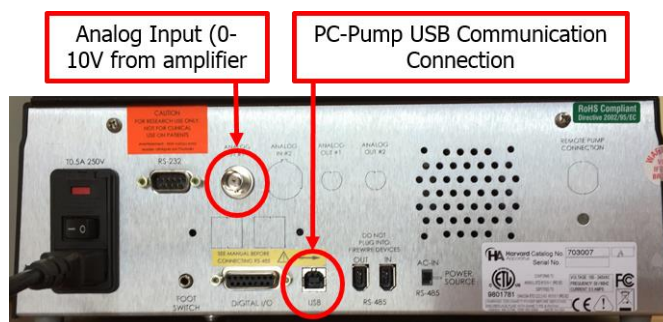
In this section, we give an example of a PHD ULTRA™ CP PID setup using a Harvard Apparatus TAM-D amplifier (Harvard Apparatus catalog number 73-1793) and APT 300 Perfusion Transducer (Harvard Apparatus catalog number 73-3862). Additional PHD ULTRA™ CP models, cases for the amplifier, and holders/stands for the sensor are available. Please contact Harvard Apparatus for additional information on available accessories.

The following is a basic block diagram of the hardware requirements along with an example using a Harvard Apparatus TAM-D amplifier and APT 300 Perfusion Transducer.



Example of a PID setup Using a Harvard Apparatus PHD ULTRA™ CP, TAM-D amplifier and APT 300 Perfusion Transducer.

- c. Connect the sensor to the amplifier and the syringe output.
- d. Connect the 0-10V analog output of the amplifier to the analog input of the PHD ULTRA™ CP. The analog input is the BNC connector found on the back of the PHD ULTRA™ CP syringe pump.
- e. Connect a PC to the pump with the supplied USB cable. The USB connection can be located on the back of the unit. (DO this only if using the PID Data Log PC application, Harvard Apparatus recommends using this application to assist in system setup.)



PHD ULTRA™ CP Analog In and USB connections

- f. Calibrate the amplifier / sensor with the PHD ULTRA™ CP. This example uses the following parameters. See section 6 for details on entering these parameters on the PHD ULTRA™ CP interface.
 - Syringe size is 100 ml
 - Volume is 80 ml
 - Setpoint is 10 mmHG
 - Sensor Range is 0 - 50 mmHG
 - Flow Rate Range (Default, min/max of syringe)
 - PID P=1, I = 0.01 & D=0

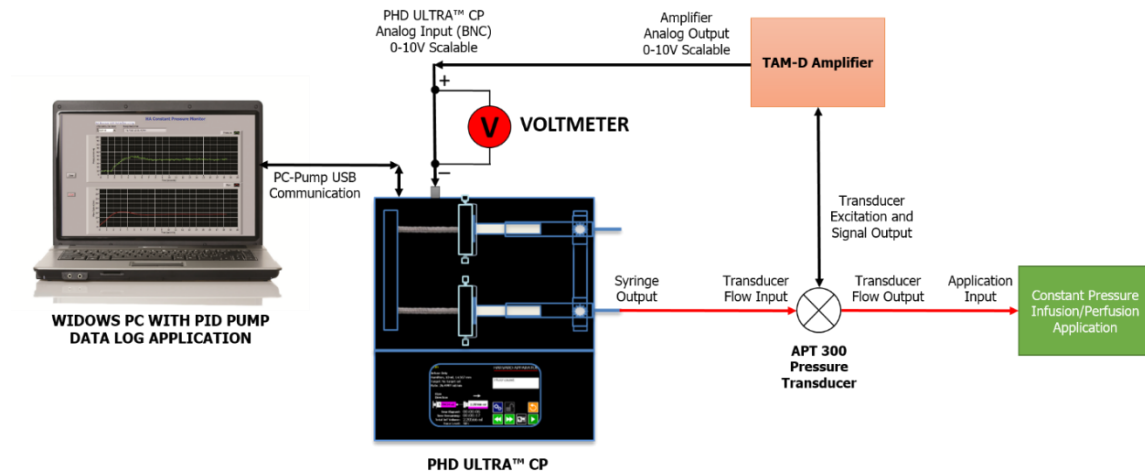
Note: Amplifier / Sensor calibration will vary based on the amplifier and sensor used. The following shows the calibration of the Harvard Apparatus TAM-D amplifier (Harvard Apparatus catalog number 73-1793) and APT 300 Perfusion Transducer (Harvard Apparatus catalog number 73-3862). Please contact your amplifier and sensor manufacturer for additional operational information.

The TAM-D ships from Harvard Apparatus calibrated with the sensor ordered with the unit. This exercise assumes that the TAM-D is calibrated for use with the APT 300.

We will now calibrate the amplifier / sensor combination to the 0 mmHG – 50 mmHG limits we specified above and in section 6.

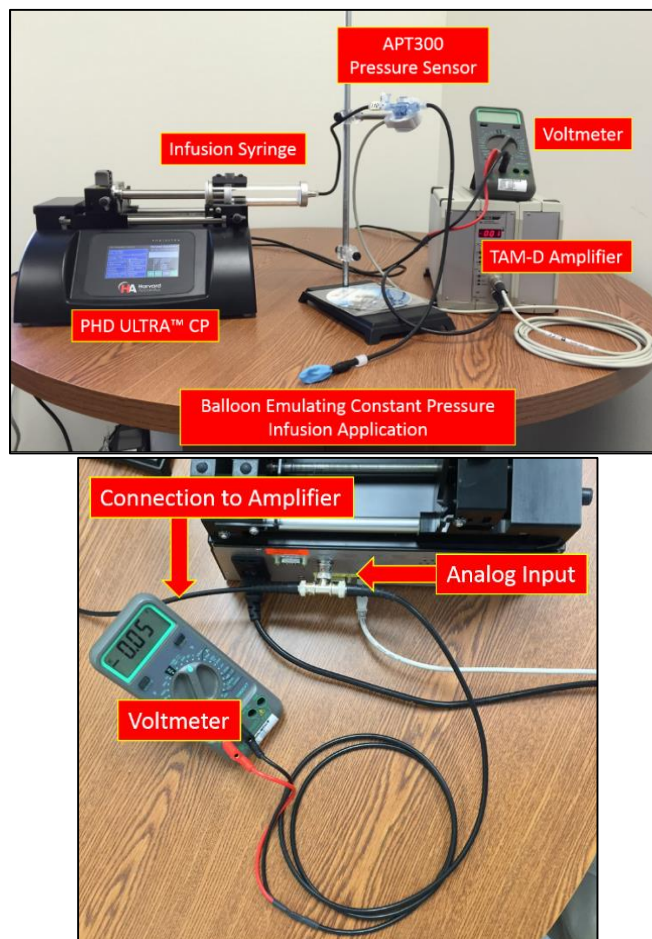
A calibrator and voltage meter are required to calibrate the TAM-D / APT 300 with the PHD ULTRA™ CP. This exercise used the Harvard Apparatus Manual Pressure Calibrator, catalog number 73-4479 and a standard voltage meter. Connect the voltage meter in parallel with the Analog Input BNC connector on the back of the unit. In this case, we used a BNC T connector to split the signal for measurement.

The following is a modified block diagram showing the connection of the voltage meter along with a picture of the actual connection.



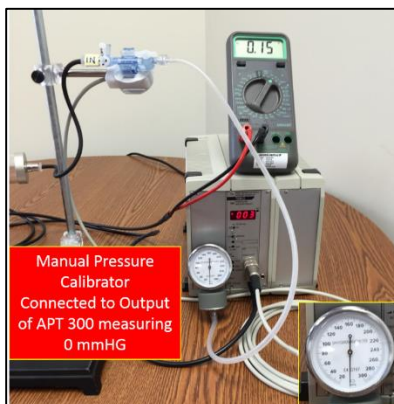
Block Diagram with Voltmeter Setup - PHD ULTRA™ CP, TAM-D and APT 300.

The following is the representative equipment for this setup. The blue balloon connected to the output of the APT 300 emulates an infusion application.



Entire Setup and Rear View of PHD ULTRA™ CP with Analog Input and Voltmeter Connection

- i. Power on the PHD ULTRA™ CP, TAM-D and voltmeter.
- ii. Attach the Harvard Apparatus Manual Pressure Calibrator, catalog number 73-4479 to the output of the APT300 Pressure Sensor as shown below. The pressure reading should be 0 mmHG, since the syringe pump is not running; there is no pressure in the system.

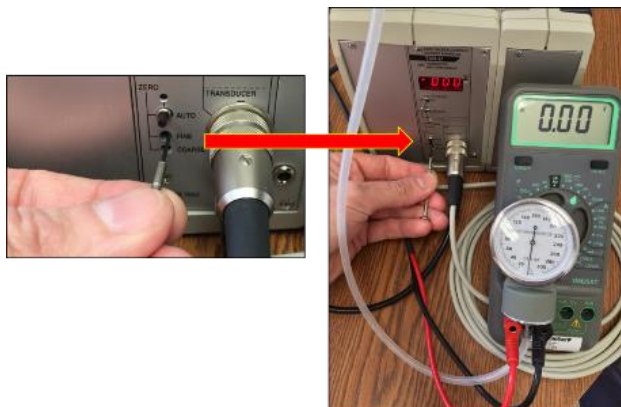


Harvard Apparatus Manual Pressure Calibrator Reading 0 mmHG

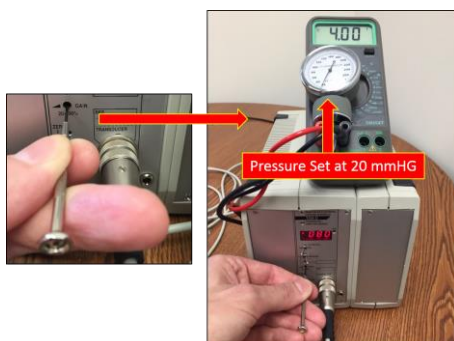
- iii. Switch the CAL/MEASURE toggle switch on the TAM-D to MEASURE.



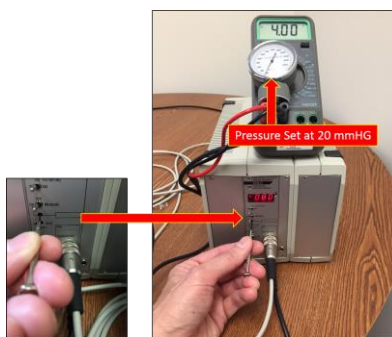
- iv. Using a small flat head screwdriver, adjust the FINE and/or COURSE adjustment until the voltmeter reads 0 V.



- v. Apply a known pressure of 20 mmHG by pressing the fast forward button on the PHD ULTRA™. If the pressure overshoots then press the fast reverse button to adjust. We will now set 20 mmHG to equal 4V. The reason for this is that the PHD ULTRA™ CP Analog Input has a range of 0-10V. The pressure range we wish to use is 0 - 50 mmHG. Therefore, if we set 4 V to equal 20 mmHG then the 0 – 50 mmHG scale we want will be set and calibrated. To explain the calculation, we take the total scale of 50 mmHG and divide it by our chosen calibration factor of 20 mmHG. This gives us a factor of 2.5. If we multiply the 2.5 factor by 4 V then we get our total analog input voltage span of 0-10 V, which will represent our desired pressure range of 0 mmHG – 50 mmHG.
- vi. Adjust the Gain screw with a small flat head screwdriver until the voltmeter reads 4 V.



- vii. Now that we have set the sensor voltage, we now need to calibrate the amplifier voltage to match. Switch the CAL/MEASURE toggle switch on the TAM-D to CAL. Adjust the CAL screw until the voltmeter reads 4 V.

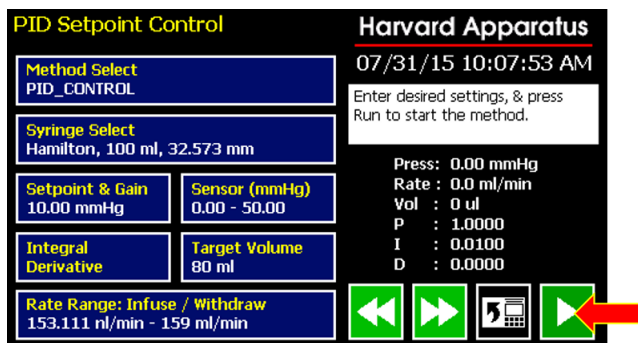


- viii. Switch the CAL/MEASURE toggle switch on the TAM-D back to MEASURE. The TAM-D and APT 300 are now calibrated for a 0 – 50 mmHG scale.

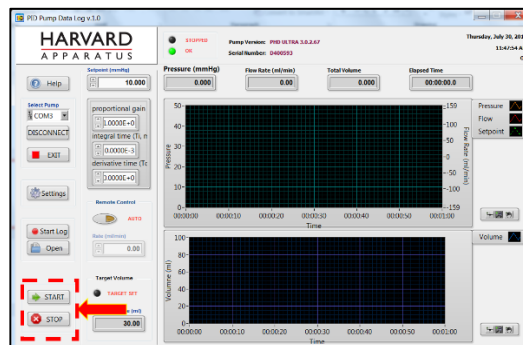


Assuming the pump has been set with the parameters we discussed in sections 6 & 7d, we can now run our experiment.

- ix. Running the Experiment: There are two ways to start the experiment. The first is through the PHD ULTRA™ CP GUI (graphical user interface) and the second is through the PC application. However, if you want to run the datalog feature, the Start Log button must be engaged before the experiment starts. To start the experiment, simply press the Run button on the PHD ULTRA™ CP or press the Start button found in the lower left hand corner of the PID Data Log Application.



Pump GUI Run Button



PC Application Start Button

Both screens show set parameters. As the experiment is running, the Pressure, Flow Rate and Volume dispensed will be updated and displayed on both the PHD ULTRA™ CP GUI and PC application. The charts (plots) will update in real time.

Section 6e discussed the impact of the PID settings on the ability of the pressure infusion to maintain the pressure setpoint. The X/Y settings on the following graphs (plots) have been adjusted to offer better resolution of the Pressure parameter (see section 7b). On the PC application, the Pressure parameter was adjusted from 50 mmHG maximum to 15 mmHG and the time scale was adjusted to 40 seconds.

The following summarizes section 6e.

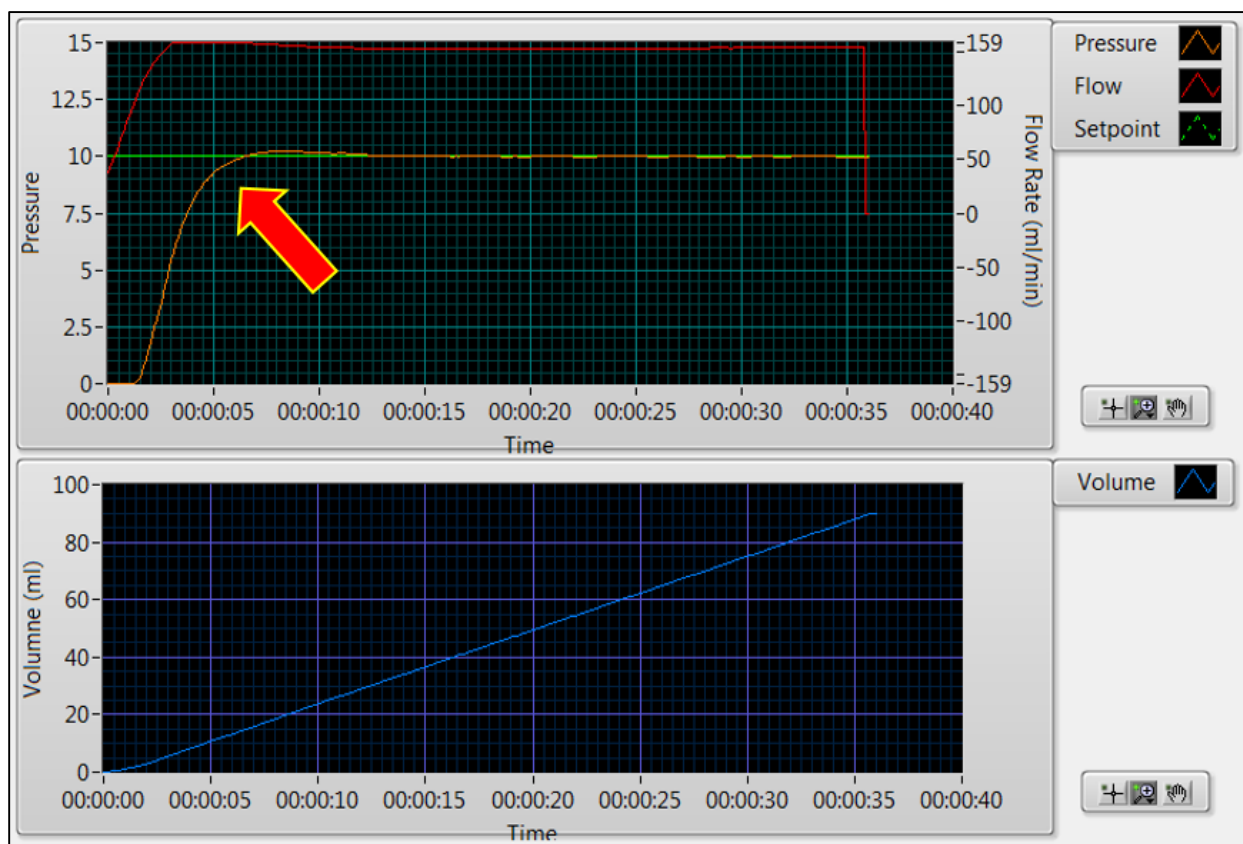
The Proportional Gain "P" term produces an output value that is proportional to the current error value.

The Integral time "I" term accelerates the output pressure towards the entered setpoint and helps mathematically eliminate the error that can occur in the PID controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the setpoint value. Adjusting the Integral time will help to mitigate overshoot.

The Derivative "D" term predicts system behavior and thus improves settling time and stability of the system. An estimated 25% of controllers use a Derivative time setting. The lower use of this term is due to its variable impact on system stability in real-world applications.

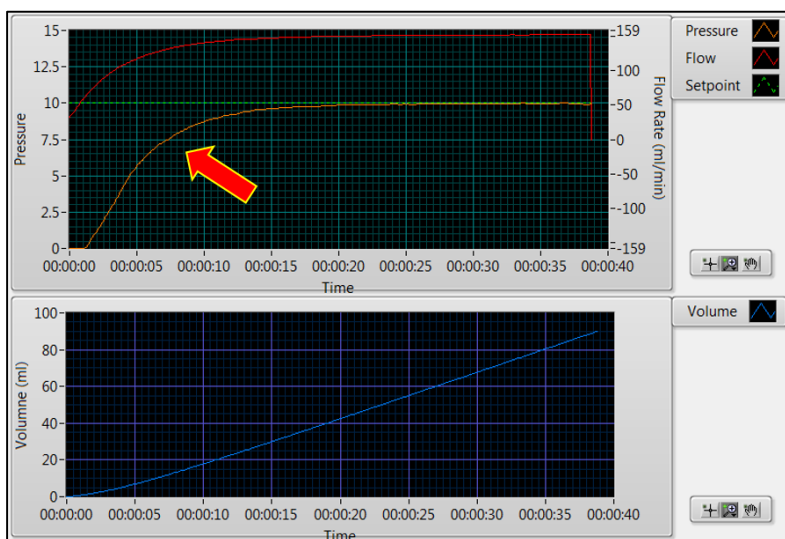
The following are examples of the impact of the PID settings on the output pressure Chart (plot). The examples focus on the time to get to the setpoint pressure along with the overshoot and stability of the pressure controlled flow as the pressure reaches the steady state value in the experiment. **Note: The following examples may or may not work for the specific experiment being performed. It is important to experiemnt to find the best PID settings for the application.**

Example 1: PID Settings P (Proportional) = 1, I (Integral) = 10 ms, D (Derivative) 0 ms
In this example, we see a smooth transision to the steady state pressure setpoint. Due to the transition from 0 mmHG to 10 mmHG, the PID loop takes this transision as error and causes a slight overshoot before settling to the steady state pressure.



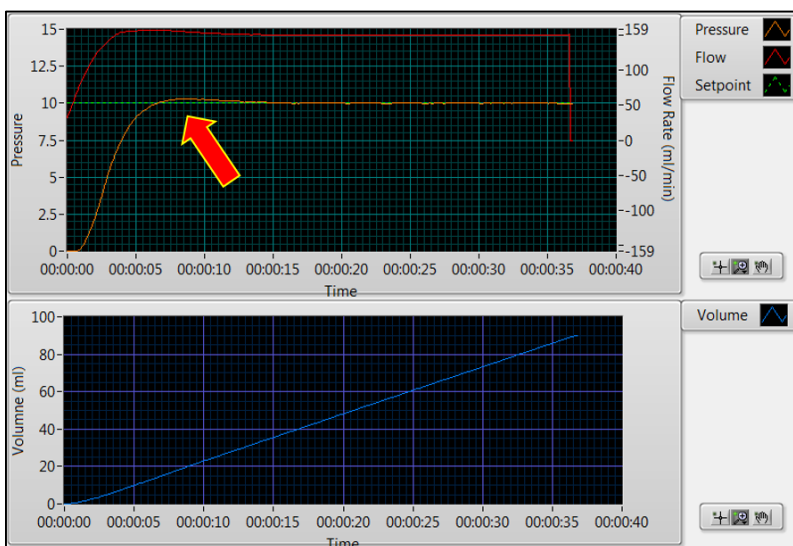
Example 1: PID Settings P (Proportional) = 1, I (Integral) = 10 ms, D (Derivative) = 0 ms

Example 2: PID Settings P (Proportional) = 1, I (Integral) = 20 ms, D (Derivative) = 0 ms
In this example, we see a smooth transition to the steady state pressure setpoint. Due to the higher "I" setting, there is more delay to process the errors as the pressure climbs to the steady state pressure. This provides a slower response to a change in pressure. Increasing the "I" time further will casue a slower rise time. Too large of an integral time setting and the pressure may take a very long time to reach the steady state value.



Example 2: PID Settings P (Proportional) = 1, I (Integral) = 20 ms & D (Derivative) = 0 ms

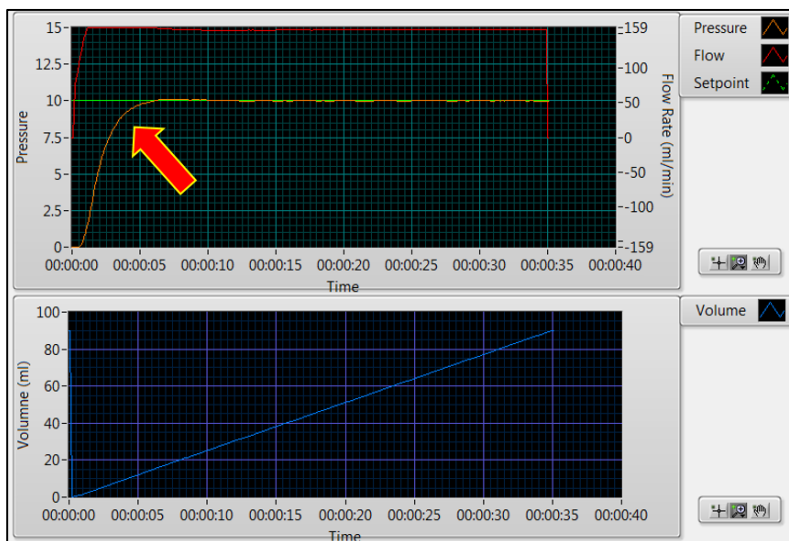
Example 3: PID Settings P (Proportional) = 1, I (Integral) = 10 ms & D (Derivative) = 10 ms
In this example, we see a smooth transition to the steady state pressure setpoint. Due to the derivative time setting of 10 ms, the PID loop estimated future error and compensated. However, there was overshoot and the settling time was a few seconds slower than example 1, where we had a "D" of 0 ms.



Example 3: PID Settings P (Proportional) = 1, I (Integral) = 10 ms, D (Derivative) = 10 ms

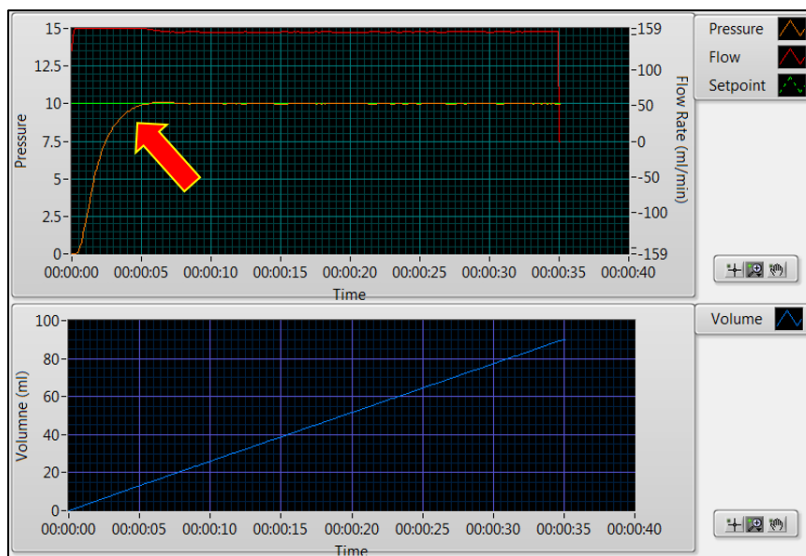
Example 4: PID Settings P (Proportional) = 2, I (Integral) = 10 ms, D (Derivative) = 0 mS

Examples 4 & 5 show the output when the proportional gain is increased. In this application, there was no impact since there was a low error value for this experiment. A higher Proportioanl Gain will provide a more unstable system if an error occurs. It is recommended that this parameter is kept at a gain of 1.



Example 4: PID Settings P (Proportional) = 2, I (Integral) = 10 ms, D (Derivative) = 10 mS

Example 5: PID Settings P (Proportional) = 4, I (Integral) = 10 ms & D (Derivative) = 0 mS



Example 5: PID Settings P (Proportional) = 4, I (Integral) = 10 ms & D (Derivative) = 10 mS

9. Appendix

The following equipment was used in the experiments detailed in this addendum.

- PHD ULTRA™ CP Dual Syringe Infuse/Withdraw Programmable syringe pump, Harvard Apparatus catalog number 88-3015.
- TAM-A Transducer Amplification Module, Harvard Apparatus catalog number 73-0065 and PLUGSYS Minicase, Type 609, Harvard Apparatus catalog number 73-1523.
- APT300 Pressure Transducer for PLUGSYS TAM Amplifier, Harvard Apparatus catalog number 73-3862.

PHD ULTRA CONSTANT PRESSURE SYRINGE PUMPS

Specifications	PHD ULTRA™ CP	PHD ULTRA™ CP Remote	PHD ULTRA™ CP 4400	PHD ULTRA™ CP 4400 Remote	PHD ULTRA™ CP HPSI Remote	PHD ULTRA™ XF-CP Remote
TYPE	Microprocessor, multiple syringe, infusion/withdrawal, programmable	Microprocessor, multiple syringe, infusion/withdrawal, programmable	Microprocessor, multiple syringe, infusion/withdrawal, programmable	Microprocessor, multiple syringe, infusion/withdrawal, programmable	Microprocessor, multiple syringe, infusion/withdrawal, programmable	Microprocessor, multiple syringe, infusion/withdrawal, programmable
FLOW ACCURACY	±0.25%	±0.25%	±0.35%	±0.35%	±0.5%	±0.5%
PRESSURE ACCURACY	< ±2%	< ±2%	< ±2%	< ±2%	< ±2%	< ±2%
SYRINGE SIZE, MIX/ MAX	0.5 µl to 140 ml	0.5 µl to 140 ml	0.5 µl to 140 ml	0.5 µl to 140 ml	20 ml to 200 ml	20 ml to 200 ml
# SYRINGES	2-10	2-10	1	1	1-4	1-4
FLOW RATE:						
MINIMUM	1.50 pL/min	1.50 pL/min	3.06 pL/min	3.06 pL/min	50.79 nL/min	50.79 nL/min
MAXIMUM	216.0 mL/min	216.0 mL/min	216.0 mL/min	216.0 mL/min	144.3 mL/min	144.3 mL/min
CONNECTORS:						
USB (PC-to-Pump)	Type B	Type B	Type B	Type B	Type B	Type B
RS-232 (PC-to-Pump)	9-pin D-Sub	9-pin D-Sub	9-pin D-Sub	9-pin D-Sub	9-pin D-Sub	9-pin D-Sub
RS-485* (Pump-to-Pump)	IEEE-1394, 6 pos	IEEE-1394, 6 pos	IEEE-1394, 6 pos	IEEE-1394, 6 pos	IEEE-1394, 6 pos	IEEE-1394, 6 pos
I/O & TTL	15-pin D-Sub	15-pin D-Sub	15-pin D-Sub	15-pin D-Sub	15-pin D-Sub	15-pin D-Sub
AVERAGE LINEAR FORCE	34 kg (75 lbs) at 100%	34 kg (75 lbs) at 100%	91 kg (200 lbs) at 100%	91 kg (200 lbs) at 100%	200 kg (433 lbs) at 100%	454.5 kg (1,000 lbs) at 100%
MAXIMUM PRESSURE (with 100 ml Syringe)	50 psi	50 psi	135 psi	135 psi	290 psi	670 psi
DIMENSIONS CONTROL BOX	30.5 x 21.6 x 17.8 cm (12 x 8.5 x 7 in)	30.5 x 21.6 x 10.6 cm (12 x 8.5 x 4.3 in)	30.5 x 21.6 x 10.6 cm (12 x 8.5 x 4.3 in)	30.5 x 21.6 x 18.5 cm (12 x 8.5 x 7.3 in)	30.5 x 21.6 x 10.6 cm (12 x 8.5 x 4.3 in)	30.5 x 21.6 x 10.6 cm (12 x 8.5 x 4.3 in)
DIMENSIONS REMOTE BOX	N/A	30.5 x 14 x 16.5 cm (12 x 5.5 x 6.5 in)	N/A	30.5 x 14 x 17.8 cm (12 x 5.5 x 7 in)	41.9 x 30.5 x 19.1 cm (16.5 x 12 x 7.5 in)	41.9 x 30.5 x 19.1 cm (16.5 x 12 x 7.5 in)
WEIGHT	4.5 kg (10 lbs)	4.8 kg (10.5 lbs)	5.4 kg (12 lbs)	7.7 kg (17 lbs)	13.6 kg (30 lbs)	20.9 kg (46 lbs)
VOLTAGE RANGE	100-240 VAC; 50/60 Hz	100-240 VAC; 50/60 Hz	100-240 VAC; 50/60 Hz	100-240 VAC; 50/60 Hz	100-240 VAC; 50/60 Hz	100-240 VAC; 50/60 Hz
Order #	PC3 88-3015	PC3 88-3315	PC3 88-3016	PC3 88-3316	PC3 88-3113	PC3 88-3314

Harvard Apparatus offers additional PHD ULTRA CP models, amplifiers, sensors and calibrators. For additional information, please visit our website at www.harvardapparatus.com. You can also contact our world-class Harvard Apparatus Applications and Technical Support Team by calling 800-597-0580 or emailing support@hbiosci.com.