

G3 LHG



User Guide

Document History

Revision History

Revision Number	Revision Date	Summary of Changes	Author
preliminary	25 Apr 2018	Initial	Bob

Table of Contents

1	Introduction	5
1.1	Background of Humidity Generation	5
1.2	Two-temperature principle	5
1.3	The RHS hybrid two-pressure, two-temperature principle.....	6
1.4	G3 Design.....	7
1.5	Common Defining Equations	10
1.6	Humidity Equations.....	13
2	System Identification and Component Location.....	16
2.1	Computer Monitor and Keyboard	16
2.2	Outside View of Panels	18
2.3	Inside View of Panels.....	19
2.4	Major System Components	20
3	Installation.....	22
3.1	Facility Requirements.....	22
3.2	Uncrating.....	22
3.3	Connection of PC and Auxiliary Components	24
3.4	Unlocking Vacuum Pump	25
3.5	Back Panel Connections	27
4	Quick Start.....	29
4.1	Power on.....	29
4.2	Introduction to RHS Control	30
4.3	Connection Window.....	30
4.4	Initializing Vacuum.....	30
4.5	Purge Mode	31
4.6	Generate.....	31
4.7	Viewing Data Numerically and Graphically	31
4.8	Idle mode	32
4.9	Power off.....	32
5	Operation.....	33
5.1	Details of Operation using RHS Control.....	33
5.2	Apply Vacuum	35
5.3	Fill, Chill, and Purge	36

5.4	Selecting Humidity Control Mode	38
5.5	Changing Set Points	40
5.6	Purge.....	40
5.7	Generate.....	41
5.8	Connection of Other Instruments	41
5.9	Auto-profiling.....	41
5.10	Viewing Data	41
5.11	Data Files	42
6	Model G3 Sub-Systems.....	43
6.1	Electrical System	43
6.2	Pneumatic System	46
6.3	Saturator Temperature Control System	50
6.4	Auxiliary Heaters.....	50
6.5	Main Controller Board	51
6.6	Temperature Measurements	52
6.7	Analog Output Module.....	53
6.8	Solenoid Control Relay	53
6.9	Stirling Controllers	53
7	Calibration.....	55
7.1	Pressure Calibration.....	55
7.2	Temperature Calibration.....	58
8	Vacuum Chamber.....	61
8.1	Opening the Vacuum Chamber	61
8.2	Closing Vacuum Chamber	63
9	Parts List.....	65
10	Drawings	69

1 Introduction

The RH Systems G3 Humidity Generator is a system capable of continuous, high-accuracy humidity generation over a wide range of humidity, temperature, and flow rates. The G3 design is an RHS hybrid two-pressure two-temperature system based on the fundamental two-pressure principle originally developed by NIST. The basis of this principle and its original development are discussed below.

1.1 Background of Humidity Generation

In 1948 at the U.S. National Bureau of Standards (now the National Institute of Standards and Technology), E.R. Weaver and R. Riley developed a “pressure method” for the generation and control of humidity. Their method, termed the *two-pressure principle*, was derived from measurements of temperature and pressure rather than requiring measurements of water vapor.

Using their technique, air or some other gas was saturated with water vapor at high pressure and then expanded to a lower pressure. When saturation and expansion were performed under constant-temperature conditions, the resulting relative humidity of the gas was simply the ratio of the lower pressure to the higher pressure (or at least very nearly).

Their equipment was designed for low rates of gas flow and was used under ambient temperature conditions. Their saturator was a small cylinder containing water and filled with fragments of pumice or stream-washed gravel through which the gas could be bubbled under pressure. This device was developed primarily for the calibration of electrically conductive hygroscopic films used in the measurement of water vapor in gases.

In 1951, also at the National Bureau of Standards, the two-pressure principle was the foundation on which A. Wexler and R.D. Daniels developed a new “pressure–humidity apparatus” with higher air-flow capability. Another significant improvement was the incorporation of temperature control. Developed primarily for hygrometer research and calibration, it was capable of producing atmospheres of known relative humidity from 10 %RH to 98 %RH over a fairly wide temperature range -40°C to $+40^{\circ}\text{C}$.

Wexler also designed and constructed a low-humidity generator based on a method termed the *two-temperature principle*. With the two-temperature principle, a stream of air or other gas is saturated with water vapor at a given temperature; then its temperature is raised to a specified higher value.

1.2 Two-temperature principle

In a two-temperature system, such as that shown in Figure 1, a stream of gas is saturated with respect to the liquid or solid phase of water at a low temperature and then warmed isobarically to a higher temperature for use. Measurements of the temperature and pressure of the cool, saturated gas stream, and in the warmer test chamber (or other point of use), are all that is required to determine the resulting humidity content of the gas stream.

Ideally, a two-temperature system exhibits no significant pressure difference between the saturator and chamber (or other point of use). Therefore, under ideal conditions, the dew point or frost point of the gas is effectively equal to the saturation temperature and may be expressed by

$$T_d \approx T_s \text{ for } T_s \geq 0.01^{\circ}\text{C}$$

$$T_f \approx T_s \text{ for } T_s \leq 0.01^{\circ}\text{C}$$

where T_d is the dew point temperature, T_f is the frost point temperature, and T_s is the saturation temperature.

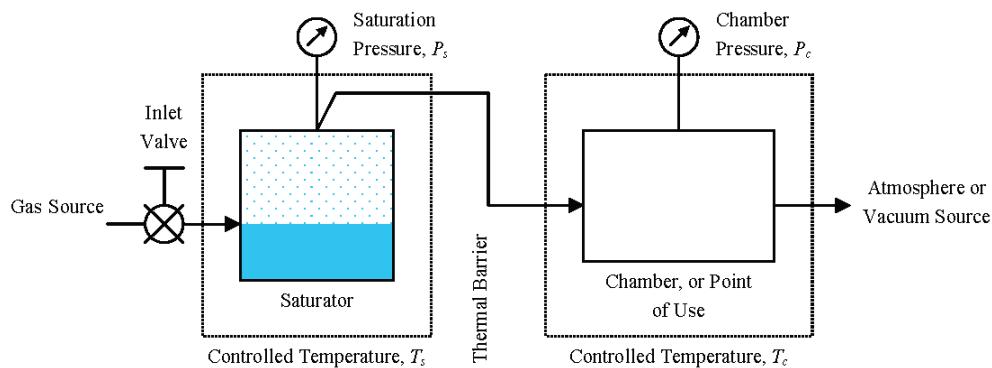


Figure 1—Simplified schematic diagram of the two-temperature principle where $P_s = P_c$.

Although dew point and frost point are easily approximated in a two-temperature system by the above equations, it is always best to measure the saturation and chamber pressures as well and then to treat the generator computationally as a combined two-pressure, two-temperature system. For this reason, all humidity equations presented in the later parts of this document are for combined two-pressure, two-temperature systems. A two-temperature system is a simplified implementation of the combined two-pressure, two-temperature principle.

1.3 The RHS hybrid two-pressure, two-temperature principle

Regardless of a generator's classification (two-pressure or two-temperature), temperature and pressure components should always be taken into account. Even though the temperatures or the pressures are *ideally* equal in a given generator design, temperature and pressure differences generally exist between the saturator and chamber.

Hybrid generators that combine the features of the two-pressure and two-temperature principles exploit the benefits of controlling temperature and pressure independently. In a hybrid generator, a stream of gas at an elevated pressure is saturated with respect to the liquid or solid phase of water at a given saturation temperature. Then the gas stream is expanded to a lower pressure and alternate temperature. Measurements of the pressure and temperature of the saturated gas stream, both at saturation and after expansion, are all that is required to determine the resulting humidity content of the gas stream.

In a hybrid generator, there are no ideal assumptions of pressure or temperature equality, as in the two-temperature principle. Thus, there is no direct simplification that can be made regarding the ideal humidity relationships between the dew or frost point temperature and saturation temperature, as with the two-temperature principle.

Since computing power is generally not a limiting factor, it is always best to use the mathematics of combined two-pressure, two-temperature principles in determining all generated parameters.

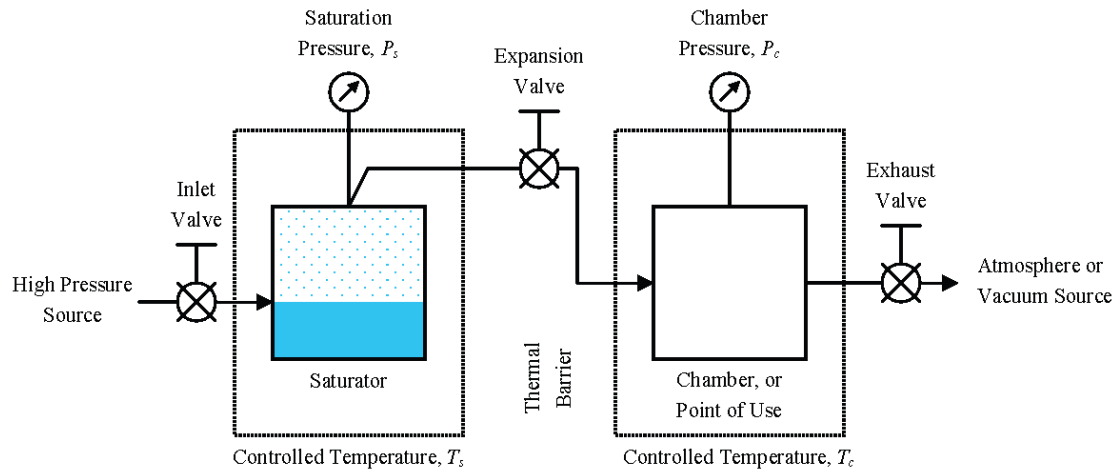


Figure 2—Simplified schematic diagram of the two-pressure, two-temperature principle where $T_s \neq T_c$ and $P_s \neq P_c$.

1.4 G3 Design

The G3, as depicted in figure 3, follows an overall design based on NIST two pressure and two temperature principles. Utilizing these principles, a stream of gas at an elevated pressure is saturated with respect to the liquid or solid phase of water at a given saturation temperature. Here, saturation temperature is the major determining factor for the quantity of water vapor admixed with the carrier gas. Pressure within the saturator is the major determining factor for the carrier gas quantity of the mixture. The humidified gas stream is then expanded to a lower pressure and warmed to an alternate temperature. Measurements of the pressure and temperature within the saturator, and the pressure and temperature following expansion (generally at the DUT), are all that is required to determine the resulting humidity content

The G3 receives an input gas (or carrier gas) at its Gas Inlet connection on the rear panel. Gas is mechanically regulated to a manually set pressure which is displayed on the mechanical pressure gauge P_r and is also measured electronically on the air-in pressure sensor P_{ai} . A mechanical over-pressure relief valve protects from accidental over pressure above 200 psig. Gas flows through the pressure controller which maintains, based on its setpoint, a downstream pressure within the saturator.

Depending on the mode, gas flows either through the Gen or Purge connection of the Gen/Purge valve, through the saturator, and finally to the flow controller. The flow rate of the gas leaving the Gas Outlet on the front panel is determined by the setpoint of the flow controller.

Saturator temperature is maintained by two stirling coolers (not shown) on the top and bottom of the saturator. Heaters are also attached there. The coolers and heaters work in tandem to provide temperature regulation of the saturator.

The saturator is a thermally controlled stacked plate unit that acts both as a heat exchanger to cool the incoming gas to saturator temperature, and as a means to allow the input gas to admix with water vapor at that same temperature.

Saturation temperature controls the partial pressure of water vapor within the saturator. The gas pressure controls the partial pressure of the background gas. The ratio of the two partial pressures (water vapor

pressure to background gas pressure) determines the mixing ratio and ultimately the humidity content of the exit gas.

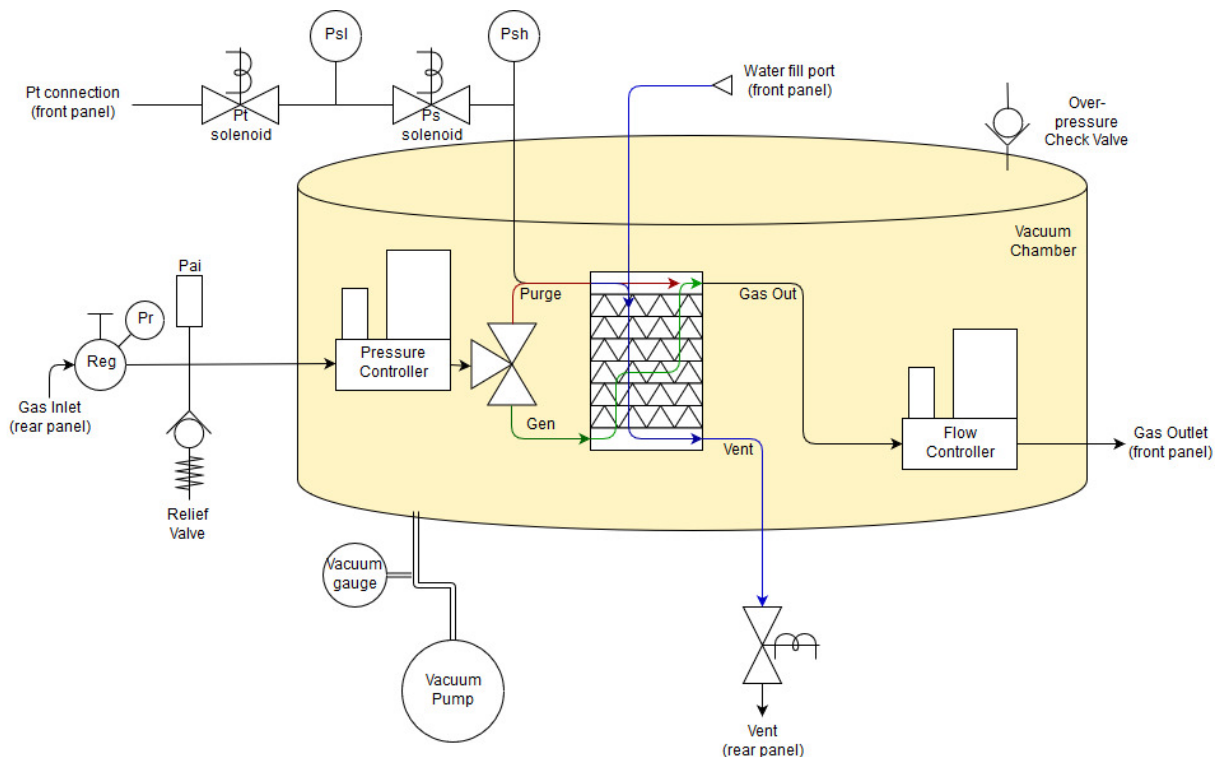


Figure 3—Pneumatic diagram of the G3 two-pressure, two-temperature system.

The electronic controls provide for automatic humidity generation based on desired humidity setpoints. The operator adjusts the desired exit flow rate setpoint and the desired dew point in the exit gas. The embedded computer control provides the computations needed to create the saturator temperature and saturator pressure PID control setpoints to achieve the desired gas dewpoint and flow rate. Through the use of appropriate mathematical algorithms within custom software programming, automated setpoint determination is employed to achieve and maintain any humidity value desired within the range of capability of the humidity generator. Although automatically determined by the computer, the operator may over-ride specific setpoints of temperature and pressure, allowing for customized testing functionality. The operator also has full control over the exit flow rate setpoint. While not controlled, both the temperature and pressure of the gas stream at the DUT are monitored, and appropriate adjustments are made to ensure the setpoints of saturator temperature and pressure are adjusted accordingly to maintain steady humidity control at the DUT.

The G3 has a unique design based on the compact FPSC Stirling cooler units utilized for saturator cooling. Typical outlet temperatures needed from the Stirling coolers are +10 °C to as low as -100 °C.

Uncertainty of the pressure measurements plays an important role in the accuracy of generated humidity. The humidity in the outlet stream is based on the absolute outlet pressure and also on the ratio of saturator to outlet (DUT) pressure. For these measurement, the system utilizes pressure sensors of 0.01% full scale accuracy. In addition, when the saturator pressure is low and within the range of the lower pressure sensor, this sensor is utilized for both the saturator and test pressures in a time-shared basis. This time-sharing of a single pressure transducer eliminates problems normally associated with differences in zero-drift between separate transducers.

The saturator input pressure is maintained to the desired value by the pressure controller. As there may be a slight pressure drop as the gas passes through the saturator, the saturator pressure used within humidity computations is measured by a pressure sensor nearest the saturator exhaust. Differences between the controlled saturator inlet pressure and the resulting saturator outlet pressure are used to adjust the saturator inlet pressure setpoint to compensated for the pressure drop. This ensures the saturator pressure nearest the saturator outlet reaches desired saturator pressure setpoint.

Uncertainty of the saturator temperature measurement is very important to the humidity in the exit gas stream. All generated humidity parameters such as dew point and frost point temperature are dependent on saturator temperature, while other values such as %Relative Humidity are also dependent on temperature of the gas at the DUT. In the case where both the saturator and DUT temperatures are required, uncertainty of both temperatures must be considered.

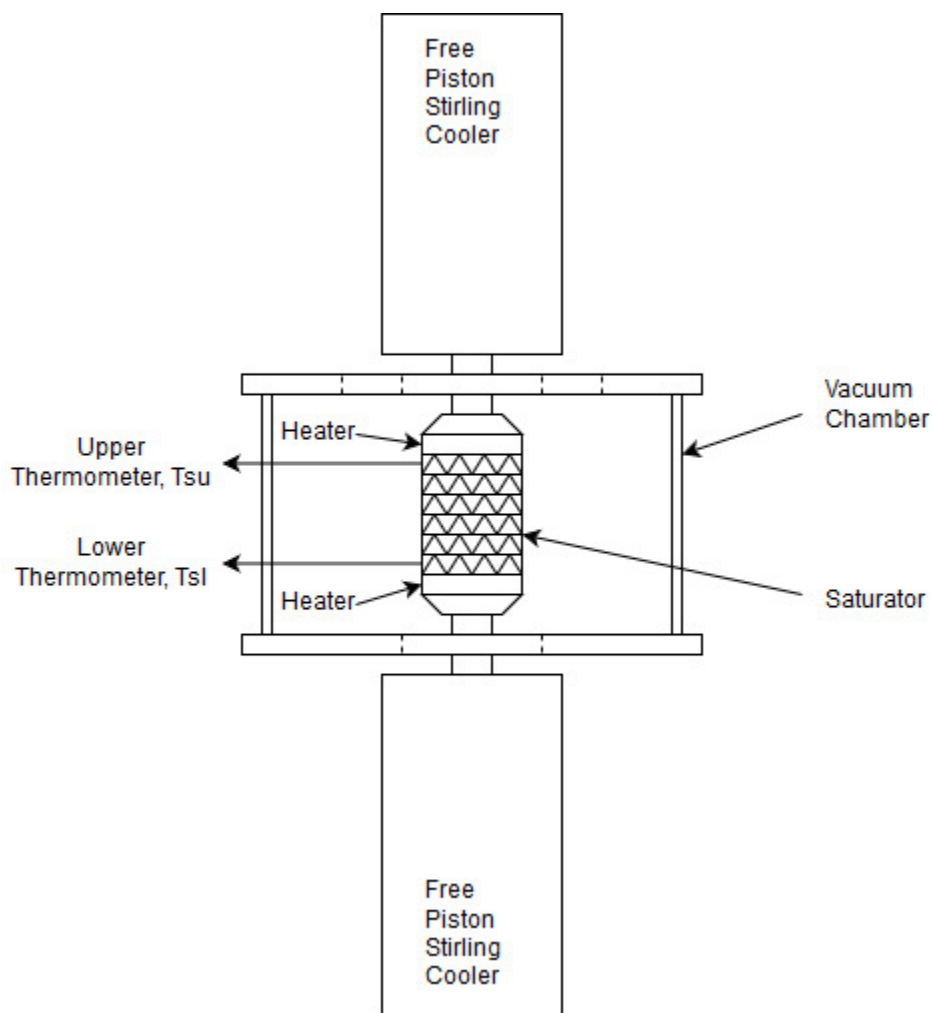


Figure 4—Thermal diagram of the G3 two-pressure, two-temperature system.

Saturator temperature is maintained by control of the Stirling coolers attached to the inlet and outlet plates of the saturator, and by heaters attached in the same locations as depicted in figure 4. The coolers and heaters work in tandem to produce stable temperatures at both the saturator inlet and outlet.

The vacuum chamber surrounding the saturator and other components serves both as a thermal isolator for the saturator, and as a barrier to prevent permeation of water vapor into the gas stream.

1.5 Common Defining Equations

The following equations of R. Hardy for saturation vapor pressure, enhancement factor, and temperature (from saturation vapor pressure) are common and fundamental to most of the humidity calculations presented here.

1.5.1 Saturation Vapor Pressure over Water

Saturation vapor pressure over *water* at a given ITS-90 temperature in the range $-100\text{ }^{\circ}\text{C}$ to $+100\text{ }^{\circ}\text{C}$ is defined by the formula

$$e = \exp\left(\sum_{i=0}^6 g_i T^{i-2} + g_7 \ln T\right) \quad (1)$$

where e is the saturation vapor pressure (in Pascals) over liquid water in the pure phase
 T is the temperature in Kelvin

and

$$\begin{aligned} g_0 &= -2.8365744 \cdot 10^3 \\ g_1 &= -6.028076559 \cdot 10^3 \\ g_2 &= 1.954263612 \cdot 10^1 \\ g_3 &= -2.737830188 \cdot 10^{-2} \\ g_4 &= 1.6261698 \cdot 10^{-5} \\ g_5 &= 7.0229056 \cdot 10^{-10} \\ g_6 &= -1.8680009 \cdot 10^{-13} \\ g_7 &= 2.7150305 \end{aligned}$$

1.5.2 Saturation Vapor Pressure over Ice

Saturation vapor pressure over *ice* at a given ITS-90 temperature in the range $-100\text{ }^{\circ}\text{C}$ to $0.01\text{ }^{\circ}\text{C}$ is defined by the formula

$$e = \exp\left(\sum_{i=0}^4 k_i T^{i-1} + k_5 \ln T\right) \quad (2)$$

where e is the saturation vapor pressure (in Pascals) over ice in the pure phase
 T is the temperature in Kelvin

and

$$\begin{aligned} k_0 &= -5.8666426 \cdot 10^3 \\ k_1 &= 2.232870244 \cdot 10^1 \\ k_2 &= 1.39387003 \cdot 10^{-2} \\ k_3 &= -3.4262402 \cdot 10^{-5} \\ k_4 &= 2.7040955 \cdot 10^{-8} \\ k_5 &= 6.7063522 \cdot 10^{-1} \end{aligned}$$

1.5.3 Enhancement Factor

The “effective” saturation vapor pressure over water or ice in the presence of other gases differs from the ideal saturation vapor pressures given in Equations 1 and 2. The effective saturation vapor pressure is related to the ideal by

$$\dot{e} = e \cdot f \quad (3)$$

where \dot{e} is the “effective” saturation vapor pressure
 e is the ideal saturation vapor pressure (as given in Equation 1 or 2)
 and f is the enhancement factor

The enhancement factor, for an air and water-vapor mixture, is determined at a given temperature and pressure from the formula

$$f = \exp \left[\alpha \left(1 - \frac{e}{P} \right) + \beta \left(\frac{P}{e} - 1 \right) \right] \quad (4)$$

$$\text{with } \alpha = \sum_{i=0}^3 a_i T^i \quad (5)$$

$$\text{and } \beta = \exp \left(\sum_{i=0}^3 b_i T^i \right) \quad (6)$$

where P is the total pressure in the same units as e
 T is temperature in Kelvin
 and a_i, b_i depend on temperature range and are given as

for water:

<u>223.15 K to 273.15 K (–50 °C to 0 °C)</u>	<u>273.15 K to 373.15 K (0 °C to 100 °C)</u>
$a_0 = -5.5898101 \cdot 10^{-2}$	$a_0 = -1.6302041 \cdot 10^{-1}$
$a_1 = 6.7140389 \cdot 10^{-4}$	$a_1 = 1.8071570 \cdot 10^{-3}$
$a_2 = -2.7492721 \cdot 10^{-6}$	$a_2 = -6.7703064 \cdot 10^{-6}$
$a_3 = 3.8268958 \cdot 10^{-9}$	$a_3 = 8.5813609 \cdot 10^{-9}$
$b_0 = -8.1985393 \cdot 10^1$	$b_0 = -5.9890467 \cdot 10^1$
$b_1 = 5.8230823 \cdot 10^{-1}$	$b_1 = 3.4378043 \cdot 10^{-1}$
$b_2 = -1.6340527 \cdot 10^{-3}$	$b_2 = -7.7326396 \cdot 10^{-4}$
$b_3 = 1.6725084 \cdot 10^{-6}$	$b_3 = 6.3405286 \cdot 10^{-7}$

for ice:

<u>173.15 to 223.15 K (–100 °C to –50 °C)</u>	<u>223.15 to 273.15 K (–50 °C to 0 °C)</u>
$a_0 = -7.4712663 \cdot 10^{-2}$	$a_0 = -7.1044201 \cdot 10^{-2}$

$$\begin{array}{ll}
a_1 = 9.5972907 \cdot 10^{-4} & a_1 = 8.6786223 \cdot 10^{-4} \\
a_2 = -4.1935419 \cdot 10^{-6} & a_2 = -3.5912529 \cdot 10^{-6} \\
a_3 = 6.2038841 \cdot 10^{-9} & a_3 = 5.0194210 \cdot 10^{-9} \\
b_0 = -1.0385289 \cdot 10^2 & b_0 = -8.2308868 \cdot 10^1 \\
b_1 = 8.5753626 \cdot 10^{-1} & b_1 = 5.6519110 \cdot 10^{-1} \\
b_2 = -2.8578612 \cdot 10^{-3} & b_2 = -1.5304505 \cdot 10^{-3} \\
b_3 = 3.5499292 \cdot 10^{-6} & b_3 = 1.5395086 \cdot 10^{-6}
\end{array}$$

1.5.4 Temperature from Saturation Vapor Pressure

Equations 1 and 2 are easily solved for saturation vapor pressure over water or ice for a given saturation temperature. However, if vapor pressure is known and temperature is the unknown desired quantity, the solution immediately becomes complicated and must be solved by iteration. For ease of computation, the following inverse equation is provided. This equation is generally used to find the dew point or frost point temperature when the vapor pressure of a gas has been determined. When vapor pressure is known, use the water coefficients to obtain the dew point and use the ice coefficients to obtain the frost point.

$$T = \frac{\sum_{i=0}^3 c_i (\ln e)^i}{\sum_{i=0}^3 d_i (\ln e)^i} \quad (7)$$

where T is the temperature in kelvin
and e is the saturation vapor pressure in pascals
with coefficients

for water:

$$\begin{array}{l}
c_0 = 2.0798233 \cdot 10^2 \\
c_1 = -2.0156028 \cdot 10^1 \\
c_2 = 4.6778925 \cdot 10^{-1} \\
c_3 = -9.2288067 \cdot 10^{-6} \\
d_0 = 1 \\
d_1 = -1.3319669 \cdot 10^{-1} \\
d_2 = 5.6577518 \cdot 10^{-3} \\
d_3 = -7.5172865 \cdot 10^{-5}
\end{array}$$

for ice:

$$\begin{array}{l}
c_0 = 2.1257969 \cdot 10^2 \\
c_1 = -1.0264612 \cdot 10^1 \\
c_2 = 1.4354796 \cdot 10^{-1} \\
c_3 = 0 \\
d_0 = 1 \\
d_1 = -8.2871619 \cdot 10^{-2} \\
d_2 = 2.3540411 \cdot 10^{-3} \\
d_3 = -2.4363951 \cdot 10^{-5}
\end{array}$$

1.6 Humidity Equations

The following equations are used in the G3 to calculate various humidity parameters. These equations are not approximations, but rather account for the temperature differences between the saturator and chamber, and the non-ideal behavior of water vapor when admixed with air or other gases.

1.6.1 Relative Humidity

Percent relative humidity is the ratio of the amount of water vapor in a gas to the maximum amount possible at the same temperature and pressure. For two-pressure, two-temperature systems, it is defined by the equation

$$RH = \frac{P_c}{P_s} \cdot \frac{e'_s}{e'_c} \cdot 100 \quad (8)$$

which then expands to

$$RH = \frac{P_c}{P_s} \cdot \frac{f_s}{f_c} \cdot \frac{e_s}{e_c} \cdot 100 \quad (9)$$

where P_c is the absolute chamber pressure

P_s is the absolute saturation pressure

f_c is the enhancement factor at chamber temperature and pressure

f_s is the enhancement factor at saturator temperature and pressure

e_c is the saturation vapor pressure at chamber temperature

and e_s is the saturation vapor pressure at saturator temperature.

1.6.2 Dew Point Temperature

Dew point temperature is the temperature to which a gas must be cooled to initiate condensing water vapor in the form of dew (note that dew point temperature can exist above or below 0°C). Dew point temperature is obtained with the following iterative steps.

- a. Make an educated guess at the dew or frost point enhancement factor f_d . Setting $f_d = 1$ is a suitable first guess.
- b. Next, compute the dew or frost point vapor pressure of the gas with the formula

$$e_d = e_s \cdot \frac{f_s}{f_d} \cdot \frac{P_c}{P_s} \quad (10)$$

- c. Use the dew or frost point vapor pressure e_d determined in the previous step, along with Equation 7 for water, to compute T . Call this value the dew point temperature T_d .
- d. Use the dew point temperature T_d , chamber pressure P_c , and Equation 4 for water to compute the dew or frost point enhancement factor f_d .

- e. Converge to the proper dew point temperature T_d by repeating steps b through d several times, as necessary.

1.6.3 Frost Point Temperature

Frost point temperature is the temperature to which a gas must be cooled to begin condensing water vapor in the form of frost or ice. Frost point exists only at temperatures below freezing. Frost point is obtained with the following iterative steps.

- a. Make an educated guess at the dew or frost point enhancement factor f_d . Setting $f_d = 1$ is a suitable first guess.
- b. Next, compute the dew or frost point vapor pressure of the gas with the formula

$$e_d = e_s \cdot \frac{f_s}{f_d} \cdot \frac{P_c}{P_s} \quad (10)$$

- c. Use the dew or frost point vapor pressure e_d determined in the previous step, along with Equation 7 for ice, to compute T . Call this value the frost point temperature T_f .
- d. Use the frost point temperature T_f , chamber pressure P_c , and Equation 4 for ice to compute the dew or frost point enhancement factor f_d .
- e. Converge to the proper frost point temperature T_f by repeating steps b through d several times, as necessary.

1.6.4 Vapor Concentration, PPMv

Vapor-concentration, traditionally referred to as parts per million by volume (ppm_v), is a ratio relating the number of moles of water vapor to the number of moles of the remaining constituents in the gas (the dry gas component). Once established by the following formula, the vapor concentration is insensitive to further changes in pressure or temperature, provided there is no subsequent condensation.

$$\text{vapor concentration} = \frac{f_s \cdot e_s}{P_s - f_s \cdot e_s} \cdot 10^6 \text{ } \mu\text{mol/mol} \quad (11)$$

1.6.5 Humidity Ratio

Humidity ratio w is defined as the mass of water vapor to the mass of the dry gas; it is computed with the formula

$$w = \frac{M_w \cdot f_s \cdot e_s}{M_g (P_s - f_s \cdot e_s)} \text{ g/g} \quad (12)$$

where M_w is the molecular weight of water vapor, 18.02
 M_g is the molecular weight of the carrier gas (28.9645 for air).

Humidity ratio may also be computed and expressed in grams per kilogram and micrograms per gram. When expressed in micrograms per gram, humidity ratio is traditionally referred to in parts per million by weight (ppm_w).

1.6.6 Absolute Humidity

Absolute humidity d_v is defined as the mass of water vapor to the unit volume of humidified gas and is computed with the formula

$$d_v = \frac{M_w}{R \cdot T_c} \cdot \frac{f_s \cdot e_s \cdot P_c}{P_s} \text{ g/m}^3 \quad (13)$$

where R is the molar gas constant 8.31472

1.6.7 Specific Humidity

Specific humidity q is defined as the mass of the water vapor to the total mass of the gas mixture and is computed with the formula

$$q = \frac{M_w \cdot f_s \cdot e_s}{M_g (P_s - f_s \cdot e_s) + M_w \cdot f_s \cdot e_s} \text{ g/g} \quad (14)$$

2 System Identification and Component Location

The RH Systems G3 Humidity Generator is comprised of multiple components that work in conjunction to generate accurate humidity in a carrier gas. The location and function these major components are discussed below.

2.1 Computer, Monitor, Keyboard, USB hub, and RS-232 serial to USB convertor hub

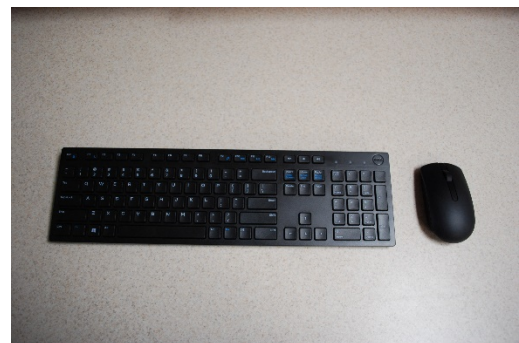
The G3 System comes with an accessory PC, an intel NUC7i3BNH VESA mounted on the back of the touchscreen monitor, which is used for G3 control and data collection. Any PC with a serial connection can be used for control and data collection, however RHS Control was developed specifically to run on the provided accessory PC.



The interface is optimized for a touch screen experience which is provided by the Dell S2240T touchscreen monitor that is provided with the G3 instrument.



Sometimes a physical keyboard and mouse are preferred and so the Dell KM636 wireless keyboard and mouse are provided as well.



A 4 port USB hub is provided to allow for the expansion of the capabilities of the accessory computer and is used to provide a connection to the RS-232 serial convertor.

A 4 port RS-232 serial convertor hub is also provided and can provide up to 4 RS-232 connections to the accessory PC. The G3 instrument itself provides two RS-232 serial connections.



2.2 Outside View of Panels



Rear panel view



Left panel view

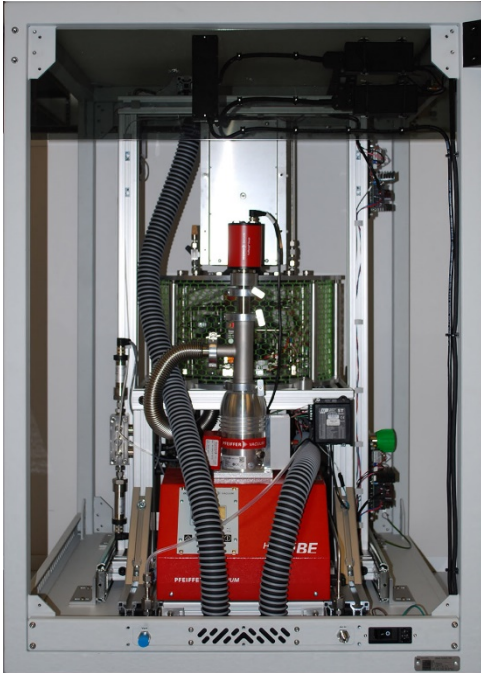


Front panel view

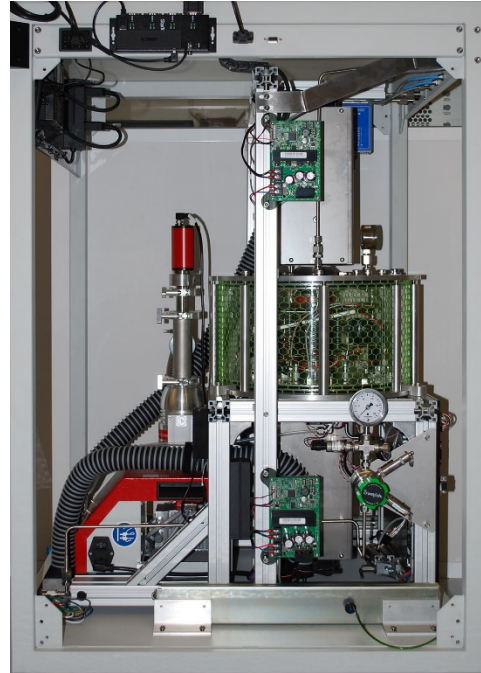


Right panel view

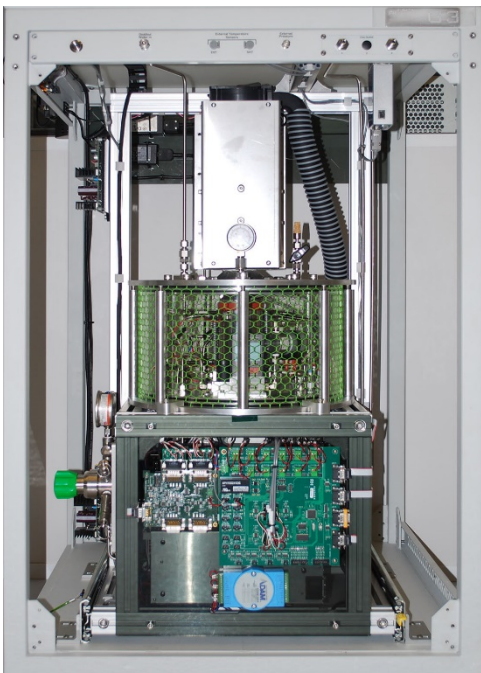
2.3 Inside View of Panels



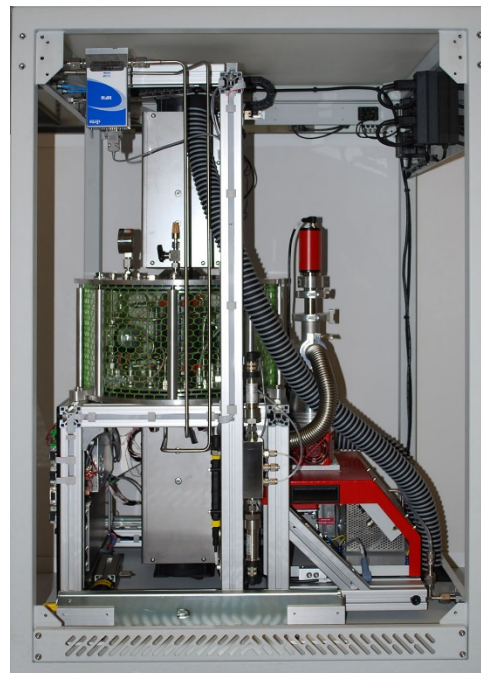
Rear view without panel



Left view without panel

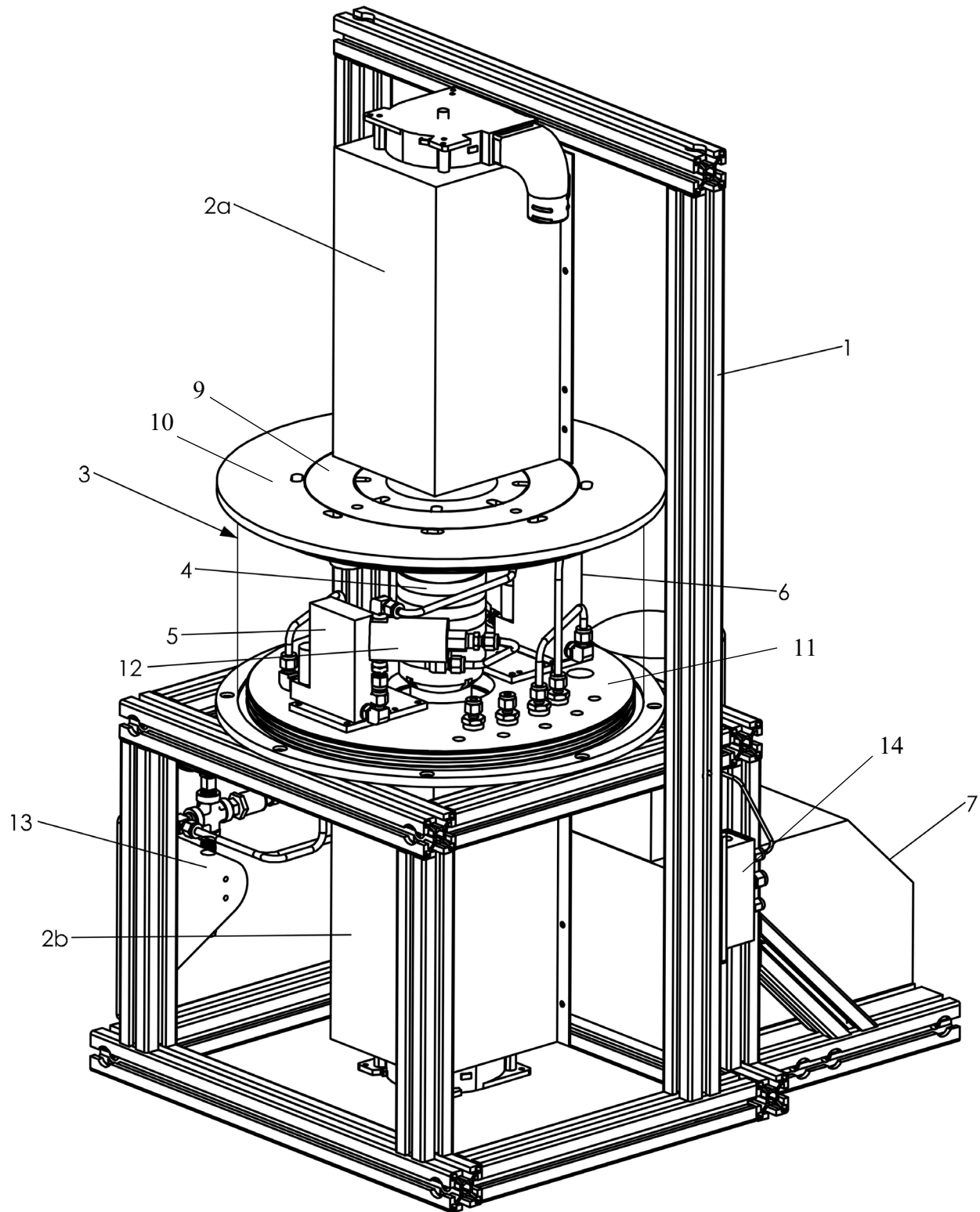


Front view without panel



Right view without panel

2.4 Major System Components



1	Humidity Generator Support Frame
2a	Top Free Piston Stirling Cooler
2b	Bottom Free Piston Stirling Cooler
3	Vacuum Chamber
4	Saturator (Plate Stack Assembly)
5	Saturator Pressure Controller Valve
6	Saturator Exit Gas Flow Controller Valve
7	Vacuum pump
8	Vacuum chamber wall
9	Top Vacuum Flange Part A
10	Top Vacuum Flange Part B
11	Bottom Vacuum Flange
12	Generate & Purge - 3 Way Valve
13	Gas Inlet Pressure Regulator Assembly
14	Pressure Sensor Manifold Assembly

3 Installation

3.1 Facility Requirements

Prior to arrival of your G3 instrument, preparations should be made to ensure you have the proper facilities available at the desired instrument location. The G3 will require the following for initial connection and continuous service.

3.1.1 Power

100-240 VAC, single phase, 15A, 50/60 Hz. The system uses a standard local power plug.

3.1.2 Compressed Gas Supply

Supply gas should meet the following specifications:

Supply pressure:	approximately 35 to 250 psi (250 kPa to 1.7 MPa), regulated prior to the G3
Flow rate:	up to 10 l/min (depending on model) while maintaining regulated pressure
Pressure dew point:	-95°C or lower when measured at the inlet pressure
Oil-free:	No mist or oil vapors
Connection:	¼" Swagelok fitting or ¼" VCR fitting (adapters available)

Recommend gas supply may be achieved via gas outlet from an N₂ gas cylinder or liquid N₂ dewar.

3.1.3 Distilled Water

Initial supply:	~1 liter of distilled water
Connection:	¼" Swagelok fitting or ¼" VCR fitting (adapters available)



Use distilled water only. Use of deionized water is not recommended as it tends to be chemically aggressive to stainless steel and other metals and may cause pitting of the saturator. The G3 requires enough distilled water for its initial fill of the presaturator, then a small on-going supply for continuous humidity generation.

3.1.4 Floor Space

The G3 requires a floor space of approximately 1.5 m x 2 m. This allows adequate space to the sides and rear of the unit for operation, service, and utility connections. The G3 is supplied on rolling casters for ease of positioning. The casters have integral leveling feet. Once rolled to position, the feet may be lowered to fix the position and level the instrument.

3.2 Uncrating

The G3 is shipped in a padded wooden shipping container. The front door doubles as a ramp to more easily remove the G3 from the crate. The G3 casters allow it to be rolled out of the crate, down the ramp, and onto the floor.

1. Position the crate in an open area using a pallet jack or fork lift.
2. Leave room at the front (about 3 meters minimum for the front door to lower downward and the G3 to be removed from the crate).
3. Twist and unhook the 4 metal buckles from the sides.
4. Open the door by lowering it downward. It is hinged at the bottom. The open door becomes a ramp.



5. There are two nylon straps attached to the G3 front wheels. Use them to pull the G3 forward out of the crate.
6. Continue to remove the G3 from the crate. You may need to lift the front a bit to properly clear without catching on the bottom.
7. Once clear, roll it down and off the ramp.
8. Roll the system to the desired location
9. Remove all packages and components stored in the upper compartment of the crate. These packages are accessory components needed for initial installation such as computer, monitor, power supplies, and power cords.



3.3 Connection of PC and Auxiliary Components

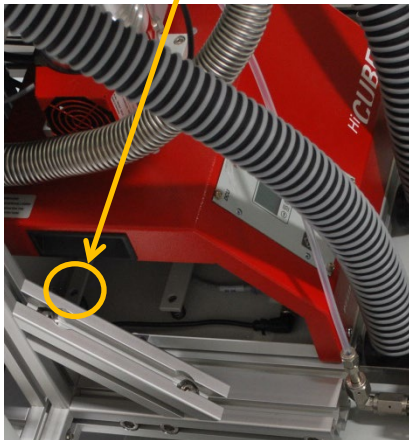
After uncrating the instrument and positioning it roughly where it will operate, now install the accessory PC and associated parts.

1. Start by installing corner mount and pole with 4 M6 x 20mm screws on the left rear corner of the instrument. Mounting holes are provided on each corner for flexibility, but the suggested mounting location is the left rear corner.
2. Mount the height adjustment ring on the mounting pole. Make sure set screw shields are in position. Tighten set screws.
3. Slide the mounting end of the monitor arm over the top of the mounting pole and slide the arm down until it contacts the height adjustment ring. Make sure that the plastic bushing stays in the mounting end of the arm and make sure that the metal set screw shields stay in position as well. While keeping the full weight of the monitor off the arm tighten the set screw. There are several extra mounting components (keyboard tray and arm) that are provided for flexibility of setup but it is suggested that only the monitor arm and attached monitor be mounted.
4. Mount the intel NUC PC to the back of the monitor. Insert the shoulder screws into the holes and slide the PC down until the shoulder screws engage with the slots.
5. Unravel the DC Power cords and USB cable attached to the left rear corner of the instrument. Route the cables up the mounting arm to the back of the monitor.
6. Use a supplied USB-A to USB-B cable to connect from one of the USB-A ports on the NUC to the monitor USB-B port on the monitor.
7. Use the supplied HDMI cable to connect from the HDMI socket on the NUC to the HDMI socket on the monitor.
8. Plug the DC power cable marked "Monitor 12v" into the power socket of the monitor.
9. Plug the USB extension cable from the coil of cables into one of the USB-A sockets on the NUC.
10. Plug the DC power cable marked "CPU 19v" into the power socket of the NUC.
11. Remove the wireless keyboard and mouse dongle from the inside of the mouse and plug it into one of the available USB ports on the NUC.
12. Turn the mouse and the keyboard on.
13. Mount the 4-port serial convertor and the attached 4-port USB hub on the left side comms sub-panel shoulder screws. Plug the USB hub into USB extension cable. Plug the USB-A end of a USB-A to USB-B cable into the USB hub then plug the USB-B end into the bottom side of the serial convertor. Then plug a RS-232 serial cable from the convertor into one of the two instrument serial connectors.
14. When power is supplied to the instrument and the main power switch has been turned on the PC and monitor can be turned on as well.
15. Once the instrument power switch has been turned on then RHS Control can be launched and communications can be established with the instrument. See RHS Control section for more information on how to use RHS Control with the G3 instrument.

3.4 Unlocking Vacuum Pump

The vacuum pump has been locked down for transportation. Prior to operation, the locking nuts must be undone.

1. Remove the rear and side panels from the G3.
2. Using a 5/16" or 8mm wrench, completely loosen the nut shown. However, do not remove the screw. This allows the bar to ride freely on the spring.
3. There is an identical nut on the opposite side of the pump. Loosen that nut in the exact same manner.



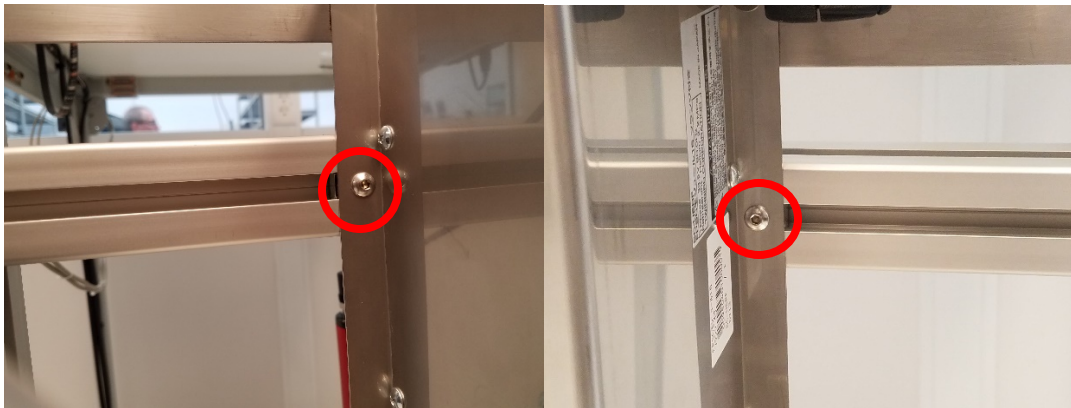
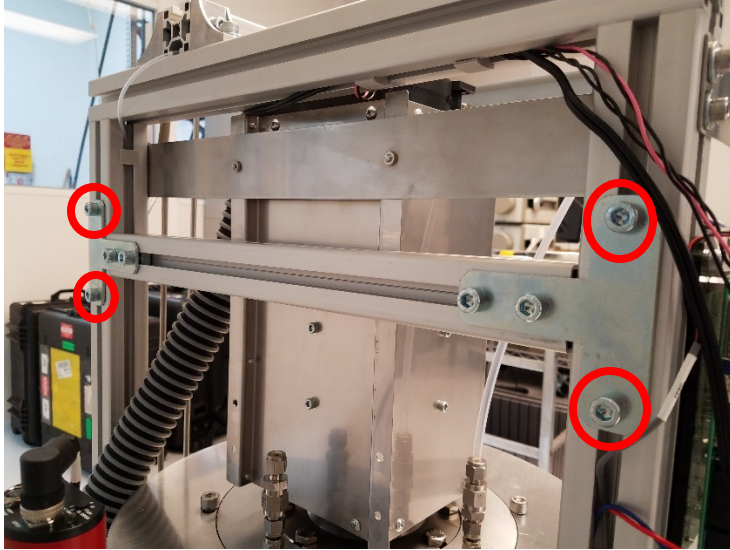
4. Reinstall the rear and side panels. While the system does not require installation of the panels for operation, it is recommended that they be installed for safety.



The vacuum chamber wall is 6mm thick acrylic tubing. Due to the high vacuum maintained within the vacuum chamber, it is possible that the acrylic chamber wall could shatter and implode if scored, cracked, or impacted from a sharp or heavy object. While plastic netting surrounds the chamber walls to lessen the impact of such a catastrophic event, it is always safest to operate the system with its system panels in place. This prevents accidental impact from foreign objects, and protects personnel from injury should any implosion ever occur for any reason.

3.5 Remove Shipping Support

1. Remove shipping support extrusion. First, remove the extrusion to sterling housing. Next, remove the end plate to vertical extrusion. Be sure to hold the extrusion when final hardware is removed to avoid it falling.



3.6 Back Panel Connections

1. Connect a short tube or hose to the **Vent** connector. Place a small tray under the tube to catch occasional water droplets. Alternatively, you may run a tube to a floor drain.
2. Connect your supply gas to the **Gas In** connection on the lower rear panel. Input gas requirements are identified in 3.1.2.



3. Using the supplied power cable (or one you've sourced locally), plug the **AC power** cord into the power receptacle. Plug the other end into your AC power source. AC power requirements are identified in 3.1.1.
4. The switch in the power receptacle is an over-current circuit breaker for safety. Prior to operation, it must be turned on. To do so, press the 1 position.



Proper grounding is important for safe and proper operation of the G3. Please ensure that the earth connection of your AC power source is sound.

3.7 Bubble Level

The vacuum chamber was pre-leveled and a reference bubble was applied to the top of the chamber. The caster wheels on the bottom of the G3 has a dial that lowers the adjustable pads onto the ground for leveling purposes. The G3 is level when the wheels are no longer touching the ground.



4 Quick Start

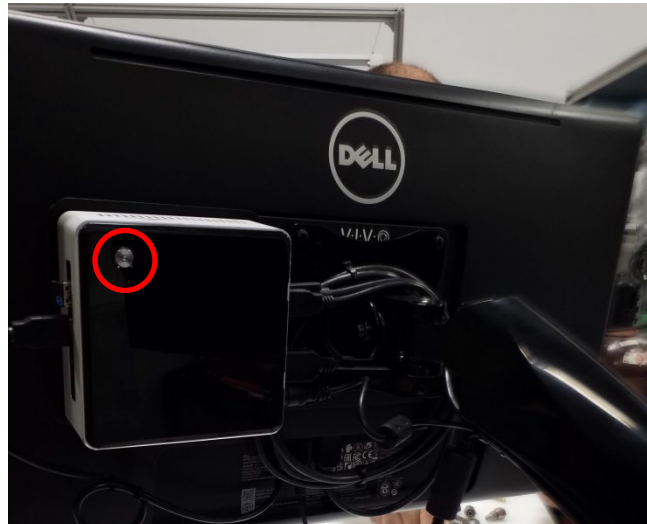
4.1 Power on




Before proceeding, ensure that the system has already been connected and prepared as outlined in section 3.

To turn on the system:

1. Turn on the monitor using its power button.
2. Turn on the computer using the small round button in the corner of the small PC located behind the monitor. Windows will load.



3. Press the  switch on the front panel. The switch will light and the system will energize.



4.2 Introduction to RHS Control

RHS Control is a PC program (available on Windows and Linux) which allows the user to operate the G3 system. Operation may be manual, through direct entry of desired setpoints, or automatically, through a series of preprogrammed, user selectable setpoints and times. The short sequence that follows will guide you quickly through a successful frost point generating session.



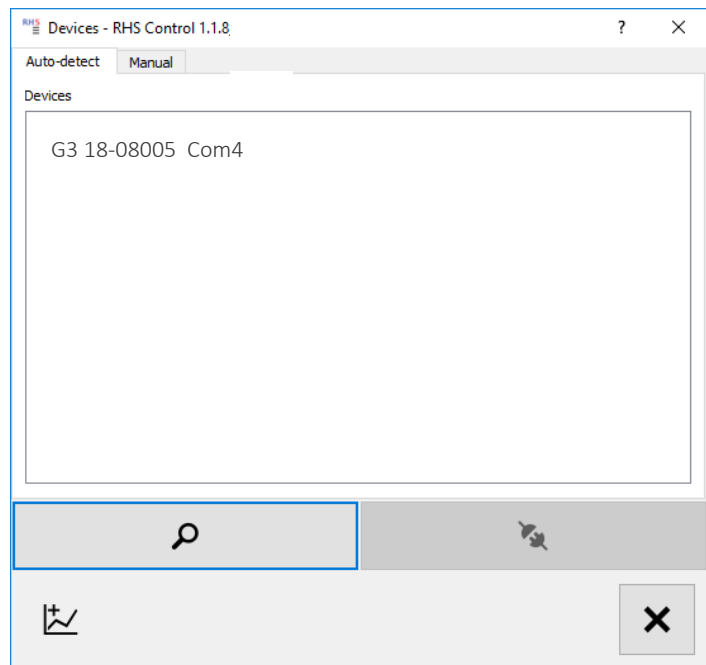
To launch **RHS Control**, simply double-click its icon. The program loads and presents you with a Connection window.

The supplied G3 computer is a touch screen. You may use a mouse to point and click, or you may touch the screen location with your finger. Either method is valid.

4.3 Connection Window

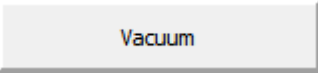
The connection window automatically appears when RHS Control is launched. It scans initially for any connected instruments and shows them in a list. Find the G3 in the list and double click it to connect.

If the Connection window is still open after connecting to the G3, close the window using the Close button



4.4 Initializing Vacuum

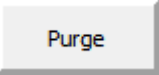
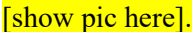
Prior to cooling the saturator, it is important that its surrounding chamber be evacuated. Evacuation removes water vapor from around the saturator and also provides for a high degree of thermal isolation. Both are highly desirable benefits/requirements to proper humidity generation

To initiate the vacuum sequence, press the Vacuum button . The vacuum pump will start (you'll likely hear a quite pumping/whirling sound). The Vacuum button will also depress to indicate that the action was taken.

4.5 Purge Mode

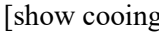
If you are following this Quick Start procedure, the system has likely been off for at least a short period of hours or more. In this case, the internal gas path is possibly wet and requires a drying out period before suitable results may be generated. To assist in this dry out, the system may be operated in a Purge mode. Purge mode allows dry input gas to bypass the saturator (so as to remain dry by preventing saturation with water vapor), drying the components and tubing following the saturator. By drying the tubing and connection following the saturator, we are removing any source of additional water vapor that could adversely affect the generated humidity.

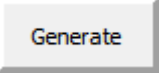
A rectangular button with a light gray background and a thin black border. The word "Purge" is centered on the button in a blue, sans-serif font.

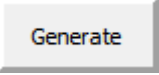
1. To enter Purge mode, press the Purge button . You may hear a short clicking sound as a mechanical relay and a solenoid valve change state.
2. Change the saturator pressure setpoint to 20. To do so, click the Saturator Pressure setpoint field . The number gets bordered in red. Enter a new number with the keyboard and press Enter (or click outside the field). The border turns yellow momentarily and the setpoint you entered should appear. The Actual value (the field to the right of the setpoint value) will move toward the value just entered.
3. Change the flow rate. Click the flow rate setpoint. Its border turns red. Enter a value of 1 using the keyboard and press enter (or click outside the field). The border changes to yellow momentarily then updates with the new value. The actual value to its right will move toward the setpoint.
4. Allow the system to operate in Purge mode for about an hour.

4.6 Generate

After allowing adequate purge time, the system should be nearly ready to generate. It will have purged for a while and also had enough time to achieve a suitable vacuum.


1. Cool the saturator to -10°C by entering a value of -10 in both the Upper Saturator and Lower Saturator temperature setpoint fields.
2. Activate the Stirling coolers by pressing the Cooling button . The button will remain depressed within a few moments.
3. Allow the saturator temperatures to achieve approximately -10°C as indicated in the Actual values for Upper and Lower Saturator temperature fields.

A rectangular button with a light gray background and a thin black border. The word "Generate" is centered on the button in a blue, sans-serif font.

4. Enter the Generate mode by pressing the Generate button .
5. Change the Frost Point setpoint. Enter a value of -15 °C in the Frost Point setpoint field. Notice that the Saturation Pressure setpoint will change to bring about an -15 °C Frost Point output.

4.7 Viewing Data Numerically and Graphically

Generated data is visible in the Actual columns. Lots of additional data is available by pressing the GEAR

icon . You'll see another window appear with data and a selection bar at the top. Use the mouse (or your finger) to select the bar at the top of this window to see a list of other data groups that may be displayed. You may select any data group at any time without affecting the operation of the system.

Data may also be displayed in a graphical form. To display data as a graph:



1. Select the Graph icon at the bottom of the window. A data selection window appears.
2. Select an instrument (the G3) on the left side and any number of data items on the right side.
[show the window selections]
3. Close the window. A graph appears.
4. The graph starts in a stripchart mode where the newest data always appears on the right side of the screen and the graph scrolls or scales to accommodate. Now, using your finger(s), slide/pinch/zoom as necessary to scale or move the graphed line(s) as desired.

4.8 Idle mode

The system does not have a shutdown mode directly, but rather it is best to operate in an idle mode. To operate in idle mode:

1. Set the flow rate setpoint to a low value such as 0.1 l/m.
2. Set the Upper and Lower saturator temperature setpoints to any future desired temperature, or leave them at the current value. The system can Idle in this mode indefinitely.
3. For extended periods of expected inactivity, you may wish to disable the Stirling coolers. Do so by pressing the Cooling button to ensure it pops back out and is no longer depressed.

Note: For quicker restart in the future, it is best to leave the system operating in idle mode at a low saturator temperature with coolers enabled rather than turning them off.

4.9 Power off

For extended periods of non-usage, the system may be powered off completely.

1. Close the RHS Control program.
2. Shutdown Windows on the PC.
3. Press the front panel Power switch. Power is then removed from the system and all functions are disabled.

Note: AC power is still applied to the DC power supplies even though they do not produce any output. However, the 48 VDC power supply fan remains on even when the system is powered off.

4. To further remove power, turn off the circuit breaker switch at the lower back panel and unplug the power cord if desired.

5 Operation

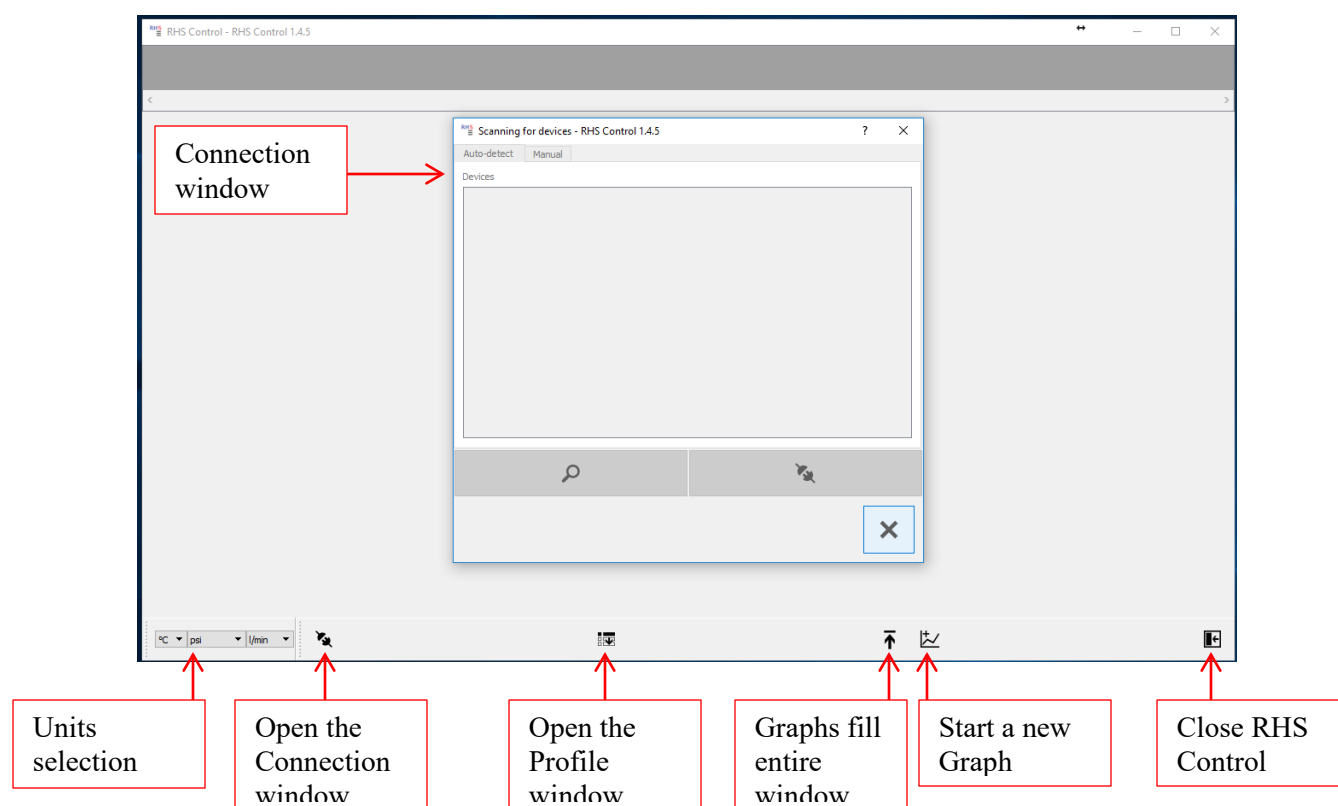
5.1 Details of Operation using RHS Control

RHS Control is a PC program (available on Windows and Linux) which allows the user to operate the G3 system. Operation may be manual, through direct entry of desired setpoints, or automatically, through a series of preprogrammed, user selectable setpoints and times.

In addition to entering setpoints for control, the program offers visualization of resulting data in real-time both in numerical and graphical formats. It also allows for connection to other instruments (such as those connected as Units Under Test, or UUT's, provided they have a serial data port. For those instruments with a serial data port, a customized protocol description in the form of a .json file is used to make the data connection. These .json files are text files utilizing our RHS Descriptor Language to define the instrument protocol, commands, and data presentation method. These instrument specific files may be created and/or modified by end users, or they may be obtained from RH Systems for particular instruments. While these descriptor files are available for RH Systems brand products, they can also be created for a wide variety of instruments and are not limited by brand and model. The main requirement is that the instrument be connected via a serial interface that can respond to command requests in a consistent manner.

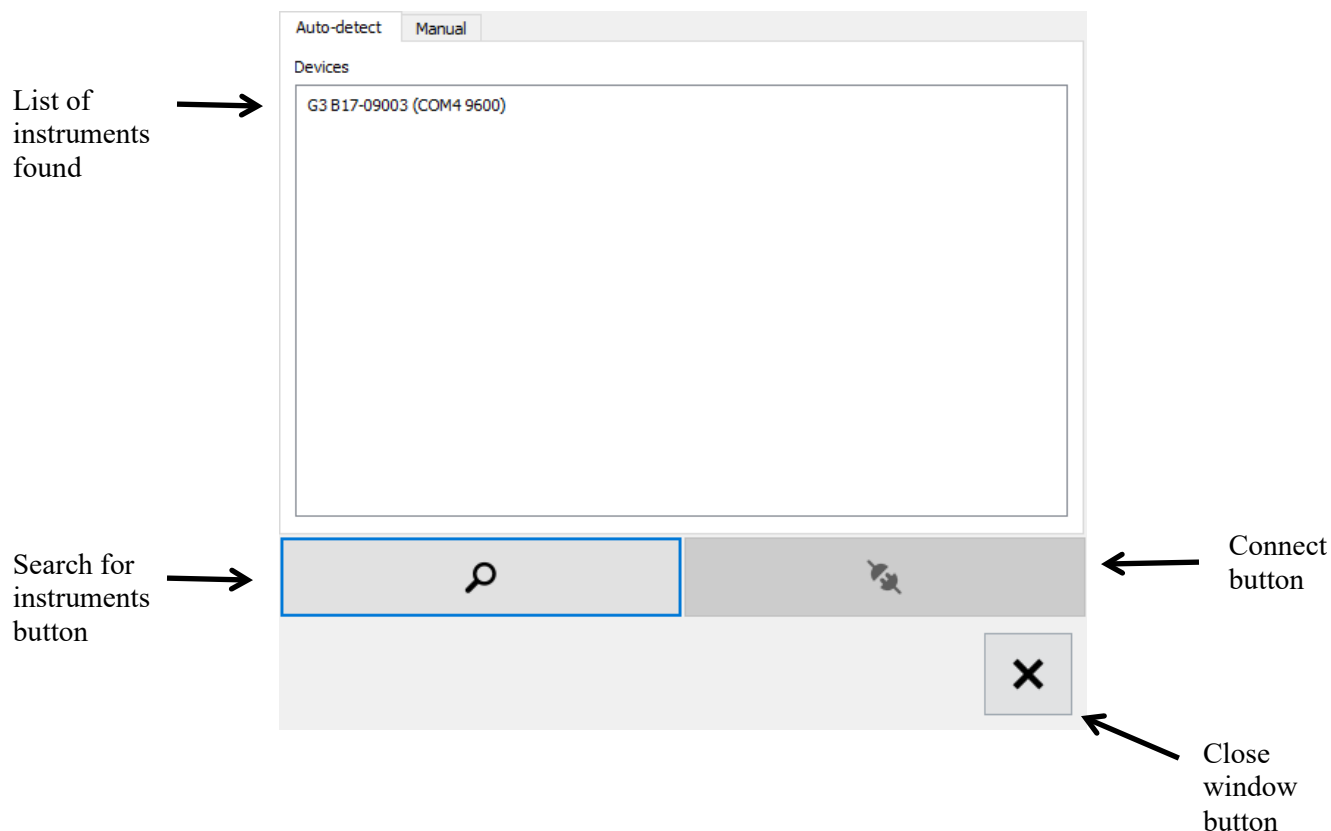
5.1.1 Launching RHS Control

To launch RHS Control, simply click its desktop icon . The main program loads and automatically presents the Connection window.



5.1.2 Connection of G3 and other instruments




All instrument connections are initiated via the Connection window. When the program is first launched, this window appears automatically. However, it may be opened for use at any time simply by pressing the Connection button on the main RHS Control screen.



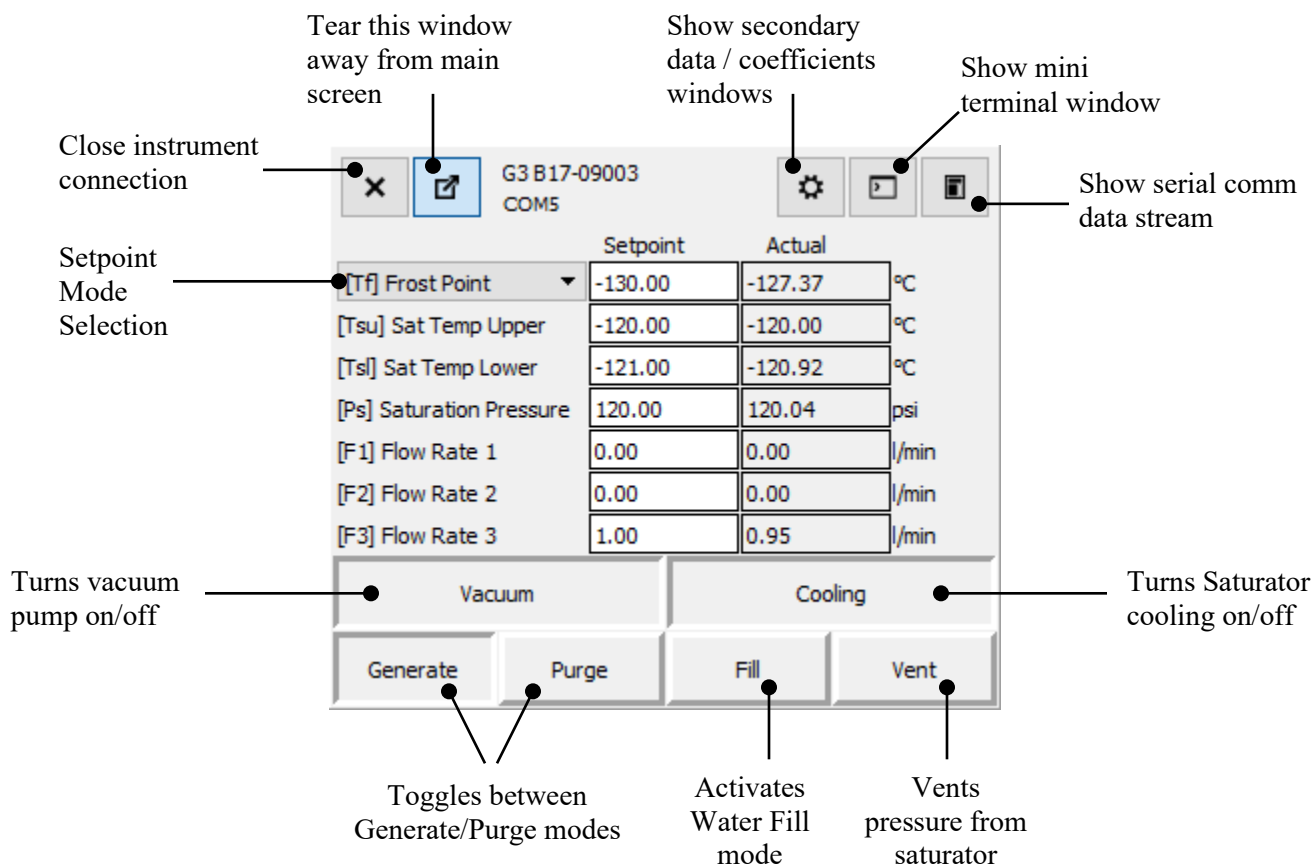
5.1.2.1 Connect the G3

When the Connection window opens, it initiates an automatic search for attached instruments.

To connect the G3:

-  1. If the instrument you want to connect with is not listed, ensure it is plugged into an RS-232 port. Then press the Search button.
2. Click on any instrument(s) listed. The selected line(s) will highlight.
-  3. Click the Connect Button. If there are no further instruments listed, the window closes automatically. If other instruments are still listed, the window remains open.
-  4. To close the window, press the Close button.

A unique window appears within the main screen for each connected instrument. The following window is typical of a running G3.



All fields within the Setpoint column that are white in color are user editable.

The Setpoint Mode Selection is a drop-down menu that allows selection of the following control modes:

- Frost Point
- Dew Point
- PPMv
- PPMw

The fields to the right of the Setpoint Mode Selection will change according to the control mode selected.

5.2 Apply Vacuum

The vacuum chamber is utilized both as a means of thermal insulation, and as a vapor barrier to prevent unwanted permeation through into the conditioned gas. Prior to generating a humidity value, vacuum is required.

1. Ensure the vacuum chamber is properly in place, its eight mounting screws secured, and the eight external supports installed and properly tensioned to light finger tightness only.
2. Press the Vacuum button to toggle it ON. It also takes a few seconds for the pump to start. Since the button always reflects the pumps current status, it also takes a few seconds before the pump button reflects an ON (or pushed in) condition.

5.3 Fill, Chill, and Purge

The saturator provides a path for the gas to travel over a surface of water or ice. Prior to first operation, and only occasionally after that, the saturator must be filled with liquid water. Each time after filling, it is recommended to chill (freeze the water) and then Purge for a period to remove any water/ice from the saturator outlet gas path.

The amount of time between filling operations is dependent on:

- Humidity levels generated (higher humidity levels use water faster)
- Flow rate of the gas (higher flow rates use water faster)
- Dryness of the incoming supply gas

The saturator holds approximately 75 ml of water. The expected run time under various conditions is listed below.

Dew/Frost Point °C	Continuous run time (approximate)
+10	4 days
0	1 week
-10	3 weeks
-20	2 months
-30	6 months
-40	18 months
-50	5 years
-60	17 years
-70	75 years
-80	350 years
-90	1500 years

The table reflects the expected run time assuming a total flow rate of 1 L/min. For higher flow rates, divide the run time by the flow rate. As an example, if the total flow rate is 4 L/min, the expected run time at -20 °C would reduce to approximately $2 \text{ months}/4 = 0.5 \text{ month}$ (about 2 weeks).

5.3.1 Fill the saturator

1. Enter a Sat temperature setpoint of +20 °C. This ensures that all ice in the saturator will melt to liquid water.
2. Set the sat pressure setpoint to 0.
3. Set the flow rates setpoints to 0.
4. Wait for the saturator temperature to reach the setpoint. The saturator must be warm enough to prevent freezing of the water as it flows through the saturator.
5. Press the Fill button. This will automatically set the needed saturation pressure, open the vent valve, and place the G3 in the Purge mode.
6. Place a catch pan under the G3 Vent port at the back panel.

7. Using a 9/16" wrench, remove the Swagelok cap on the fill port.
8. Using a syringe with 1/4" Teflon hose attached, slowly inject about 75 ml of water into the saturator.
9. After injecting the water, inject about 100 ml or more of air. This helps to clear the inlet tube of any remaining liquid water.
10. Reinstall the 1/4" Swagelok cap.
11. Press the Fill button to toggle it OFF. The Vent and Purge buttons will remain ON. The saturation pressure will remain slightly above ambient pressure.
12. Allow the system to remain in this state for about 5 minutes. This allows all excess water to leave the saturator through the vent.
13. Press the Vent button to toggle the vent OFF.

5.3.2 Chill the saturator after filling

Once the saturator has been filled, and the excess water expelled through the vent port at the rear panel, it is ready to begin chilling.

1. Enter a Sat Temp setpoint below freezing (a setpoint of -10 works well).
2. Ensure the G3 is in Purge mode.
3. Enter a saturation pressure of about 20 psia (about 1.5 bar)
4. Enter a flow setpoint of 0.25 L/min or more.
5. Wait until the saturation temperature has reached the setpoint.

5.3.3 Purge the saturator after filling & chilling

After filling and chilling the saturator, it is recommended to purge it for a while to assist in drying the saturator output port and tube.

1. Confirm a saturator temperature setpoint of -10 °C, saturator pressure setpoint of about 20 psia (1.5 bar), and flow setpoint of 0.25 L/min.
2. Confirm that Purge mode is enabled
3. Confirm that Cooling is enabled
4. Allow the G3 to run at these conditions for an hour or more.
5. Connect a hygrometer to the G3 gas output (a chilled mirror such as the RH Systems Model 373LX is recommended).
6. Monitor the hygrometer output. It should have a reading well below the indicated humidity value of the generator. Continue to run and monitor until the hygrometer reading remains relatively steady, and well below the G3 indicated humidity value.

The G3 should now be ready for use.

5.4 Selecting Humidity Control Mode

The G3 can control is one of several different humidity control modes which automatically picks suitable parameters for saturation temperature and saturation pressure. As an alternative, it may also be operated by entering setpoints for saturation temperature and saturation pressure directly.

5.4.1 Humidity Control Mode

While in a valid humidity control mode (FP, DP, PPMv, or PPMw), the G3 automatically determines suitable target values for saturation temperature and saturation pressure.

1. Using a mouse or finger, select the drop-down menu to reveal the various control mode options.

The screenshot shows the G3 B17-09003 COM5 interface. A red dot points to the drop-down menu for the first parameter, which is currently set to '[Tf] Frost Point'. The menu is open, showing options: '[Tf] Frost Point', '[Tf] Frost Point', '[Td] Dew Point', '[PPMv] Volume Ratio', '[PPMw] Mass Ratio', and '[Psi] Saturation Pressure'. The table below shows setpoints and actual values for various parameters.

	Setpoint	Actual	
[Tf] Frost Point	-90.000	-89.999	°C
[Tf] Frost Point	-84.000	-83.999	°C
[Td] Dew Point	-85.000	-84.996	°C
[PPMv] Volume Ratio	42.030	42.020	psi
[PPMw] Mass Ratio			
[Psi] Saturation Pressure			
[F1] Flow Rate 1	0.25	0.25	l/min
[F2] Flow Rate 2	0.00	0.00	l/min
[F3] Flow Rate 3	0.75	0.75	l/min

Buttons: Vacuum, Cooling, Generate, Purge, Fill, Vent.

2. Select one of the listed control modes by clicking on it.

The screenshot shows the G3 B17-09003 COM5 interface. A red dot points to the '[PPMv] Volume Ratio' option in the drop-down menu. The table below shows setpoints and actual values for various parameters.

	Setpoint	Actual	
[Tf] Frost Point	-90.000	-90.001	°C
[Tf] Frost Point	-84.000	-84.000	°C
[Td] Dew Point	-85.000	-84.997	°C
[PPMv] Volume Ratio	42.010	42.020	psi
[PPMw] Mass Ratio			
[Psi] Saturation Pressure			

3. Click the value in the Setpoint column, change it, and hit Enter.

The screenshot shows the G3 B17-09003 COM5 interface. A red dot points to the '0.10077' value in the Setpoint column for '[PPMv] Volume Ratio'. The table below shows setpoints and actual values for various parameters.

	Setpoint	Actual	
[PPMv] Volume Ratio	0.10077	0.10071	ul/l
[Tsu] Sat Temp Upper	-84.000	-84.001	°C
[Tsl] Sat Temp Lower	-85.000	-84.005	°C

4. The field border highlights. Edit the value and press Enter.

The screenshot shows the G3 B17-09003 COM5 interface. A red box highlights the '0.1' value in the Setpoint column for '[PPMv] Volume Ratio'. The table below shows setpoints and actual values for various parameters.

	Setpoint	Actual	
[PPMv] Volume Ratio	0.1	0.10077	ul/l
[Tsu] Sat Temp Upper	-84.000	-83.000	°C

5. After pressing Enter, the highlight changes color to indicate the new setpoint is being sent.

The screenshot shows the G3 B17-09003 COM5 interface. A yellow box highlights the '0.1' value in the Setpoint column for '[PPMv] Volume Ratio'. The table below shows setpoints and actual values for various parameters.

	Setpoint	Actual	
[PPMv] Volume Ratio	0.1	0.10075	ul/l
[Tsu] Sat Temp Upper	-84.000	-83.000	°C

6. Once the value is sent to the G3, the highlight disappears. A new value is then read from the G3 and will be displayed. Saturation Temperature and Saturation Pressure setpoints will be automatically recomputed if needed.

	Setpoint	Actual	
[PPMv] Volume Ratio	0.10000	0.10080	ul/l
[Tsu] Sat Temp Upper	-84.000	-83.998	°C
[Tsl] Sat Temp Lower	-85.000	-84.997	°C
[Ps] Saturation Pressure	42.020	42.010	psi
[F1] Flow Rate 1	0.25	0.25	l/min
[F2] Flow Rate 2	0.00	0.00	l/min
[F3] Flow Rate 3	0.75	0.75	l/min

Vacuum

Cooling

Generate

Purge

Fill

Vent

Note that the new setpoint and control mode are changed at the same time, but not until you've entered a new value. What this means is that you can look at the associated humidity Setpoints without affecting the current control mode. In other words, you can perform steps 1 and 2 above without causing any change to the control mode. The mode changes only after you edit the setpoint and press Enter, as in step 4.

In all humidity control modes, the saturation temperature setpoint fixes at a reasonable value and does not change any further until you once again change the humidity setpoint.

Note that although the G3 automatically determines a suitable saturation temperature setpoint when entering a new humidity setpoint, you have the option to over-ride it. If the new saturation temperature setpoint you enter is still within the range of suitable values for the current humidity setpoint, the new saturation temperature setpoint will be accepted. If, however, the saturation temperature setpoint you chose would not allow the G3 to reach your humidity setpoint, a new automatic setpoint will be chosen by the system, over-riding your saturation temperature setpoint. Changing the Saturation Temperature does not change the humidity mode.

Automatic calculation of saturation pressure is, however, an entirely different matter. Unlike temperature, which fixes to a single value, the saturation pressure setpoint is constantly varying to bring about the desired humidity output. When controlling on humidity, you should not attempt to change the saturation pressure setpoint. Doing so will cancel the humidity control mode, putting the G3 into Sat Pressure Control Mode.

5.4.2 Sat Pressure Control Mode

There may be times that you prefer to control at a fixed saturation pressure rather than a fixed humidity. When controlling on saturation pressure, the saturation pressure setpoint will remain constant while the humidity may vary.

1. Click the Saturation Pressure setpoint. Its border highlights.
2. Enter a new value and press Enter.

Saturation Pressure becomes the new setpoint, attempting to hold its value constant. Humidity setpoints and values may vary. Changing saturation temperature or flow rate setpoints has no influence on control mode, and saturation pressure control mode remains unchanged. To exit saturation pressure control mode simply re-enter a humidity control mode as described in 5.4.1.

	Setpoint	Actual	
[Tf] Frost Point	-60.000	-59.999	°C
[Tsu] Sat Temp Upper	-52.000	-52.001	°C
[Tsl] Sat Temp Lower	-53.000	-52.999	°C
[Ps] Saturation Pressure	40.980	40.970	psi
[F1] Flow Rate 1	0.25	0.25	l/min
[F2] Flow Rate 2	0.00	0.00	l/min
[F3] Flow Rate 3	0.75	0.75	l/min

Vacuum Cooling

Generate Purge Fill Vent

5.5 Changing Set Points

Setpoints are used to inform the G3 of the desired humidity output, flow rate, and other factors. Setpoints are used as the target values for control.

1. With a mouse or your finger, click on a setpoint field. The field highlights with a colored border.
2. With either a physical or on-screen virtual keyboard, enter the desired setpoint value.
3. Press Enter. The highlight color changes while the G3 is informed of the new value and is read back. The value read back is then displayed and the highlight removed.
4. Confirm that the number displayed is the number entered.

	Setpoint	Actual	
[Tf] Frost Point	-57.842	-58.764	°C
[Tsu] Sat Temp Upper	-52.000	-52.002	°C
[Tsl] Sat Temp Lower	-53.000	-53.012	°C
[Ps] Saturation Pressure	30.000	34.730	psi
[F1] Flow Rate 1	0.25	0.26	l/min
[F2] Flow Rate 2	0.00	0.00	l/min
[F3] Flow Rate 3	0.75	0.67	l/min

Vacuum Cooling

Generate Purge Fill Vent

5.6 Purge

Purge mode is used to dry the saturator outlet tube to prevent unintended humidity from entering the gas stream once it exits the saturator. Enter purge mode by pressing the Purge button. The Purge and Generate modes are exclusive, meaning that Generate mode turns off when Purge mode is enabled.

While purging, you'll need at least 20 psi (about 1.5 bar) saturation pressure, and at least 0.25 L/min or more of combined flow rate. All purge gas flows through the Gas Outlet ports at the front panel and may be monitored by connected measurement devices.

When in Purge mode, the supply gas entering the system at the back panel is used as the purge gas and should therefore have a frost point value much lower than the sat temperature during purge. As a general rule, the saturator should not be cooled lower than about -70 °C while in purge mode and using LN2 boil-off as the purge gas.

5.7 Generate

Generate mode is used to generate humidified gas. The humidified gas is directed to the Gas Outlet ports at the front panel. When generating, it is normal to use a humidity setpoint and at least one flow rate setpoint. Press the Generate button to enter Generate mode. Enabling Generate mode disables Purge mode.

5.8 Connection of Other Instruments

A variety of other instrument may also be connected to RHS Control. If the instrument has a serial port, and a properly written description file (.json file), the Connection window should be able to find and connect to it. The system is already supplied with several .json files for connection to most RHS brand instrument. The .json files may also be written to communicate with other brands of instruments. Contact RH Systems, LLC for more information.

5.9 Auto-profiling

Any instrument connected may be used in an Auto-Profile sequence. Auto-profiling allows you to predetermine a specific run sequence with setpoints and desired times. Each individual setpoint may have an associated time. The system steps through the profile list sequentially, waiting for the correct time to change specific settings. In this way, the system may be run without any further user interaction over a predetermined set of points, for predetermined amounts of time each, all the while collecting and storing data.

1. Open the profile window by pressing the Profile button at the bottom of the screen.
2. Enter the sequence of points to execute.
3. Press the VCR-style RUN button.

The profile will run to completion and remain at the final point until further manual input.

5.10 Viewing Data

Data may be viewed numerically, or as a graph. You may show several graphs at one time, each with independent variables, axes, and timing. All graphs have the ability to show fixed data, or running strip-chart-style data where it is always up to date with current information.

Graphs may show a combination of data from any connected instruments. Each parameter may be shown in a different color, and may be quickly and easily shown or hidden during analysis.

Graphs respond to normal pinch-and-zoom, multi-touch gestures of the touch screen. They also work with a mouse to move/zoom/scale as desired.

5.11 Data Files

All instrument data is stored in log files. Each connected instrument has a separate log file with common time stamps for easy post-run analysis using Excel or other programs of your preference. Data files are stored in CSV (comma separated) format for easy import.

Log files are stored in RHS Control\logs\

Files names are identifiable by instrument name, serial number, and time stamp.

6 Model G3 Sub-Systems

This section provides details of the functional systems within the G3. These subsystems include the Electrical System, Pneumatic System, and Temperature Control System.

6.1 Electrical System

The G3 requires 100-240 VAC, 50/60 Hz, single phase power.

6.1.1 AC Power

AC power enters the system via the power connector located at the back panel, transferring AC into the system via a two-pole 15 amp circuit breaker. When the breaker is turned on, power is also applied to two auxiliary power receptacles on the G3 upper side panel and to an AC power outlet strip located within the G3's sliding support frame. The AC power outlet strip feeds AC power to the vacuum pump, the 24 VDC power supply, and the 48 VDC power supply. Even though AC power is applied to the vacuum pump and the two DC power supplies, they all remain off until given command signals to turn on.

6.1.2 DC Power, 48 VDC

48 VDC is used exclusively for powering the two Stirling cooler circuits. When AC power is applied, the fan within the 48 VDC power supply runs, but 48 VDC remains off. It is equipped with a low-voltage remote control circuit that is wired through the front panel power switch. When the front panel power switch is turned on, the 48 VDC power is enabled, therefore applying 48 VDC to the Stirling cooler circuit boards.

6.1.3 DC Power, 24 VDC

24 VDC is used to power the Main Controller Board, relays, solenoids, heaters, and sensors. The 24 VDC power supply is equipped with a low-voltage remote control circuit that is wired through the front panel power switch. When AC power is connected to the supply, and the front panel power switch is turned on, 24 VDC power is enabled.

6.1.4 Main Controller Board, MCB

The Main Controller Board, MCB, operates the Model G3 by performing all functions required for system control and humidity generation. Temperature, pressure and flow are continuously monitored and controlled by actuation of valves, relays, coolers, heaters, and other outputs. It communicates to the outside world (for instance, to the PC running RHS Control) through one of three independent bidirectional RS-232 serial communication ports (2 of which are brought out to the G3 side panel). All data and control parameters are communicated via these communication ports.

The G3's embedded controller software resides within the MCB's Flash memory. The embedded controller software consists of RHS custom developed code, coupled with a high-speed multi-tasking real-time operating system. Via this multi-tasking embedded software, the controller orchestrates the second-to-second operation of the G3 based on command input from any of the RS-232 ports. Using a variety of communication methods (Terminal Emulator, a custom written PC program, or our RHS Control program), set points (frost point, dew point, saturation temperature, flow rate, etc.) are transmitted to the controller board. The job of the controller board is to accept these set points, continuously measure the various analog and digital sensors, and control the various electro-mechanical and thermal actuators in order to bring about and maintain the desired set point conditions.

Instrument specific configuration and calibration information, such as sensor coefficients, may also be written and read via any of the three RS-232 ports and resides within the MCB's Electrically Erasable Read Only Memory (EEPROM).

Voltage regulators on the Controller Board take the 24VDC input power and generate +12VDC, +5VDC, and +3.3VDC needed for various components on and off the board. DC power for sensors, solenoids, controllers, and others are supplied directly from the MCB.

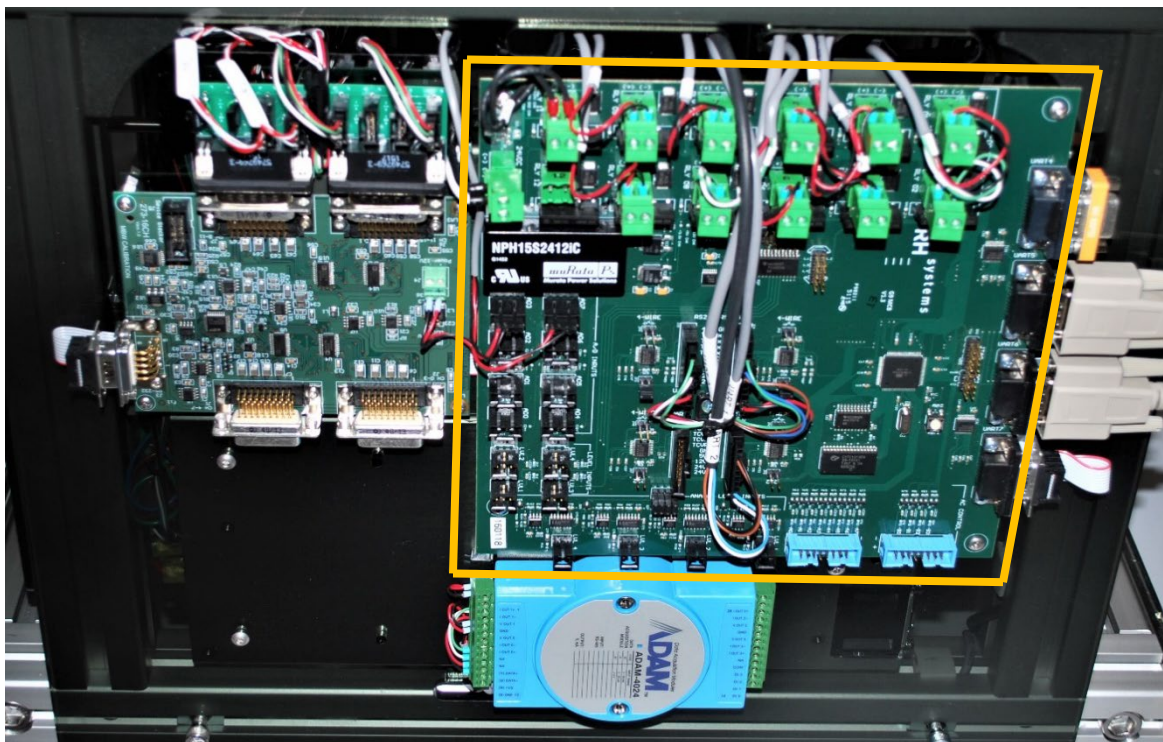


Figure 1 MCB Controller Board

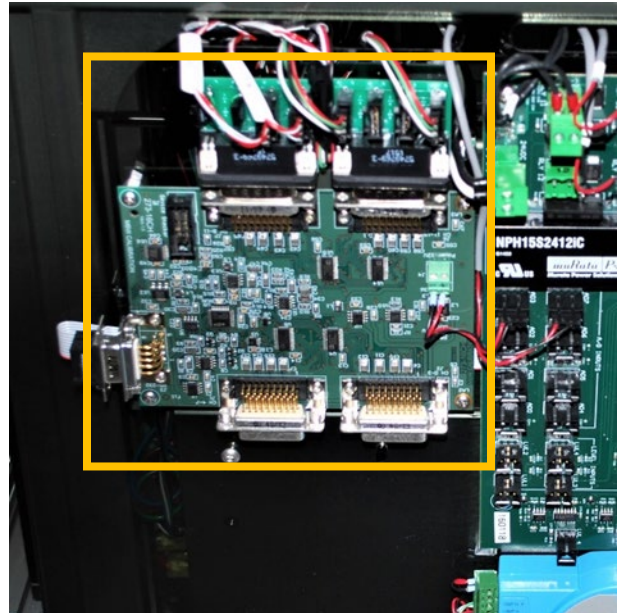
6.1.5 Precision Resistance Measurement Board

A Precision Resistance Measurement Board containing a 16 channel, 24 bit, analog-to-digital converter measures all temperature sensors. Two of the 16 channels are dedicated to system reference resistors. In addition to the reference resistors, the following temperature probes are measured:

- Tsu, Tsl, Tsx (Saturator Temperature)
- Tso, Tsc (Sat Outlet Tube temperature)
- Txt (External Thermometer)

All temperature sensors in the G3 are 100 Ω Platinum Resistance Thermometers (PRT's). The board measures all thermometers using full current reversal DC pulse mode excitation and reports these raw values to the MCB via an internal RS-232 connection to the MCB via UART 7. The MCB ratio-metrically compares these raw probe measurements to measurements of the precision reference resistors to determine their precise resistance values. The resistance values are then computed into individual temperatures using each probe's specific coefficients.

The Precision Resistance Measurement Board requires 12 VDC which is supplied from the MCB.

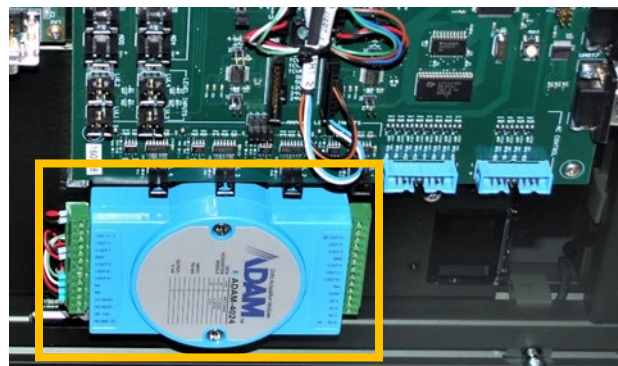


6.1.6 Analog Output Module

The analog output module provides setpoints for the Stirling cooler controller boards.

I OUT1 drives the upper Stirling cooler setpoint.
I OUT0 drives the lower Stirling cooler setpoint.

Power (24 VDC) and data connection to the MCB is via UART 2, a common RS-485 bus also used for pressure sensors, vacuum gauge, and the vacuum pump.



6.1.7 Solenoid Control Relay

The Purge/Generate solenoid valve has two separate coils and a permanent magnet. When one coil is pulsed, the solenoid opens in one direction, closing in the other direction. When the other coil is pulsed, the solenoid toggles direction, closing the open side and opening the closed side. The two coils are wired together via steering diodes, meaning that if the coil assembly is pulse with power in one polarity, the solenoid pulls in one direction. When the coil assembly is pulse with the polarity in the opposite direction, the solenoid pulls in the opposite direction. They are wired as one coil with directional polarity rather than as two separate and independent coils. For this reason, a polarity changing Solenoid Control Relay is utilized. This relay is used to select which polarity the solenoid coil will see.

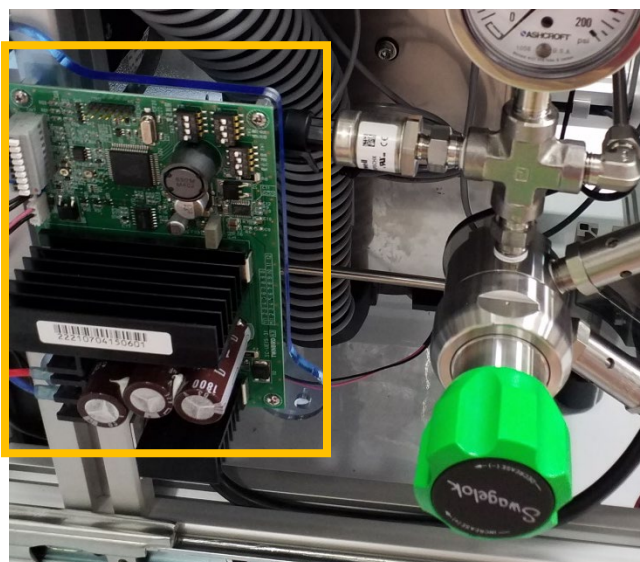
To enter Purge mode, the relay is energized via RLY 6 of the MCB. A pulse is then sent to the solenoid coil via RLY 5.

To enter Generate mode, the relay is de-energized by deactivating RLY 6 and a pulse is sent to the solenoid coil via RLY 5. The Generate mode pulse seen at the coil will be of a polarity opposite that of the Purge mode pulse.

6.1.8 Stirling Controller Boards

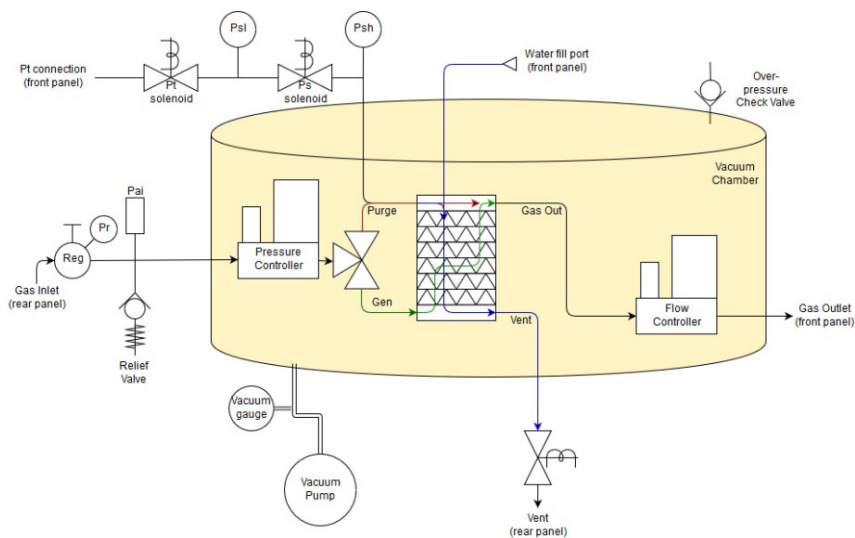
The Stirling cooler controller boards operate from 48 VDC. Each receives a 4-20 mA signal from the Analog Output Module to set its cooling output power between 0 to 100%. The Stirling controller boards drive the coolers by producing an 80 Hz variable amplitude drive signal which is frequency modulated on a high frequency carrier wave.

In addition to providing cooler power, the Stirling controller boards provide power to the Stirling cooler fans. They also monitor Stirling hot side temperature to auto-stop the coolers under fault conditions.



6.2 Pneumatic System

The pneumatic system is responsible for control of gas flow and pressures throughout the system. The pneumatic system consists of the following major components: pressure inlet regulator, regulated pressure measurement, sat pressure regulator, saturator, flow control valve, flow meter, and gas outlet.



Compressed air enters the system at the back panel fitting labeled *Gas In*. The Gas In fitting is connected via tubing to the pressure regulator.

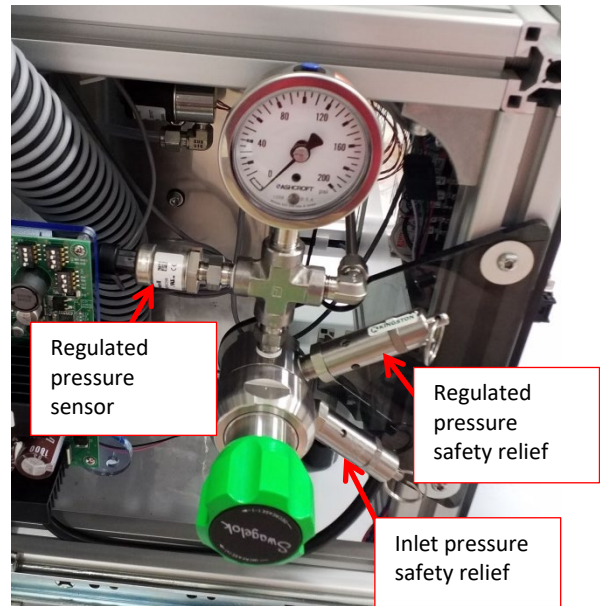
6.2.1 Regulator and Pressure Sensor

The pressure regulator is used to regulate the system pressure, isolating it from upstream pressure variations. Gas enters the regulator assembly. The inlet pressure safety relief valve protects the system from input pressure in excess of 300 psig. The regulated pressure safety relief valve protects the system from regulated output pressure in excess of 200 psig. Regulated pressure is adjusted by turning the knob to increase or decrease the regulated pressure output.

Pressure should be adjusted between 35 psi minimum and 140 psi maximum but should always be set for a value below your available supply pressure.

Regulated pressure output is indicated on the attached dial gauge and is also measured by the Regulator Pressure Sensor through AD7 of the MCB.

Gas is then connected inside the vacuum chamber to the pressure controller.

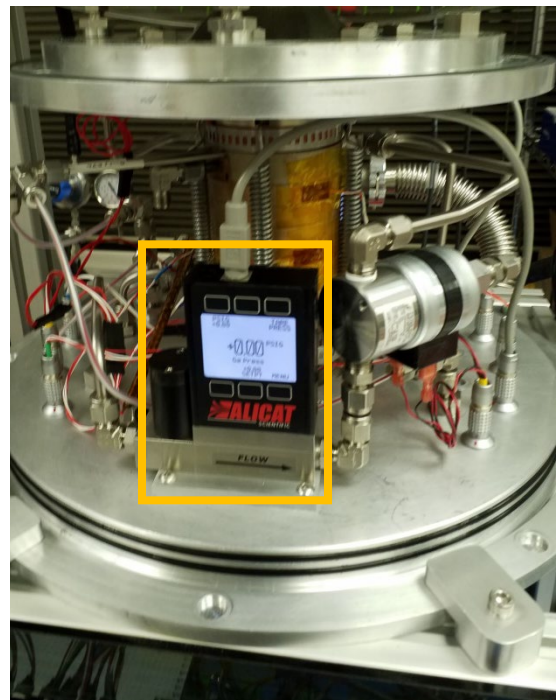


6.2.2 Pressure Controller

The pressure controller is used to maintain a selectable pressure within the saturator, independent of flow rate. It has an integral gauge pressure sensor with measurement relative to its ambient environment pressure. Since the controller is located within the vacuum chamber, its ambient environment pressure is vacuum, or 0. This causes the sensor to effectively measure absolute pressure rather than what we would traditionally refer to as gauge pressure.

Pressure regulation of the saturator is accomplished via an internal closed loop control using its pressure measurement and its proportional solenoid valve. Rather than relying on the integrated pressure measurement for system accuracy, a higher accuracy independent pressure is used to measure the saturator pressure. Any differences between the two sensors are automatically accounted for to ensure the saturator is controlled with the highest accuracy measurement.

Controller power (12 VDC) and communication is via UART 0, at address 'P' on a multi-drop RS-232 connection. This multi-drop RS-232 connection is shared with the flow controller. Queries go out from the MCB on UART 0_Z. Replies from the pressure controller are received on UART 0_A. Signal ground connection is at UART 0_GND. Typical communication occurs at 19200 baud, 8 data bits, 1 stop bit, no parity.

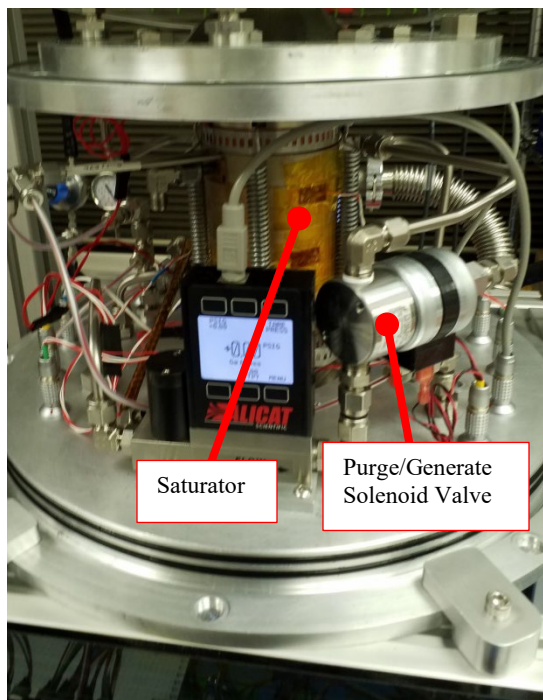


6.2.3 *Purge/Generate Solenoid Valve*

The Purge/Generate Solenoid Valve is a directional valve used to determine the entry point of gas flowing into the saturator. When generating, gas flows out the center stem of the valve and is directed into the bottom of the saturator. Gas then flows up and out the top of the saturator. This is the normal direction while generating.

When purging or filling with water, gas flows up through the Purge/Generate valve and is directed into the top of the saturator. If the vent solenoid is closed, gas may flow through the flow controller. This allows dry gas to be used to dry out the top gas exit tube of the saturator, resulting in a purge mode. If the vent solenoid is open, gas flows from top to bottom in the saturator allowing the saturator to be filled with water while also pushing out any excess.

Flow direction through the Purge/Generate valve is controlled via signals from RLY 6 and RLY 5 of the MCB.



6.2.4 *Vent Solenoid*

For venting the saturator of pressure, and for draining of excess water during filling operations, the G3 is equipped with a vent solenoid. The vent valve is a normally closed solenoid valve. To vent, the solenoid is energized via RLY 11.

6.2.5 *Saturator*

The saturator is an efficient heat exchanger constructed from disks of solid copper. Channels for water and gas are machined into the solid disks which are then nickel plated, stacked, and vacuum brazed into a single, solid column structure. Normal flow is bottom to top. Purge flow is across the top plate only. Flow during water fill/clear is top to bottom.

6.2.6 *Flow Controller – Alicat*

Flow controller(s) measure and control the flow rate through the saturator and finally through device(s) under test. It is powered from 12 VDC and is read via RS-232 communication. It is connected directly to the MCB's UART 0. Power to the flowmeter (12 VDC) is provided by UART 0 12+ and UART 0. Measurements from the flow meter are queried at address 'F' and received via RS-232. Queries go out from the MCB on UART0_Z. Replies from the flow meter are received on UART0_A. Signal ground connection is at UART0_GND. Typical communication is at 19200 baud, 8 data bits, 1 stop bit, no parity.

6.2.7 *Flow Control via Stepper Valve and Flowmeter*

The flow controller(s) mentioned in section 6.2.6 work well when generating frost point data higher than about -70 °C. For lower values, a different flow control approach is utilized. This alternate approach relies on a custom designed linear positioning needle valve placed within the vacuum chamber. For control feedback, flow measurement is made via a separate flowmeter. Although the flowmeter physically resides

outside the vacuum chamber, it is a hermetically sealed flow meter (all welded and construction and connections, no elastomers). The flowmeter is powered from 24 VDC and is read via RS-485 communication on device address 2, 3, or 254 (depending on system configuration). Typical communication parameters are 9600 baud, 8 bits, 1 stop bit, no parity. It shares communication with other devices on UART2 of the MCB.

The needle valve, physically located within the vacuum chamber, is actuated via a stepper motor driven linear actuator. The stepper motor is physically located outside the vacuum chamber. The stepper motor is operated by a stepper motor controller connected to the MCB via either RS-232 or RS-485, and connected via UART 0. The stepper motor controller is powered by 24 VDC.

6.2.8 High Range Pressure Sensor, Ph

The high range pressure sensor, Ph, continually measures the saturation pressure. It is powered from 24 VDC and is read via RS-485 communication on device address 01. It is connected directly to the MCB's UART 2. 24 VDC to the pressure sensor is provided by UART 2 24+ and UART 2 24- (this pin is actually the 24 ground, not -24 V). Measurements from the pressure sensor are queried and received via addressable RS-485, 2-wire, half-duplex mode RS-485 connection between the MCB and pressure sensor occur on UART 2 Z and Y. Communication parameters are typically set at 9600 baud, 8 data bits, 1 stop bit, no parity. The UART 2 communication channel is also shared with the analog output module, the other pressure sensor Pl, the vacuum gauge, and the vacuum pump.

If Keller brand pressure sensors are utilized, communication with pressure sensors is made via a separate connection on UART 3 rather than a shared connection on UART2.

6.2.9 Low Range Pressure Sensor, Pl

The low range pressure sensor, Pl, measures the saturation pressure during those times when sat pressure is low enough to be within its measuring range. When this occurs, the sensor shares its time between measurements of the saturator, and measurements of the external (front panel) pressure. Use of the low range sensor for measurement of the saturator is activated by energizing RLY 9 and de-energizing RLY 10 of the MCB.

When the saturation pressure rises above the measuring range of this sensor, the low range sensor disconnects from the saturator. The saturator is once again monitored only by the high range sensor, freeing the low range sensor to exclusively monitor the external (front panel) pressure. Use of the low range sensor for measurement of the external (front panel) pressure is activated by de-energizing RLY 9 and energizing RLY 10 of the MCB.

The sensor is powered from 24 VDC and is read via RS-485 communication on device address 02. It is connected directly to the MCB's UART 2. 24 VDC to the pressure sensor is provided by UART2 24+ and UART 2 24- (this pin is actually the 24 ground, not -24 V). Measurements from the pressure sensor are queried and received via addressable RS-485, 2-wire, half-duplex mode RS-485 connection between the MCB and pressure sensor occur on UART 2 Z and Y. Communication parameters are typically set at 9600 baud, 8 data bits, 1 stop bit, no parity. The UART 2 communication channel is also shared with the analog output module, the other pressure sensor Ph, the vacuum gauge, and the vacuum pump.

If Keller brand pressure sensors are utilized, communication with pressure sensors is made via a separate connection on UART 3 rather than a shared connection on UART2.

6.2.10 External Pressure Sensor

There is no dedicated external pressure sensor in the G3. Rather, the low range sensor, PI, is used exclusively to monitor external (front panel) pressure, or it operates in a time-sharing mode between the external (front panel) pressure and the saturation pressure. See 6.2.9 for further details.

6.3 Saturator Temperature Control System

Saturator temperature is controlled by two Stirling coolers, one at the top and one at the bottom, which provide a direct contact surface to cool the top and bottom of the saturator assembly. The cooling is readily transferred by conduction from contact between plates in the saturator assembly. Contact heaters are also installed to heat the saturator. Saturator temperature is maintained by control of the Stirling coolers and heaters attached to the inlet and outlet plates of the saturator. The coolers and heaters work in tandem to produce stable temperatures at both the saturator inlet and outlet.

6.3.1 Upper and Lower Cooler

The upper cooler is nearest the saturator outlet. Cooling power applied via the Stirling cooler is controlled by output I OUT 1 of the analog output module. I OUT 1 provides a 4-20 mA signal representing a desire for 0 to 100% cooling power. The 4-20 mA signal is injected at CN7 pins 2(+) and 3(-) of the upper Stirling controller board. 48 VDC power input to the Stirling controller board is connected at CN1 pins 1(+48 VDC) and 2(GND). The Stirling drive output is connected to CN8 pins 1 and 2.

The lower cooler is nearest the saturator inlet. Cooling power applied via the Stirling cooler is controlled by output I OUT 0 of the analog output module. I OUT 0 provides a 4-20 mA signal representing a desire for 0 to 100% cooling power. The 4-20 mA signal is injected at CN7 pins 2(+) and 3(-) of the lower Stirling controller board. 48 VDC power input to the Stirling controller board is connected at CN1 pins 1(+48 VDC) and 2(GND). The Stirling drive output is connected to CN8 pins 1 and 2.

6.3.2 Upper and Lower Heaters

The upper and lower saturator heaters are contact heaters on the circumference of each of the Stirling cooler's cold flanges. The heaters are used to counteract the effects of cooling and work in tandem with the coolers to control upper and lower saturator temperature. The heaters are operated from 24 VDC. The heaters are connected to fixed frequency pulse width modulated (PWM) output signals of the MCB. The upper heater is connected to RLY1. The lower heater is connected to RLY2.

6.4 Auxiliary Heaters

6.4.1 Outlet Tube Heating

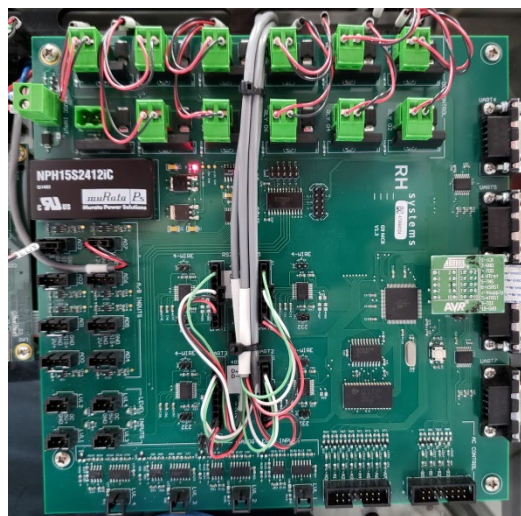
Heaters on the saturator outlet tubing are used to assist in the purge process, driving condensed water vapor from undesired areas of the saturator outlet. In addition, they are used to warm the gas to a suitable exit temperature. Thermometers on the tube heaters measure the temperatures and are used to control fixed frequency PWM output signals. Both saturator outlet heaters operate from 24 VDC. The heater closest to the saturator outlet is connected to RLY 4 of the MCB. The other heater, located further from the saturator but over a longer area of the tube, is connected to RLY 3.

6.4.2 Flow Controller Heating

Heaters are also installed on the flow controller to assist in the drying the flow controller's gas path. Flow controller temperature is an integral measurement of the flow controller itself and is queried along with its other parameters. Heating of the flow controller is accomplished through fixed frequency PWM of contact heaters installed on the outside of the flow controller body. The flow controller heater is connected to the MCB's RLY 7. If a second flow controller option is installed, it's heater is connected to RLY 8.

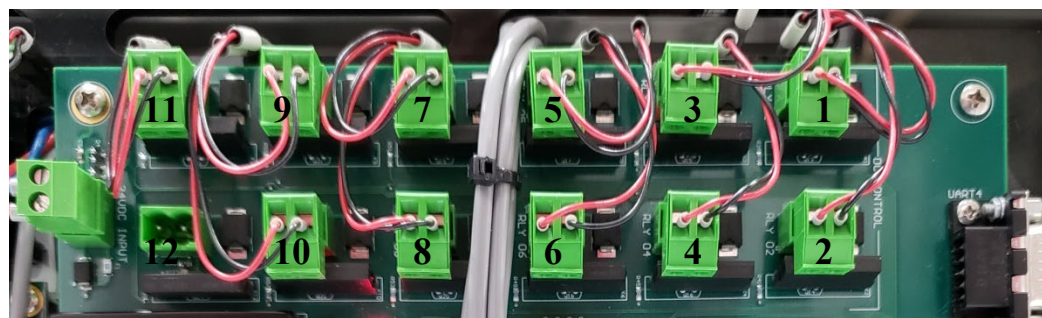
6.5 Main Controller Board

The Main Controller Board (MCB) has many different inputs and outputs used to operate the G3. Grouped by functional type, the following tables in this chapter list the various inputs and outputs of the MCB and reference the specific sections of this manual where each input or output is discussed.



6.5.1 DC CONTROL

The MCB's DC CONTROL section (RLY1 through RLY12) powers valves, motors, heaters, fan, etc. These devices receive their 24 VDC power directly from the relay connector. These relay outputs power their connected devices directly, sourcing up to 2 amps each. . The (+) pin of each relay connector is hard wired to 24 VDC. The (-) pin of each channel switches in ground via the relay. Each output channel has an adjacent LED. When an LED is on, it indicates that the connector's (-) pin is pulled to ground, allowing current to flow through a connected device



Relay	Description	Reference
RLY 1	Upper Sat Heat	6.3.2
RLY 3	Outlet Tube Heat	6.4.1
RLY 5	Purge/Gen Pulse	6.2.3
RLY 7	Flow Ctrl Heat	6.4.2
RLY 9	Low Sat P Select	6.2.9
RLY 11	Vent	6.2.3

Relay	Description	Reference
RLY 2	Lower Sat Heat	6.3.2
RLY 4	Sat Port Heat	6.4.1
RLY 6	Purge/Gen Polarity	6.2.3
RLY 8	Reserved	6.4.2
RLY 10	Ext P Select	6.2.9
RLY 12	Reserved	

6.5.2 A/D INPUTS

The MCB's A/D INPUTS section (AD0-AD7) has an 8 channel, 14 bit, 5 volt analog to digital converter system. Each connector also has 12 VDC power available to directly power the connected devices or sensors.

Analog Input	Description	Reference
AD0		
AD1		
AD2		
AD3	12VDC to Temp Board	6.1.5
AD4		
AD5		
AD6		
AD7	Reg P sensor	6.2.1

6.6 Temperature Measurements

The Precision Resistance Measurement board is a 16 channel, 24 bit, A/D converter system used to measure all temperatures in the G3. It connects to the MCB via its RS-232 port. While two of the A/D converter channels are configured for reference resistor measurements, the remaining channels are configured for connection of 100 ohm platinum resistance thermometers (PRTs). The following table lists the probe channels and functions of the G3.

Channel	Probe name	Function	Reference
CHs 0-7		Unused	
CH 8	RefOhmsLow	Low Ohm Reference	6.1.5
CH 9	RefOhmsHigh	High Ohm Reference	6.1.5
CH 10	Tsu	Upper Sat Temp	6.1.5
CH 11	Tsl	Lower Sat Temp	6.1.5
CH 12	Tsx	User Ext/Sat Temp	6.1.5
CH 13	Tx1	External Temp 1	6.1.5
CH 14	Tx2	External Temp 2	6.1.5
CH 15	Tso	Sat Outlet Tube Temp	6.1.5

All probes are wired to the temperature board as 4-wire, 100 ohm PRTs. There are four 26 pin D connectors on the board. Two intermediary interface boards connect to two of these D connectors. All

probe connections are then made via straight single row Molex plugs via the intermediary interface boards. The two reference resistors (RefOhmsHi and RefOhmsLow) are soldered permanently to one of the intermediary interface.. The reference resistors are known resistances, whose values are programmed into the MCB for use in determining resistances of the PRTs.

The Precision Resistance Measurement board communicates via RS-232 to the MCB UART 7.

6.7 Analog Output Module

The analog output module is an ADAM-4024. It communicates via RS-485 on UART 2 of the MCB and is used to control the setpoint of the Stirling coolers.

Channel	Output Signal	Function	Reference
I OUT 0	4-20 mA	Lower Stirling Ctrl	6.1.6
I OUT 1	4-20 mA	Upper Stirling Ctrl	6.1.6
I OUT 2&3		Unused	
D0-3		Unused	

6.8 Solenoid Control Relay

The solenoid control relay is a two-pole, two-throw (2P2T) mechanical relay wired in this system as an H-bridge to allow for polarity reversal of an input signal at its output contacts. It relies on two 24 VDC binary inputs. One input (pins 0 and 1) controls the state of its internal electromagnetic switch to activate or de-activate the H-bridge. The other signal is applied to the H-bridge so that when deactivated, the signal (applied to pins 2&7 and 3&6) passes through unaltered (at pins 4 and 8) to a connected device (in this case the Purge/Generate solenoid). When the H-bridge is activated, it reverses the polarity (seen at pins 4 and 8) to the connected device.

This solenoid control relay's H-bridge polarity is activated by the MCB RLY 6. The Purge/Generate solenoid is then toggled to either Purge or Generate mode by a short pulse applied to MCB RLY 5. This signal will either hit the Purge/Gen solenoid in normal polarity, or reverse polarity depending on the state of the H-bridge at the time.

6.9 Stirling Controllers

The Stirling cooler controller boards operate from 48 VDC. Each receives a 4-20 mA signal from the Analog Output Module to set its cooling output power between 0 to 100%. The Stirling controller boards drive the coolers by producing an 80 Hz variable amplitude drive signal which is frequency modulated on a high frequency carrier wave.

In addition to providing cooler power, the Stirling controller boards provide power to the Stirling cooler fans. They also monitor Stirling hot side temperature to auto-stop the coolers under fault conditions.

The upper cooler is nearest the saturator outlet. Cooling power applied via the Stirling cooler is controlled by output I OUT 1 of the analog output module. I OUT 1 provides a 4-20 mA signal representing a desire

for 0 to 100% cooling power. The 4-20 mA signal is injected at CN7 pins 2(+) and 3(-) of the upper Stirling controller board. 48 VDC power input to the Stirling controller board is connected at CN1 pins 1(+48 VDC) and 2(GND). The Stirling drive output is connected to CN8 pins 1 and 2.

The lower cooler is nearest the saturator inlet. Cooling power applied via the Stirling cooler is controlled by output I OUT 0 of the analog output module. I OUT 0 provides a 4-20 mA signal representing a desire for 0 to 100% cooling power. The 4-20 mA signal is injected at CN7 pins 2(+) and 3(-) of the lower Stirling controller board. 48 VDC power input to the Stirling controller board is connected at CN1 pins 1(+48 VDC) and 2(GND). The Stirling drive output is connected to CN8 pins 1 and 2.

Connector	Pin	Signal	Function
CN1	1	+48 VDC	Power In
CN1	2	Gnd	Power In
CN2	1	Warm side thermistor	Measurement
CN2	2	Warm side thermistor	Measurement
CN6	1	DC (+)	Fan
CN6	2	DC (-)	Fan
CN7	2	4-20 mA(+)	Input SetPt
CN7	3	4-20 mA(-)	Input SetPt
CN7	4,8	Jumper 4-8	Enable
CN8	1	Stirling Output	Drive Output
CN8	2	Stirling Output	Drive Output

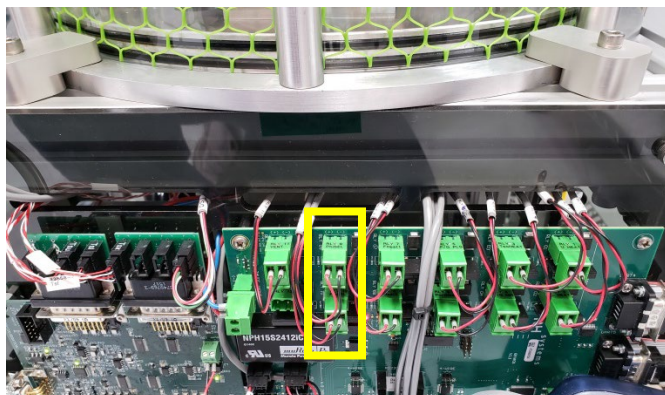
7 Calibration

7.1 Pressure Calibration

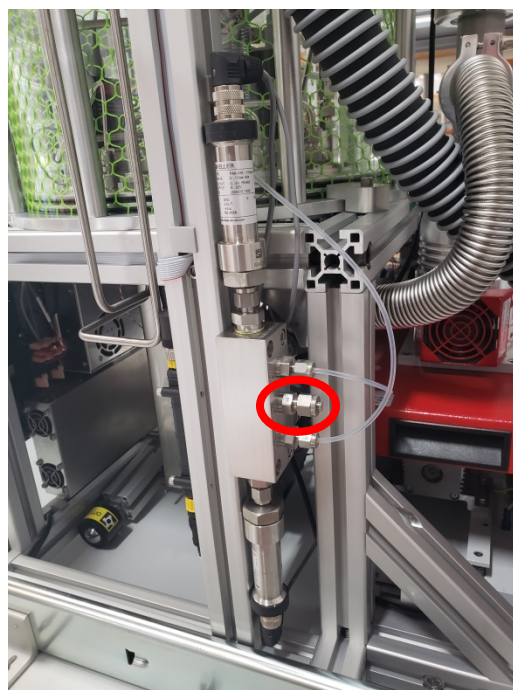
Proper calibration of the transducers used for measurement of saturation and test instrument pressure is needed to ensure adequate system performance. There are two separate sensors, each with a different operating range. Calibration of these two sensors should be performed individually, one at a time.

7.1.1 Calibration of Low Range Transducer

1. Set the Saturator Pressure setpoint to 0 (it will show its minimum but that's ok).
2. Set all Flow Rate setpoints to 0.
3. Unplug the green connectors at RLY 9 and RLY 10 of the MCB (see section 6.5.1). This pneumatically isolates the pressure transducer.



4. Remove the 1/4" Swagelok cap on the CAL port of the pressure transducer manifold.
5. Connect a pressure calibrator (a source of regulated pressure and a pressure reference) to the CAL port.
6. For easy visualization of steady conditions, show *Psi* on a graph.
7. In the secondary data window, show **Low Range Pressure Coefficients**. In addition to the transducers coefficients, you'll also see both the **Pressure** and **Raw Reading** of the transducer.
8. Apply a minimum of 4 different calibration pressures over the range of the transducer. Since the low range transducer is a barometer, its measurement range is approximately 800 to 1200 mb (11 to 17 psia).
9. For each applied pressure, record your Reference Pressure along with the Raw Reading and Pressure of the transducer. This information can be used as your As-Found calibration data.



- Using the **Reference Pressure** and **Raw Reading** data, compute new calibration coefficients A0, A1, A2, and A3 to the formula

$$P = A0 + A1*Raw + A2*Raw^2 + A3*Raw^3$$

where *P* is **Reference Pressure**
Raw is **Raw Reading**

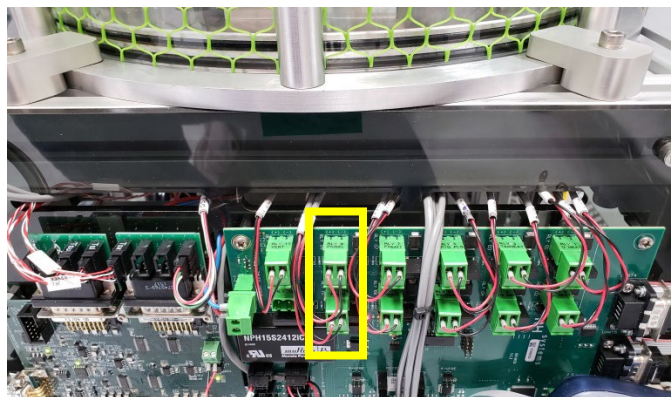
- Enter the new coefficient into the appropriate field of the **Low Range Pressure Coefficients** window.
- Re-run the pressure calibration points again to collect your As-Left calibration data.
- Disconnect the pressure calibrator from the CAL port.
- Re-install the ¼” Swagelok cap on the CAL port.
- Re-install the green connectors of RLY 9 and RLY 10

Range of reasonable expected values for A0...A3

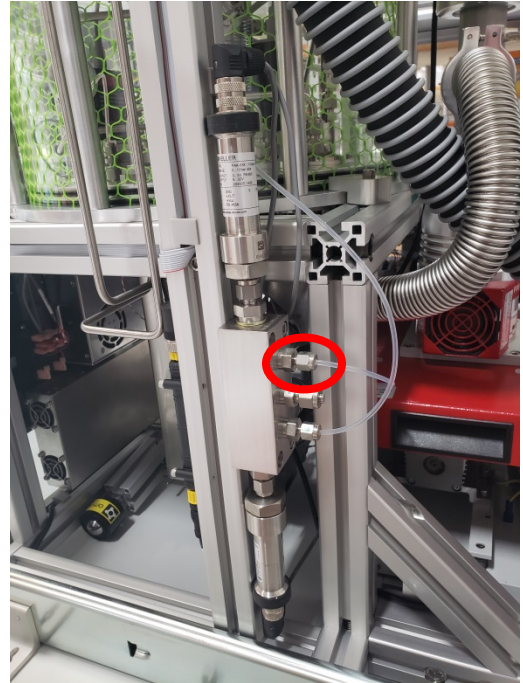
Coefficient	Default	Expected range of computed value
A0	0.0	Value of A0 should be between 0 and ±1
A1	1.0	Value of A1 should be between +0.9 and +1.1
A2	0.0	Value should be between 0 and ±1E-5
A3	0.0	Value should be between 0 and ±1E-9

7.1.2 Calibration of High Range Transducer

- Set the Saturator Pressure setpoint to 0 (it will show 10 psia as a minimum but that’s ok).
- Set all Flow Rate setpoints to 0.
- Unplug the green connectors at RLY 9 and RLY 10 of the MCB (see section 6.5.1). This pneumatically isolates the pressure transducer.



4. Remove the 1/8" tube from the HIGH port of the pressure transducer manifold.
5. Connect a pressure calibrator (a source of regulated pressure and a pressure reference) to the HIGH port.
6. For easy visualization of steady conditions, show **Psh** on a graph.
7. In the secondary data window, show **High Range Pressure Coefficients**. In addition to the transducers coefficients, you'll also see both the **Pressure** and **Raw Reading** of the transducer.
8. Apply a minimum of 4 different calibration pressures over the range of the transducer. The measurement range of the high range transducer is approximately ambient to 10 bar (ambient to 145 psia).
9. For each applied pressure, record your Reference Pressure along with the Raw Reading and Pressure of the transducer. This information can be used as your As-Found calibration data.



10. Using the **Reference Pressure** and **Raw Reading** data, compute new calibration coefficients A0, A1, A2, and A3 to the formula

$$P = A0 + A1*Raw + A2*Raw^2 + A3*Raw^3$$

where **P** is **Reference Pressure**
Raw is **Raw Reading**

11. Enter the new coefficient into the appropriate field of the **High Range Pressure Coefficients** window.
12. Re-run the pressure calibration points again to collect your As-Left calibration data.
13. Disconnect the pressure calibrator from the High port.
14. Re-install the 1/8" tube to the HIGH port
15. Re-install the green connectors of RLY 9 and RLY 10

Range of reasonable expected values for A0...A3

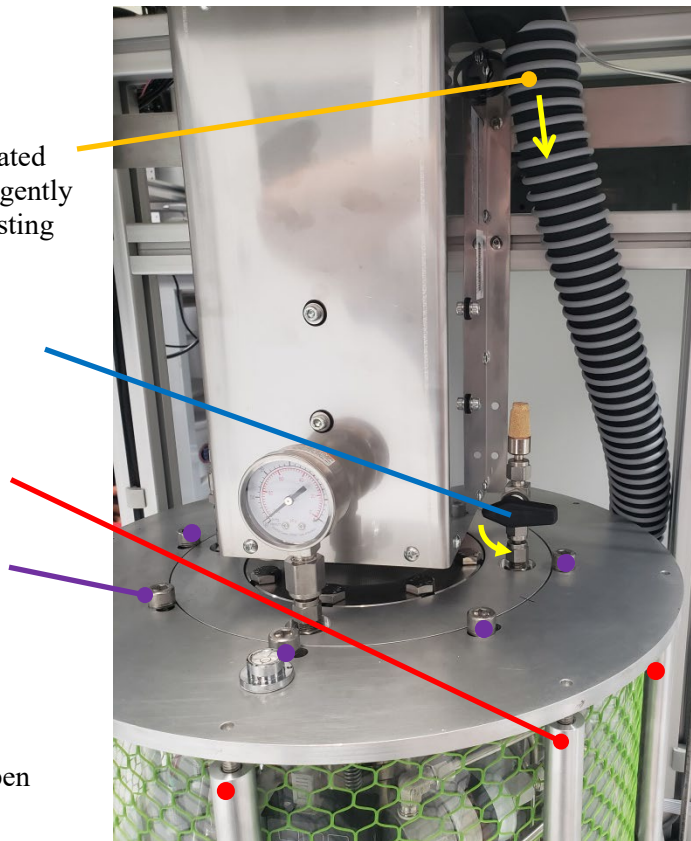
Coefficient	Default	Expected range of computed value
A0	0.0	Value of A0 should be between 0 and ±1
A1	1.0	Value of A1 should be between +0.9 and +1.1
A2	0.0	Value should be between 0 and ±1E-5
A3	0.0	Value should be between 0 and ±1E-9

7.2 Temperature Calibration

Proper calibration of the sensors used for measurement of the saturator temperature assures adequate system performance. There are three sensors used for measurement of the saturator (Tsu, Tsl, Tsx). Optionally, there are two additional sensor channels available (Tx1, Tx2). The use of these additional channels is dependent on user requirements.

7.2.1 Calibration of Sat Temperature Probes (Tsu, Tsl, Tsx)

1. Warm the saturator to a temp of 20°C. Since the saturator exterior will be exposed to room ambient air during the calibration procedure, warming the saturator prevents unwanted condensation on its outer surface.
2. Set the Saturator Pressure setpoint to 0 (it will show a value below ambient pressure as its minimum, rather than 0, but that's ok).
3. Set all Flow Rate setpoints to 0.
4. Stop *Cooling*.
5. Stop *Vacuum*.
6. Remove the air hose from the fan located on top of the upper stirling cooler by gently pulling the hose downward while twisting back and forth.
7. Open the vacuum vent valve (turning counter-clockwise) and wait for the vacuum chamber to reach ambient pressure.
8. Remove the vacuum chamber's 8 exterior support bars.
9. Remove 8 screws from the upper vacuum plate. 8 mm hex key required.
10. Open the vacuum chamber by carefully lifting the vacuum plate upward.
11. Secure the vacuum chamber in the open position.
12. Note the location and identification of the three temp probes installed in the saturator.
13. Remove the temperature probes and wipe them with a cloth to remove thermal grease residue.
14. Remove the 1/4" Swagelok nut attaching the probe to the bottom vacuum plate.
15. Unbundle the excess wire from under the vacuum plate and feed the wire through the fitting, allowing the probe to be located away from the vacuum plate. Do the same for all three probes.



16. Install the probes in your temperature calibration bath along with your reference thermometer. You can calibrate them all together at the same time.
17. For easy visualization of steady conditions, show ***Tsu, Tsl, and Tsx*** on a graph.
18. In the secondary data window, show ***Temperatures***. This window shows temperatures and resistances of all probes.
19. Using the calibration bath, run at least 4 temperature points over the desired range. A range of at least -90 °C to +10 °C is preferable however a larger range may also be used for purposes of calibration. For the lowest point, an LN2 calibration may be a suitable option.
20. Record the As-Found data for each calibration point which consists of Reference Temperature, Probe Temperature and Probe Resistance for each probe being calibrated.
21. Using the Reference Temperature and Probe Resistance, compute the R_0 , a , b , and c coefficients to the Callendar-Van Dusen equation

$$R = R_0[1 + at + bt^2 + c(t-100)t^3]$$
 where R is resistance of the probe in ohms, and
 t is the Reference Temperature in °C
22. Select the secondary window for the specific probe, such as ***[Tsu] Sat Temp Upper Coefficients***, and enter the new R_0 , a , b , and c coefficients.
23. Press the ***Save Coefficients*** button to store the new coefficients to the G3 permanent memory.
24. Repeat steps 21 through 23 for each of the remaining probes being calibrated.
25. Re-run the temperature calibration points to record your As-Left calibration data.
26. Using a syringe or other suitable instrument, insert a small amount (~0.5 ml) of low temperature thermally conductive vacuum grease into the hole where the temp probes will be re-installed. (Apiezon® N cryogenic vacuum grease is suitable.)
27. Carefully pull the excess wire back down through the fittings in the bottom vacuum plate and reattach each probe's 1/4" Swagelok nut to their fittings. Don't tighten them yet.
28. Reinsert each probe it the proper location to an insertion depth of 50 mm (2").
29. Tighten the 1/4" Swagelok nuts properly (usually no more than 1/4 turn past finger tight).
30. Re-install the vacuum chamber, paying attention to the alignment marks on the top vacuum plate and flange.
31. Insert and sequentially tighten the 8 large flange screws. Recommended tightening sequence is to place all screws finger tight, then tighten every 3rd screw about 1/4 turn at a time until all 8 screws have been fully seated.
32. Insert the 8 exterior support posts. Adjust to FINGER TIGHT only.
 Reinstall the hose onto the upper stirring fan.

7.2.2 Calibration of External Temperature Probes (Tx1, Tx2)

1. Plug the probe cables into the front panel connectors.
2. Install the probes in your temperature calibration bath along with your reference thermometer. You can calibrate them together at the same time.

3. For easy visualization of steady conditions, show ***Tx1*** and ***Tx2*** on a graph.
4. In the secondary data window, show ***Temperatures***. This window shows temperatures and resistances of all probes.
5. Using the calibration bath, run at least 4 temperature points over the desired range.
6. Record the As-Found data for each calibration point which consists of Reference Temperature, Probe Temperature and Probe Resistance for each probe being calibrated.
7. Using the Reference Temperature and Probe Resistance, compute the R_0 , a , b , and c coefficients to the Callendar-Van Dusen equation

$$R = R_0[1 + at + bt^2 + c(t-100)t^3]$$

where R is resistance of the probe in ohms, and
 t is the Reference Temperature in °C

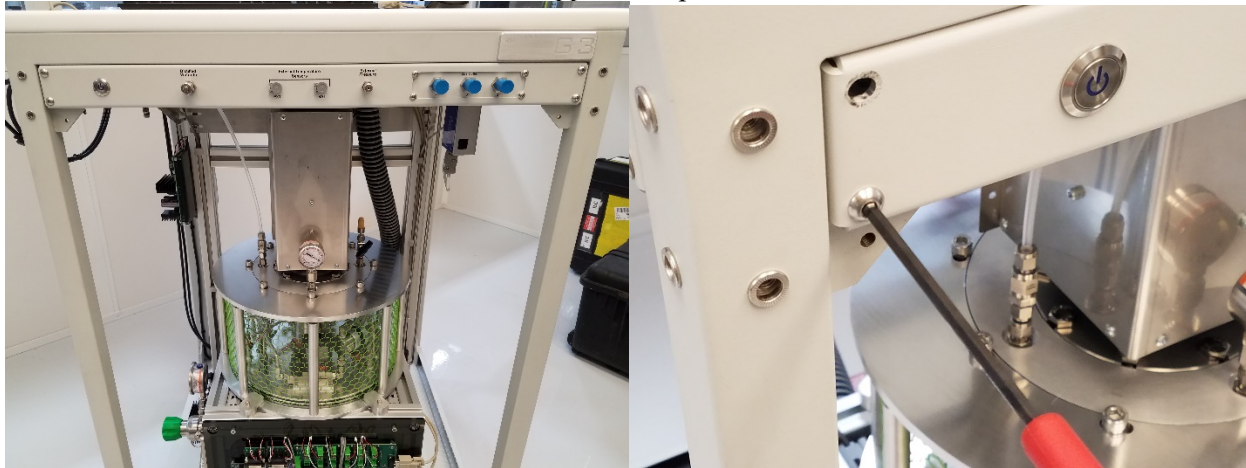
8. Select the secondary window for the specific probe, such as ***[Tx1] External Temp 1 Coefficients***, and enter the new R_0 , a , b , and c coefficients.
9. Press the ***Save Coefficients*** button to store the new coefficients to the G3 permanent memory.
10. Repeat steps 7 through 9 for each of the remaining probes being calibrated.
11. Re-run the temperature calibration points to record your As-Left calibration data.

8

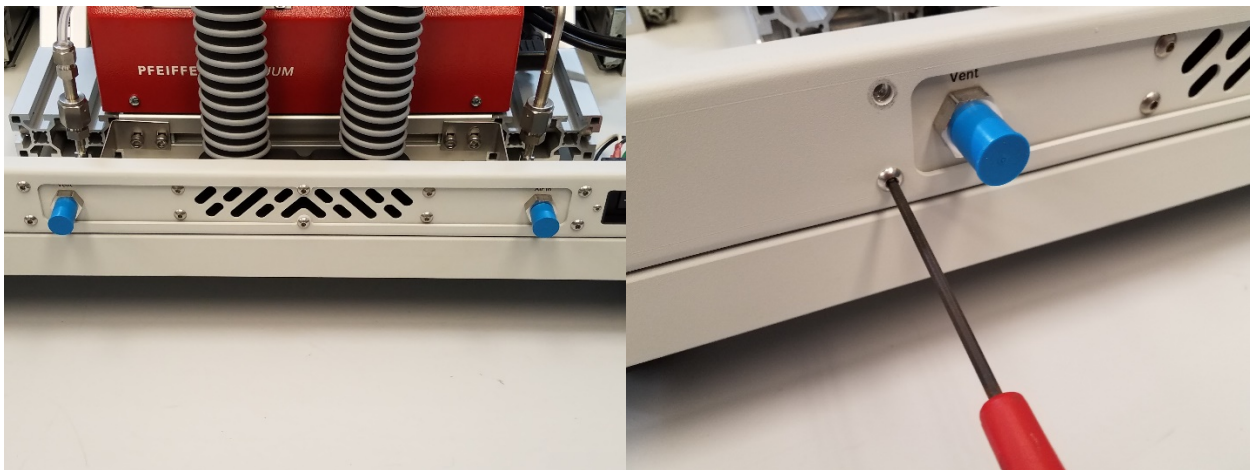
8 Vacuum Chamber

8.1 Extracting Vacuum Chamber

1. Remove the panel for access to the vacuum chamber. It may be best to remove the side panels as well.
2. Remove hardware to separate the upper front panel from the frame.

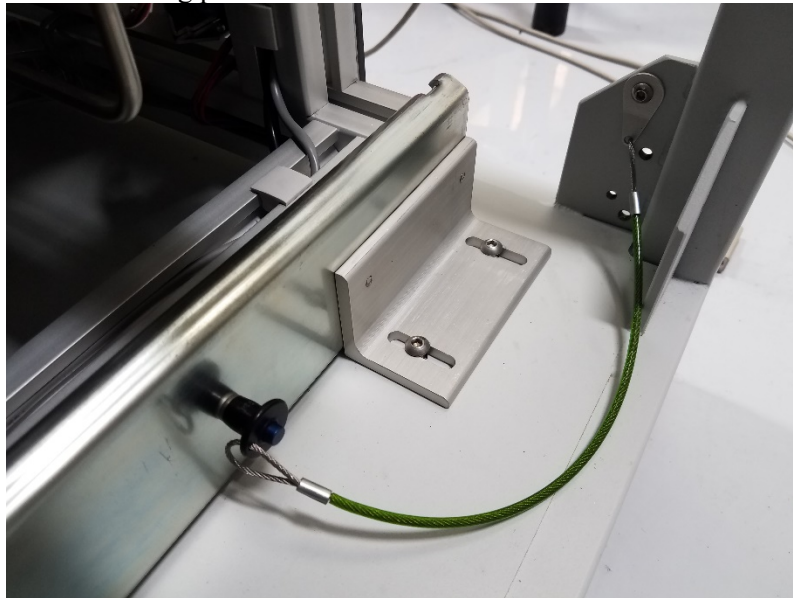


3. Remove the lower rear panel. Do this by removing the hardware in the center section as shown below.

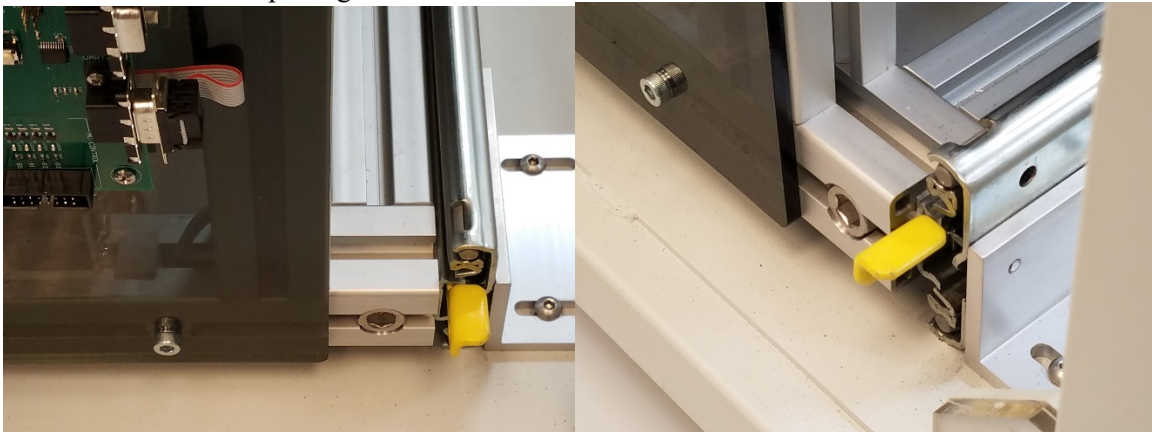




4. Pull out pin from slide rail and set aside. Be sure that this does not interfere with the slide rail when it is being pulled out of the frame.



5. Slide rail must be unlocked by using your hand or foot. Pull out chamber only 6 to 8 inches. Use caution when pulling out chamber.

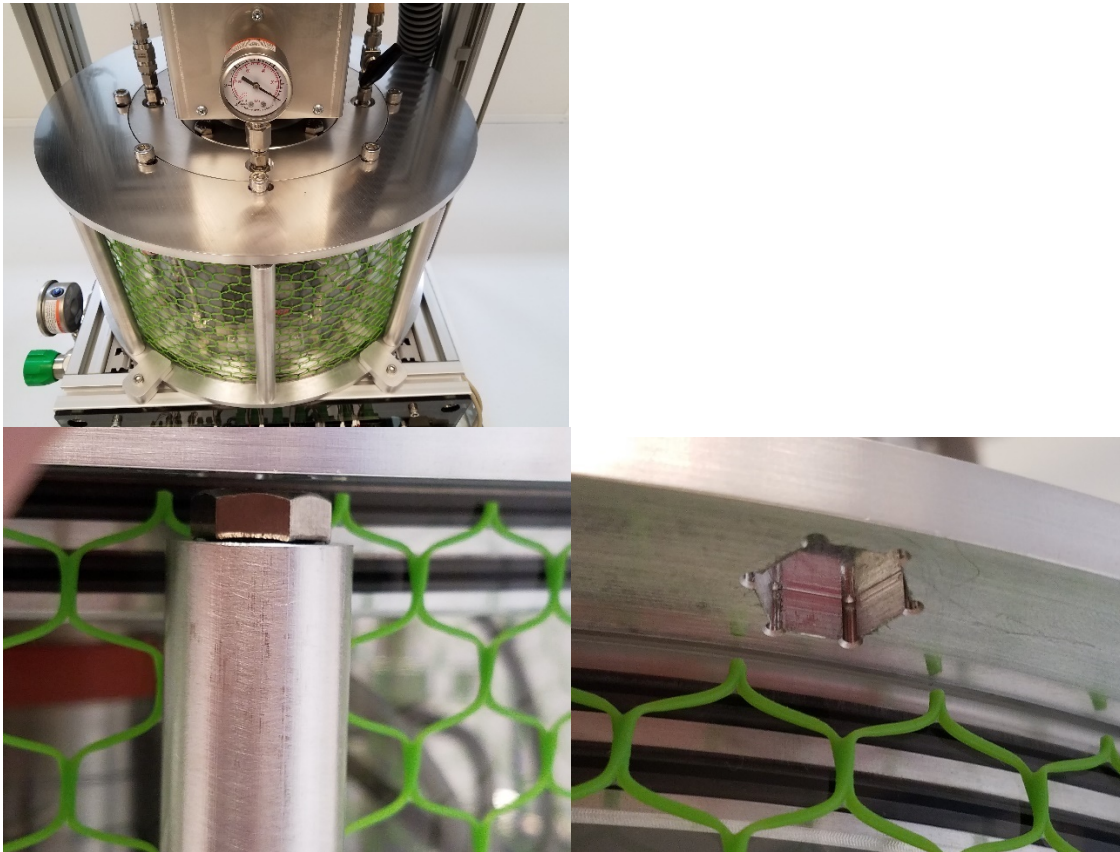


6. Position the roller kick stand for balance. Reach under chamber assembly and pull pin lever to release kick stand from its locked position. Rotate kick stand 90 degrees and secure pin lever. Ensure the kick stand is locked in that position.



8.2 Opening Vacuum Chamber

1. Remove vertical columns by rotating counter clockwise, if you are looking at them from the top. The hex bolt is pocketed inside the bottom of the top plate. The column may need to be lifted for the bolt to travel. This allows for better clearance for removal.



2. Loosen top chamber plate. This is done slowly and in two steps to avoid damage to plate and acrylic tube. Loosen first screw approximately $\frac{1}{4}$ turn and move to next screw. Repeat this

pattern in the same direction until all eight are loosened the same amount.



3. Once the top chamber plate is ready to be removed, hold the ring plate underneath with your fingers and apply pressure with thumbs on the sterling flange. Plate will lift slightly and rotate in different areas until acrylic clears bottom plate o-rings.



8.3 Closing Vacuum Chamber

9 Parts List

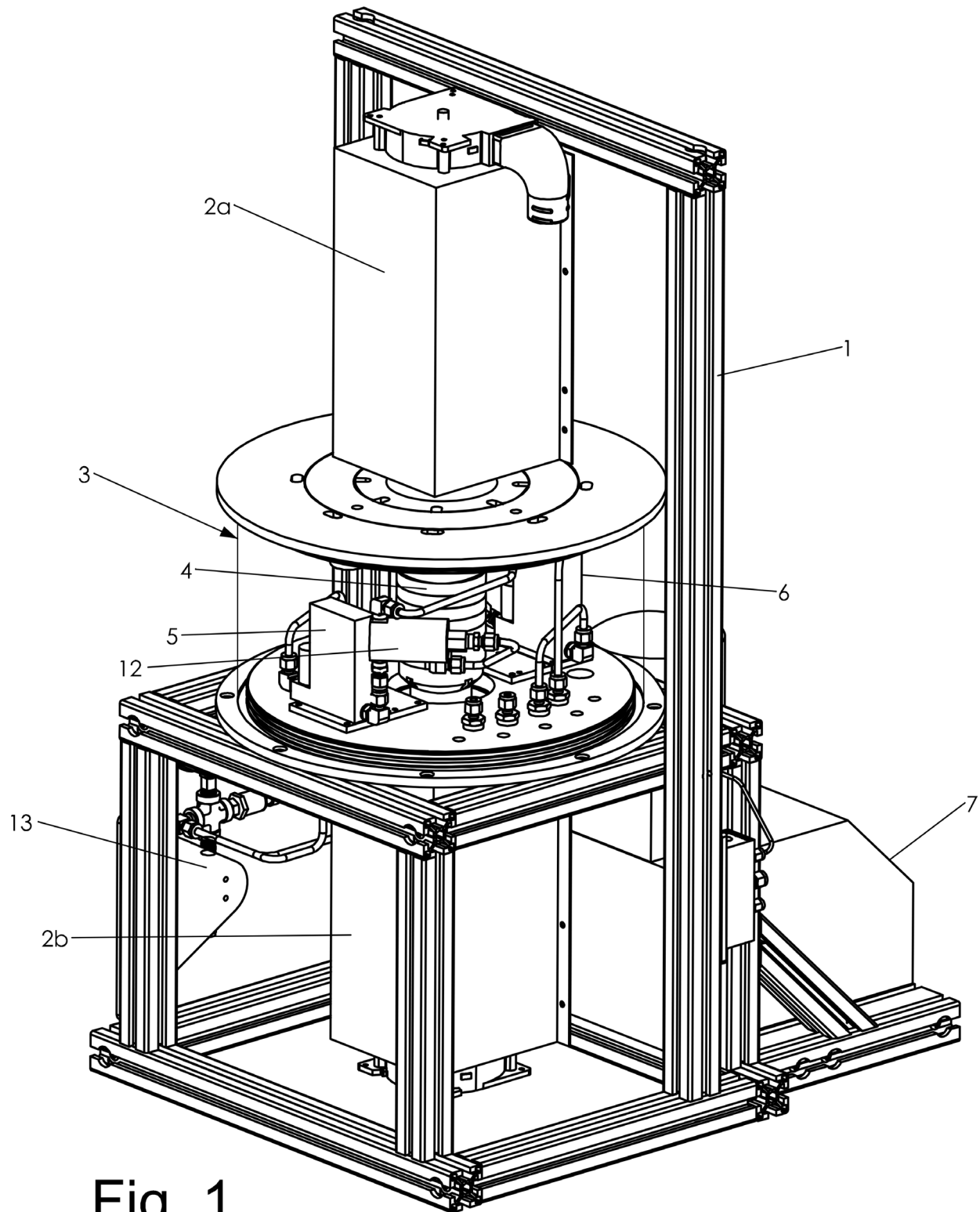


Fig. 1

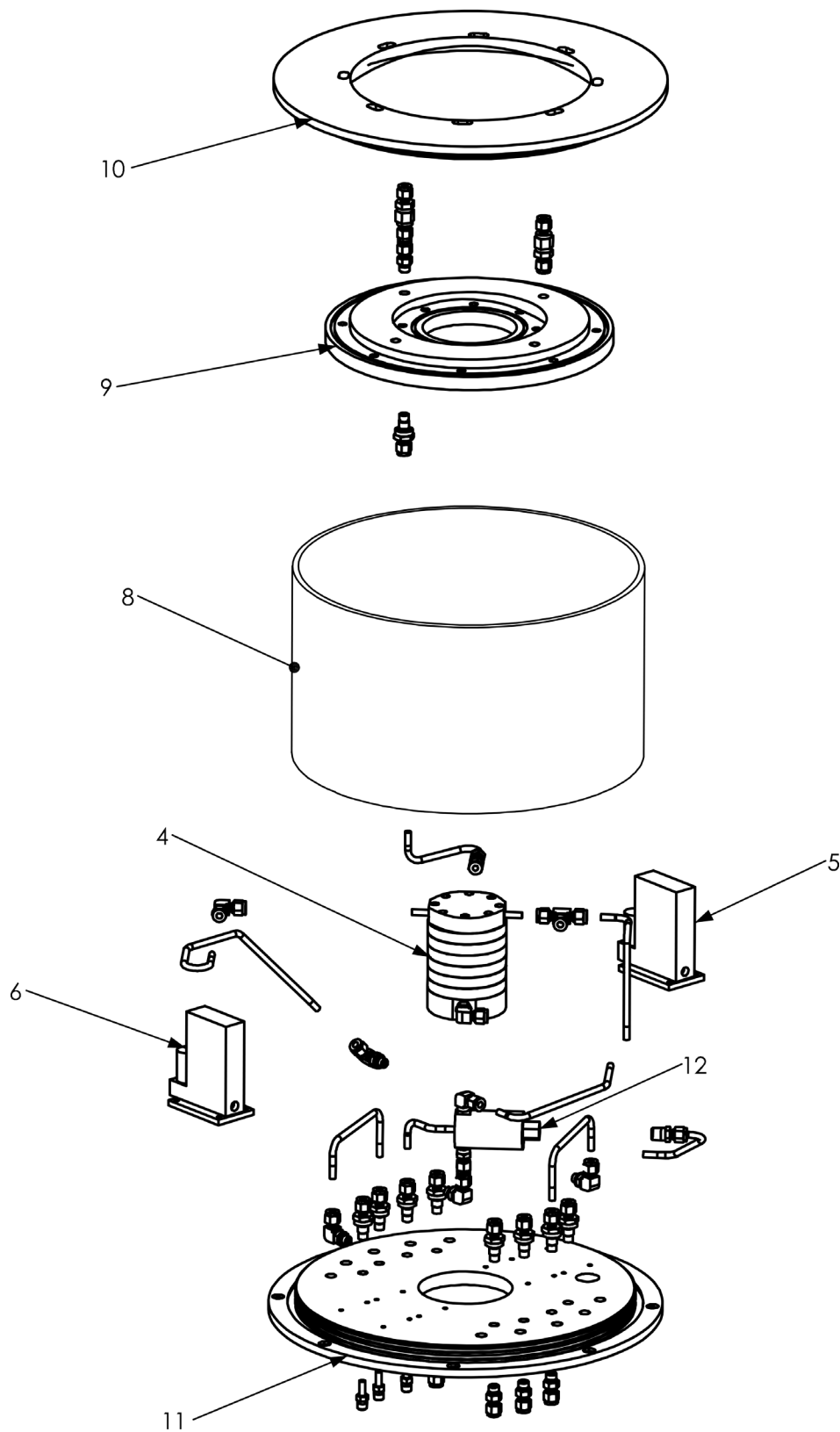


Fig. 4

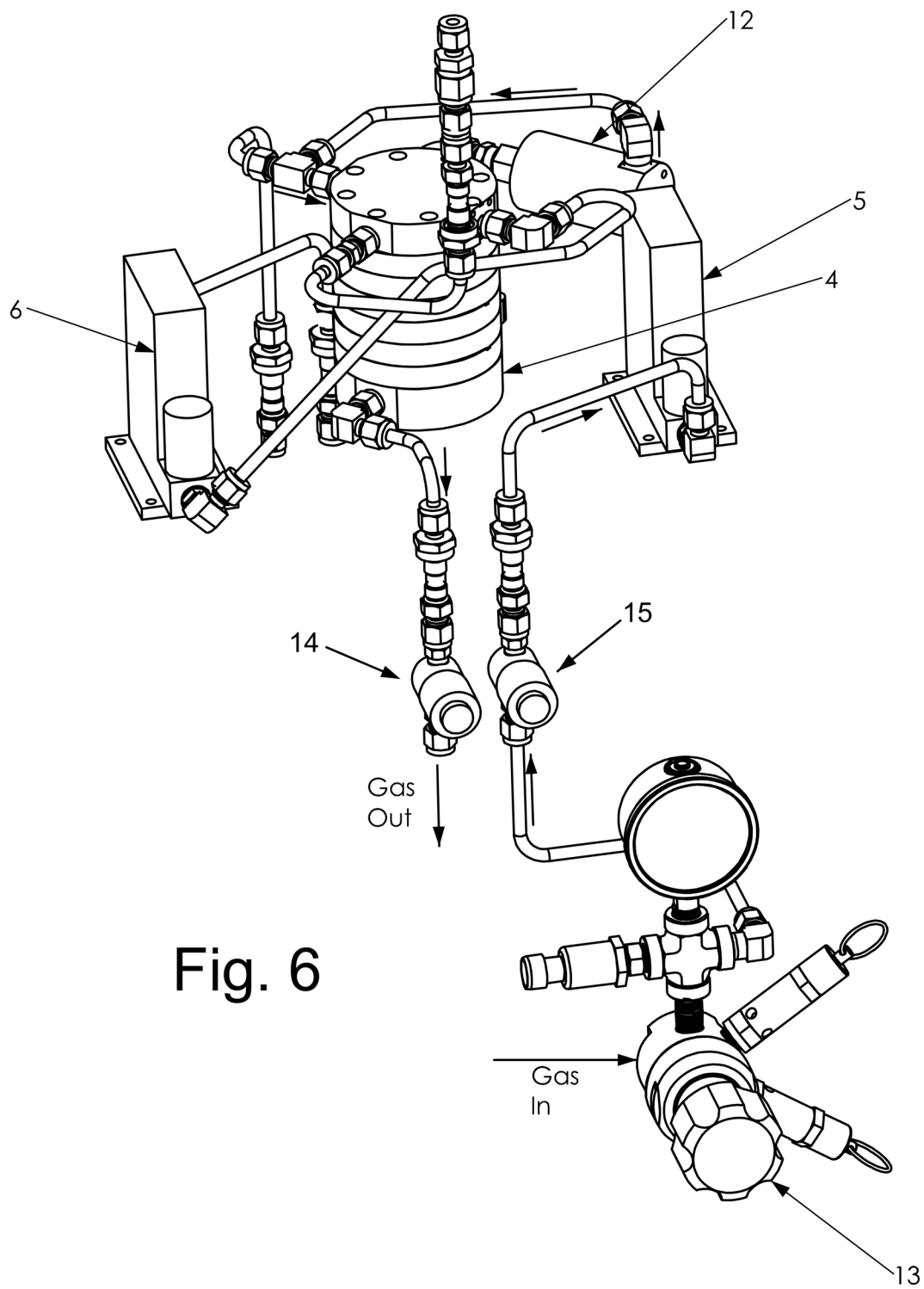


Fig. 6

Figures 1,4 and 6 show different views of the humidity generator assembly. The items shown in Figures 1, 4 and 6 are:

1	Humidity Generator Support Frame
2a	Top Free Piston Stirling Cooler
2b	Bottom Free Piston Stirling Cooler
3	Vacuum Chamber
4	Saturator (Plate Stack Assembly)
5	Saturator Pressure Controller Valve
6	Saturator Exit Gas Flow Controller Valve
7	Vacuum pump
8	Vacuum chamber wall
9	Top Vacuum Flange Part A
10	Top Vacuum Flange Part B
11	Bottom Vacuum Flange
12	Flow-generator & Purge - 3 Way Valve
13	Nitrogen Inlet Pressure Regulator
14	Purge outlet valve
15	Entry On-off Valve

10 Drawings

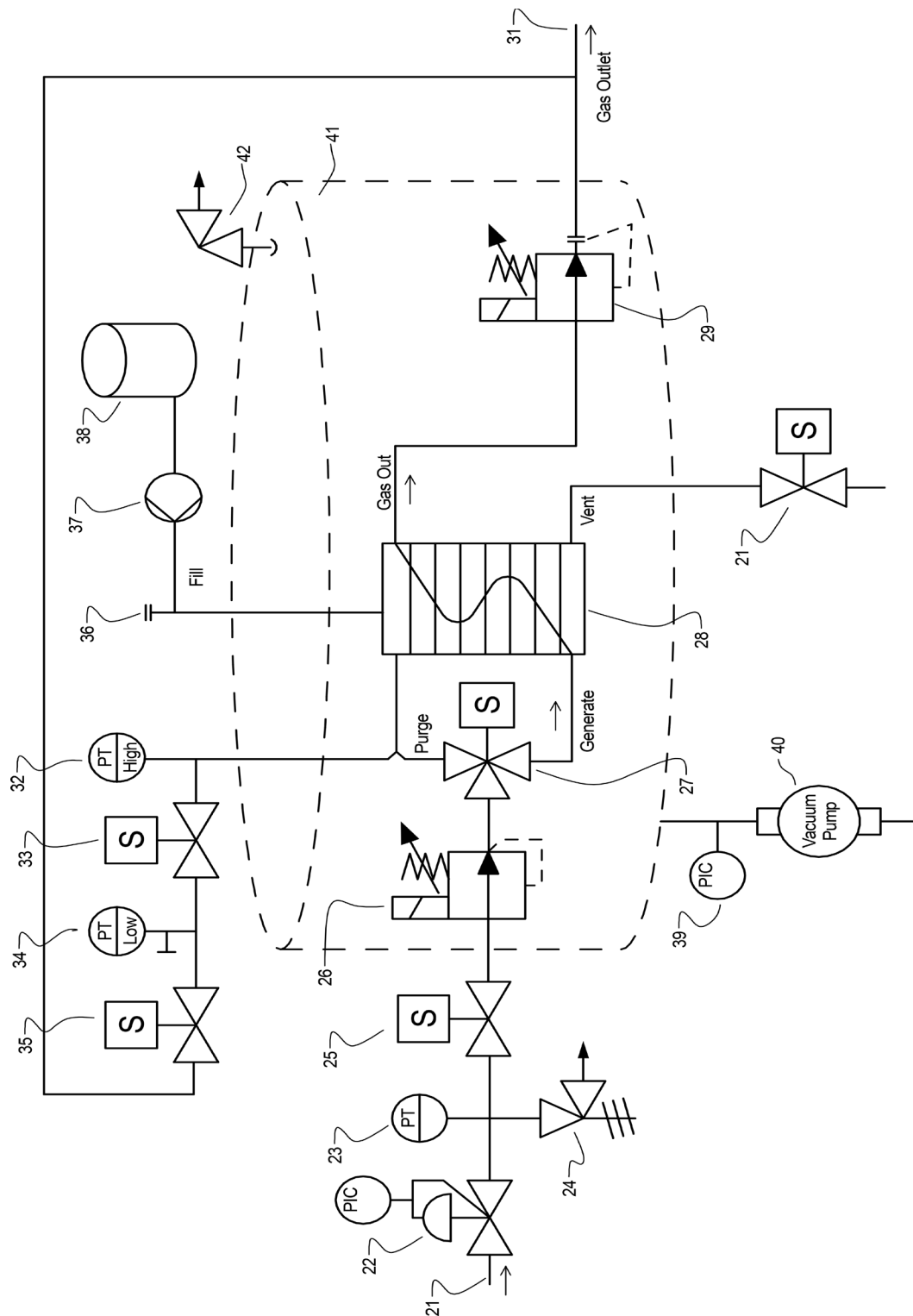


Fig. 7

Elements Illustrated in Figure 7:

21	Inlet gas
22	Inlet pressure regulator
23	Inlet pressure transmitter
24	Inlet relief valve
25	Saturator on/off valve
26	Saturator pressure control valve
27	Three way valve
28	Saturator
29	Exit flow control valve
31	Exit Pressure
32	Saturator pressure transmitter (high range)
33	Blocking valve (1)
34	Exit pressure transmitter (low range)
35	blocking valve (2)
36	Water fill point
37	Water fill pump
38	Water fill tank
39	Vacuum pressure gauge
40	Vacuum pump
41	Vacuum chamber
42	Vacuum chamber over pressure valve

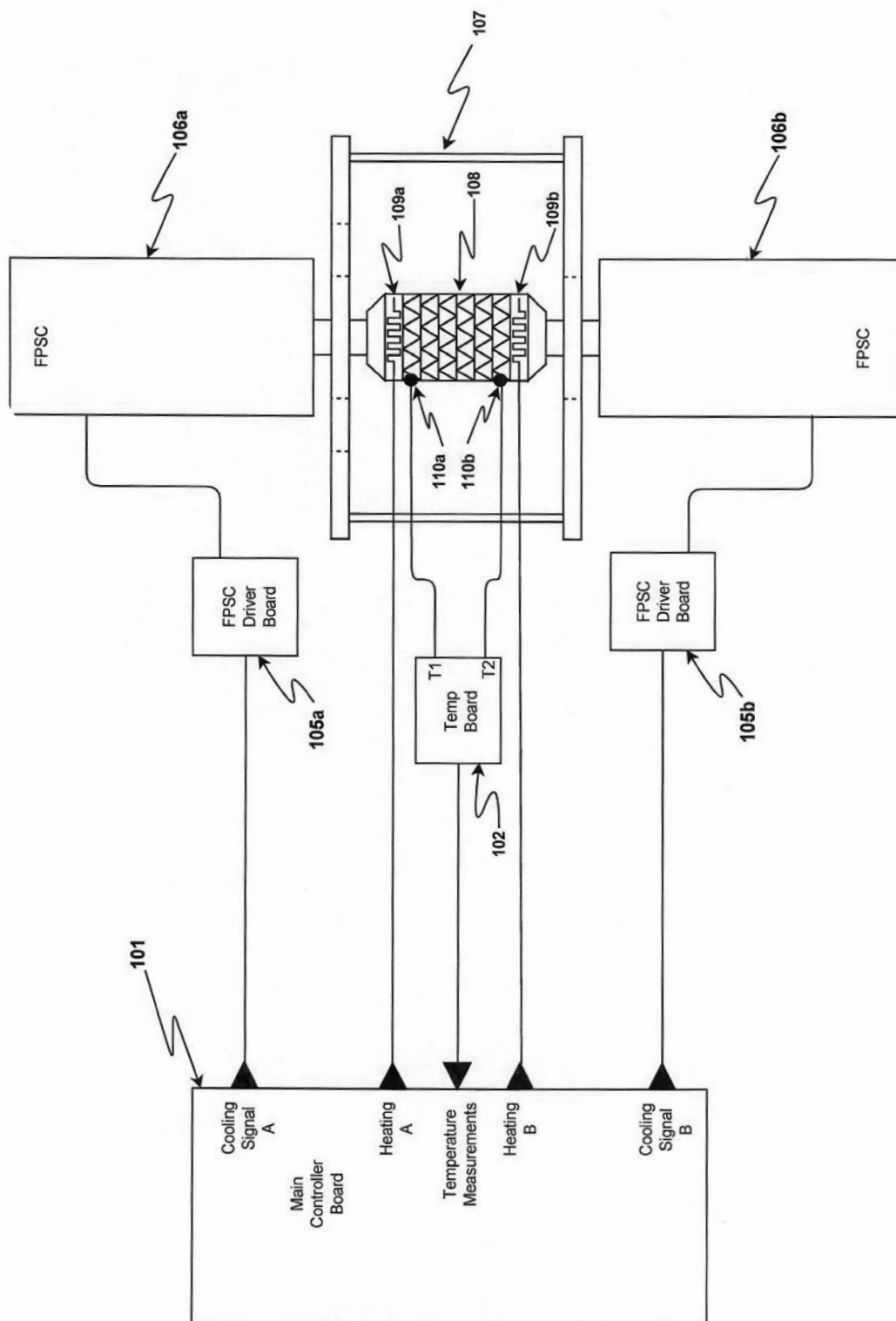


Fig. 8

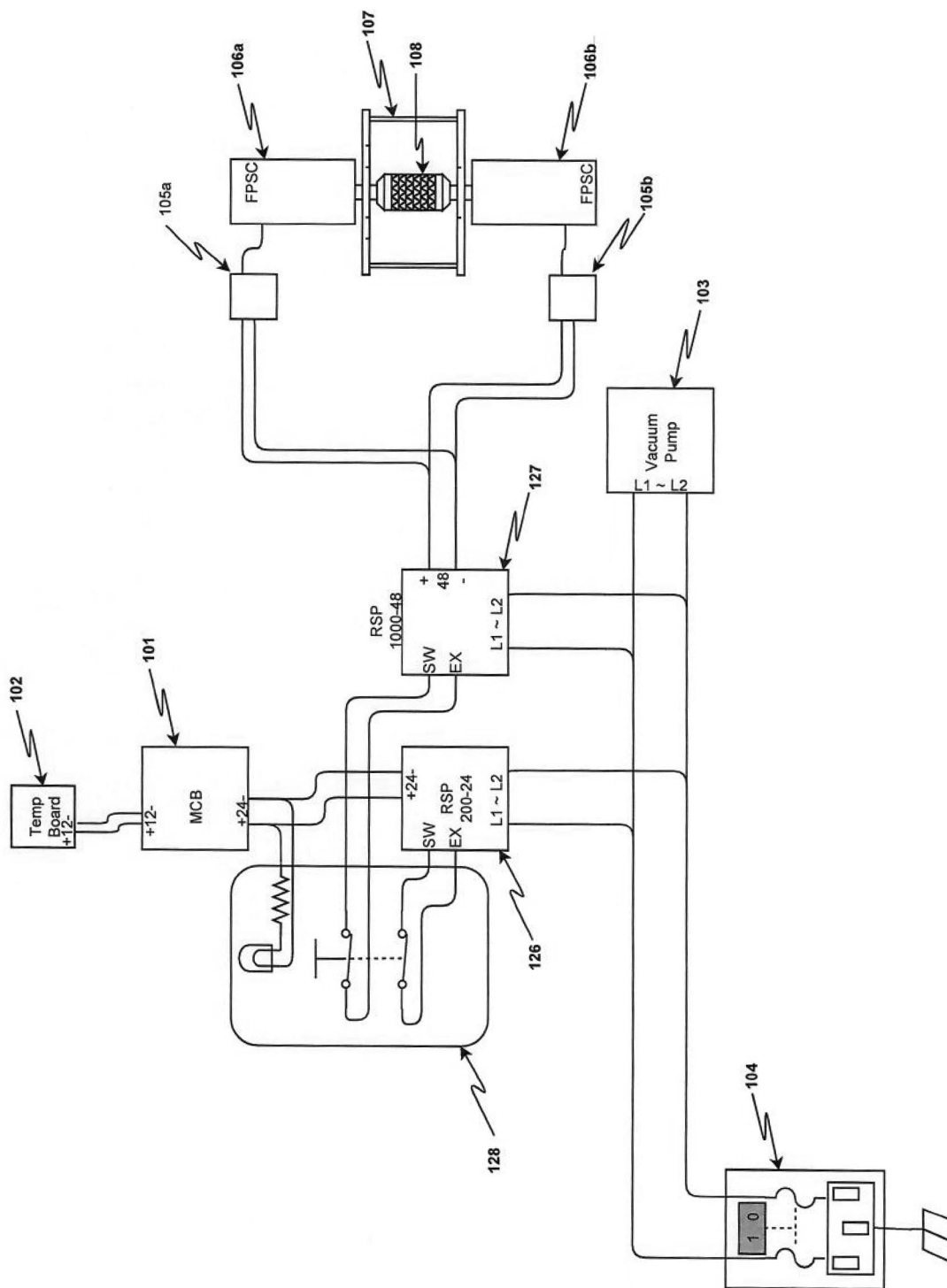


Fig. 9

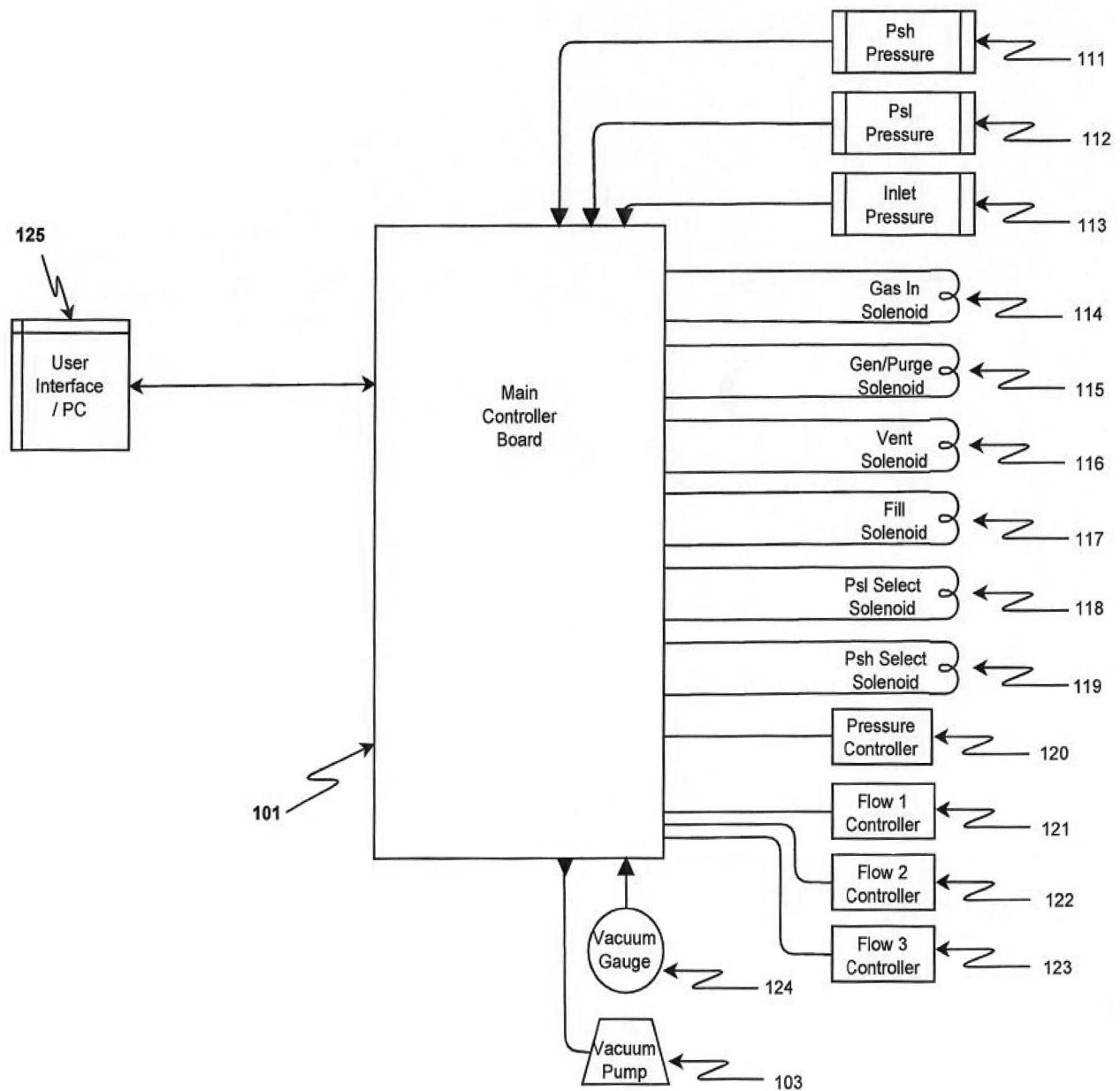


Fig. 10

In Figures 8-10, the following items are illustrated:

101	Main controller board with analog and digital I/O, custom Firmware
102	Multi-channel high accuracy temperature measuring circuit
103	Vacuum Pump
104	AC input power receptacle
105a	Electronic control circuit to drive 106a
105b	Electronic control circuit to drive 106b
106a	Free Piston Stirling Cooler (FPSC)
106b	Free Piston Stirling Cooler (FPSC)
107	Vacuum chamber
108	Saturator
109a	Heater Top
109b	Heater Bottom
110a	Saturator Temperature Sensor a (upper)
110b	Saturator Temperature Sensor b (lower)
111	Saturator pressure sensor (transmitter)
112	Exit pressure sensor (transmitter)
113	gas inlet pressure sensor
114	Gas inlet valve
115	Directional valve to select gas flow path purge / generate
116	Vent valve solenoid

117	Water fill valve solenoid
118	Pressure selection valve low (Psl)
119	Pressure selection valve high (Psh)
120	Pressure controller
121	Flow 1 controller
122	Flow 2 controller – optional
123	Flow 3 controller – optional
124	Vacuum gauge sensor
125	User Interface with PC – custom programming
126	24 VDC power supply
127	48 VDC power supply
128	Power switch with integrated LED indicator