

# Operation Manual and Programming Reference

## **Universal Gas Analyzers**

---

### **UGA100, UGA200, UGA300**



---

## **Certification**

Stanford Research Systems certifies that this product met its published specifications at the time of shipment.

## **Warranty**

This Stanford Research Systems product is warranted against defects in materials and workmanship for a period of one (1) year from the date of shipment.

## **Service**

For warranty service or repair, this product must be returned to a Stanford Research Systems authorized service facility. Some components may be serviceable directly from the supplier. Contact Stanford Research Systems or an authorized representative before returning this product for repair.

## **Trademarks**

Ultra-Torr® and VCR® are registered trademarks of Swagelok Co.

Tygon® is a registered trademark of Norton Co.

All other brand and product names mentioned herein are used for identification purposes only, and are trademarks or registered trademarks of the respective holders.

## **Contact Information**

Stanford Research Systems, Inc.  
1290-D Reamwood Avenue  
Sunnyvale, CA 94089 USA

Phone: (408)744-9040

Fax: (408)744-9049

[www.thinkSRS.com](http://www.thinkSRS.com)

[info@thinkSRS.com](mailto:info@thinkSRS.com)

*Information in this document is subject to change without notice.*

*Copyright © Stanford Research Systems, Inc., 2007–2010. All rights reserved.*

*Printed in U.S.A.*

# Contents

Safety . . . . .	ii
Symbols . . . . .	iii
Checklist . . . . .	iv
Materials List . . . . .	v
Specifications . . . . .	vi
Quick Start. . . . .	ix
<b>Chapter 1 UGA Basics</b>	
Introduction . . . . .	1–2
Configuration . . . . .	1–6
Options. . . . .	1–13
<b>Chapter 2 Guide to Operation</b>	
Introduction . . . . .	2–3
Front Panel Operation . . . . .	2–3
Remote Operation . . . . .	2–17
<b>Chapter 3 Remote Programming</b>	
Introduction . . . . .	3–2
Commands . . . . .	3–4
<b>Chapter 4 UGA Error Messages</b>	
Introduction . . . . .	4–2
Error Messages . . . . .	4–3
<b>Chapter 5 Calibration and Input Design</b>	
Mass Spectrometry Basics . . . . .	5–2
Calibration of Partial Pressure. . . . .	5–13
Pressure Reducing Inlet . . . . .	5–21
References . . . . .	5–33
<b>Appendices</b>	
Appendix A UGA Menu Table . . . . .	A–1
Appendix B UGA State Diagram . . . . .	A–3
Appendix C Calibration Log . . . . .	A–4

---

# Safety



## **Warning**

Hazardous voltages, capable of causing injury or death, are present in this instrument. Use extreme caution whenever the top back and the bottom covers of the instrument are removed. Always unplug the unit while removing those covers.



## **Ventilation**

The UGA system requires forced air cooling to operate at a reasonable temperature. Do not block the air inlet or exhaust on the back of the unit. Components will fail without this cooling.



## **Lifting**

The UGA system is heavy; use care when lifting. Two people are recommended for lifting the system. The handles provided are used for lifting. Do not move when system is running.

## **Line Voltage**

The UGA system is specified for line power of either 110 V / 60 Hz or 220 V / 50 Hz. All the components inside the instrument will only be operated on 24 VDC. Operating at other voltages will damage the components. Two 3 A fuses must be used in the power entry module.

## **Exhaust**

As shipped, the UGA system exhausts to the atmosphere. If the system is analyzing hazardous gases, the user must make provisions to handle the exhaust from the system. A standard 1/4 inch ID Tygon tube connection is provided for this purpose.

## **Elastomer Seals**

Silicone has been reported to react adversely and irreversibly with the glass contained in an electron multiplier. Since the UGA contains an electron multiplier, do not use silicone greases or oils on seals; use only hydrocarbon based materials.

# Symbols on SRS products

Symbol	Description
	Alternating current
	Caution - risk of electric shock
	Frame or chassis terminal
	Caution - refer to accompanying documents
	Earth (ground) terminal
	Battery
	Fuse
	On (supply)
	Off (supply)

---

# Checklist

Open the box(es) and inspect all components of the UGA system. Report any damage to Stanford Research Systems immediately. Compare the contents of the shipping boxes against your original order and the checklist below. Report any discrepancies to Stanford Research Systems immediately.

## Standard System

UGA base unit  
Power cord  
25' RS232 cable  
6' 1/16" OD, 175  $\mu$ m ID capillary, unheated, with the connector  
UGA manual  
RGA manual  
UGA setup CD

## Option 1. Multiple Inlet Valve

16 port Valve  
Valve base  
Valve controller  
Valve controller holder  
Control cord  
Power cord for the controller  
RS232 communication cord for the controller  
Accessory box  
Channel plug, 2 pkg  
2' 1/16" OD, 175  $\mu$ m ID capillary, unheated with connectors for the Valve outlet and the UGA sample inlet  
3' 1/16" OD, 175  $\mu$ m ID capillary, unheated with the connector for the sampling, 2 ea  
Top front cover for this option, installed

## Option 2. System Vent Valve

Vent valve, installed  
Purging gas line connector, installed  
Vent line tube

## Option 3. Sample Line Heater

Capillary with a DB 9 female connector for the heater and a TC (thermocouple)  
Sample line heater set (a heater, a TC, and heating jackets)  
Ultra-Torr connection heater and insulator

---

# Materials List

SRS receives many requests for information about corrosion compatibility. It is our policy not to state the compatibility of our system with various corrosive environments. We simply cannot test the myriad combinations of environments that our customers use.

We do provide a list of all the materials exposed to the gas being introduced into the system. Our expectation is that users who need to measure corrosive environments already have some type of system that creates, handles and contains the corrosive gases. Given that they have designed and operate said system, they are the best people to decide the compatibility of the materials in our system with the specific corrosive environment.

The UGA system contains the following materials:

## Body

- 304 stainless steel - high vacuum tube
- 316 stainless steel - quarter inch tube and fittings
- molybdenum - electrical feedthrough
- ceramic - electrical feedthrough
- AgCuIn - braze material on feedthroughs
- alumina - contained in the RGA
- aluminum - body of diaphragm pump

## Replaceable Components

- glass - if an electron multiplier is installed in the RGA
- chromium - surface of the electron multiplier
- IrO<sub>2</sub>•ThO<sub>2</sub> - filament of RGA

## Seals

- copper - seals in the CF high vacuum flanges
- 316SS - major component of VCR® seals
- silver - a thin layer on the VCR® seals to prevent gauling
- Viton - o-ring seal in the KF flange
- buna-N - seal in the high conductivity valve
- neoprene - diaphragms in diaphragm pump
- nitrile butyl rubber(NBR) - diaphragm pump valves - backing line
- Tygon® - connections to diaphragm pump (can be substituted)

---

# Specifications

## ***Inlet***

Type	capillary: available in stainless steel, PEEK, and glass lined plastic
Flowrate	1 to 10 milliliter per minute at atmospheric pressure
Response time	<200 ms
Pressure	selectable from $1 \times 10^{-6}$ bar to 1 bar

## ***Mass Spectrometer***

Type	quadrupole
Detector	Faraday cup (FC) & Electron multiplier (CDEM)
Range	1 to 300 atomic mass units (amu)
Resolution	<0.5 amu at 10% of peak height
Detection limit	<10 ppm with Faraday cup detector <1 ppm with electron multiplier
Operating pressure	10 <sup>-4</sup> mbar for FC 10 <sup>-6</sup> mbar for CDEM

## ***Connections***

Inlet	1/8 inch Ultra-Torr® fitting
Exhaust	1/4 inch Tygon tube adapter
Computer	RS-232C, DB9 connector or Ethernet
Power	3 pin grounded cable

## ***System***

Pumps	hybrid turbomolecular/drag pump, 81 liter/s, ultimate pressure $2 \times 10^{-9}$ mbar diaphragm pump with ultimate pressure less than 1 mbar protection class IP44
-------	--

## ***Materials***

(see full materials list for details)  
construction: SS304 and SS316  
insulators: alumina, ceramic  
seals: Viton, buna-N, and nitrile butyl rubber  
misc: aluminum, Tygon

**General**

Startup time	5 minutes from full stop
Max. Ambient Operating Temperature	35 °C
Power requirement	either 110 V / 60 Hz or 220 V / 50 Hz (not field selectable) less than 600 W total
Dimensions	28 cm H x 30 cm W x 65 cm D ( 11 in H x 12 in W x 26 in D ) without Handles 33 cm H x 35 cm W x 67.5 cm D (13 in H x 14 in W x 27 in D) with Handles
Weight	41 kg (85 lb. )



# Quick Start

This section will describe a quick start procedure for operating the UGA and getting air analysis data from a remote PC through RS232 connection. If you find any damage to the UGA, do not proceed. For detailed control procedures, please refer to Chapter 2, "Front Panel Operation of UGA".

## *Capillary connection*

(For UGA systems with Option #3 – Sample Heaters, see the option section of Chapter 2)



- Pop off the front upper panel by grasping both sides of the panel and pulling up (see photo).



- Unscrew the Ultra-Torr fitting and remove the pin (see photo).
- Use the pin holder to the right to store the pin.
- Insert your capillary into the Ultra-Torr fitting and tighten.
- Replace the panel.

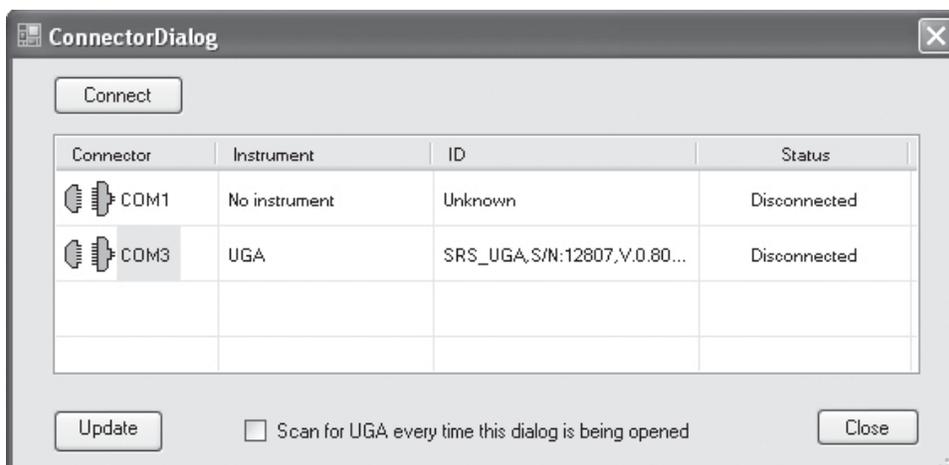
## ***UGA control through a remote PC***

- Insert the UGA/RGA software CD into your PC and follow the prompts to install the UGA and RGA software.
- Connect the provided serial cable between the UGA and the COM port on your PC.
- Start the UGA software.
- Power up the UGA if it is off.
- Click the “Main” tab of the UGA software, and select “Setup”. The ‘Settings’ window will pop up.

In the ‘Settings’ dialog box, choose ‘Serial’ tab. Verify that the serial resource is enabled (as shown below). Baud Rate can be either 38400 or 28800 for this application (38400 is recommended.).

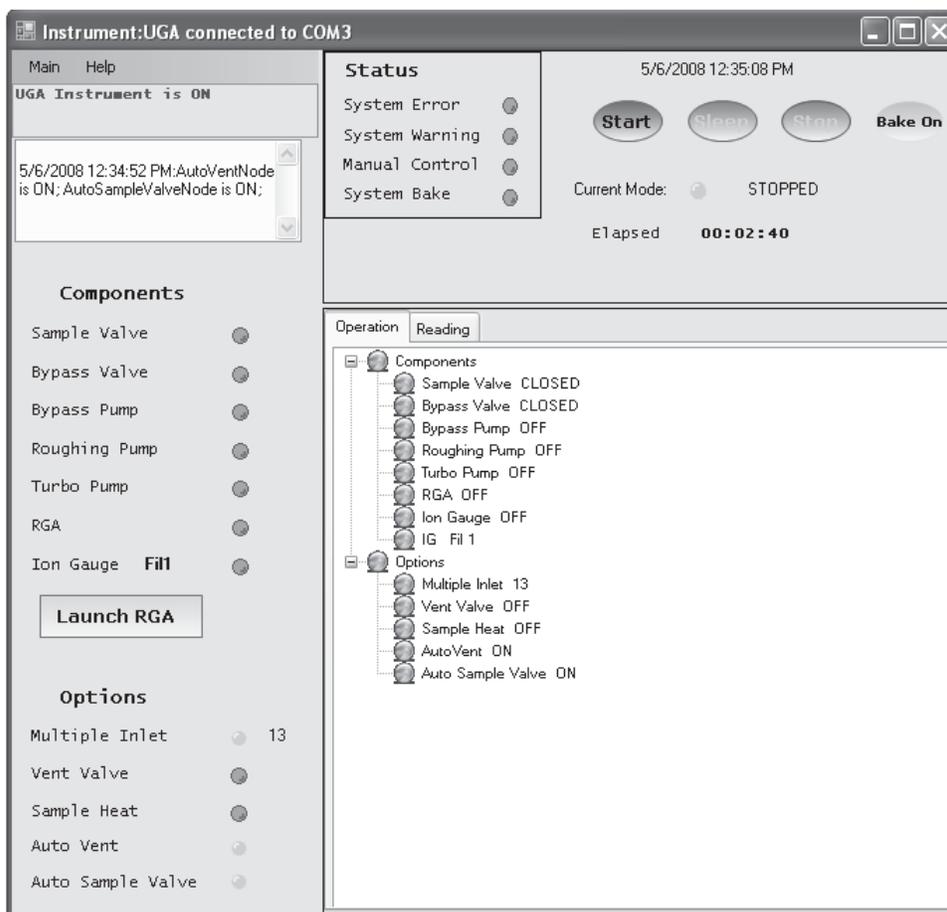


- Click on the “Main” tab, and select “Connect” The following ‘ConnectorDialog’ box will be shown.



- The software will now show available resources. Select the appropriate COM port and click the “Connect” button. In the example screenshot above, the UGA is found on COM3. Note if you are using a USB to serial adapter, you must know what COM port the USB driver has allocated. Use the Windows device manager to find the USB to serial COM port.

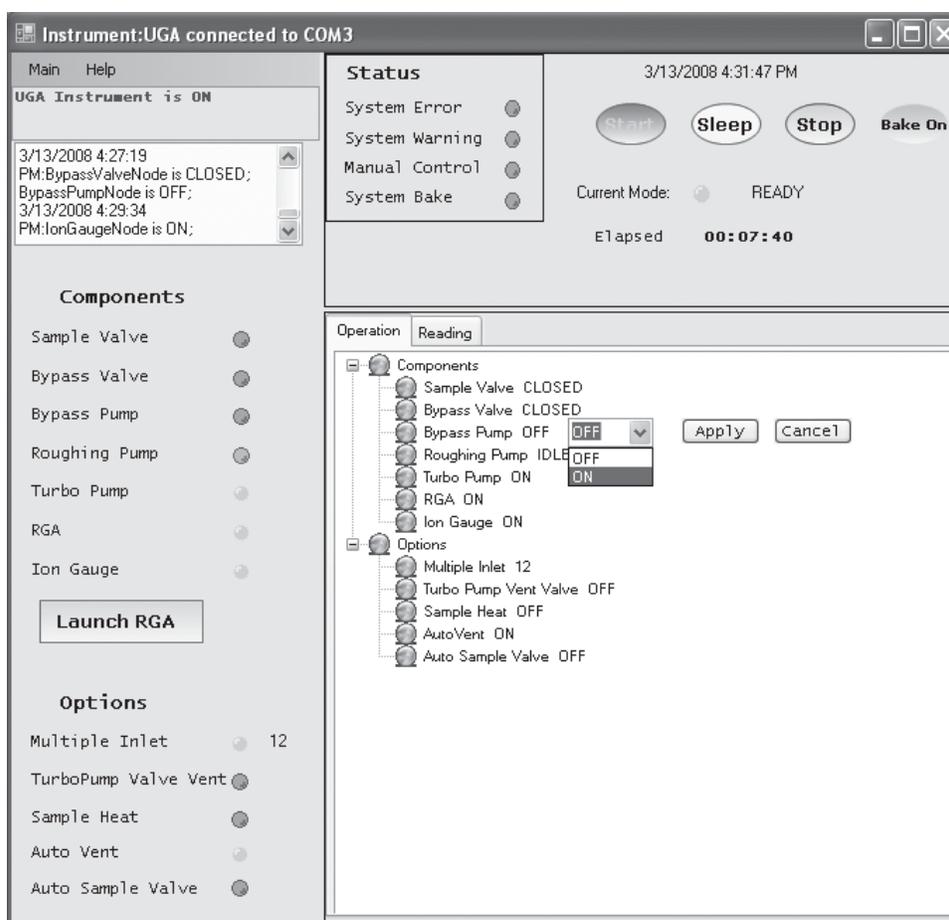
- After the proper port changes status to “Connection” (the icon turns green), close the ConnectorDialog window. The following screen will be shown. The title bar indicates the present connection
- In the control software, click the green “Start” button (Top right window) to start UGA and wait till the current status become “Ready”. It will take about 5 min. to reach this state.



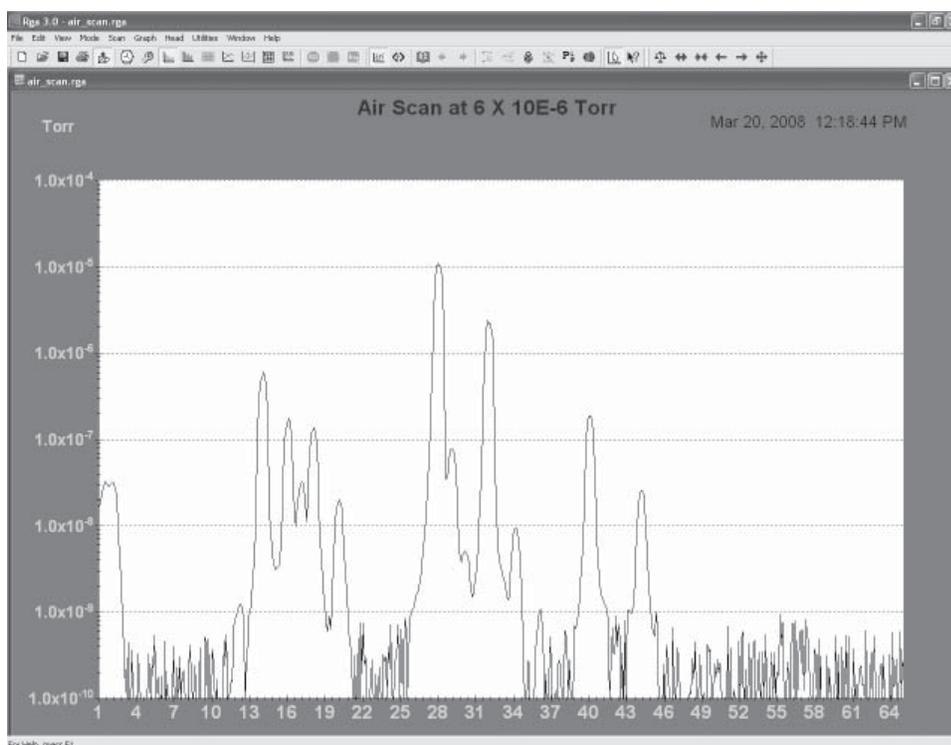
## Start Analog Scan

- When the Current Mode indicator shows “Ready”, launch RGA software by clicking the “Launch RGA” button.

- In the RGA software, click the filament button on the toolbar to activate the ionizer. Click the “GO” button on the tool bar and a scan will begin from 1 to 65 amu. The mass spectrum will show a rough background spectrum.
- Stop the scan.
- If you plan to sample atmospheric pressure, be sure you followed the directions under the previous section, “Capillary Connection”, above.
- Next, move back to the UGA control software and prepare for atmospheric sampling. Turn on the “Bypass pump” by clicking on the item on the operation window. After clicking on the item, you will see a drop down control list. Select “ON” and then click “Apply”.



- Set the Bypass Valve to open by clicking the “Bypass Valve” item on the operation window and choose “OPEN”
- Do the same thing for the Sample Valve to open. Select “OPEN” and then click “Apply”.
- The system will read about 1.5 torr at the bypass line, and about  $5 \times 10^{-6}$  torr for the mass spectrometer chamber if you use the provided 3' capillary.
- On the RGA software, start scan again by clicking the “GO” button.
- The spectrum of air will be displayed, which can be compared to the example below.



---

# Chapter 1

## UGA Basics

---

### **In This Chapter**

This chapter gives the user the necessary information to get used to the Universal Gas Analyzer (UGA) series.

1.1	Introduction . . . . .	1-2
1.2	Configuration . . . . .	1-6
	Front panel . . . . .	1-6
	Rear panel . . . . .	1-7
	Top front components . . . . .	1-8
	Top back components . . . . .	1-10
	Bottom components . . . . .	1-10
	Covers . . . . .	1-12
	Miscellaneous parts . . . . .	1-12
1.3	Options . . . . .	1-13

## 1.1 Introduction

Universal Gas Analyzer (UGA) series instruments are modern mass spectrometers designed for the analysis of light gases. The three systems, 100, 200 and 300, differ only in the mass range they can detect. A quadrupole mass spectrometer (also called a residual gas analyzer or RGA) performs the task of analyzing the gas.

The spectrometer operates at high vacuum and therefore, pumps are required to draw the gas out of the instrument and maintain the vacuum. A turbomolecular pump (TP) is commonly used to generate the high vacuum region ( $<10^{-5}$  Torr) required to operate the ionizer and quadrupole. The inlet continuously samples gas at low flow rates (several milliliters per minute) making the instrument ideal for on-line analysis. Not only is data acquired continuously (as opposed to batch sampling employed by gas chromatographs) but also very quickly. A change in composition at the inlet can be detected in about 0.2 second. The system allows data to be collected quickly - a complete spectrum can be acquired in under one minute and individual masses can be measured at rates up to 25 ms per point.

The SRS UGA systems enable many new applications where traditional mass spectrometer were too large and heavy. More recently, a variety of applications for atmospheric sampling were developed including fuel cell research, Freon detection, specialty gas production monitoring, fermentation process monitoring, and catalysis studies.

To accommodate atmospheric sampling, a pressure reduction scheme is required. A two-stage pressure reducing inlet samples gases at high pressure - from atmospheric pressure to a few Torr at the first stage and then to a mass spectrometer operating pressure (about  $10^{-6}$  Torr) at the second stage. In order to achieve this performance, most commercially available systems employ a capillary tube, pinhole, high vacuum pump (generally TP), and single backing pump. The single backing pump performs double duty, evacuating a bypass line (the first stage) and backing the TP (the second stage). The drawback to this architecture is that the bypass flow is recombined with the sample flow at the backing pump, which allows backstreaming through the TP. This backstreaming can cause real problems for users measuring low molecular weight gases (e.g. hydrogen, helium). When high concentrations of corrosive gases are used, this backstreaming pathway also allows a fraction of the corrosive gas to reach the RGA and TP. Exposure to corrosives can

dramatically shorten the usable life of the RGA filament and the TP.

The UGA systems can be considered as two main subsystems: gas handling and the analyzer. The analyzer is the quadrupole mass spectrometer, which can only operate in high vacuum. The class of quadrupole mass spectrometer employed belongs to a class referred to as residual gas analyzers (RGA). These spectrometers specialize in large dynamic range measurements of light gases. The gas handling system consists of pumps and valves that deliver the sample gas to the analyzer. The UGA employs two separate diaphragm pumps (DP) for each stage. In this way, the high pressure sample line is completely separated from the analysis system. (see figure 1-1)

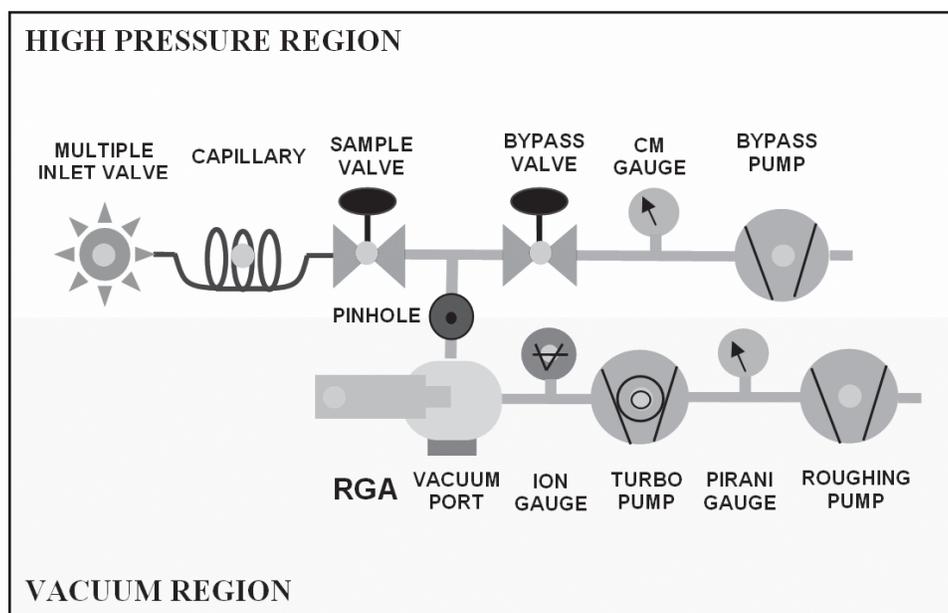


Figure 1-1. UGA Schematic

In UGA systems, an atmospheric pressure gas sample is drawn through a capillary (6 ft of 175  $\mu\text{m}$  ID) which drops the pressure by 3 decades. A small amount of gas sample is drawn by the TP through a pinhole (40  $\mu\text{m}$ ) which reduces the pressure to about 10-6 Torr, while most of the inlet gas (about 99.9%) flows directly to the bypass DP. UGA systems are also simple to operate and maintain. All the components can be controlled from both front-panel and

a remote computer. The user can directly control all the pumps, valves and heaters from the front panel. A convenient display allows menu-driven operation. A capacitance manometer, pirani gauge, and an ion gauge monitor the status of the system continuously and this data is available on the front panel. The variety of gauges allows the system to automate the pump down procedure and to implement interlocks for unattended fail-safe operation. Control of the UGA is governed by a built-in microprocessor. This CPU handles all the data flow between the Auxiliary PCB, Ion gauge control PCB, TP driver, and RGA to itself and also to a PC.

The RGA chamber is a six-way cross with 2-3/4" conflat flanges. One port is assigned for a user to use the built-in capillary pressure reduction system to sample atmospheric pressures. This capability makes it possible to use the UGA as a helium leak detector or for other "sniffing" applications. Two extra ports are available for direct connection to various vacuum regions (from 0.1 Torr to  $10^{-7}$  Torr) using the proper connection. For gas sampling in the  $10^{-1}$  to  $10^{-4}$  torr range, a low vacuum inlet assembly can be designed using appropriately sized tubing (0.125 inch OD to 0.5 inch OD ) and a valve. The assembly can be attached to the port with a 2.75 inch CF flange. Proper selection of tubing size is necessary, to ensure a low enough operating pressure at the mass spectrometer. For high vacuum application (less than  $10^{-4}$  torr), 1.5 inch OD tubing can be attached to the port with 2.75 inch CF flange directly.

The system may be configured with a multiple inlet valve, allowing the user to monitor up to 16 different capillaries at various locations in their system. Some ultra high vacuum and ultra clean chambers cannot tolerate venting with ambient air because of the water vapor present. An optional valve allows venting with dried nitrogen or other gas supply. The entire system is under microprocessor control to ensure ideal operation of all pumps and valves. Two heaters (built-in) surround the chamber, and the connection to the TP. Bakeouts up to 120 °C can be performed easily and safely - all the heaters are under microprocessor control. Optional heaters can be provided for heating the capillary and the sample line up to 80 °C. Windows software controls the UGA and the RGA, graphically displays the data, and provides analysis.

The UGA is designed to be compact. All the components – two diaphragm pumps, one turbo-molecular pump, the chamber, the

RGA, three gauges, two solenoid valves, heaters and the insulating cabinet, power supplies, and even the multiple capillary inlet valve – fit inside an enclosure of 12”(W) X 11”(H) X 25”(L). The system is designed to run in either horizontal or vertical orientation (See figure 1-2). This flexibility in the operating orientation means it can fit almost anywhere, even in space constrained labs. For the vertical orientation, a right angle power cord is needed, which is not supplied from SRS. (A user should buy the cord: ex. Digi-Key AE9887-ND)

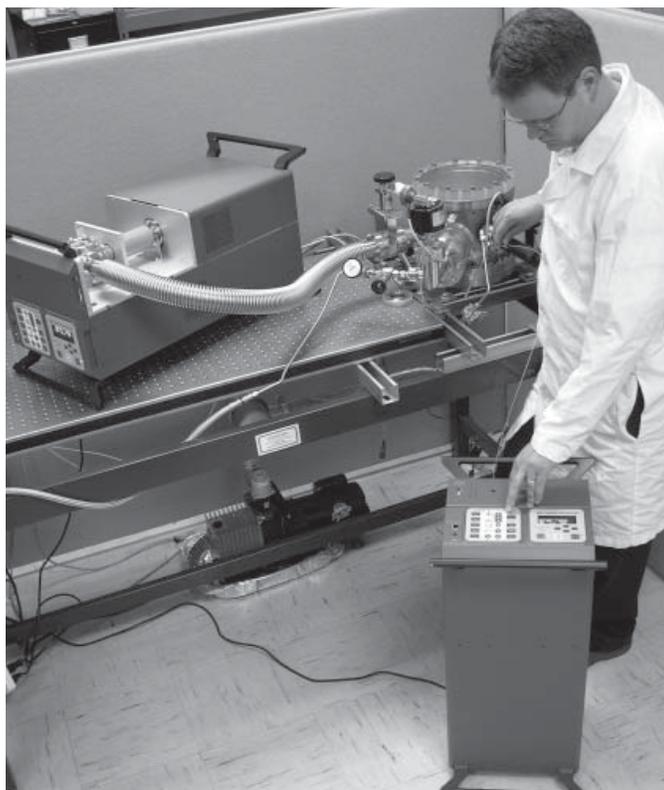


Figure 1-2. UGA operating orientation



Figure 1-3. Front Panels

## 1.2 Configuration

### 1.2.1 Front Panel

There are two front panels on the UGA: the upper panel and the lower panel. The upper panel has two holes: one for capillary connection, and another for a D9 connector which connects the capillary heating control cables (heater power and thermocouple cables). The lower panel holds two control pads, along with one RJ45 Ethernet connector and an RS232 serial connector. (Fig. 1-3)



Figure 1-4. Rear Panels

### 1.2.2 Rear Panel

On the rear panel (also in two parts), there are a main power AC socket, an electrical ground knob, and a fan for the power distribution PCB on the rear upper panel. There are two BNC connectors - an analog output and a user interlock. Two exhaust ports for the Bypass pump and the Roughing pump are also provided. If Option #2 is included, a port for the vent gas for the vacuum chamber is also available. (Fig. 1-4)

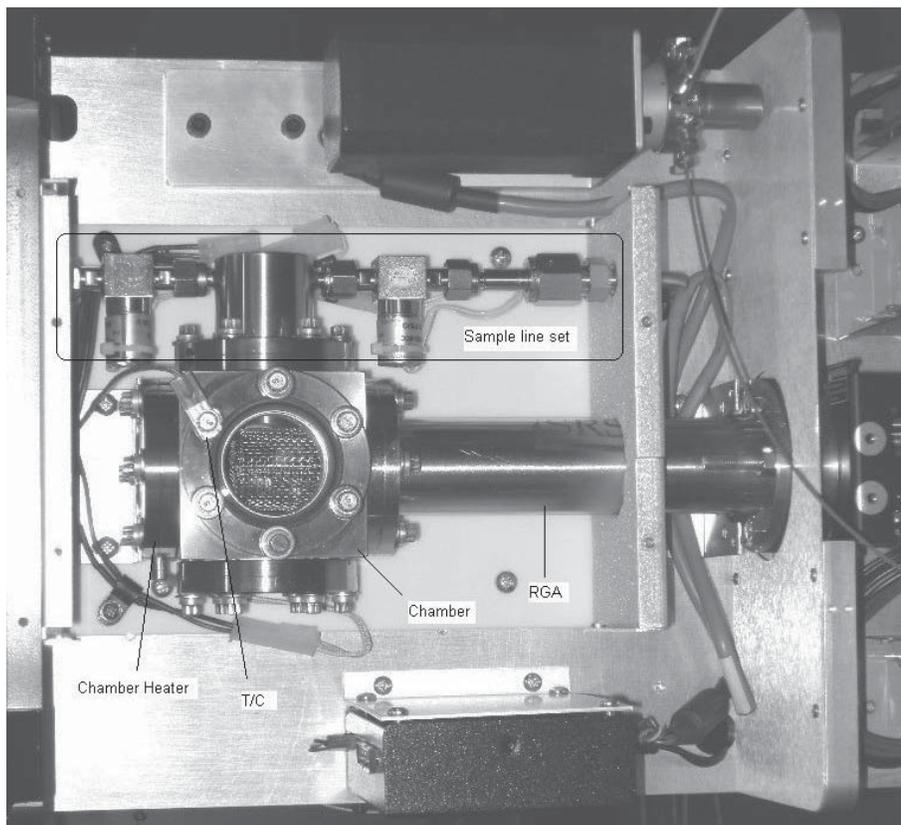


Figure 1-5a. Top Front Components

### 1.2.3 Top Front Components

In Fig. 1-5a, the main chamber is shown. It consists of a sample line set, a cubic chamber, an RGA analyzer, a chamber heater (CHA), and a thermocouple. The sample line set is composed of 1/8"-UltraTorr connector, sample valve (SV), 40  $\mu$ m pinhole port, bypass valve (BV), and bypass line. The sample line set, the RGA analyzer, and the chamber heater connect at a 2.75" cubic chamber as shown in Fig. 1-5a.

These components are covered by the heat insulating box. (Fig. 1-5b)

If Option #1 is ordered, a multiple inlet valve and its controller are installed here. (Fig. 1-5b) If Option #3 is ordered, a sample line heater (SAM), a sample line heating jacket set, and an Ultra-Torr connection set (heater and insulator) will be assembled as shown in Fig. 1-5c.

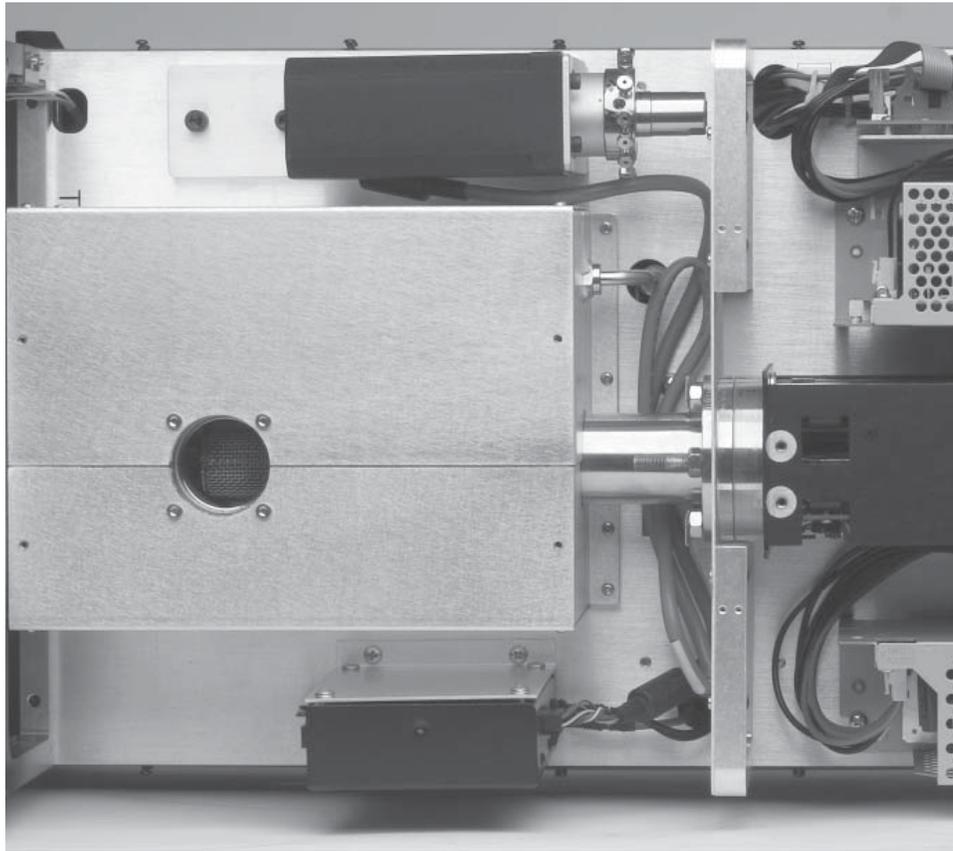


Figure 1-5b. Top Front Area after the heat insulating box is installed

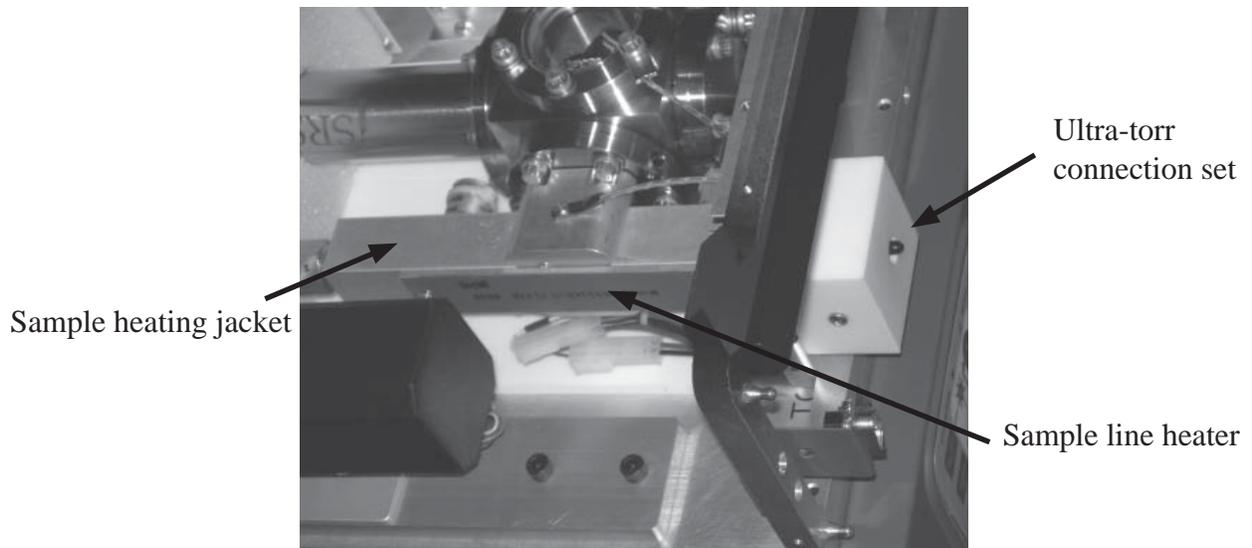
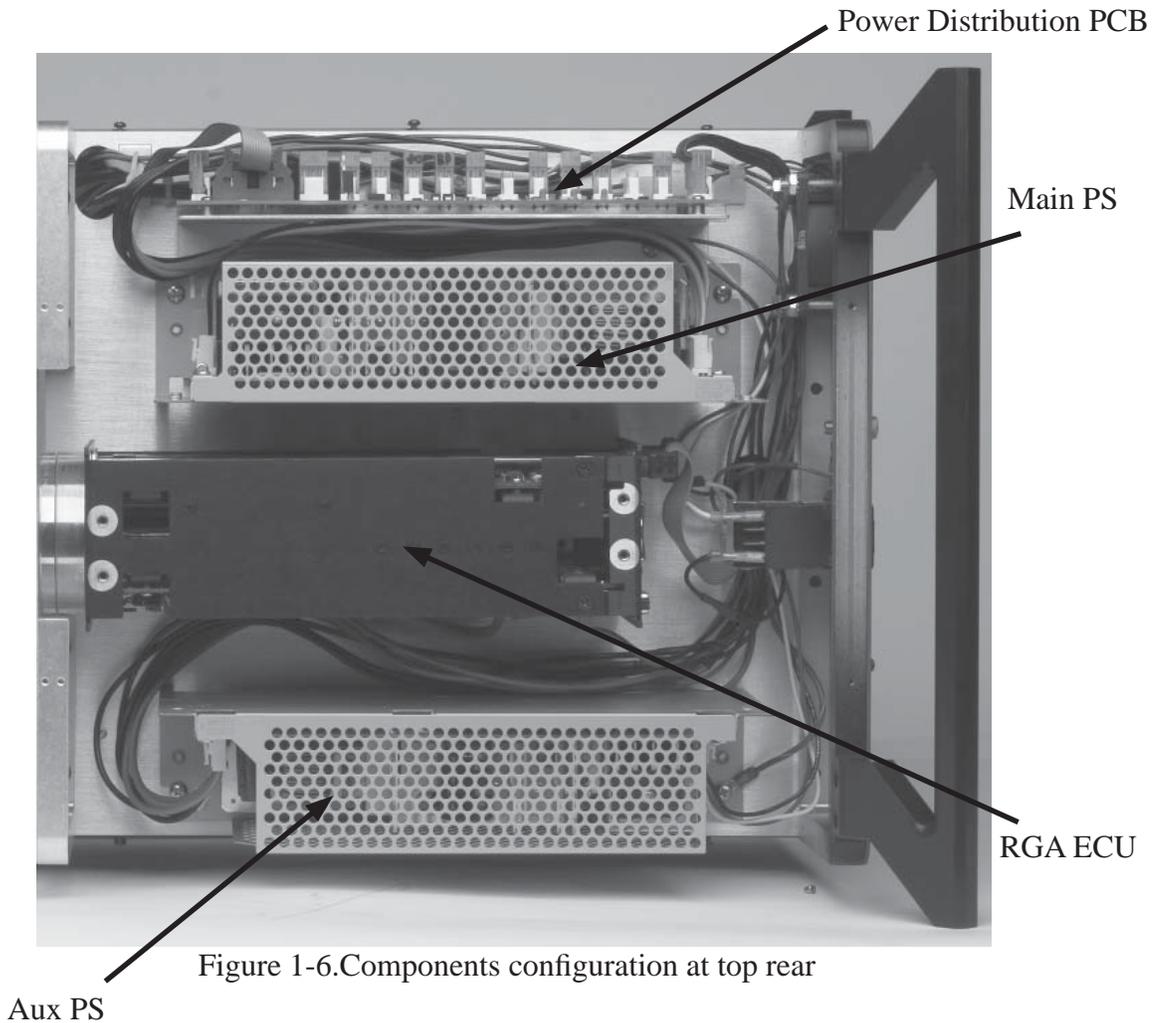


Figure 1-5c. Picture of the sample line heating assembly

### 1.2.4 Top Rear Components

This area contains all the power supply related components: RGA ECU, a main power supply, an auxiliary power supply, and a power distribution PCB. (Fig. 1-6)



### 1.2.5 Bottom Components

This volume houses vacuum control and system control consisting of TP connection elbow with its heater (ELB), TP, Diaphragm pump for the bypass line (BP), Diaphragm pump of TP backing (RP), Capacitor manometer (CM), Pirani gauge (PG), Ion gauge (IG), roughing line, part of bypass line, Main control PCB, Auxiliary control

PCB, Ion gauge control PCB, TP control PCB, a speaker, and a TP cooling fan. On the elbow, a heater for system baking is attached. The elbow area is surrounded with an insulating box. (Fig. 1-7a)

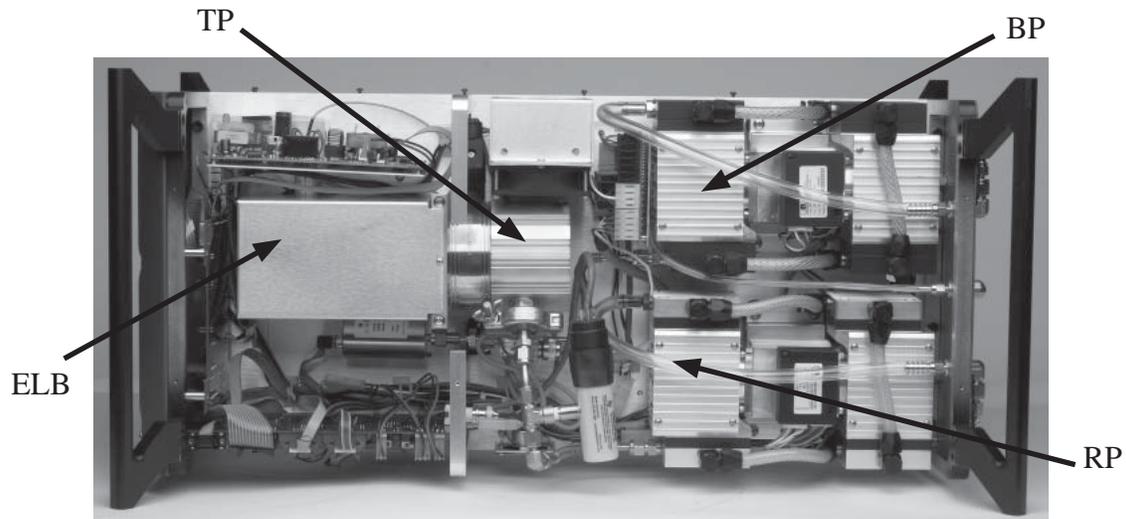


Figure 1-7a. Bottom view of UGA - component configuration

If Option #2 is ordered, a venting valve is shown connected to the TP near the fan. See figure 1-7b. PVC tubes are used to connect exhaust lines and the system venting line.

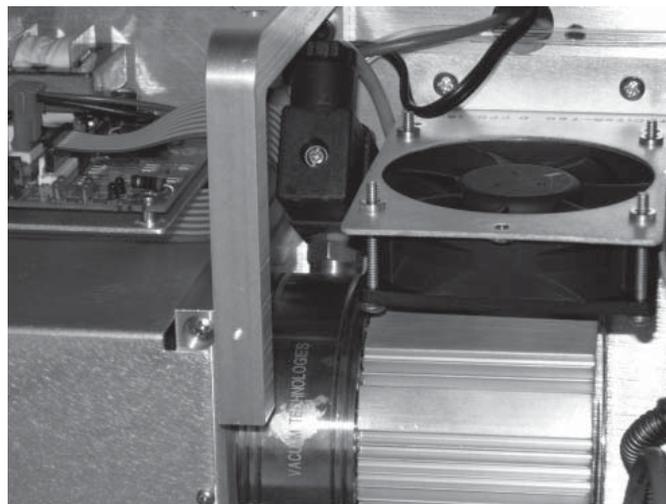


Figure 1-7b. Detailed view of the TP vent valve configuration

### 1.2.6 Covers

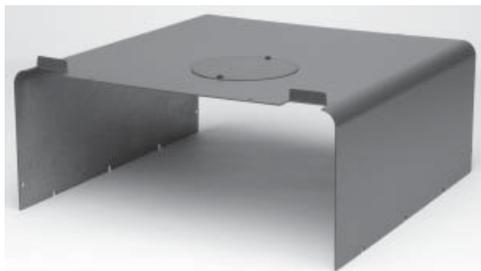


Figure 1-8a. Top front cover

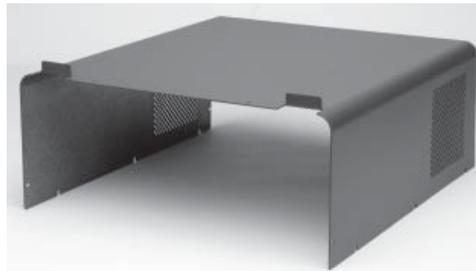


Figure 1-8c. Top rear cover

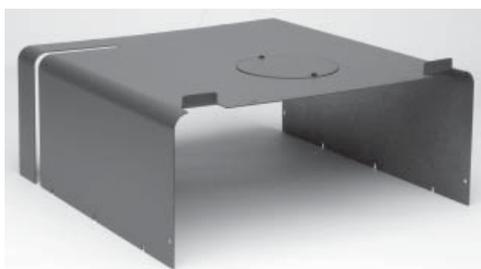


Figure 1-8b. Option #1 Top front cover



Figure 1-8d. Bottom cover

### 1.2.7 Miscellaneous parts

A 6' capillary of 175 mm ID and 1/16" OD is provided for atmospheric pressure sampling. A 25' long RS-232 DB9 cable, a power cord, two sample inlet plugs, UGA manual, RGA manual, and an RGA spare kit are also included.

## 1.3 Options

There are three system options for the UGA.

- Multiple inlet valve option (Option #1),
- Vacuum purging vent valve option (Option #2), and
- Sample heating option (Option #3).

All these options can be ordered separately and installed by the user.

### 1.3.1 Option #1. Multiple inlet valve option

Parts :

Multiple inlet valve system

Valve base

Valve controller

Valve controller holder

Control cord

Power line

RS232 comm. Line

Channel plug 2 pkg.

Top front cover for Option #1

2' 1/16" OD, 175  $\mu$ m ID capillary, unheated, with connectors for the valve outlet and the UGA inlet

3' 1/16" OD, 175  $\mu$ m ID capillary, unheated, with a connector, 2 ea

Self-control accessory box

Related hardware

The multiple inlet valve system is installed on the UGA setup plate along with its special holders. Power line and communication lines are connected. A 2' long, 1/16" OD, 175 mm ID capillary for the main outlet, two 3-foot long same kind capillary, and two channel plug packages are accessories for this option. The self-control accessory box contains a hand controller and connection cables for the multiple inlet valve. This unit can control the multiple inlet valve by itself without the UGA.

### **1.3.2 Option #2. Vacuum purging vent valve option**

Parts :

Vent valve  
Purge gas line connector  
Vent line tube

The vent valve is installed on the Turbo molecular pump. (See Fig. 1-7b.) The main controller board controls the function of this valve. The purge gas line should be connected at the rear lower panel before the vent valve is used. During shipping, this connection line is plugged. Release the plug before connection.

### **1.3.3 Option #3. Sample heating option**

Parts :

Capillary with heater  
Washer thermocouple, #6  
Sample line heater  
Bypass heat jacket  
Pinhole heat jacket  
Sample line heat jacket  
Sample line heater holder  
Ultra-torr connector heater  
Ultra-torr insulator  
Related hardware

The parts related with this option are shown in the following pictures (Fig. 1-9 & 1-10). The full assembly of the Option #3 parts is presented in Fig. 1-5c.

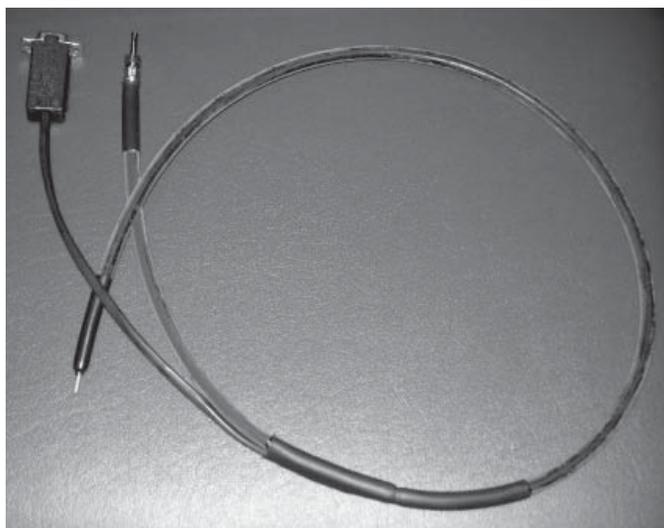


Fig 1-9. Capillary with heater. The connector for heater power and TC is also shown.

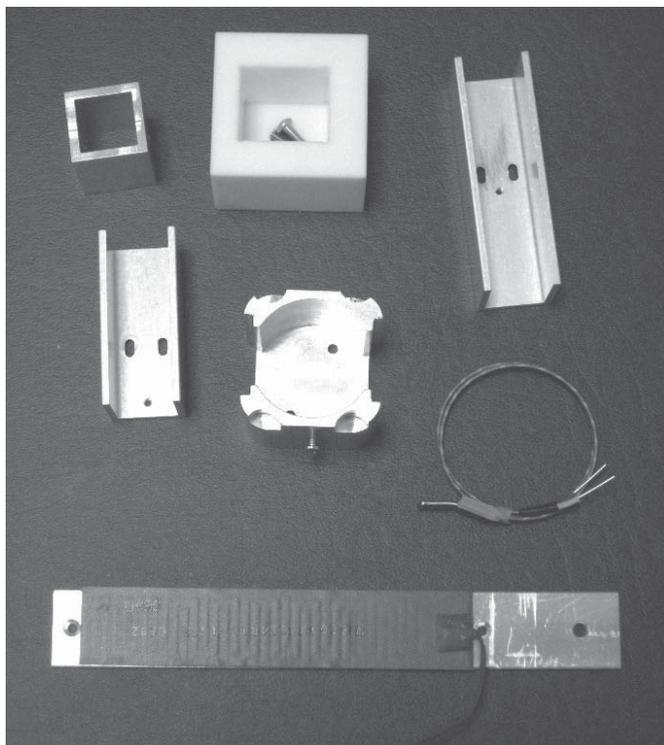


Figure 1-10. Option #3 components for sample line heating

Power for the capillary heater is controlled from the auxiliary control board. The thermocouples for the capillary and the sample line

are also connected to the auxiliary control board. To conserve heat from the tip of the capillary to the pinhole, and all the way out to the bypass line, a custom designed heating jacket and insulating block are used. In order to change the capillary for this option, follow the procedure below.

- Disconnect the heater power and TC cable from the connector.
- Pop off the front upper panel.
- Using a long Philips driver, unscrew the Ultra-Torr insulator, and take out the insulator. The driver passes through the hole on the line connector bracket. (See Fig. 1-11 below.)
- Unscrew the Ultra-Torr fitting and remove the capillary.
- Pull out the capillary through the Ultra-Torr insulator and the front upper panel.
- Put a new capillary into the front upper panel and the Ultra-Torr insulator.
- Plug into Ultra-Torr fitting and tighten up the fitting.
- Screw back the Ultra-Torr insulator.
- Pop in the front upper panel.
- Connect the heater power and TC cable to the connector.



Figure 1-11. Option #3 capillary connection rear

---

## Chapter 2

# Guide to Operation

---

### In This Chapter

This chapter gives the user the detailed information on controlling the UGA (Universal Gas Analyzer) Series.

2.1	Introduction . . . . .	2-3
2.2	Front Panel Operation. . . . .	2-3
	Keypads . . . . .	2-3
	Status Keypad . . . . .	2-3
	Control Keypad. . . . .	2-4
	Using Front Panel Menu System . . . . .	2-7
	Entering Menu System . . . . .	2-7
	Menu Navigation. . . . .	2-7
	Automatic versus Manual. . . . .	2-8
	Manual Pump-Down Procedure . . . . .	2-8
	Base pressures . . . . .	2-9
	Manual Venting Procedure . . . . .	2-10
	Manual Sleeping Procedure. . . . .	2-11
	System Bake. . . . .	2-11
	Leak Test . . . . .	2-12
	Options Operation . . . . .	2-13
	Multiple Inlet valve . . . . .	2-13
	Vent Valve. . . . .	2-14
	Sample Heaters. . . . .	2-14
	Advanced Operation. . . . .	2-14
	Interlocks . . . . .	2-14
	User Interlock Input . . . . .	2-15
	Diaphragm Pump Tuning. . . . .	2-16
	Auto Sample Valve. . . . .	2-16
	Auto Vent Valve . . . . .	2-16

---

2.3	Remote Operation . . . . .	2-17
	Overview . . . . .	2-17
	Installation of Software . . . . .	2-17
	Connection to a PC . . . . .	2-19
	RS232 Serial Connection . . . . .	2-19
	TCP/IP Connection . . . . .	2-22
	Menus and Displays . . . . .	2-28
	Launching RGA Software . . . . .	2-37
	Option Operation . . . . .	2-39
	Multiple Inlet Valve . . . . .	2-39
	Vent Valve . . . . .	2-40
	Sample Heaters . . . . .	2-41

## 2.1 Introduction

The UGA can be in one of six modes (5 states, 1 function): OFF, READY, IDLE, INDIVIDUAL, BAKE, and LEAK TEST.

Each state can be reached from the other state with some restrictions. For example, BAKE state can be reached from READY, IDLE, INDIVIDUAL, or OFF state. And LEAK TEST function can be reached only from READY, not from any other states. But during LEAK TEST function, the system can go to STOP. The UGA can be stopped from any condition. The stop command is handled on an emergency basis.

Careful control of the UGA is required to get to the Ready state safely. This will be achieved with proper vacuum control. After the system is in the Ready state, it can perform the function of analyzing gas; running the RGA and collecting data. In order to reach the Ready state, there are several ways depending on test conditions. The UGA is designed to be applicable to as many situations as possible by allowing auto control and individual control. Automatic control means that the UGA will perform the pre-designed sequences to reach the requested state: Ready state by 'START/WAKE' button, Idle state by 'SLEEP' button, Off state by 'STOP' button. Individual control means that each component of the UGA can be controlled individually by pushing a component button. These two control modes are easily interchangeable. For the detailed operational schematics, refer to Appendix B.

## 2.2 Front Panel Operation

### 2.2.1 Keypads

#### 2.2.1.1 Status Keypad

The left-hand keypad on the front lower panel of the instrument indicates the status of the instrument. It is a flow diagram showing which components are active at any given time. We will refer to this keypad as the "status keypad".

This keypad shows the status of components by illuminating LEDs. When a component is in the process of changing state, the LED will blink. This normally occurs while the UGA microprocessor verifies it is safe to actuate some component.

Note that the status keypad has several grey rectangular buttons associated with the components in the UGA. These buttons are shortcuts to menus that will be shown on the display of the control keypad which is beside the status keypad. You can navigate the menu system on the control keypad or use the shortcuts on the status keypad for quick access.

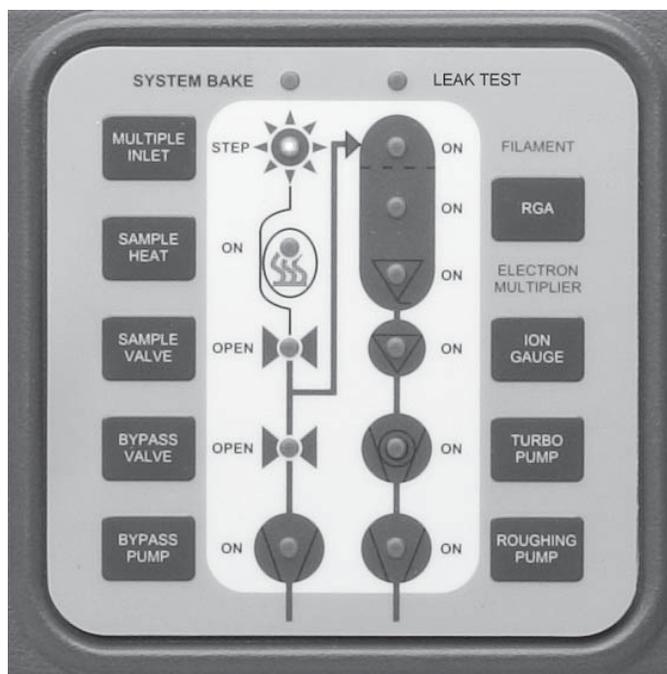


Fig. 2-1. The Status Keypad

### 2.2.1.2 Control Keypad

Any change to the state of the UGA must be made using this keypad. We will refer to this keypad as the “control keypad”. No changes will occur until the user pushes the enter key or auto control buttons on the control keypad. The control keypad has several components; each is briefly defined below.

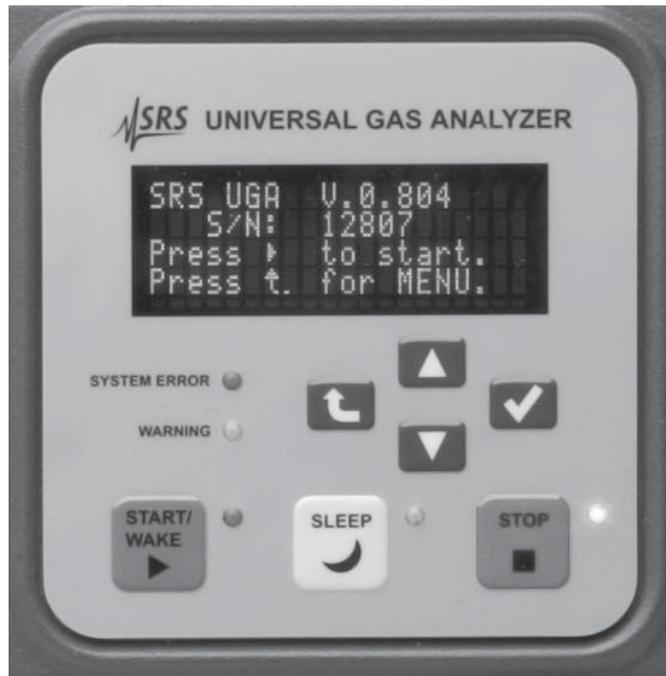


Fig. 2-2. The Control Keypad

### **Display device**

The display serves two functions. It presents system information, and allows the user to enter menu driven commands. The default function is the information display. You can select a different display (pressures, temperatures, etc.) using the menu system; therefore we refer to a “selected display” when discussing the menu system below. You can also cycle through the info displays (Pres, Temp, Turbo) via the Up / Down keys.

### **Level Up button**



This button will bring the user to the main menu from the information display mode and vice versa. In the menu tree, this button will move the user up one level.

### **Up / Down buttons**



In the menu, this button will move the cursor or change a parameter value.

### **Enter button**



In the menu, this button confirms the selection of a state, a parameter, or a submenu item.

### **System Error LED**

This red LED will be lit when the system has a fatal error. An accompanying error message is shown on the display. A fatal error refers to an error condition that is preventing the UGA from continuing to operate. Operation cannot continue until the error is corrected.

### **Warning LED**

This yellow LED will blink when the system has a warning error and the error message is shown on the display for 4 seconds. The warning error means the unit can not process a command due to the restrictions of the process, a command syntax error, or no component installed. Because the warning does not affect the performance of the UGA, there is no error correction needed.

### **Start / Wake**

When the green button is pushed, the green LED beside the button will blink. The UGA will perform an automated pumping-down procedure to reach the Ready state. At the end of the sequence, this LED will stop flashing and remain lit.

### **Sleep**

Pushing this button will put the system in an idle state. This state consumes less power and prolongs the useful life of the pumps.

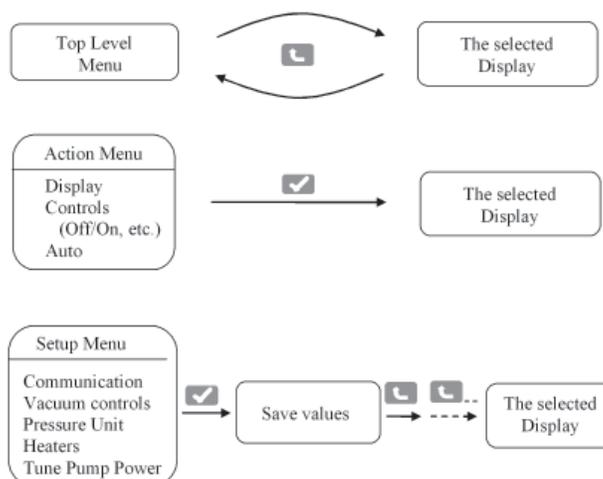
### **Stop**

Pushing this button will cause the UGA to automatically turn off all components as quickly as possible.

## 2.2.2 Using the Front-Panel Menu System

### 2.2.2.1 Entering the Menu System

You can toggle between the menu system and the selected display using the “level up” button. To enter the menu system, push the “level up” button on the control keypad. To leave the menu system, push the “level up” button again from the top menu. Whenever the user makes a change from the control menu, the display changes from the menu system to the selected display. From non-control menus, the user must “level up” key repeatedly to return to the selected display as shown in the following drawing.



### 2.2.2.2 Menu Navigation

The UGA menus are navigated by moving a diamond-shaped cursor with the arrow keys on the control keypad. The UGA menu system indicates you are at the bottom of a menu by putting the cursor at the last visible menu item. Likewise, the top of a menu is indicated by locating the cursor at the first visible menu item. Use the control pad arrow keys to scroll through menu items.

At the end of each menu tree branch is a setting change. The UGA indicates a setting change menu by showing the current state with an asterisk. To change the state, move the cursor to the desired state and push the enter key. The detailed menu tree is summarized in Appendix A.

### **2.2.2.3 Automatic versus Manual**

For most day-to-day operations, use of the automatic pump-down and venting functions is adequate. For times in which an automated procedure is not desirable, a manual procedure is given below, along with the key presses required for quick operation. Note that any automatic procedure will stop if you make a change to the system while the procedure is running. Also note that you can start (or re-start) an automatic procedure at any time except during leak test and system bake.

### **2.2.2.4 Manual Pump Down Procedure**

Note that this procedure can be accomplished automatically simply by pressing the green “start / wake” button on the control keypad.

1. Enter the UGA menu system (push the “level up” key on the control keypad).
2. Enter the Display menu and select Pressure.
3. Push the “Bypass Pump” button on the status keypad.
4. Turn on the Bypass Pump (BP) with the control keypad (you will automatically be returned to the pressure display).
5. Wait for the bypass line pressure (read from a capacitance manometer) to be below 1 Torr; this usually occurs within two minutes. If the condition is not met after two minutes, this indicates a leak in the system. If this occurs, the error LED is lit, an error message appears, and the system is turned off.
6. Push the “Bypass Valve” button on the status keypad.
7. Open the Bypass Valve (BV) with the control keypad.
8. Push the “Roughing Pump” button on the status keypad.
9. Turn on the Roughing Pump (RP) with the control keypad.
10. Wait till the roughing line pressure (read from a Pirani gauge) is below 5 Torr. Note if this condition is not achieved within 5 minutes, this indicates a leak in the system. If this occurs, the error LED is lit, an error

- message appears, and the system is turned off.
11. Push the "Turbo Pump" button on the status keypad.
  12. Turn on the Tubormolecular Pump (TP) with the control keypad. The TP speed can be checked in the TP display. Push the up arrow button to see the TP information during the pressure display.
  13. Watch the turbo pump speed on the TP display. Wait until the TP reaches full speed (81 kRPM). Note if this condition is not met after 10 minutes, this indicates a leak in the system. If this occurs, the error LED is lit, an error message appears, and the system is turned off.
  14. Push the "Bypass Valve" button on the status keypad.
  15. Close the Bypass Valve (BV) with the control keypad.
  16. Push the "Bypass Pump" button on the status keypad.
  17. Turn off the Bypass Pump (BP) with the control keypad.
  18. Push the "RGA" button on the status keypad.
  19. Turn on the RGA with the control keypad.
  20. Wait for 2 minutes to turn on the ion gauge (IG).
  21. Push the "Ion Gauge" button on the status keypad.
  22. Turn on the ion gauge (IG) with the control keypad.
  23. At this point it is safe to put the roughing pump in idle mode. This prolongs pump life. Push the "Roughing Pump" button on the status keypad.
  24. Change RP to the idle state with the control keypad.

#### **2.2.2.5 Base Pressures**

Once the system is pumped down, these approximate base pressures should be realized under the given conditions. Note that if lower base pressures are required, baking may be necessary. When the system is at vacuum sufficient to support RGA operation, we refer to the state of the system as the "ready state".

UGA Settings	Case	Pressure ranges
RP idle TP full speed IG on RGA on	General Ready state	PG : < 1.5 Torr CM : maximum reading (10 Torr) IG : < 1.0 x 10 <sup>-6</sup> Torr
RP idle TP full speed IG on RGA on BP on BV open SV open 6' 175 µm ID capillary	Atmospheric gas intake	PG : < 1.5 Torr CM : 1.5 ~ 2.0 Torr IG : 5.0 ~ 8.0 x 10 <sup>-6</sup> Torr

#### 2.2.2.6 Manual Venting Procedure

Note that this procedure can be accomplished automatically simply by pushing the red "stop" button on the control keypad. This procedure assumes the UGA is currently sampling atmospheric pressures.

1. Push the "Sample Valve" (SV) button on the status keypad.
2. Close the SV with the control keypad.
3. Push the "Bypass Valve" (BV) button on the status keypad.
4. Close the BV with the control keypad.
5. Push the "Bypass Pump" (BP) button on the status keypad.
6. Turn off the BP with the control keypad.
7. Push the RGA button on the status keypad.
8. Turn off the RGA with the control keypad.
9. Push the "Ion Gauge" (IG) button on the status keypad.
10. Turn off the IG with the control keypad.
11. Push the "Turbo Pump" (TP) button on the status keypad.
12. Turn off the TP with the control keypad.
13. Wait for two minutes to allow the TP to spin down.
14. Push the "Roughing Pump" (RP) button on the status keypad.
15. Turn off the RP with the control keypad.

If the vent valve option is installed, the vent valve will be open when the RP is off. If not, wait until the TP stops completely to open the chamber.

### **2.2.2.7 Manual Sleeping Procedure**

Note that this procedure can be accomplished automatically simply by pushing the yellow “sleep” button on the control keypad. This procedure assumes the UGA is currently sampling atmospheric pressures.

1. Push the “Sample Valve” (SV) button on the status keypad.
2. Close the SV with the control keypad.
3. Push the “Bypass Valve” (BV) button on the status keypad.
4. Close the BV with the control keypad.
5. Push the “Bypass Pump” (BP) button on the status keypad.
6. Turn off the BP with the control keypad.
7. Push the RGA button on the status keypad.
8. Turn off the RGA with the control keypad. (If the stability of RGA is concerned, the user can let the filament of RGA on during idling. The user may skip these RGA steps.)
9. Push the “Ion Gauge” (IG) button on the status keypad.
10. Turn off the IG with the control keypad.
11. Push the “Turbo Pump” (TP) button on the status keypad.
12. Set idle for the TP with the control keypad.
13. Wait till the TP spins down to 66 kRPM.
14. Push the “Roughing Pump” (RP) button on the status keypad to check the status.
15. If RP status is not the idle state, set the RP idle with the control keypad.

In order to get the Ready state from the Idle state (WAKE), simply turn on the TP as stated in the manual pump-down procedure above and turn on the RGA and the IG.

### **2.2.2.8 System Bake**

When the bake command is issued, the heaters for the RGA chamber (the cube) and the elbow adapter (between the cube and TP) are on and heat up the chamber and the elbow to the specified temperatures. This command can be accessed by pushing the Heaters button or in the main menu tree.

1. Push the Up-level button to enter the main menu of UGA.
2. Select "System Bake".
3. Select "Bake Time".
4. Set the baking time in hours (2-100) and press the enter key.
5. Select "Bake Temperature".
6. Select "Elbow".
7. Use the arrow keys to set the elbow bake-out temperature (40 - 120 °C) and press the enter key.
8. Select "Chamber".
9. Use the arrow keys to set the chamber bake-out temperature (40 - 120 °C) and press the enter key.
10. Select "On" and press the enter key to start the bake out.

The display will show the time remaining on the bake, the temperature of the elbow and chamber.

Note that because the user can enter the system bake from any state except leak test, the UGA will automatically configure itself for a system bake. During this process, the system bake LED will blink and the heaters LED is off. After the UGA reaches the proper setting, the heaters LED will be lit and the system bake LED will remain lit. At the end of the bake, the UGA will turn off the heaters and will return to the ready state by turning on the RGA and the IG.

#### **2.2.2.9 Leak Test**

The UGA can perform a software independent (stand-alone) leak test from the front panel. When the UGA is engaged in the Leak test function, however, this function will block RGA communications from a remote PC until it is ended. UGA control software will show RGA and Current Mode LED's are flashing and indicates the current mode is Leak Test. Only the front panel can control the Leak test function. And this function only starts when the UGA is in the Ready state. The Leak test function can check for gas leaks from a system under test, sniff from a pressurized system or helium leak test from an evacuated system attached to the RGA chamber.

### Leak test Procedure

1. Push the Up-level button to enter the main menu of UGA.
2. Select 'Leak test'.
3. Select "Mass Selection"
4. Use the control keypad arrow keys to choose the mass (in AMU) and press the enter key.
5. Select "Audio Volume"
6. Select the desired volume level and press the enter key.
7. Select "ElectronMultiplier" (EM).
8. Select On and press the enter key to turn on EM.
9. Select "On"

The resulting leak test display will show the mass setting, the sensitivity level, the volume level and the detected partial pressure. A bar graph on the last row of the display indicates relative signal intensity. To change the sensitivity, use the up and down arrow keys of the control keypad.

The analog out BNC on the rear panel of the UGA will give a voltage proportional to the leak signal. The logarithmic value of this level is converted to an analog voltage signal from 0 to 10 VDC; 0 V for  $1 \times 10^{-14}$  Torr and below, 5 V for  $1 \times 10^{-9}$  Torr, and 10 V for  $1 \times 10^{-4}$  Torr and above. The audio frequency and pitch is also proportional to the bar graph level in its own level. This audio indicator helps to check for leaks when a user can not see the front panel. The audio can be turned off by selecting 'Off' in the Audio menu.

Note that under leak test, the automatic keys Start and Sleep do not function. The Stop key functions in any mode.

## **2.2.3 Options Operation**

### **2.2.3.1 Multiple inlet Valve**

When the button for Multiple inlet valve on the front panel is pushed, the Controls menu will display the present channel of the valve. You can change channels using the Up or the Down buttons. After the confirmation button is pushed, the valve will rotate to the new position and the display returns to the pre-selected display.

### 2.2.3.2 Vent Valve

On the front panel, click the Roughing Pump button to enter the RP control menu tree. The last item is the vent valve. Choose 'Close' or 'Open' as desired.

When 'Open' is selected, the UGA will open the valve for 1 second, then close the valve. After 40 seconds, the UGA will open it again for a minute to vent the system. After the one minute period, the valve closes again. By doing this, the TP will stop smoothly without a pressure shock.

### 2.2.3.3 Sample Heaters

In the sample heaters option two heaters-the capillary heater and the sample line heater- will be added to the UGA system. The heating temperatures can be set from 40 °C to a maximum of 80 °C. This temperature limit is important for the valves' (Sample valve & Bypass valve) performance.

On the front panel, click the Heaters button to enter the heater control menu tree. Here the users can set the temperatures of the sample heaters (the capillary heater and the the sample line heater) including other two heaters (the chamber heater and the elbow heater) and turn on the sample heaters.

## 2.2.4 Advanced Operation

### 2.2.4.1 Interlocks

The UGA has several interlocks to protect the instrument. There are interlocks tied to pressure and temperature. For example, the TP cannot be turned on until the roughing line pressure is low enough. If the TP temperature reading is above 60 °C, the UGA shuts down the turbo pump and other components to reach a safe state. The following table summaries the interlocks used.

As can be seen in the table, CM and PG readings are critical for UGA operation. If either of these gauges is malfunctioning, the

UGA is not operable. If an interlock activates, an error message is produced. For a list of all UGA error messages, please refer to the chapter 4.

#### Interlocks

Action	Conditions
BP off	CM reading above 1 Torr during start up
BV close	CM reading above 1.5 Torr with SV closed
RP off	PG reading above 5 Torr
TP off	PG reading above 1.5 Torr, TP temperature reading above 60 °C
IG off	IG reading above $2.1 \times 10^{-5}$ Torr
SV close	CM reading above 2.5 Torr with SV on

There are several other operational restrictions for control of the components. For example, the RGA cannot be on when TP is not at full speed or in the idle state. When a component is set to change, the UGA checks the present conditions to determine whether the action would damage the vacuum or not. If an action is disallowed, a warning message is generated and the warning LED will blink for 4 seconds. Detailed explanations of all the warnings are listed in the chapter 4 in this manual.

The pressure interlocks listed above are in place to maintain safe operation of the UGA. Under certain conditions, users may desire to defeat the pressure interlocks. Enter the UGA main menu system and navigate to "Controls">"Pressure Interlock". Select "Off" and press the enter key. Only manual control is possible while the pressure interlocks are defeated.

#### 2.2.4.2 User Interlock input

A BNC connector on the rear lower panel allows a user-defined interlock. It behaves as an emergency shut down switch when it receives a TTL low signal. In any state of the UGA, it stops the system completely. By using this BNC connection with a user's external equipment, the UGA can be safely shut down if an emergency occurs.

### **2.2.4.3 Diaphragm Pump Tuning**

SRS has already set default values for the power consumed by the diaphragm pumps. These levels are a good overall compromise between conserving pump life and maintaining good vacuum. Advanced users may wish to change the level of power consumed by the pumps. To tune the power level used by the pumps in idle, navigate to the pump tuning menu, select the level with the arrow keys and press the enter key. This function work whether the pumps in on, idle, or off.

### **2.2.4.4 Auto Sample Valve**

If the Auto sample valve option is set to be on, the sample valve state controls all the components of the sample line. When the user opens the sample valve, the system does everything necessary to reach a state in which the valve may be opened. This may require turning on the bypass pump, and opening the bypass valve before opening the sample valve. When the sample valve is closed, the system closes the valve, but also closes the bypass valve and shuts off the bypass pump. The default setup is on. One can change the setting using the Sample Valve menu. Click the Sample Valve button. Then choose 'Auto Sample Valve' item. The UGA control software also controls this option.

### **2.2.4.5 Auto Vent Valve**

If the Auto vent valve option is set to be on, the TP vent valve will open whenever the RP stops. This happens automatically as part of the stopping procedure. Sometimes users do not want this automatic behavior and would like to handle the vent valve manually. In this case, the Auto vent valve option should be set to be off. The RP button has a shortcut to the vent valve control. The default is on. The UGA control software also controls this option.

## 2.3 Remote Operation

### 2.3.1 Overview

The software controls the whole UGA system and provides many data acquisition modes, which should fulfill the needs of most users. This user manual discusses those aspects of the instrument that are relevant to controls of UGA and data acquisition from the RGA.

A full featured software application included with the instrument provides an intuitive graphical user interface to the controls (See figure 2-3). All pumps, valves and heaters can be controlled from within the software. Every operation that takes place (valve open or close, pumps turned on or off, heaters activated, etc.) is logged as a time stamped "event" by the software. The event log is stored as a file on the PC hard drive. This log can be very useful for troubleshooting: if a user finds the UGA's interlocks activated while he was away, the event log will show what gauge registered an overpressure and when. This allows the user to track exactly where a problem began instead of guessing what went wrong. This can save hours of time in debugging a vacuum process.

In order to obtain RGA data, the UGA needs to be connected to a PC. This means that even though the system can be operated from the front panel, RGA software will be used to analyze the gas sample. SRS provides UGA control software and RGA software to operate the system and also to handle the analysis. By installing these applications, a user can control the experiment remotely. Generally, the software mimics the front panel controls; there are auto control and individual control modes. It also displays system status. The UGA/RGA software is a Windows based application which runs on a PC running at least Windows 2000 as the OS with 256M bytes system memory. The UGA software supports both RS-232 and Ethernet remote interfaces.

### 2.3.2 Communications

In this section, software installation, communication and operation will be explained in detail. The RGA software will be discussed separately in the last section of this chapter. The programs are shipped in a CD. A user can also download the programs from the SRS website at [www.thinksrs.com](http://www.thinksrs.com)

## Installation of UGA control &amp; RGA software

1. Insert the provided CD into the CD driver. The setup program for UGA control software will be launched automatically. If not, explore the CD and double click the file 'UGASetup.exe'.
2. Follow the prompts to install UGA control software. The default directory for the installation is C:\Program files\SRS\UGA. You may change the installation directory during this process, but SRS recommends using the default directory.
3. At the end of the installation of UGA control software, the installer will ask to continue RGA software installation. Click 'YES' to continue.
4. Select or double click 'UGA.exe'. You should see the screen above. (Fig. 2-3)

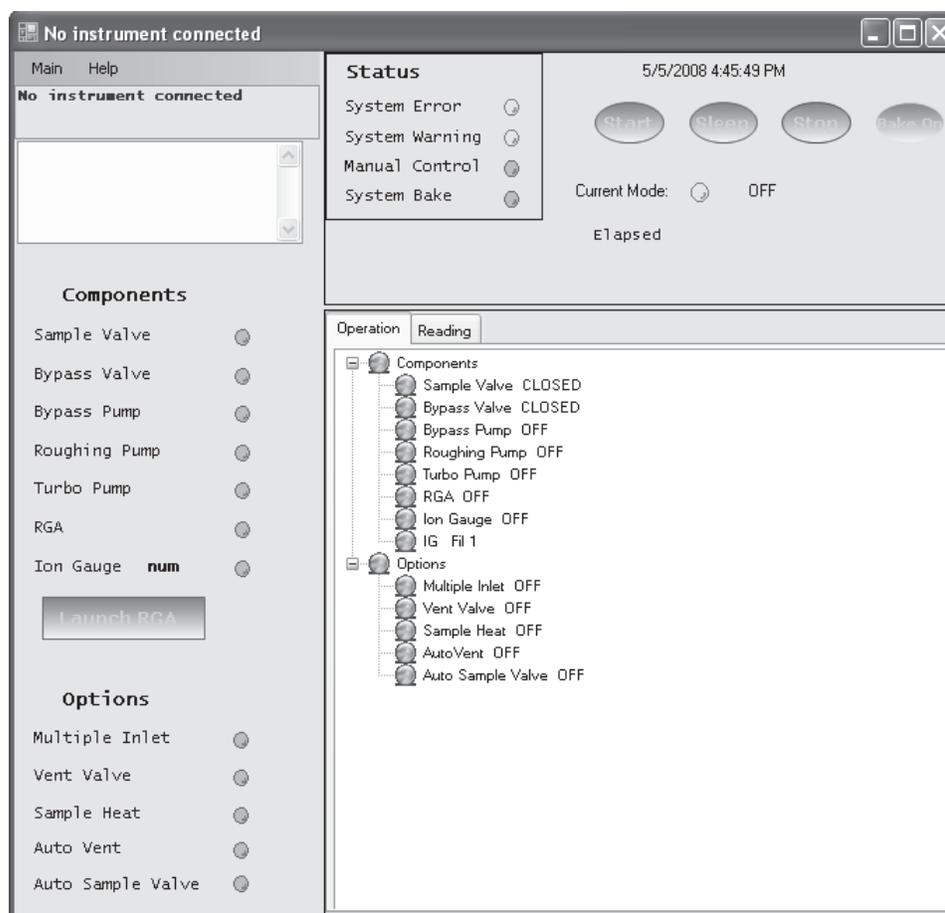


Fig. 2-3 Screenshot of the initial window of UGA control software.

### 2.3.3 Connection to a PC

In order to use this program, at least one UGA must be connected to the PC. There are two ways to connect between UGA and a PC; TCP/IP Ethernet or an RS232 serial connection. In this section, we provide step-by-step instructions for setting up communication.

#### 2.3.3.1 RS232 Serial Connection

The communication between UGA and a PC through RS232 serial connection is possible with two different baud rates: 28800 and 38400. The baud rate of 38400 is for a general COM port communication between UGA control and PC. 28800 baud rate is used for direct communication between the RGA and the PC. A user can select either baud rate from the front panel.

1. Connect between UGA and a PC using the provided serial cable.
2. Power up the UGA.
3. From the front panel choose the baud rate as follows. The default rate is 38400.
  - Push the Level-up button to enter the UGA menu.
  - Select 'Setup' with the Down button and confirm it.
  - Choose Communication to move to the next menu tree.
  - Choose 'RS232 Baud Rate'.
  - Choose the desired baud rate at the menu.
  - Push the Level-up button several times to escape the menu.
4. Click the "Main" menu of the UGA software, and select "Setup". The following screen will appear as shown in Fig. 2-4

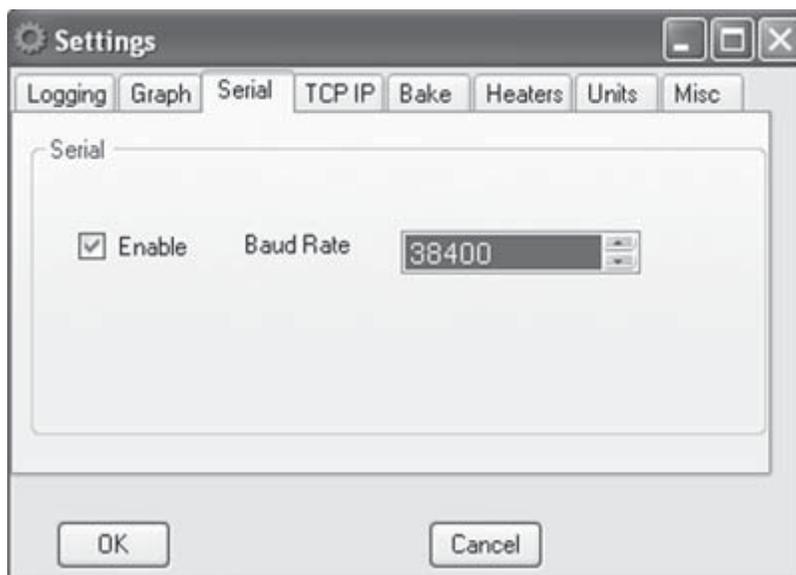


Fig. 2-4. Screenshot of 'Serial' selection in the Settings dialog box

5. In the 'Settings' window, choose 'Serial' tab. Verify that the serial resource is enabled (as shown below). Match the baud rate with UGA settings. Click "OK".
6. Click on the "Main" tab, and select "Connect"

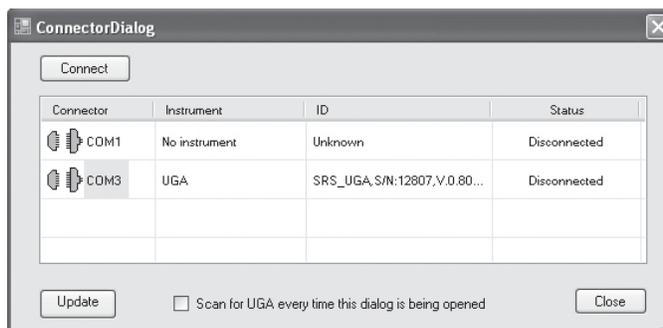


Fig. 2-5. Screenshot of UGA control software after selecting 'Connect' in the Main menu. The available Serial connector is shown.

7. The software will show the available resources. Select the appropriate COM port and click the "Connect" button. In the example screenshot above, the UGA is found on COM3. Note if you are using a USB to serial adapter, you must know what COM port the USB driver has allocated. Use the Windows device manager to find the USB to serial COM port.

8. After the proper port changes to the connection (the icon indicates connected status with green color), close the ConnectorDialog window.
9. The following screen will appear at the UGA control program.

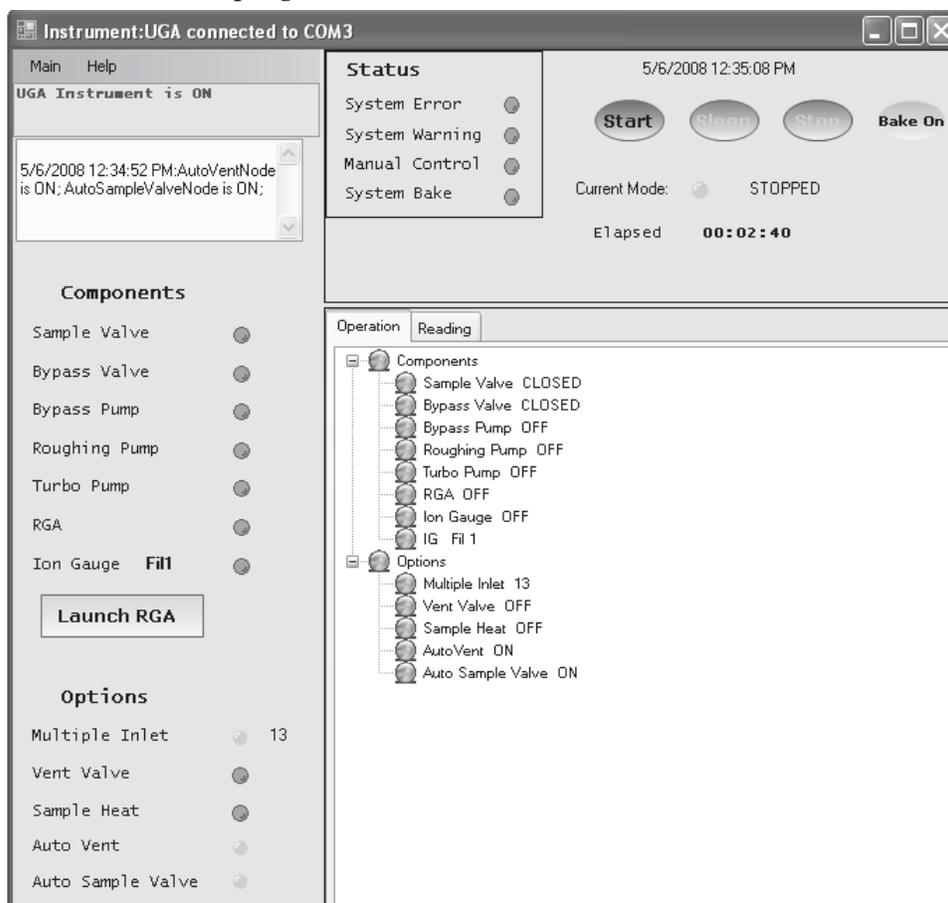


Fig. 2-6. Screenshot of UGA control software after proper serial connection. In the title bar, the connection is described.

10. Now a user can explore the program by clicking each item on the graph. Refer to the next section (Menus and Displays) for detailed information.
11. For operation of UGA, refer to the previous section, Front Panel Operation. As mentioned before, the program mimics the functions of the front panel. After this point, the operations of UGA are exactly the same as those with Ethernet connection.

### 2.3.3.2 TCP/IP Ethernet Connection

In order to use this connection, a user should know the network environment for the UGA and the PC. The UGA firmware and software both need proper TCP/IP parameters.

1. First of all, you need to determine the IP address, Subnet Mask, and Gateway for communication. The following are default values.

IP address :	0.0.0.0	Subnet Mask :	255.255.255.0
Gateway :	0.0.0.0	Port # :	818

2. Punch in those parameters at the front panel with the following procedure. Alternatively, a user may type in these parameters through RS232 serial communication. (Refer to the previous section)

From the front panel;

- Power up the UGA.
- Push Level-up button to enter MENU at the front panel.
- Select 'Communication' and hit the confirmation button.
- Ethernet items are now shown on the display.
- Choose 'IP Address'. The display shows the default IP address.
- Using Up or Down button, change the value. Then hit the confirmation button.
- The next number will be blinking. Repeat as above to set the proper value.
- After keying in all four numbers, the display will move up to the Ethernet menu. Choose 'Subnet Mask' and set the parameters.
- Follow the same procedure for 'Gateway' item.
- Push the Level-up button several times to escape the menu tree and enter the display mode.

From the RS232 connection;

After UGA control software is connected through RS232 serial port, the TCP/IP parameters (IP address, Subnet mask, Gateway, User ID, and Password) can be typed in from the software using 'Wizard' menu in the UGA control software. The 'Wizard' menu can be engaged in only when the serial port connection is activated.

- Check the connection through the serial port.
- In the Main menu, select "Wizard". The following screen will appear.

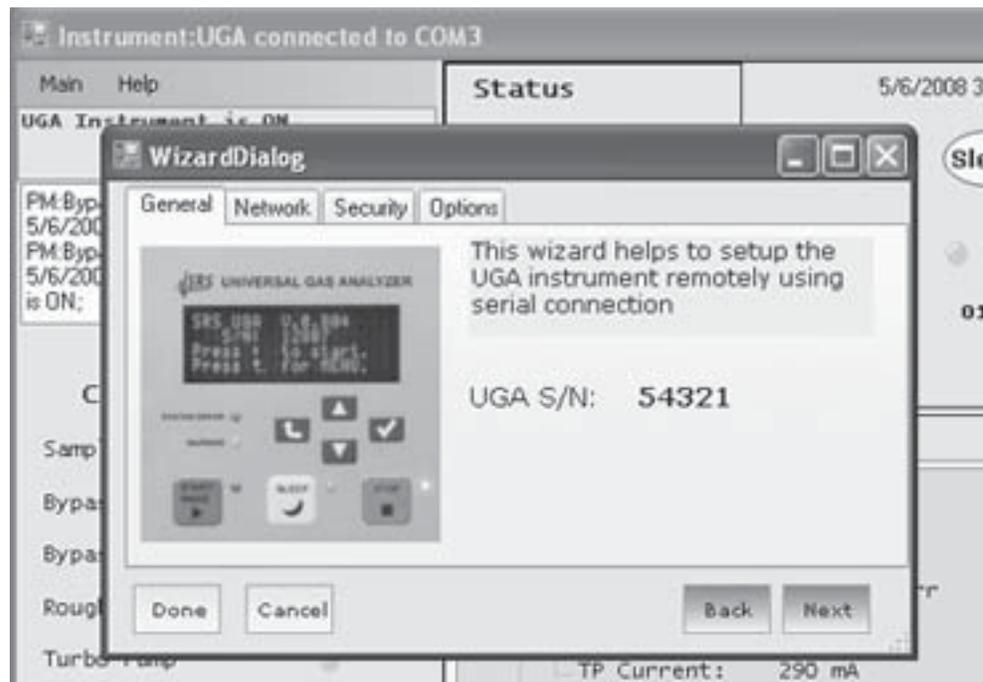


Fig. 2-7. Screenshot of the 'Wizard' menu in the Main menu of UGA control software.

- Click the network tab to type in IP address, Subnet mask, and Gateway.



Fig. 2-8. Screenshot of 'Network' tab in the Wizard menu.

- Click the Security tab to type in User ID and Password.

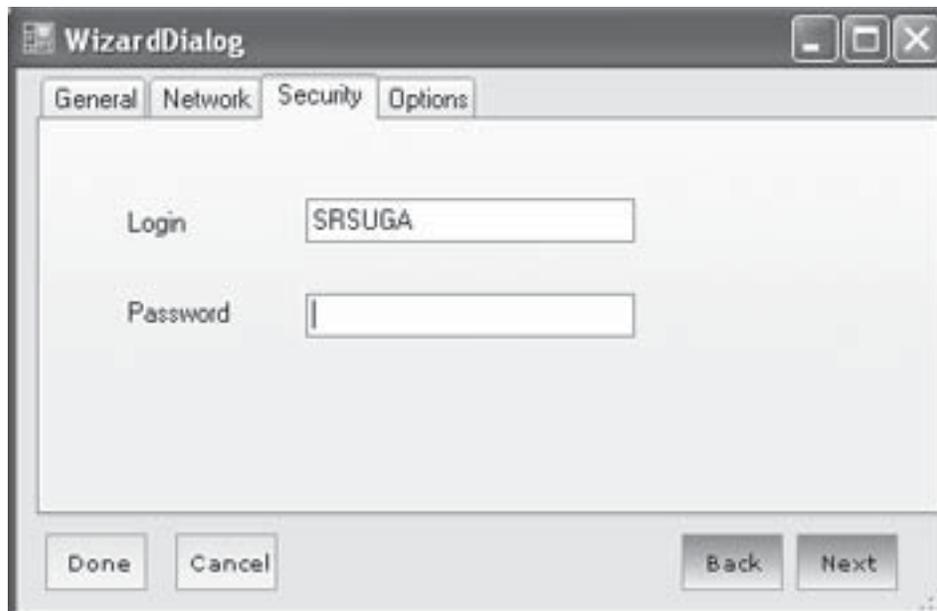


Fig. 2-9. Screenshot of 'Security' tab in the Wizard menu.

- After finishing typing, click 'Done' Button.
  - Check the TCP/IP parameters in the Communication menu of the front panel. The parameters should be saved in the UGA.
3. Now the UGA is ready to connect through TCP/IP Ethernet connection. For the quick test of this connection, the user can try 'telnet.exe' command with the proper telnet port or 'ping.exe' command. It is time to setup the UGA control software. Follow the procedure below.
- Launch UGA control program.
  - Make sure Ethernet cable is connected to UGA and a PC. If the connection is active, the yellow LED will be lit on the RJ45 connector.
  - In the Main menu, select 'Setup'. The 'Settings' dialog box will pop up as shown in Fig. 2-4
  - In the setting window, choose 'TCP IP' tab.

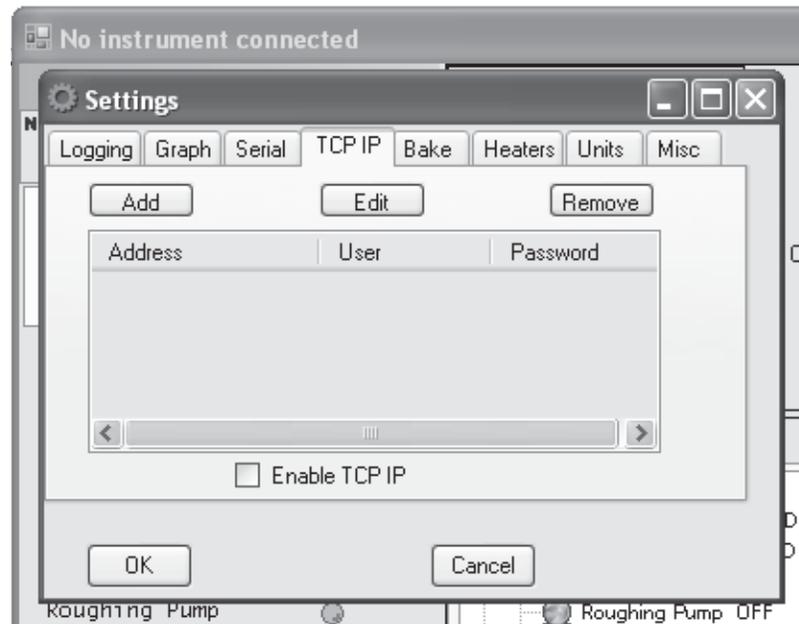


Fig. 2-10. Screenshot of 'TCP IP' selection in the Settings dialog box. TCP/IP connection setting is established here.

- Click 'Add' button. Then another dialog box (User Info) will pop up.

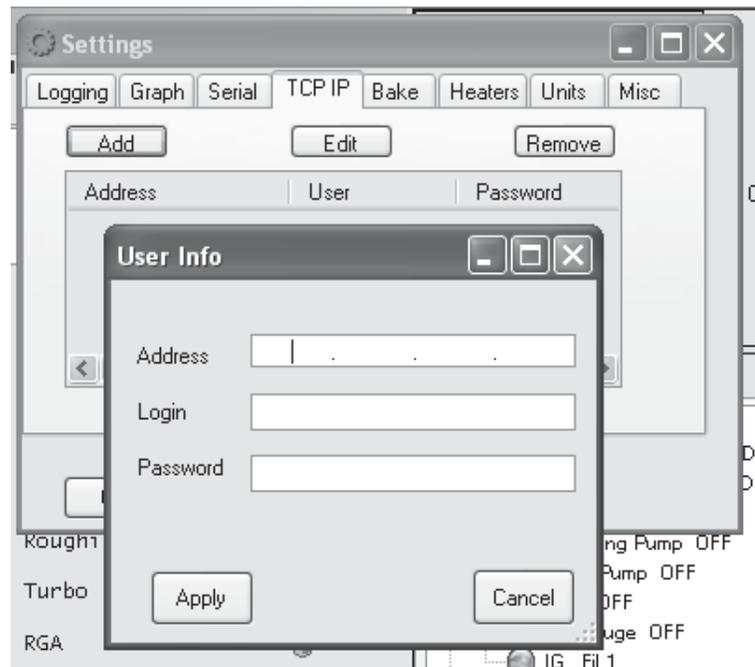


Fig. 2-11. Screenshot of User Info box for TCP/IP connection.

- Type in the proper IP Address, Port number, User ID, and password. Then click 'Apply'. The setting dialog box should have the information typed in before.

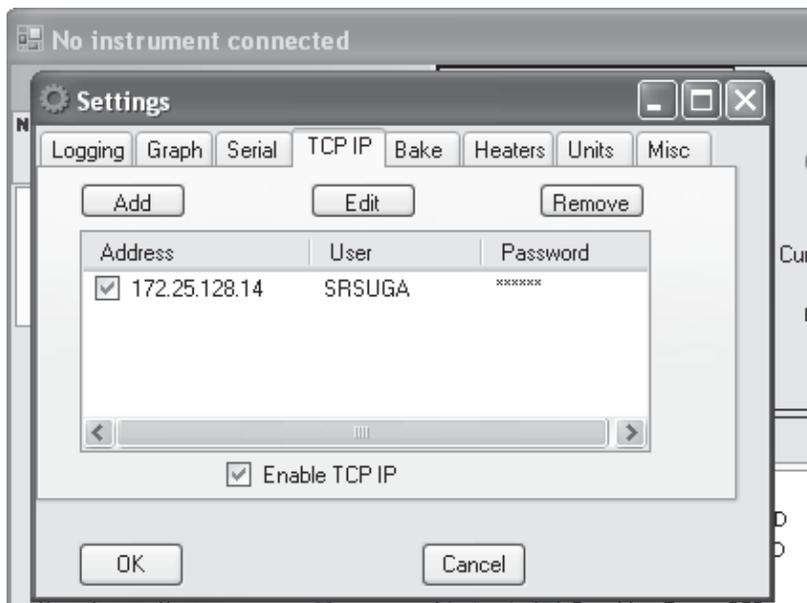


Fig 2-12. Screenshot of the Settings dialog box after the data typed in at the 'User Info' box.

- Make sure the TCP/IP connection is enabled.
- Click the 'OK' button. This will close the Settings dialog box.
- In the main menu, select 'Connect'. The following 'ConnectorDialog' window will be shown.

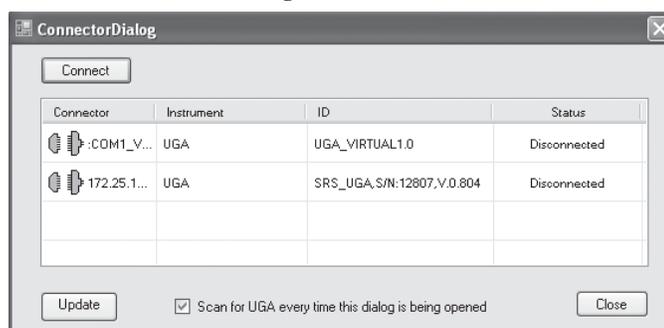


Fig. 2-13. Screenshot of UGA control software after selecting 'Connect' in the Main menu. The available TCP/IP connector is shown

- Choose the proper one by clicking on the connector. Then click 'Connect'.

- The icon of the connector will change to indicate a connected status..

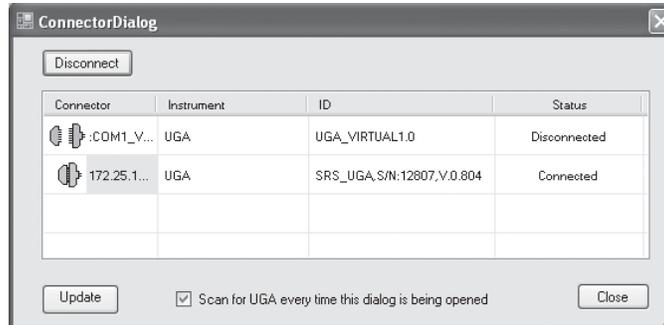


Fig. 2-14. Screenshot of 'ConnectorDialog' window after proper connection.

- Close the ConnectorDialog window.
  - The UGA control program title shows how the connection has been completed.
  - The program shows the complete present state. Fig. 2-15 shows that Multiple inlet is installed in this Unit and the position is at #12 channel. The unit is stopped, which is the Off state, etc.
4. Now a user can explore the program by clicking each item on the graph. Refer to the next section (Menus and Displays) for detailed information.
  5. For operation of UGA, refer to the previous section, Front Panel Operation. As mentioned before, the program mimics the functions of the front panel.



Fig. 2-15. Screenshot of UGA control software after proper TCP/IP Ethernet connection. In the title bar, the connection is described.

### 2.3.4 Menus and Displays

The UGA control program is a Windows based software written in C language using .NET framework. The main user interface window is composed of several areas - Title bar, Menu bar, Message sub-window, Log sub-window, etc as seen in Fig. 2-15. In this section, the menus and displays of the program are described in detail. Fig. 2-16 will categorize each area to be explained.

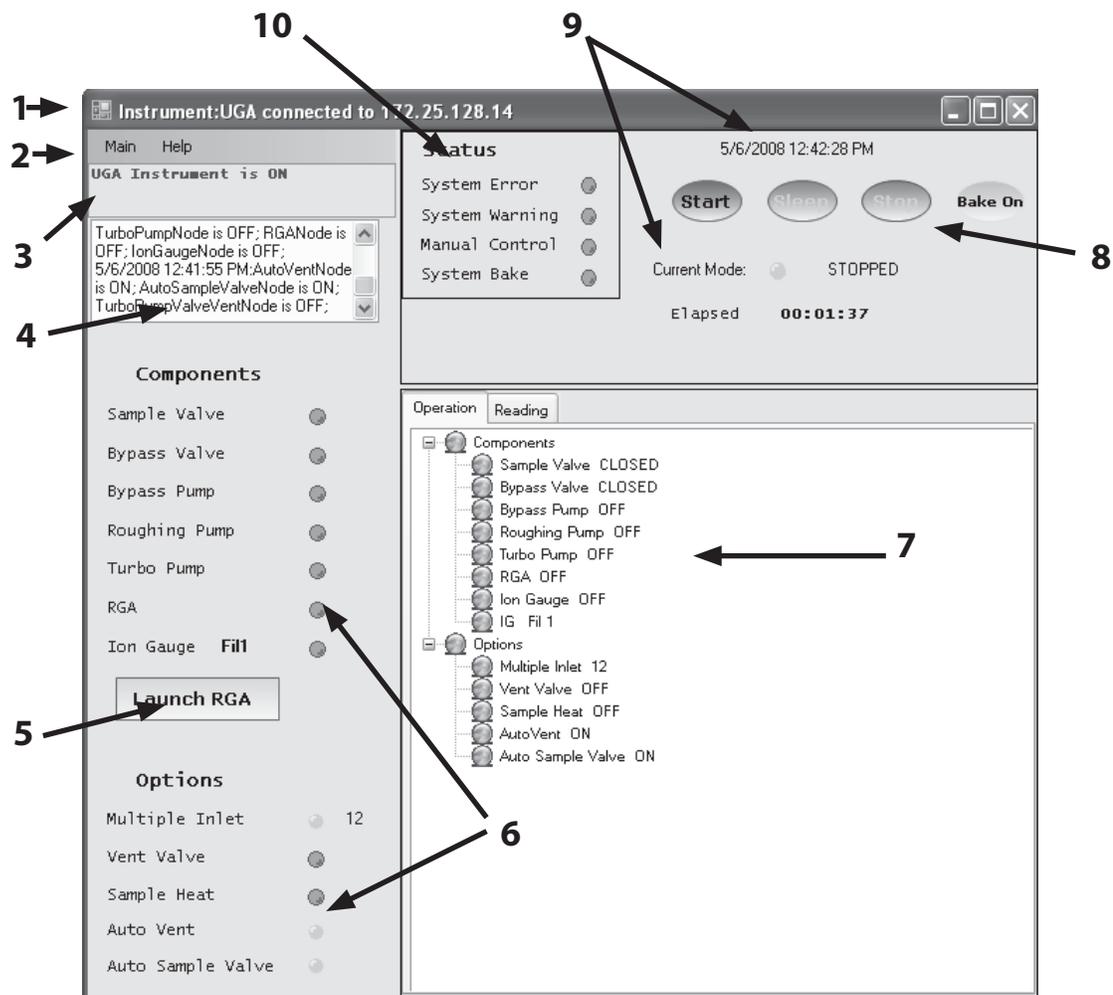


Fig. 2-16. Section indications of UGA control software window. The name for each numbered section is written below.

- 1 : Main title bar
- 2 : Menu bar
- 3 : Message board
- 4 : Log board
- 5 : RGA software launch button
- 6 : State indicators for components and control options
- 7 : Operations and displays sub-window
- 8 : Auto control buttons
- 9 : Time information and current mode board
- 10 : Functional indicator board

### 1. Main title bar

This bar has the same functions as a normal windows application.. Title on the left, window control icons on the right. In the title, it indicates the connection status.

### 2. Menu bar

There are two menus on the bar; Main and Help. 'Help' menu explains all the functions of the program. In the 'Main' menu, there are four submenus; Connect, Setup, Wizard, and Quit.

'Connect' submenu connects UGA to a PC through an assigned connector - TCP/IP Ethernet or RS232 Serial.

'Quit' submenu closes the program any time it is clicked.

'Wizard' submenu provides tools to type in the TCP/IP parameters only when the UGA is connected through RS232 serial port.

'Setup' submenu will show the following pop up dialog box called Settings. In this box, there are eight submenus; Logging, Graph, Serial, TCP IP, Bake, Heaters, Units, and Misc. After changing values in this window, click the 'OK' button to save the data. 'Serial' and "TCP IP" tabs have been explained before in the 'Connection to a PC' section.

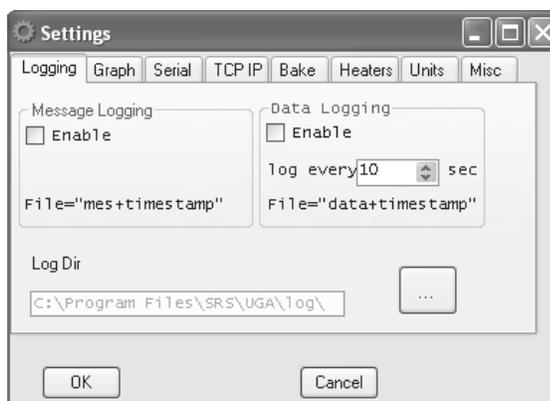


Fig. 2-17. Screenshot of 'Settings' dialog box for Logging tab

Logging tab contains all the logging conditions for UGA control as shown above; enabling message log and data log, data log time interval, log directory. The Message log contains all the events of component controls with the time stamp, which are shown in #4, the log board of Fig 2-16. In the data log, there are all 8 data (3 pressures-roughing line, bypass line, and RGA chamber; 5 temperatures-elbow, RGA chamber, sample line, capillary, and TP) with the time stamp. A user can make their own log directory by typing in a name or selecting an existing one at Log Dir.

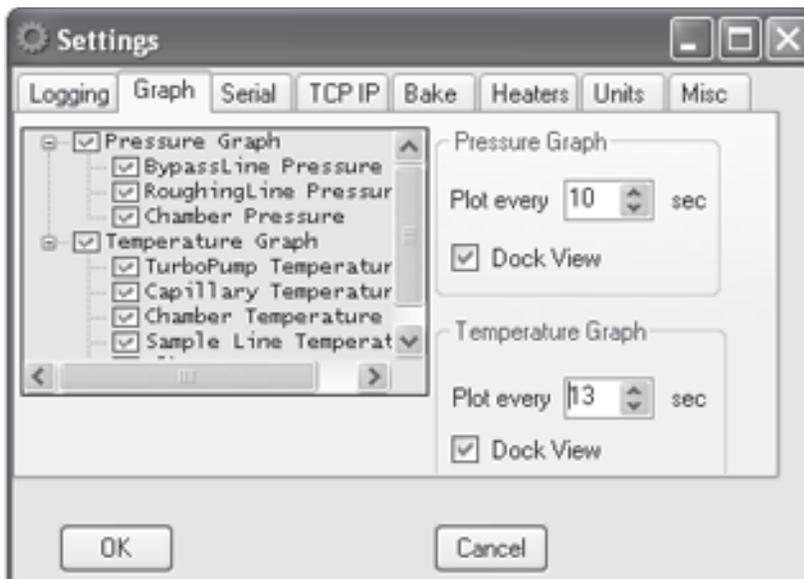


Fig. 2-18. Screenshot of 'Settings' dialog box for Graph tab

The Graph tab has some selections for displaying pressure and temperature data on the Operations and sub-window displays (#7 on Fig. 2-16). If a user checks 'Dock View' after selecting some items from the left box, the related data graph will be shown on #7 sub-window. The graphs will be recorded with the setting interval time. The selected data will be recorded in the data log file, if enabled at the Logging tab.

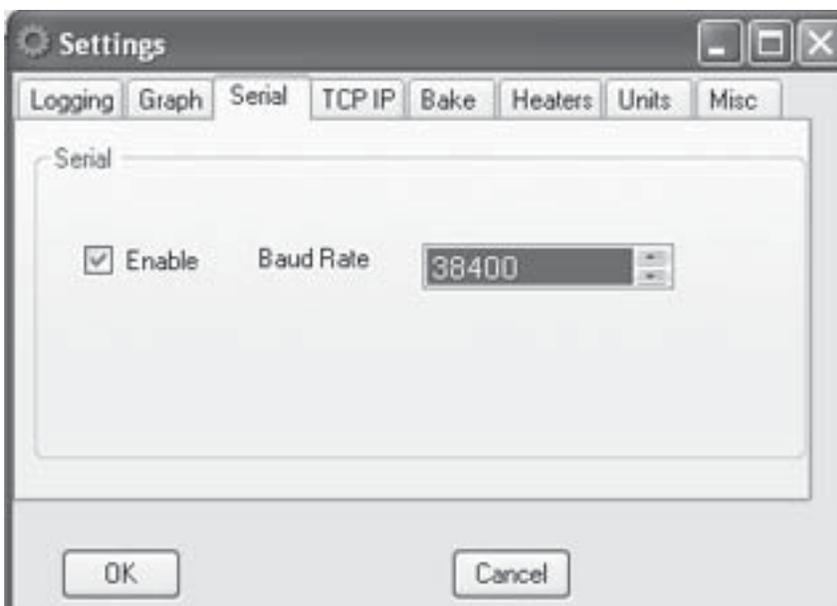


Fig. 2-19. Screenshot of 'Settings' dialog box for Serial tab

In the Serial tab, the baud rate can be set and enable or disable the RS232 serial port.

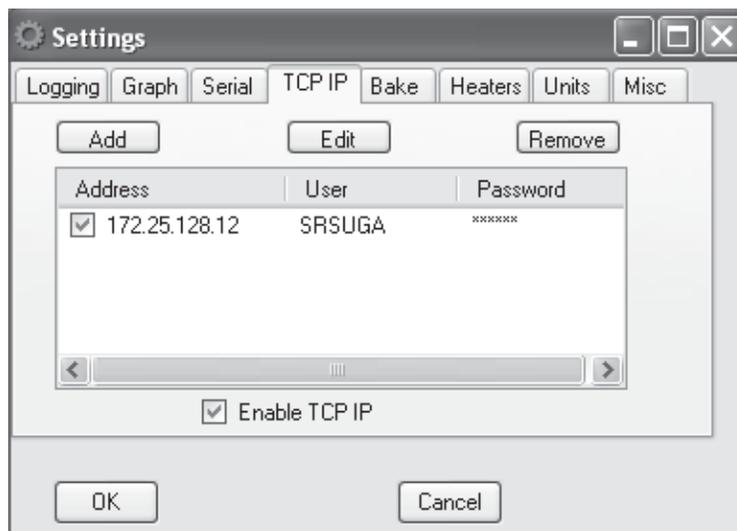


Fig. 2-20. Screenshot of 'Settings' dialog box for TCP IP tab

As explained before, a user can set the parameters for TCP/IP connection in this tab. More than one set of the parameters can be added. A user can type in the parameter sets as many as he can. And the parameters of an activated IP address can be edited in the 'User Info' dialog box using "Edit" button. The 'Remove' button will erase an activated IP address connection.

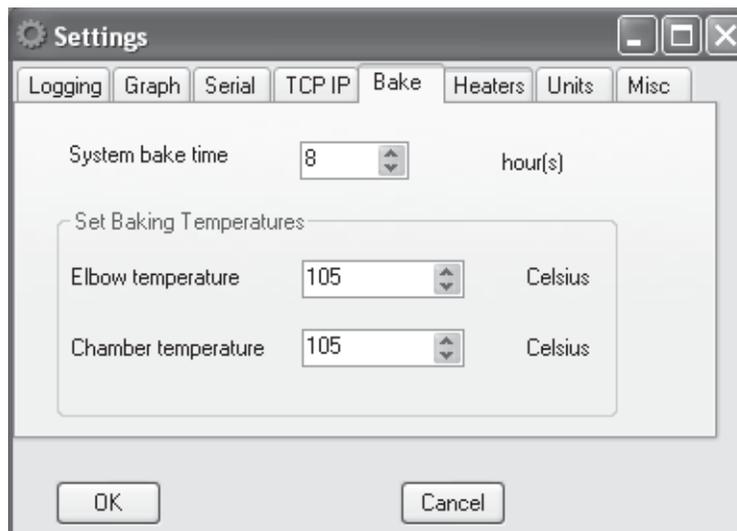


Fig. 2-21. Screen shot of "Settings" dialog box for Bake tab

Bake tab contains the parameters setting for the System Bake; System bake time and Baking temperatures of Elbow and Chamber. The baking hour is in the range of 2 to 100 hours. Each temperature can be set from 0 to 105 °C. Setting 0 °C means the system does not turn on heaters even heater-on command proceed successfully. In this way, a user can control each heater separately. The default values are 8 hours for the system bake time, 105 °C for both Elbow and Chamber temperature.

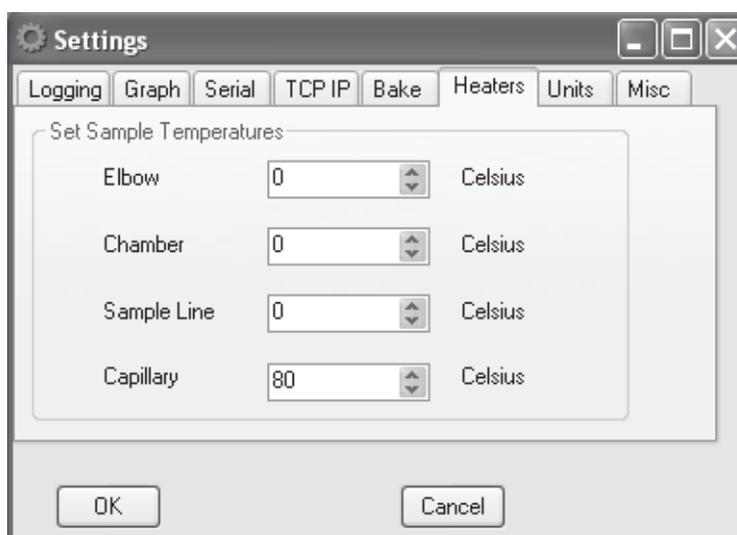


Fig. 2-22. Screen shot of “Settings” dialog box for Heaters tab

If Option#3 is ordered, the system has two more heaters; sample line heater and capillary heater in addition to the baking heaters-elbow and chamber heaters. For heated gas sampling the capillary and the sample line of UGA also are needed to heat up. Sometimes the RGA chamber might be needed to heat, too. In this tab, all four temperatures can be set individually for each heater. The default values are 0 °C for Elbow and RGA chamber, 80 °C for Sample line and Capillary.

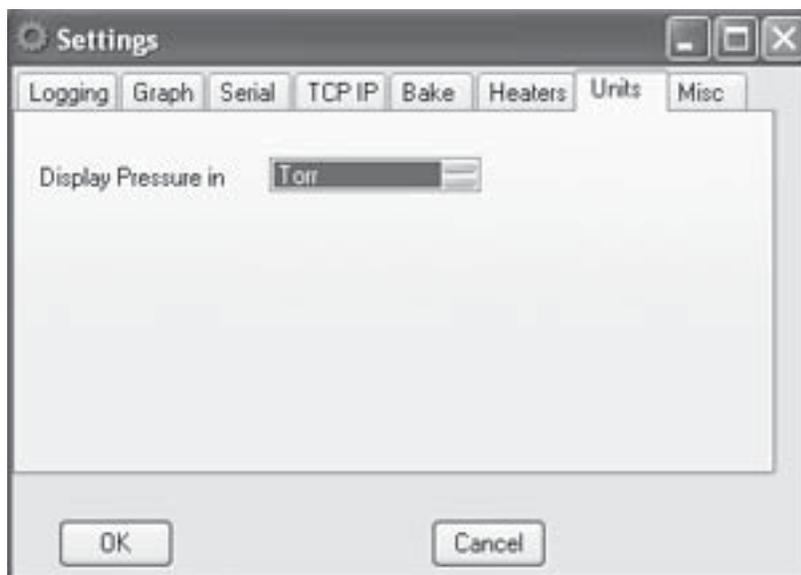


Fig. 2-23. Screenshot of 'Settings' dialog box for Pressure Unit tab

The pressure unit in the reading section or in the graph can be set among Torr, bar, mbar, Pascal, and atm using this tab. The default setting is Torr.

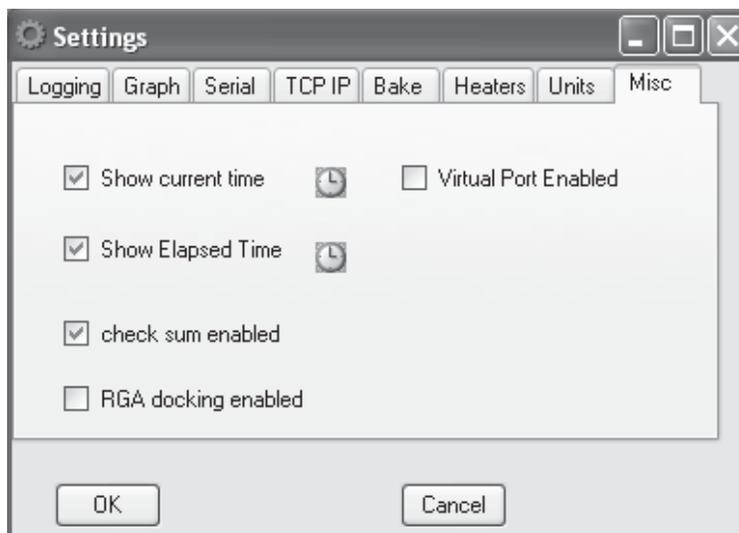


Fig. 2-24. Screenshot of 'Settings' dialog box for Misc tab

In the Misc tab, several display items can be selected. 'RGA docking enabled' means that when a user runs RGA software, the program window will be docked on the Operations and displays sub-window. With UGA control software, a developer can mimic the functions without a real UGA by checking 'Virtual Port Enabled'.

### 3. Message board

In the Message board, all error and warning messages are shown. If enabled, these will be recorded in the message log file.

### 4. Log board

In the Log board, every event will be written with the time stamp. If enabled, these logs will be recorded in the message log file.

### 5. RGA software launch button

If RGA software is installed, clicking this button will start the program. If RGA is on inside the UGA, this process will automatically connect to the RGA. At the end of the launching, a user can see the following screen.

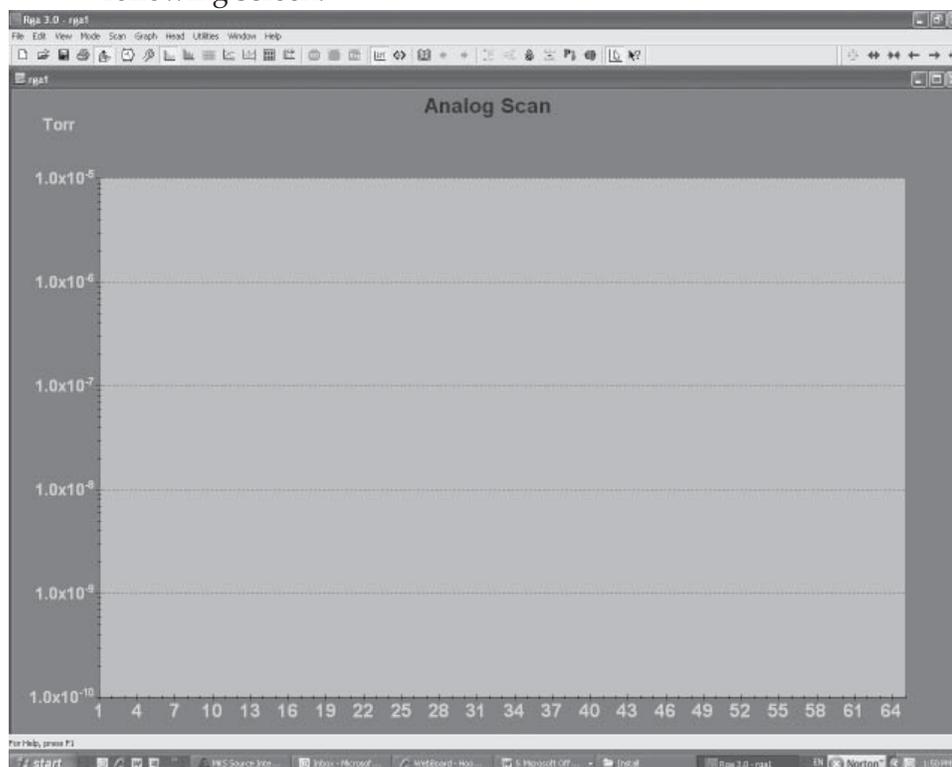


Fig. 2-25. Screenshot of RGA software.

6. State indicators for option components and control options  
 The present states of all the components and control options are indicated with LED graphics. If it is lit, the item is on or open. If off, the item is off or closed. If blinking, the item is in transition. The number beside 'Ion Gauge' indicates the filament number which the ion gauge is using presently. There are two filaments in the ion gauge. The filament can be selected from the front panel or from the operation window of UGA control software. If the LED for Multiple Inlet is on, it means the valve is installed. If it is off, there is no valve in the unit.

### 7. Operations and displays subwindow

This area is for individual controls and data displays. Graphs of pressure and/or temperature data will be docked here, if selected. The RGA window can also be docked, if selected. All windows are tabbed as shown below.

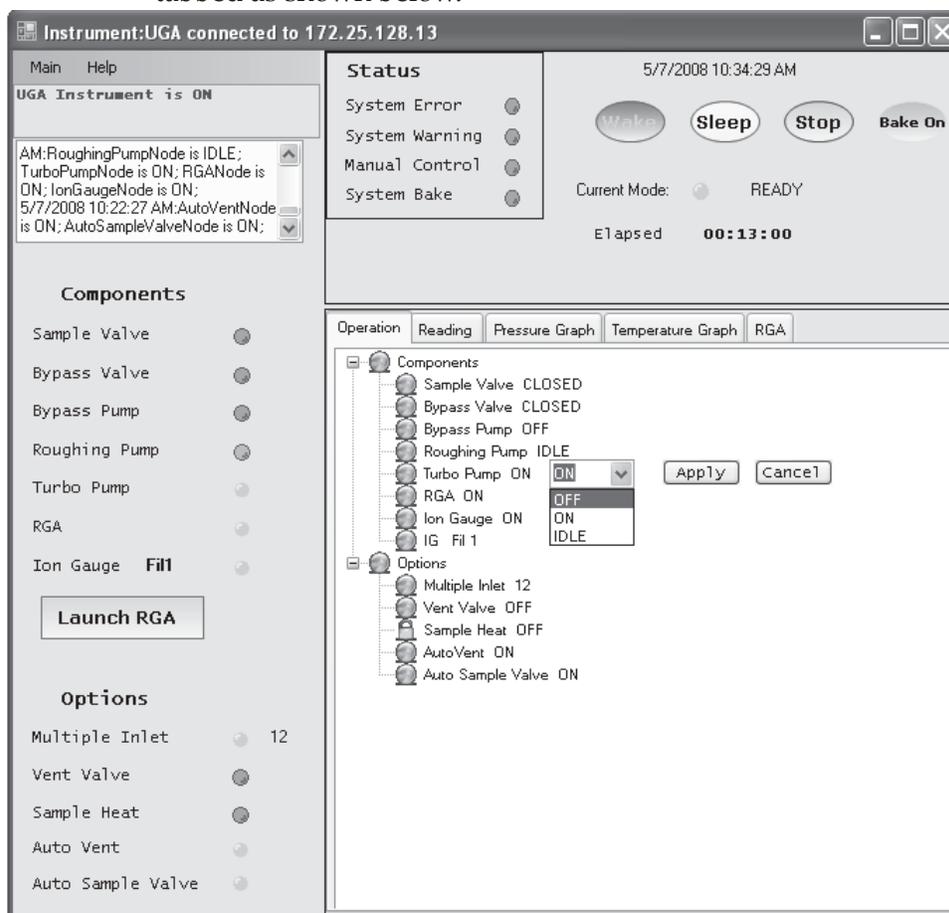


Fig. 2-26. Screenshot of UGA control software window for various window tabs and operations.

In the Operation tab, there is a components list. The components are listed under the Manual head. The present states are also written beside each component. The list of IG indicates the current filament used. One of two filaments can be selected here. By one click on the component name, a control bar will appear as shown for 'Turbo Pump'. Just select the desired state and confirm it by clicking the Apply button. By double clicking the component name, the action will be locked as shown for 'Sample Heat'

Using the same manner, two advanced operations can be set here: Auto Sample Valve and Auto Vent Valve. These items are shown in the Option menu tree.

#### 8. Auto control buttons

These buttons operate the same as the buttons on the front panel. Only 'Bake On/Off' button is added here, because the system baking function is a kind of mode function. In addition, only the applicable mode buttons are activated depending on the situation of the UGA. Others will be grayed and not functioning at that time.

#### 9. Time information and current mode indicator board

A user can display this information on the board by selecting the items in the Misc tab of 'Settings' window.

#### 10. Functional indicator board

This board indicates errors, any warnings, system baking, or manual control.

### **2.3.5 Launching RGA Software**

After a user brings the UGA to the Ready state, the unit is ready for using the RGA to analyze gas mixtures. In order to obtain RGA data, the UGA needs to be connected to a PC running the RGA software. In this section, only RGA software launching is described. For the detailed explanation of RGA software, a user should refer to the RGA manual.

A user can connect to the RGA in two ways - within UGA control software, or without UGA control software.

- A. Launching RGA software from UGA control software
- Check that the connection is established
  - Check that the RGA is on. If not, turn it on as shown below.

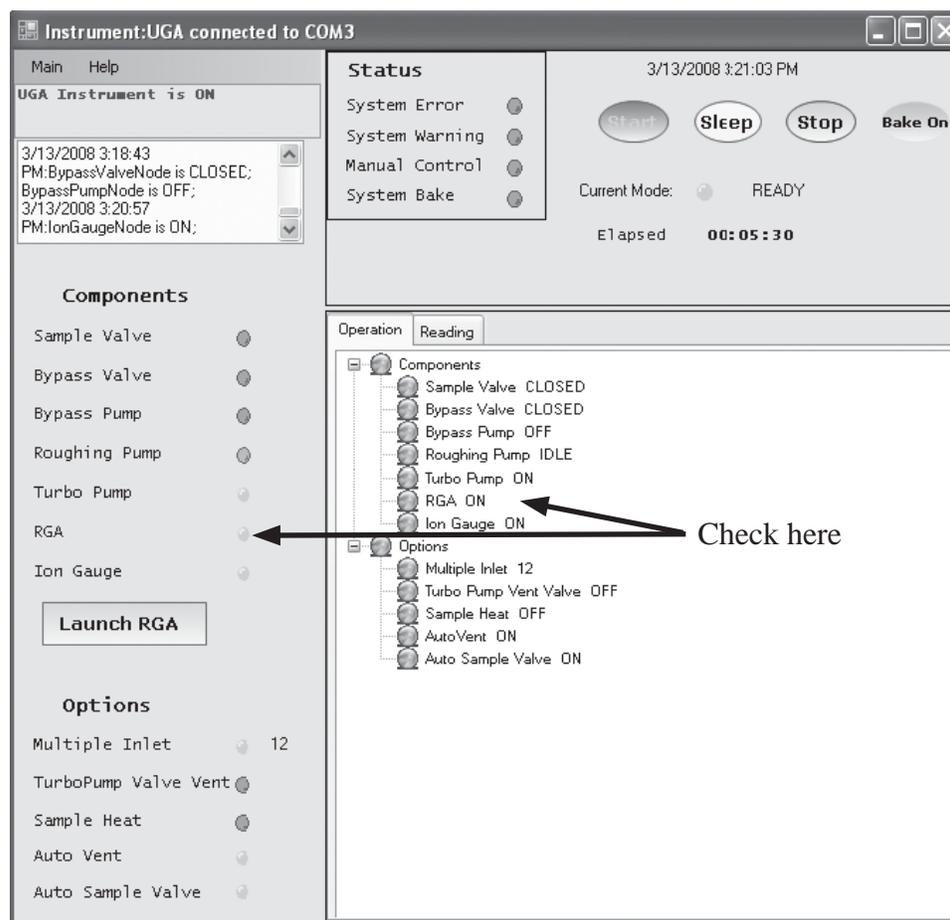


Fig. 2-27. Check points of RGA status in the UGA control software.

- Click 'Launch RGA'. You should see the same screen as Fig. 2-25.
  - This process will connect a PC to RGA automatically.
  - Now you can start gas analysis.
- B. Launching RGA software by itself (Only through RS232 serial connection)
- Check the Baud rate is set to be 28800 on the front panel. If not, set it from the front panel.

- Check RGA status from the front panel. If RGA is not on, bring UGA to ready state for RGA.
- Establish RS232 serial connection between UGA and the PC.
- Start 'RGA3\_0.exe'.
- Click the connection button (  ) the toolbar. The following dialog box will show up.

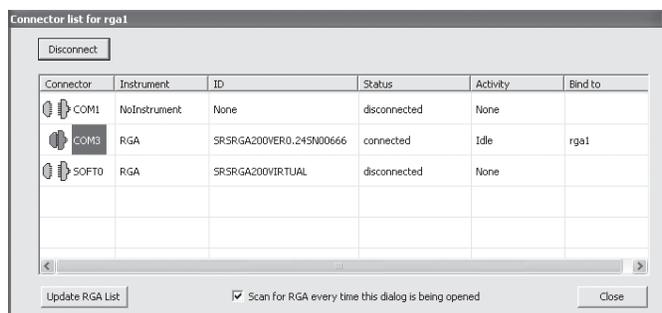


Fig. 2-28. Screenshot of RGA connection dialog box.

- Select the proper com port (Here it is COM3.).
- Click the 'Connect' button and close the dialog box.
- You can now start gas analysis.

## 2.3.6 Option Operation

### 2.3.6.1 Multiple inlet valve

The UGA control software shows the present valve position in the state indication area and also the Operation sub-window. Clicking the entry for the Multiple inlet valve on the Option section of the Operation sub-window will display the channel selection menu. (See Fig. 2-29.)

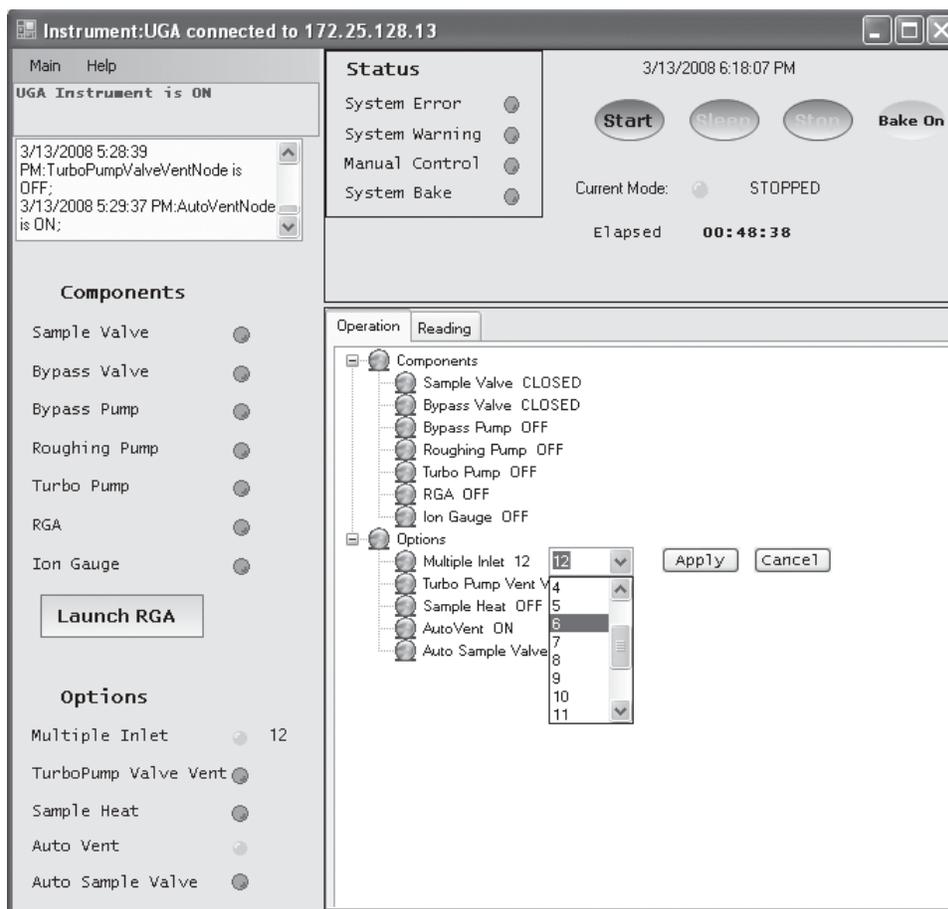


Fig. 2-29. Screenshot of Multiple inlet valve control. The present position is displayed in the component state section and also the operation sub-window.

Select the desired channel number, then apply it. The valve will rotate to the new position. Before the valve is used, plug the unused channels with the provided plugs. A user can use any length of capillary. Please note, however, that the response time will be affected by the length of the capillary.

### 2.3.6.2 Vent valve

From the UGA software, just click the name of the Vent valve as shown in Fig. 2-30. Choose the desired action menu item (Close or Open). When 'Open' is selected, the UGA will first open the valve

for 1 second. Then it will wait for 40 seconds to open it again for a minute. After this, the valve will be not open. By doing this, the TP will stop smoothly without a pressure shock. This function will help the system stop in several minutes and protect the RGA chamber from contamination.

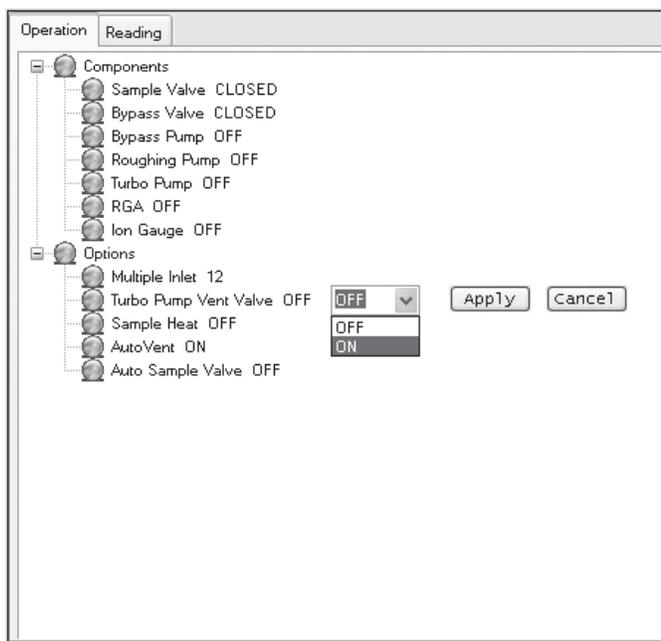


Fig. 2-30. Screenshot of the Vent valve control on the UGA software.

### 2.3.6.3 Sample heaters

Go to the Setup menu, followed by the 'Heaters' sub-menu. In this sub-menu, choose 'Sample Temperature' item. Type in the desired temperature settings. The default values are 0 °C for ELB, 0 °C for CHA, 80 °C for SMP, 80 °C for CAP. In the UGA control software, a user can set the temperature limits at the 'Heaters' tap in the 'Settings' dialog box. Fig. 2-28 shows the details.

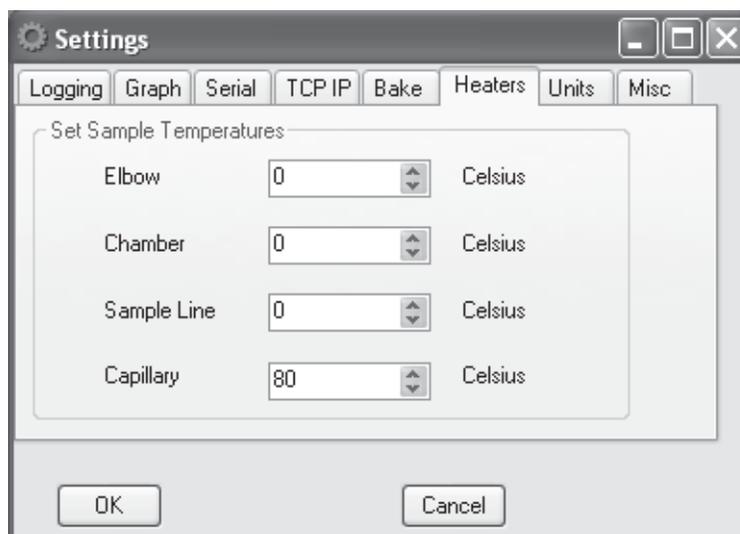


Fig. 2-31. Screenshot of Set Sample Temperature in Settings dialog box.

After the heating temperatures are set, press 'Sample heater on' from the front panel or from the UGA control software. This will heat up the capillary, the pinhole holder and the sample line till right after the bypass valve.

---

# Chapter 3

## Remote Programming

---

**In This Chapter** This chapter discusses remote programming of the UGA.

3.1	Introduction . . . . .	3-2
	Comuunication via RS232 . . . . .	3-2
	Communication via ethernet . . . . .	3-2
	Command format . . . . .	3-2
	Command syntax. . . . .	3-3
3.2	Commands . . . . .	3-4
	Mode setting commands . . . . .	3-4
	Components control commands . . . . .	3-7
	Status query commands . . . . .	3-13
	Query commands . . . . .	3-14
	Error query commands . . . . .	3-16
	Parameter setting commands . . . . .	3-17

## 3.1 Introduction

The UGA may be controlled via either Ethernet interface or RS-232 interface. See the chapter 2 of the manual for how to get connected.

### *3.1.1 Communication via RS-232*

The UGA uses a DB9 connector for serial communications. The female DB9 connector on the UGA is configured as a DCE (transmit on pin 2, receive on pin 3) device and supports CTS/DTR hardware handshaking. The RTS signal (pins 8) is an output indicating that the UGA is ready, while the CTS signal (pin 7) is an input that is used to control the UGA's data transmission. Ground is pin 5. The UGA uses hardware handshaking, one stop bit, no parity, baud rate either 28800 or 38400.

### *3.1.2 Communication via Ethernet*

You may connect the UGA either directly to the host computer with a cross-over cable, or to a hub or switch with a straight-through CAT5 cable. To connect UGA to internet, you will need a static IP (Internet Protocol) address, subnet mask, and gateway address. See your network administrator to obtain addresses appropriate for your network environment.

### *3.1.3 Command Format*

Communications with the UGA uses ASCII characters. Because the UGA is case insensitive, all commands may be in either UPPER or lower case. A command starts from a character after a termination character and ends with a termination character. The UGA uses carriage return, <CR> as the termination character.

The UGA has two separate sets of commands that are handled by separate microprocessors. One is the UGA command set which is

processed by UGA main controller, and the other is the RGA command set which is processed by RGA controller. A command starting with a 'Z' is handled by the UGA main controller, and a command starting with other characters is handled the RGA controller. A command in the UGA command set consists of a four character command mnemonic, arguments if necessary, and a command terminator. The command, arguments and terminator may be separated by spaces. No command processing occurs until a <CR> terminator is received.

Commands may require one or more parameters. Multiple parameters are separated by commas (,).

The present value of a particular parameter may be determined by querying the UGA for its value. A query is formed by appending a question mark '?' to the command mnemonic and omitting the desired parameter from the command. Values returned by the UGA are sent as a string of ASCII characters terminated by a carriage return <CR>.

### *3.1.4 Command Syntax*

The four letter mnemonic (shown in CAPS) in each command sequence specifies the command. The rest of the sequence consists of parameters. Parameters shown in { } are not always required. Generally, parameters in { } are required to set a value in the UGA. Multiple parameters are separated by commas. The present value of a parameter may be determined by sending a query command.

- Commands that MAY be queried show a question mark in parentheses (?) after the mnemonic.
- Commands that are ONLY queries have a '?' after the mnemonic, with no parentheses.
- Commands that MAY NOT be queried have no '?'.

A query is formed by including the question mark ? after the command mnemonic and omitting the queried parameter from the command. The query parameters shown in { } are NOT sent with a query. The query returns the value of these parameters. Values are returned as a string of ASCII characters (unless otherwise noted).

Do NOT send ( ) or { } as part of the command. For example, the command sequence ZPTB(?) i {, j} is used as follows.

ZPTB1, 105 Set the bake temperature for the chamber heat (1) to 105 C.

ZPTB? 1 Query the bake temperature for the chamber heater (1).

Variables are defined as follows.

i, p	integers
i.i.i.i	Dotted decimal format for IP address, subnet mask, and default gateway address
s	text string for login name and password

Commands to set values which may be different for each channel require the p parameter.

These values must be queried separately for each channel. All numeric variables should be expressed in integer (i.e., 5), neither floating point (5.0) nor exponential formats (0.5E1). Strings are sent as a sequence of ASCII characters.

## 3.2 Commands

### 3.2.1 Mode setting commands

#### ZMST Start

The ZMST command initiates START mode. It turns on all the components according to the automated START sequence, and brings the instruments to the READY state.

#### Example

ZMST begins START mode.

#### Errors and warnings

The command will be ignored if any of these conditions are true. ZMST may cause these errors.

Warning	47	“Leak Test ON”
Warning	48	“System Bake ON”
Warning	51	“Pressure Check off”

<b>ZMSP</b>	<b>Stop</b> The ZMSP command initiates STOP mode. Turn off all the components according to the automated STOP sequence.  <b>Example</b> ZMSP           begins STOP mode.  <b>Errors and warnings</b> ZMSP should work in any condition.
<b>ZMSL</b>	<b>Sleep</b> The ZMSL command initiates SLEEP mode. It puts the UGA to IDLE state from READY state. If the turbo pump is off, the ZMSL command will fail with the warning 42.  <b>Example</b> ZMSL           begins SLEEP mode.  <b>Errors and warnings</b> The command is ignored if any of these conditions are true. Warning       42       "Turbo not ready" Warning       47       "Leak Test ON" Warning       48       "System Bake ON"
<b>ZMLT (?) {i}</b>	<b>Leak Test mode</b> The ZMLT i command turns the leak test mode Off (i=0) or On (i=1). The ZMLT? command returns whether the leak test mode is On or Off. If the RGA is not On, ZMLT will fail with the warning 44.  <b>Example</b> ZMLT 1        starts the leak test. ZMLT?        returns the status of the Leak test function, On(1) or Off(0).  <b>Errors and warnings</b> The command is ignored if any of these conditions are true. Warning       44       "RGA OFF" Warning       48       "System Bake ON"

**ZMBK (?) {i} System Bake mode**

The ZMBK i command turns the system bake mode Off (i=0) or On (i=1). The ZMBK? command returns whether the system bake mode is On or Off.

**Example**

ZMBK 1 starts the system bake.  
ZMBK? returns the state of the Bake mode, On(1) or Off(0).

**Errors and warnings**

The command is ignored if any of these conditions are true.

Warning	47	"Leak Test ON"
Warning	51	"Pressure Check off"

**ZMOD? System mode query**

The ZMOD? Query returns the current UGA mode described below.

Off	(1)	all components are OFF
START	(3)	Automatic START sequence in progress
STOP	(4)	Automatic STOP sequence in progress
READY	(6)	RGA is on
SLEEP	(7)	Automatic SLEEP sequence in progress
IDLE	(8)	TP and RP are idle, all other components are off.
LEAK TEST	(10)	Leak test mode is ON
SYSTEM BAKE	(12)	System Bake is ON
MANUAL	(13)	Manually changed of the state of a component from a pre-defined state

### 3.2.2 Components control commands

#### ZCBP (?) {i} Bypass pump Off/On

The ZCBP i command turns the bypass pump Off (i=0) or On (i=1). The ZCBP? query returns whether the bypass pump is Off (0), On (1), turning on (3 or 4), or turning off (6 or 7).

#### Example

ZCBP 1 Turns the bypass pump On.  
ZCBP? Returns the state of the bypass pump.

#### Errors and warnings

The command is ignored if any of these conditions are true.

ZCBP 0 :

Warning 33 "Bypass valve OPEN"

ZCBP 1 :

Warning 48 "System Bake On"

Error 96 "CM malfunction"

Error 98 "BP too high"

#### ZCRP (?) {i} Roughing pump Off/On/Idle

The ZCRP i command turns the roughing pump Off (i=0), On (i=1), or Idle (i=2). The ZCRP? query returns whether the roughing pump is Off (0), On (1), Idle (2), turning on (3 or 4), turning off (6 or 7), or turning idle (8 or 9).

#### Example

ZCRP 1 Turns the roughing pump On.  
ZCRP? Returns the state of the roughing pump.

#### Errors and warnings

The command is ignored if any of these conditions are true.

ZCRP 0 :

Warning 41 "Turbo pump running"

ZCRP 1 :

Warning 33 "Bypass valve OPEN"

Warning 34 "Sample valve OPEN"

Error 102 "RP too high"

ZCRP 2 :		
Warning	33	"Bypass valve OPEN"
Warning	34	"Sample valve OPEN"
Warning	38	"Rough pressure HIGH"

#### ZCTP (?) {i} Turbo pump Off/On/Idle

The ZCTP i command turns the turbo pump Off (i=0), On(i=1), or Idle(i=2). The ZCTP? query returns whether the turbo pump is Off (0), On (1), Idle (2), turning on (3, 4 or 5), turning off (6 or 7), or turning idle (8, 9 or 10), or in Error state (12).

#### Example

ZCTP 1	Turns the turbo pump On.
ZCTP?	Returns the state of the turbo pump.

#### Errors and warnings

The command is ignored if any of these conditions are true.

ZCTP 0 :		
Warning	43	"RGA ON"
Warning	46	"IG ON"
Warning	48	"System Bake ON"
Error	110	"TP stop failed"

With Error 110, the ZCTP? query returns Error state (12), until the turbo pump turns off.

ZCTP 1 :		
Warning	36	"Roughing pump OFF"
Error	104	"TP too high"
Error	111 – 120	Error conditions detected by the turbo pump controller. Once one of these errors occurs, the UGA has to be turned off and turned on again to clear the error.

ZCTP 2 :		
Warning	36	"Roughing pump OFF"
Warning	48	"System Bake ON"
Error	104	"TP too high"
Error	111 – 120	Error conditions detected by the turbo pump controller. Once one of these errors occurs, the UGA has to be turned off and turned on again to clear the error.

With Error 104, the ZCTP? query returns Error state (12), until the turbo pump turns off.

**ZCBV (?) {i} Bypass valve Off/On**

The ZCBV i command turns the bypass valve Closed (i=0) or Open (i=1). The ZCBV? query returns whether the bypass valve is Closed (0), Open (1), turning open (3 or 4), turning closed (6 or 7).

**Example**

ZCBV 1            Opens the bypass valve.  
ZCBV?            Returns the state of the bypass valve.

**Errors and warnings**

The command is ignored if any of these conditions are true.

ZCBV 0 :  
Warning        34        "Sample valve OPEN"  
  
ZCBV 1 :  
Warning        48        "System Bake On"  
Warning        30        "Bypass pump OFF"  
Error    99        "BV too high"

**ZCSV (?) {i} Sample valve Off/On**

The Sample valve operates differently depending on the automatic sample valve states (associated with ZPAS command).

- (1) With the automatic sample valve Off,  
The ZCSV i command turn only the sample valve Closed (i=0) or Open (i=1).
- (2) With the automatic sample valve On,  
The sample valve, the bypass valve, and the bypass pump work as a unit. The ZCSV 1 command turns the bypass pump on, opens the bypass valve, and then opens sample valve. The ZCSV 0 command closes the sample valve, closes the bypass valve, and turn off the bypass pump.

**Example**

ZCSV 1            Opens the sample valve.  
ZCSV?            Returns the state of the sample valve.

**Errors and warnings**

The command is ignored if any of these conditions are true.

ZCSV 1 :

Warning	32	"Bypass valve CLOSED", when ZPAS is off
Warning	48	"System Bake On"
Error	100	"SV too high"

#### ZCRG (?) {i} RGA Off/On

The ZCRG i command turns the RGA Off (i=0) or On (i=1). The ZCRG? query returns whether the RGA is Off (0), On (1), in the leak test mode (2), turning on (3 or 4), turning off (6 or 7), or going into the leak test mode (8 or 9).

#### Example

ZCRG 1	Turns the RGA On.
ZCRG?	Returns the state of the RGA.

#### Errors and warnings

The command is ignored if any of these conditions are true.

ZCBP 0 :

Warning	47	"Leak Test On"
Error	80	"RGA off failed"

ZCBP 1 :

Warning	42	"Turbo not ready"
Warning	47	"Leak Test On"
Warning	48	"System Bake On"

#### ZCIG (?) {i} Ion gauge Off/On/Degas

The ZCIG i command change the ion gauge state to Off (i=0), On (i=1), or Degas (i=2). The ZCIG? query returns the current ion gauge state.

#### Examples

The ZCIG 2 Degasses the ion gauge for 3 minutes and returns the gauge state to the previous state, depending on it was on or off.

#### Errors and Warnings

The command is ignored if any of these conditions are met.

Error 73 " No IG detected"

ZCIG 0  
Error 78 "IG off failed"

ZCIG 1  
Warning 42 " Turbo not ready"  
Error 74 " IG unexpected off"  
Error 76 "IG voltage"  
Error 77 "IG emission"  
Error 105 "IG too high"

ZCIG 2  
Warning 42 " Turbo not ready"

#### **ZCVV (?) {i} Vent valve Off/On**

The ZCVV i command turn the vent valve Off (i=0), or On (i=1). The ZCVV? query returns the current vent valve state.

ZCVV 1 command opens the vent valve for 1 second, closes it for the next 40 seconds, opens again for the next 60 seconds, and finally closes it. This command goes in the cycles not to vent the chamber too fast while the turbo pump is running in full speed.

ZCVV? returns 1 through the whole cycles. and return 0 after the final closure.

#### **Errors and Warnings**

The command is ignored if any of these conditions are met.

ZCVV 1  
Warning 37 "Roughing pump ON"  
Error 85 " No Vent valve"

#### **ZCPC (?) {i} Pressure interlock Off/On**

The ZCPC i command set Pressure Interlock state to Off (i=0), or On (i=1). The ZCPC? query returns the current value of Pressure Interlock state.

If the state is 1, UGA keeps monitoring pressures from PG, CM, and IG to protect itself from any pressure changes. If 0, it disables protection based on PG, CM readings. It should be used only by very advanced users or for trouble shooting.

## Errors and Warnings

The command is ignored if any of these conditions are met.

## ZCPC 1

Warning 48 "System Bake ON"

Warning 49 " AUTO sequence ON"

**ZCHT (?) {i} Heaters Off/Bake/Heat**

The ZCHT i command turns heaters Off (i=0), the bake mode On (i=1), or the sample heat mode On(i=2).

The ZCHT? query return the current heater state.

If the mode is 1, the heater temperature is controlled to the bake temperatures set by ZPTB command.

If the mode is 2, the heater temperature is controlled to the sample heat temperatures set by ZPTH command.

## Errors and Warnings

Th command is ignored if any of these conditions are met

Error 61 " Heater initialize"

## ZCHT 0

Warning 48 "System Bake ON"

## ZCHT 1

Warning 42 "Turbo not ready"

Error 62 "Elbow Heater T/C"

**ZCMI (?) {i} Multiple inlet channel**

The ZCMI i command changes the multiple inlet valve channel to i. the valid values for the channel number are from 1 to 16. The ZCMI? query returns the current channel number if it is installed. If not, it returns 0. If the channel number reported from the multiple inlet valve controller is different from the channel number set by the main controller, it returns 17.

## Example

ZCMI 12 Changes the channel number to 12

ZCMI? Returns the current channel number, as well as 0 or 17 if it has an error condition.

Errors and warnings

The command is ignored if any of these conditions are true.

Error 81 “No Mux detected”

### ZCVL (?) {i} **Speaker volume**

The ZCVL i command set the speaker volume to Off (i=0), Low (i=1), Medium (i=2), or High (i=3). The ZCVL? query returns the current speaker volume.

Example

ZCVL 1 sets the speaker volume to Low.

## 3.2.3 State Query commands

### ZBST? **Component states**

The ZBST? query returns the component current state bits. It returns an integer that contains the following bit information.

Bit Name	Bit Number	Bit set on
STATE_BIT_ERROR	BIT15	Any error condition
STATE_BIT_POWER	BIT14	Power up
STATE_BIT_AUTO	BIT13	Automatic mode is entered
Reserved	BIT12	Reserved
STATE_BIT_BAKE	BIT11	Bake mode is entered
STATE_BIT_HEAT	BIT10	A heater is active
STATE_BIT_VENT	BIT9	The vent valve is open
STATE_BIT_IG	BIT8	IG active
STATE_BIT_RGA	BIT7	RGa active
STATE_BIT_SV	BIT6	SV open
STATE_BIT_BV	BIT5	BV open
STATE_BIT_TPIDLE	BIT4	TP goes idle
STATE_BIT_TP	BIT3	TP is on
STATE_BIT_RPIDLE	BIT2	RP goes idle
STATE_BIT_RP	BIT1	RP is on
STATE_BIT_BP	BIT0	BP is on

**ZBCT?**            **Components changed**  
The ZBCT? query returns the component change state bits. This returns only the bits (defined above in the ZBST command) that have changed either from Off to On or from On to Off, since the ZBCT query was last issued.

**ZBTT?**            **Components in transition**  
The ZBTT? query returns the component transition bits. If a bit is set, it indicates the corresponding component is in transition either from off to on, or from on to off. Once the transition is over, the bit value returns to zero.

### 3.2.4 Query commands

**ZQID?**            **Identification**  
The ZQID? query returns UGA ID string, the serial number, and the firmware version.

Example

ZQID? if the command returns "SRS\_UGA,S/N:91000,V.1.000", it means the unit is a UGA, the serial number is 91000, and the firmware version is 1.000.

**ZQFV?**            **Firmware version**  
The ZQFN? query returns the firmware version of the unit.

Example

ZQFV? returns the firmware version (e.g., 1.000).

**ZQSN?**            **Serial number**  
The ZQFN? query returns the serial number of the unit.

Example

ZQFN? returns the firmware version (e.g., 91000).

- ZQMC?**      **MAC address**  
The ZQMC? query returns the Ethernet media access control (MAC) address of the unit. The numbers are 6 bytes in the hexadecimal format.
- Example  
ZQMC? return the MAC address
- ZQAD? i**      **Pressures**  
The ZQAD? i query returns a pressure reading corresponding to the following index.
- Index 0: Pirani gauge reading in uTorr  
Index 1: N/A  
Index 2: CM gauge reading in uTorr  
Index 3: IG reading in pTorr
- If the corresponding gauge is not on, the reading is meaningless.
- Example  
ZQAD? 0 if the command returns 100000, it means the the Pirani gauge reading is 0.1 Torr.
- ZQAD? 3 if the command returns 100000, it means the ion gauge reading is 1.0E-7 Torr.
- ZQHZ?**      **Turbo pump speed**  
The ZQHZ? query returns TP speed in revolutions per second.
- ZQCU?**      **Turbo pump current**  
The ZQCU? query returns TP current in mA.
- ZQTT?**      **Turbo pump temperature**  
The ZQTT? query returns TP Temperature in degrees Celcius.

---

<b>ZQTA?</b>	<b>Elbow temperature</b> The ZQTA? query returns the elbow temperature in degrees Celcius.
<b>ZQTB?</b>	<b>Chamber temperature</b> The ZQTB? query returns the chamber temperature in degrees Celcius
<b>ZQTC?</b>	<b>Sample inlet temperature</b> The ZQTC? query returns the sample inlet temperature in degrees Celcius.
<b>ZQTD?</b>	<b>Capillary temperature</b> The ZQTD? query returns the capillary temperature in degrees Celcius.
<b>ZQBR?</b>	<b>Remaining bake time</b> The ZQBR? query returns baking time remaining in minutes.

### *3.2.5 Error query commands*

<b>ZERR?</b>	<b>Error query</b> The ZERR? queries Error code. Whenever ZBST? Bit 15 is set, use "ZERR?" to read errors.
--------------	---

Latest Errors up to 10 will be stored into the error stack. If there are more than 10 errors occur, the last error will replaced with TOO\_MANY\_ERRORS (126). "ZERR?" returns the latest error first. To clear ZBST bit 15, you must issue ZERR? until you get 0. For the complete error list, refer to Chapter 4 (?).

<b>ZEDS? i</b>	<b>Error message</b> The ZEDS? i queries the error message corresponding to an error number (9 to 126) returned with ZERR?. This query returns a verbose string corresponding to the given error code.
----------------	---

### 3.2.6 Parameter setting commands

Parameters changed with the following commands are saved in EEPROM, preserved even after power off, and loaded into system when UGA start again next time.

ZPBO (?) {i}

#### **Bypass pump on power**

The ZPBO i command sets the bypass pump on-power to a value from 30 % (i=30) to 100 % (i=100). The ZPBO? query returns the current power setting for the bypass pump.

The parameter change is immediately effective all the time, even the bypass pump is running.

ZPRO (?) {i}

#### **Roughing pump on power**

The ZPRO i command sets the roughing pump on-power to a value from 30 % (i=30) to 100 % (i=100). The ZPRO? query returns the current on-power setting for the roughing pump.

The parameter change is immediately effective all the time, even the roughing pump is running.

ZPRI (?) {i}

#### **Roughing pump idle power**

The ZPRI i command sets the roughing pump idle-power to a value from 30 % (i=30) to 100 % (i=100). The ZPRI? query returns the current idle-power setting for the roughing pump.

The parameter change is immediately effective all the time, even the roughing pump is idle.

ZPBA (?) {i}

#### **RS232 baud rate**

The ZPBA i command sets the RS232 baud rate to 28800 (i=0), or 38400 (i=1). The ZPBA? query returns the current RS232 baud rate setting.

**ZPIP (?) {i.i.i.i}****IP address**

The ZPIP i.i.i.i command set the Internet Protocol (IP) address of the instrument. The ZPIP? query return the current IP address setting.

**Example**

ZPIP 192.168.1.12    Sets the IP address to 192.168.1.12.

**Errors and Warnings**

The command is ignored if the following error is issued after the command input.

ZPIP i.i.i.i

Warning 16 "Bad parameter"

**ZPSM (?) {i.i.i.i}****IP subnet mask**

The ZPSM i.i.i.i command set the Internet Protocol (IP) subnet mask of the instrument. The ZPSM? query return the current IP subnet mask setting.

**Example**

ZPSM 255.255.255.0    Sets the IP subnet mask to 255.255.255.0.

**Errors and Warnings**

The command is ignored if the following error is issued after the command input.

ZPSM i.i.i.i

Warning 16 "Bad parameter"

**ZPGW (?) {i.i.i.i}****IP default gateway**

The ZPGW i.i.i.i command set the Internet Protocol (IP) default gateway of the instrument. The ZPGW? query return the current IP default gateway setting.

**Example**

ZPGW 192.168.1.1    Sets the IP default gateway to 192.168.1.1.

#### Errors and Warnings

The command is ignored if the following error is issued after the command input.

ZPGW i.i.i.i

Warning 16 "Bad parameter"

#### ZPNM (?) {@s}

##### TCP/IP login name

The ZPNM @ABC command set the login name of the instrument to ABC for the TCP/IP connection. The ZPNM? query returns the current login name.

The command accepts only alphanumeric characters, a-z, A-Z, and 0-9. The default is "SRSUGA"

##### Examples

ZPNM @SRSUGA sets the login name to SRSUGA

ZPNM @ clears the login name.

With blank login name and password, a user can login to the instrument by typing carriage returns only.

#### Errors and Warnings

The command is ignored if the following error is issued after the command input.

ZPNM @s

Warning 16 "Bad parameter"

#### ZPPW (?) {@s}

##### TCP/IP password

The ZPPW @ABC command set the password of the instrument to ABC for the TCP/IP connection. The ZPPW? query returns the current password.

The command accepts only alphanumeric characters, a-z, A-Z, and 0-9. The default is "SRSUGA"

##### Examples

ZPPW @SRSUGA sets the password to SRSUGA

ZPPW @ clears the password.

With blank login name and password, a user can log into the instrument by typing carriage returns only.

Errors and Warnings

The command is ignored if the following error is issued after the command input.

ZPPW @s

Warning 16 "Bad parameter"

- ZPDU (?) {i} Ethernet Half Duplex/Full Duplex**  
The ZPDU i command sets the Ethernet half duplex (i=0) or full duplex (i=1). The default value is full duplex. The ZPDU? queries whether the Ethernet is full duplex, or half duplex.
- ZPSP (?) {i} Ethernet Speed Auto/10 Mbps/100 Mbps**  
The ZPSP i command sets Ethernet speed Auto-negotiation (i=0), 10 Mbps (i=1), or 100 Mbps (i=2). The default value is 100 Mbps.
- ZPTO (?) {i} TCP/IP connection timeout (Power reset function)**  
The ZPTO i command sets the TCP/IP connection timeout between 3 to 1800 seconds. The ZPTO? query returns the value. If TCP/IP communication is inactive for the timeout period, the connection will be closed. The default value is 2 minutes.
- ZPFL (?) {i} Ion gauge filament**  
The ZPFL i command selects either of the filament 1 (i=0), or the filament2 (i=1), which is used when the ions gauge turns on or degasses. The ZPFL? returns the selected filament (0 or 1).

**ZPPU (?) {i}****Pressure unit**

The ZPPU i command sets the pressure unit used for the front panel display: Torr(i=0), Pa(i=1), mbar(i=2), or bar(i=3). The ZPPU? query returns the current pressure unit for the display. This unit selection has NO effect on the unit used by the ZQAD command.

**ZPAV (?) {i}****Automatic vent valve**

The ZPAV i command turns the automatic vent valve option Off (i=0) or On (i=1). The ZPAV? query returns the current value of the option.

If this option is on, the vent valve will be opened at the end of the automatic STOP sequence. If not, the STOP sequence ends without opening the vent valve.

**ZPAS (?) {i}****Automatic sample valve**

The ZPAS i command changes the the automatic sample valve option to Off (i=0), or On (i=1). The ZPAS ? query returns the current value of the option.

If a user opens the sample valve with this option on, the UGA turns on the bypass pump, and opens the bypass valve, before opens the sample valve automatically. If the user closes the sample valve with this option on, the UGA closes the sample valve and bypass valve sequentially, and turns off the bypass pump.

If the option off, the user can open the sample valve only when the bypass valve is open, otherwise it will generate a warning.

**ZPLM (?) {i} Leak test mass**

The ZPLM command sets and queries the mass that is monitored in the leak test mode. The mass can be between 1 and 100 AMU.

**Example**

ZPLM 44 Sets the mass used for the leak test to 44 AMU.  
ZPLM? Returns the mass used for the leak test.

**ZPBT (?) {i} System bake time**

The ZPBT command sets and queries the system bake time in hours. It can be set between 2 and 100 hours. The system bake mode is on for this system bake time, and turns off.

When the system bake mode is on, the time remaining can be queried with the ZQBR? command

**Example**

ZPBT 10 Sets the system bake mode to 10 hours.  
ZPBT? Returns the system bake time.

**ZPTB (?) p {i} Bake temperature**

The ZPTB command sets the bake temperature of a heater when Bake mode is on. The parameter p selects the elbow heater (0), or the chamber heater (1). The parameter i is a set temperature in Celsius for the heater p, and ranges from 0 to 120. The default value for the parameter i is 105.

If a set value for a heater is 0, the heater stays off during the bake mode, and it is not tested for its faulty conditions.

**Example**

ZPTB 1, 105 Sets the bake mode set temperature of the chamber heater to 105 °C.  
ZPTB? 1 Returns the bake mode set temperature of the chamber heater.

**Errors and Warnings**

The command is ignored if this condition is met.

Error 66 "Temp. Set Failed"

**ZPTH (?) p {,i}****Sample temperature**

The ZPTH command sets the Sample temperature of a heater when the sample mode is on. The parameter p selects the elbow heater (0), the chamber heater (1), the sample line heater (2), or the capillary heater (3). The parameter i is a set temperature in Celsius for the heater p.

For for the elbow heater and the chamber heater, range is from 0 to 120, and the default value is 105. For sample line heater and capillary heater the range is from 0 to 80, and the default value is 80. If a set value for a heater is 0, the heater stays off during the sample mode, and it is not tested for its faulty conditions.

**Example**

ZPTH 2, 80 Sets the sample mode set temperature of the sample line heater to 80 °C.

ZPTH? 2 Returns the sample mode set temperature of the sample line heater.

**Errors and Warnings**

The command is ignored if this condition is met.

Error 66 "Temp. Set Failed"

**ZPDF****Factory default**

The ZPDF command resets all the parameter saved in EEPROM to the factory default values.

It is useful to set the UGA to the known initial state, when the user experiences problems due to corrupted parameters. After loading Factory default values, the user has to re-enter all the network parameters (IP address, subnet mask, and default gateway) to access to Ethernet interface again.



---

# Chapter 4

## UGA Error Messages

---

### **In This Chapter**

This chapter lists and explains all the error messages displayed on the UGA.

4.1	Introduction . . . . .	4-2
4.2	Error messages . . . . .	4-3
	Communication errors messages . . .	4-3
	Warning error messages . . . . .	4-5
	Critical error messages . . . . .	4-8

## 4.1 Introduction

The UGA reports various errors as they are detected. When an error is detected, a message is shown on the front panel display and the error is logged for retrieval over the remote interface. Users must also check for RGA head errors. The RGA has its own microprocessor and its own error reporting commands. The RGA error status is monitored with the error query command, ER? For details, refer to RGA manual chapters 7 and 9.

UGA error messages are divided into three groups: communication errors, warning errors, and critical errors.

Communication errors are those related to miscommunication with a host computer. When a communication error is detected, UGA flashes the warning LED once without changing display. It stores the error number corresponding to the error into the error stack. The error numbers for communication errors range from 9 to 29.

Warnings are issued when UGA is not able to carry out a command sent over the remote interface or a menu selection chosen from the front panel. With a warning, the warning LED flashes for 4 seconds, a warning sound beeps, and the warning message is displayed. After several seconds, the warning is no longer shown, and the display returns to the previously active display. The range of the warnings is from 30 to 60.

Critical errors are issued when the UGA detects problems while monitoring various internal conditions, or trying to carry out a command or a menu selection.

The front panel displays the error message with error beeps, until a button on the front panel is pressed, or all the errors in the error stack are read up by sending "ZERR?" commands until it returns 0. The range of the critical errors is from 61 to 120.

ZERR? Returns only an error code. To get a string describing the error code, use the ZEDS? [error number] Query. For example, "ZEDS? 42" returns "Turbo not ready".

Following is the list of errors that UGA reports. The first column shows the error code, and the second column shows error messages showing on the display, followed by a description of each error.

## 4.2 Error Messages

### 4.2.1 Communication Error Messages

- 1 – 8 Reserved
- 9 “Invalid Command”,  
The command string does not start with a valid command name.
- 10 “Incomplete Command”,  
The command string ends without a ? or a parameter.
- 11 “Illegal Command”,  
Either a set only command was issued as a query or a query only command was issued as a set.
- 12 Reserved
- 13 “Missing Parameter”,  
A second parameter in a set command is missing.
- 14 “Extra Parameter”,  
Extra character(s) follow a valid command.
- 15 “Out of range”,  
A parameter is out of range
- 16 “Bad parameter”,  
A parameter is misformatted, such as an IP address, a sub net mask, a gateway address, a login name, or a password.
- 17 “Missing comma”,  
Command string does not have a comma after the first parameter.
- 18–19 Reserved
- 20 “Not a number”,  
A Parameter is not a number.
- 21 Reserved

- 22    "RGA on network",  
When TCP/IP connection is open, the serial communication cannot talk to RGA.
- 23    "Command buffer full",  
The UGA received too many commands to process before time critical operations occur. Some of the commands are rejected.
- 24    "RGA buffer full",  
The RGA received too many commands to process in time. Some of the commands are rejected.
- 25    "RGA unavailable",  
RGA is not available to communicate when transitioning between power on and off, or transitioning into and out of leak test mode.
- 26    "String too long",  
The login name and password should be 15 characters or less.
- 27    "Illegal character",  
The login name and password changing commands, ZPNM and ZPPW accept alphanumeric characters 0-9, A-Z, a-z only.
- 28    "RGA OFF",  
Communication to RGA is not allowed when the RGA is off.
- 29    "Leak Test ON",  
Communication to RGA is not allowed when the leak test is running.

### 4.2.2 Warning Error Messages

- 30     “Bypass pump OFF”,  
The bypass valve is not allowed to open, when the roughing pump is not off (i.e. on or idle), and the bypass pump is off.
- 31     Reserved
- 32     “Bypass valve CLOSED”,  
The sample vale is not allowed to open, when the roughing pump is not off, and the bypass valve is CLOSED.
- 33     “Bypass valve OPEN”,  
The bypass pump is not allowed to turn off, when the roughing pump is not off, and the bypass valve is open.  
The roughing pump is not allowed to turn on or idle, when the bypass pump is not on, and the bypass valve is open.
- 34     “Sample valve OPEN”,  
The bypass valve is not allowed to CLOSE, when the roughing pump is not off, and the sample valve is open.  
The roughing pump is not allowed to turn on or idle, when the bypass pump is not on, and the sample valve is open.
- 35     Reserved
- 36     “Roughing pump OFF”,  
The turbo pump is not allowed to turn on or idle, when the roughing pump is not on, or idle.
- 37     “Roughing pump ON”,  
The vent valve is not allowed to turn on, when the roughing pump is on.
- 38     “Rough pressure HIGH”,  
The roughing pump is not allowed to turn idle, when the roughing pressure is higher than 2 Torr.
- 39 – 40 Reserved

- 
- 41 "Turbo pump running",  
The roughing pump is not allowed to turn off, when the turbo pump is not off.
- 42 "Turbo not ready",  
The RGA, the ion gauge, and the bake heater are not allowed to turn on, when the turbo pump is not on, or idle.
- 43 "RGA ON",  
The turbo pump is not allowed to turn off, when the RGA is on.
- 44 "RGA OFF",  
The leak test mode is not allowed to start, when the RGA is off.
- 45 Reserved
- 46 "IG ON",  
The turbo pump is not allowed to turn off, when the ion gauge is on.
- 47 "Leak Test ON",  
When the leak test is running, the following actions are not allowed:  
(1) Start and sleep automatic sequences are not allowed to start.  
(2) The system bake is not allowed to start.  
(3) The RGA is not allowed to turn off.
- 48 "System Bake ON",  
When the system bake is on, the following actions are not allowed:  
(1) Start and sleep automatic sequences are not allowed to start.  
(2) The leak test is not allowed to start.  
(3) The bypass pump, bypass valve, and sample valve are not allowed to open.  
(4) The turbo pump is not allowed to turn idle or off.  
(5) The RGA is not allowed to turn on.  
(6) The heater is not allowed to turn off.  
(7) Pressure Interlock Option may not be disabled

- 49 "AUTO sequence ON",  
Pressure Interlock Option is not allowed to change during one of the automatic sequences: start, sleep, and stop.
- 50 "Interlock triggered",  
The user interlock on the back panel is triggered to stop the system.
- 51 "Pressure Interlock off",  
START sequence and the system bake are not allowed to initiate with Pressure Interlock off.
- 52 "Leak test timeout",  
Communication time-out occurred during Leak Test. It may happen once in a while. If it happens every 10 second or so, the communication between the main control board and the RGA is down. If so, turn RGA off and on again to recover.
- 53 "Fac. Default Loaded",  
(1) With turning UGA on with the STOP button pressed, Factory default setting is loaded instead of the saved parameter setting. It is used to reset the instrument to a known setting.  
(2) Factory default setting is loaded during the power up due to EEPROM setting corruption.
- 54 - 60 Reserved

### 4.2.3 Critical Error messages

- 61 "Heater initialize",  
Heater temperature settings are not initialized in time, probably due to miscommunication between the main control board and the auxiliary control board.
- 62 "Elbow Heater T/C",  
The thermocouple sensor attached on the elbow is an open circuit. The temperature cannot be read.
- 63 "Chamber Heater T/C",  
The thermocouple sensor attached on the main chamber is an open circuit. The temperature cannot be read.
- 64 "Sample Heater T/C",  
The thermocouple sensor attached on the sample line is an open circuit. The temperature cannot be read.
- 65 "Capillary Heater T/C",  
The thermocouple sensor attached on the capillary is an open circuit. The temperature cannot be read.
- 66 "Temp. Set Failed",  
Temperature setting was not updated in time probably due to miscommunication between the main control board and the auxiliary control board.
- 67 "No Sample Heater"  
Both thermocouple sensors on the sample line and the capillary are open.
- 68 – 72 Reserved
- 73 "No IG detected",  
The ion gauge control board is not detected.

- 74 "IG unexpected off",  
The ion gauge turned off without reporting an error to the UGA.
- 75 Reserved
- 76 "IG voltage",  
The ion gauge failed to maintain the grid voltage. This condition turns off the ion gauge.
- 77 "IG emission",  
The ion gauge failed to maintain the emission current. This condition turns off the ion gauge.
- 78 "IG off failed",  
The ion gauge is not turned off in time, probably due to miscommunication between the main control board and the auxiliary control board.
- 79 Reserved
- 80 "RGA off failed",  
The RGA is not turned off in time, probably due to miscommunication between the main control board and the auxiliary control board.
- 81 "No Mux detected",  
Multi-inlet valve controller is not detected.
- 82 "Mux malfunction",  
The multi-inlet valve channel reported from the controller does not match with that of the main control board, probably due to miscommunication between the main control board and the auxiliary control board.
- 83 - 84 Reserved
- 85 "No Vent valve",  
No vent valve was detected.
- 86 - 88 Reserved

- 89     “AUX comm. error”,  
Communication between the main control board and the auxiliary control board did not work properly at least for a second.
- 90     “Main board reset”,  
When the main control board powers up, the auxiliary control board reports that the turbo pump is on. It indicates the main control board is reset, while the auxiliary control board is on.
- 91     Reserved
- 92     “No PG detected “,  
Pirani gauge is not detected.
- 93     “No PG filament”,  
The detected current through the Pirani gauge is too small; this probably means the PG filament is damaged.
- 94     “PG short-circuited”,  
Too much current flows through the Pirani gauge.
- 95     “PG malfunction”,  
The roughing line pressure reading of the Pirani Gauge is lower than 10 mTorr or higher than 1100 Torr for 10 seconds. This condition initiates the STOP sequence.
- 96     “CM malfunction”,  
The sample line pressure reading of the capacitance manometer is lower than 10 mTorr for 10 seconds. It indicates the capacitance manometer is disconnected, or not working properly. This condition closes the sample valve and the bypass valve, and turns off the bypass pump.
- 97     Reserved

- 98     “BP too high”,  
The sample line pressure did not reach 1.5 Torr in 2 minutes with the sample valve closed. Or the sample line pressure did not reach 5 Torr in 2 minutes with the sample valve open.
- 99     “BV too high”,  
The sample line pressure did not reach 1.5 Torr in 1 minute. The bypass valve closes with this error.
- 100    “SV too high”,  
The sample line pressure is over 5 Torr for 2 second, when the sample valve is open, and the roughing pump is not off. The sample valve closes with this error.
- 101    Reserved
- 102    “RP too high”,  
The chamber pressure did not reach 5 Torr in 2 minutes.
- 103    Reserved
- 104    “TP too high”,  
Turbo pump did not reach the full speed in 10 minutes.
- 105    “IG too high”,  
The ion gauge reading is over 2.1E-5 Torr for 6 seconds.
- 106 - 108    Reserved
- 109    “No TP controller”,  
The turbo pump controller is not detected.
- 110    “TP stop failed”,  
The turbo pump is not turned off in time, probably due to probably due to miscommunication between the main control board and the auxiliary control board.

**Error 111 – 120** These error conditions are detected by the turbo pump controller. Once one of these errors occurs, the UGA must be power cycled to clear the error.

- 111 “TP current”,  
Turbo pump controller output current exceeded 15 A.
- 112 “No TP connected”,  
No turbo pump is connected to the controller.
- 113 “TP overload”,  
Turbo pump controller output current exceeded 1.5 A longer than 15 seconds.
- 114 “TP bearing hot”,  
Turbo pump bearing temperature is higher than 60 °C.
- 115 “TP hot”,  
Turbo pump heat exchange temperature is higher than 60 °C.
- 116 “TP start”,  
Turbo pump did not reach the full speed at run up time.
- 117 “TP input voltage”,  
TP controller input voltage is lower than 16 V for 5 seconds.
- 118 “TP op voltage”,  
TP controller operating voltage is lower than 10 V for 5 seconds.
- 119 “TP low voltage”,  
TP controller  $V_p$  is 8V lower than nominal for 5 seconds.
- 120 “TP soft start”,  
Soft start ramp has not ended within the expected time.
- 121 - 125 Reserved
- 126 “Too many Errors”,  
More than 10 errors have occurred since errors were read with the “ZERR?” command. The subsequent errors are discarded. This error will not be displayed on the front panel at all.

---

# Chapter 5

## Calibration and Input Design

---

### In This Chapter

This chapter discusses procedures to help the user make accurate measurements with the UGA. Several sections are devoted to calibration and correcting procedures. The last sections discuss specific design for the pressure reduction.

5.1 Mass Spectrometry Basics . . . . .	5-2
How Mass Spectra are Interpreted . . . . .	5-2
Partial Pressure Measurement . . . . .	5-3
Partial Pressure Sensitivity Factors . . . . .	5-6
Single Gas Measurement Example . . . . .	5-8
Calibration. . . . .	5-9
Effect of Total Pressure. . . . .	5-10
Operating off the Design Pressure . . . . .	5-11
Total Pressure and Composition . . . . .	5-12
5.2 Calibration of Partial Pressure . . . . .	5-13
Initial Calibration. . . . .	5-15
Basic Recalibration . . . . .	5-16
Calibration for Multiple Operating Conditions	5-17
Calibration with Fixed Reservoir . . . . .	5-18
Corrections . . . . .	5-18
Correcting for the chamber background. . .	5-18
Correcting for multiple specises . . . . .	5-19
Operation with Condensable Gases . . . . .	5-20
5.3 Pressure Reducing Inlet . . . . .	5-21
Flow Calculations. . . . .	5-23
Diaphragm Pump . . . . .	5-26
Turbo Pump. . . . .	5-27
Capillary Design . . . . .	5-28
Length & Bore. . . . .	5-29
Materials and Fittings . . . . .	5-31
Extensions . . . . .	5-32
5.4 References . . . . .	5-33

## 5.1 Mass Spectrometry Basics

The RGA can perform both qualitative and quantitative analysis of the gases in a vacuum system. Obtaining spectra with the RGA is very simple. Interpreting the spectra, that is, understanding what the spectra is trying to tell you about your vacuum system requires some work. The following sections will introduce some basic concepts of Spectral Analysis emphasizing the main aspects of Residual Gas Analysis. For additional information on the subject of Residual Gas Analysis refer to:

J. Drinkwine and D. Lichtman, *Partial Pressure Analyzers and Analysis*, AVS Monograph Series published by the Education Committee of the American Vacuum Society

Basford et. al., *J. Vac. Sci. Technol. A* 11(3) (1993) A22-40 "Recommended Practice for the Calibration of Mass Spectrometers for Partial Pressure Analysis. Update to AVS Standard 2.3".

For information on multiple linear regression analysis consult:

William H. Press, et. al., 1992, *Numerical Recipes in C, The Art of Scientific Computing*, Second Edition, Cambridge Univ. Press, section 15.4, page 671.

Bevington, P.R., 1969, *Data Reduction and Error Analysis for the Physical Sciences*, New York, McGraw-Hill, Chapters 8-9.

### 5.1.1 How Mass Spectra are Interpreted

A mass spectrum, taken in a real system, will almost always contain signals from a mixture of various gases. Careful and complete interpretation of the spectrum (i.e. a complete spectral analysis) should reveal the identity, as well as the concentrations, of the various components which have produced the spectrum.

The first step in the spectral analysis process is to correctly identify the mass-to-charge ratio of all the peaks in the mass spectrum. A well calibrated mass scale is essential to this task. See the RGA Tuning Chapter in the RGA manual for a detailed description of the mass scale calibration procedure.

Once all the peaks have been labeled, the next step is to identify the residual gases that have produced the spectrum. A knowledge of the recent history of your system may provide very valuable clues as to the possible gases that may be residuals in the vacuum chamber. A familiarity with the standard spectra of commonly expected gases will generally help to determine the major and minor components in the system. Any peak in the spectrum may consist of contributions from molecular ions and/or fragment ions, or multiply ionized species. **The qualitative spectral analysis is completed when all the peaks in the spectrum have been “uniquely assigned” to the components of a gas mixture, in complete agreement with the known fragmentation patterns of the components.**

In cases where only the major components are of interest, some of the minor peaks of the spectrum will remain unassigned. If only a few species are being monitored, only the peaks corresponding to the substances of interest need to be assigned and monitored.

**Notes on Fragmentation Patterns:** The electron impact type of ionizer used in modern RGAs almost always causes more than one kind of ion to be produced from a single type of gas molecule. Multiple ionization, molecular fragmentation and changes in the isotopic composition of the molecule are responsible for the effect. All ions formed contribute to the mass spectrum of the molecule and define its **fragmentation pattern**. The identification and interpretation of mass spectra must begin with a knowledge and understanding of the standard fragment patterns of atoms and molecules that may exist in the system. The standard fragment patterns of most molecules commonly encountered in residual gas analysis are well established and listed in the general RGA Literature. A very complete library can also be accessed through the Library Search Utility of the RGA Windows software. The Gas Library has a standard text file format, and can easily be read, extended or modified by the user to fit his individual needs.

### 5.1.2 Partial Pressure Measurement

Once the different components of a mixture have been identified it is possible to use the RGA to obtain quantitative values for the various partial pressures. This section describes the basic steps needed to perform quantitative measurements with the instrument. The

formalism presented assumes multiple gas analysis, but is equally valid for single gas measurements. Please consult the suggested references for details and examples of these procedures.

The entire mathematical formalism used to derive the partial pressures of a mixture based on a single mass spectrum is based on one assumption:

The total spectrum is a linear combination of the spectra of the different species that are present in the mixture. In other words, the total spectrum is equal to the sum of the individual peaks that would be observed if each constituent were alone in the system. In mathematical terms, the assumption stated above can be written as the following linear equation:

$$H_M = \sum_g h_{Mg} \quad (1)$$

where:

**g** is an integer variable that represents the gases present (i.e. assign an integer to each gas starting with one)

**M** is an integer variable that represents the mass numbers for the entire mass range of the spectrum.

**H<sub>M</sub>** = total peak height (amps) of the spectrum at mass number M.

**h<sub>Mg</sub>** = peak height contribution (amps) from gas g at mass M.

**h<sub>Mg</sub>** is related to the fragmentation pattern, the RGA's sensitivity and the partial pressure of gas g by the equation:

$$h_{Mg} = \alpha_{Mg} S_g P_g \quad (2)$$

where:

**α<sub>Mg</sub>** = Fragmentation factor of gas g at mass M: Ratio of ion signal at mass M to the ion signal at the principal mass peak for gas g.

**S<sub>g</sub>** = RGA's partial pressure sensitivity factor for gas g, in amp/Torr (see Partial Pressure Sensitivity Factor below)

**P<sub>g</sub>** = Partial pressure of gas g in the system.

Equations (1) and (2) are combined to obtain the system of equations:

$$H_M = \sum_g (S_g \alpha_{Mg}) P_g \quad (3)$$

Since all gases have more than one peak in their fragmentation pattern, the number of peaks (M) in a real spectrum is generally larger than the number of gases (g). As a result, the system of equations (3) usually has more equations than unknowns. This situation is sometimes simplified eliminating some of the extra equations; however, the best results are obtained using all the equations and a multiple linear regression procedure to calculate the best possible fit to the data.

Obviously, accurate results can only be obtained if the constants  $\alpha_{Mg}$  and  $S_g$  are well known for the RGA being used.

**Note:** The Analyze Utility of RGA Windows uses a multiple linear regression algorithm, as mentioned above, to automatically calculate the composition of a “typical residual gas environment” at the end of any 1-65 amu spectral scan. Please see the RGA On-Line Help files for details.

Standard fragmentation patterns (for example, the fragmentation patterns included in the RGA Library of RGA Windows) can be used as a source of  $\alpha_{Mg}$  values in moderately quantitative determinations. However, when very precise numbers are desired, one should obtain the appropriate fragment patterns by introducing pure gas into the RGA being used. The fragment patterns must be obtained under the same conditions that will be used during regular spectral analysis since they depend on many instrumental parameters, including: electron energy, emission current, ionizer design, mass filter settings, detector type, multiplier gain, etc. The principal mass peak of a fragmentation pattern is simply the most intense peak of the spectrum, and the intensity of all the other peaks in the pattern are normalized to its height for the calculation of fragmentation factors. **Note that by our definition the  $\alpha_{Mg}$  value for the principal mass peak of any gas is equal to one.** Principal mass peaks are used in the calculation of the sensitivity of the RGA to different gases as shown below.

### 5.1.3 Partial Pressure Sensitivity Factors

The partial pressure sensitivity of the RGA to a gas  $g$ ,  $S_g$ , is defined as the ratio of the change  $(H-H_0)$  in principal mass peak height to the corresponding change  $(P-P_0)$  in total pressure due to a change in partial pressure of the particular gas species.  $H_0$  and  $P_0$  are background values.

$$S_g = (H-H_0) / (P-P_0)$$

The units of  $S_g$  are of ion current per unit pressure (amp/Torr, for example).

The sensitivity of the RGA varies with different gases, changes with time due to aging of the head, and is a strong function of the operating conditions of the instrument. Careful quantitative analysis requires that the sensitivity factor,  $S_g$ , be determined for every gas which may be a component gas in the system being analyzed. The sensitivity factors must be obtained under the same operating conditions that will be used during general partial pressure analysis since they depend on many instrumental parameters, including: ionization energy, emission current, mass filter setting, type of detector, etc.

In order to separate the gain of the electron multiplier from the intrinsic sensitivity of the RGA head, the sensitivity factors of the RGA are defined for Faraday Cup detection. A separate Electron Multiplier Gain Factor, is used to correct the ion signals when the electron multiplier is turned on. See the Sensitivity and Electron Multiplier Tuning sections of the RGA Tuning Chapter for details.

The basic procedure for determining the sensitivity of a particular gas in the RGA is the following:

- Introduce the pure gas into the vacuum system, at a known or calculable pressure (typically around  $10^{-6}$  Torr).
- Measure the output signal from the RGA for the principal mass peak of that gas using the Faraday cup detector.
- The ratio of this output signal to the pressure of the gas is the sensitivity factor,  $S_g$ .

During these measurements it is very important to insure that the partial pressures of all other gases in the system are small enough so that they may be neglected. The sensitivity factors calculated can only be applied to situations where the RGA is used with the same operating parameters. See the Sensitivity Tuning section in the RGA Tuning chapter of this manual for more details on this calibration procedure.

A **total pressure sensitivity factor** is also needed by the RGA to convert the ion currents obtained during total pressure measurements into total pressures. Total pressure sensitivity factors vary with different gases and share many of the properties of the partial pressure factors. They are determined by a procedure identical to the one described above, but with the partial pressure measurements replaced by total pressure measurements.

The underlying assumption when using sensitivity factors in quantitative calculations is that there is a linear relation between the partial pressure and the corresponding RGA signals of the gases. Deviations from linearity are to be expected above  $10^{-5}$  Torr due to space charge effects in the ionizer and ion-neutral scattering interactions in the filter. A more thorough check of the RGA's sensitivity involves measuring the RGA signals over several orders of magnitude of partial pressure to determine the range over which a linear relationship exists. The sensitivity factor for the gas is calculated as the slope of the "signal vs. partial pressure" response over the linear range.

**RGA Windows** uses two sensitivity factors stored in the non-volatile memory of the RGA Head. The sensitivity factors, one for total pressure and one for partial pressure, are used as conversion factors between the ion currents received from the head and the pressure units selected by the user. The sensitivity factors are measured with the Faraday Cup detector and can be updated or changed very easily by using the Sensitivity Tuning command in the Head menu. A separate Electron Multiplier Gain Factor, stored in the non-volatile memory of the RGA Head, is used to correct the ion signals for the gain of the electron multiplier. The gain of the electron multiplier is highly mass dependent and defined relative to the corresponding FC signal. An automatic Electron Multiplier Gain Adjustment command, built into the program, can adjust the CDEM voltage for any gain between 10 and  $10^6$ . Consult the RGA On-Line Help Files

for details on the automated tuning procedures built into the RGA Windows program. Also see the Sensitivity and Electron Multiplier Tuning sections of the RGA Tuning Chapter for more general information.

The Table mode of RGA Windows offers scaling factors for all of its channels eliminating the limitations imposed by the single sensitivity factor on multiple partial pressure calculations. For example, the scaling factors can be used to display correct partial pressure for all the species in a table if the ratios between the partial pressure sensitivities of the different components are known and only principal mass peaks are used to monitor them. The scaling factors can also be adjusted to correct against the mass discrimination of the electron multiplier's gain.

**Important:** Following current industry standards, the partial pressure sensitivity factor stored at the factory corresponds to N<sub>2</sub> measured at 28 amu with  $\Delta m_{10\%} = 1$  amu, default ionizer settings and Faraday Cup Detection.

#### 5.1.4 Single gas measurement example

Monitoring the concentrations of one or few components in a system is easy in the absence of severe spectral interference.

Suppose a system where argon is measured at 40 amu (principal mass), in the absence of any other gases that contribute a signal at that mass value. The sensitivity to argon was previously measured at  $S_{Ar} = 10^{-4}$  amps/Torr, and the electron multiplier is biased and its gain at mass 40 was previously measured at  $g_{CDEM} = 1.02 \times 10^3$  relative to the FC signal.

The partial pressure of argon,  $P_{Ar}$  is easily calculated measuring the intensity (i.e. peak height) of the ion current at mass 40,  $I_{40}$ .

$$P_{Ar} = I_{40} / (g_{CDEM} \bullet S_{Ar}), \text{ units of Torr} \quad (4)$$

The peak value,  $I_{40}$ , can be extracted from a spectral scan or measured directly using the single mass measurement mode of the RGA. For example, a  $10^{-9}$  amp peak value corresponds to  $9.8 \times 10^{-9}$  Torr of Ar. Note that equation (4) is a particular case of equation (3), and that the fragmentation factor for the principal peak of Ar is one by definition.

### 5.1.5 Calibration

The UGA has been calibrated at the factory to measure the partial pressure of nitrogen correctly. For many purposes this will be suitable. Overtime the calibration can change or operating conditions may change. There are many factors involved in calibrating the UGA and interpreting the mass spectra. To make accurate measurements, the following conditions need to be met:

- The total pressure needs to be known.
- The main sensitivity factor needs to be calibrated. Sensitivity factors change as a factor of time due to aging and periodic recalibration is necessary.
- For careful quantitative analysis, it is important that the sensitivity of the RGA be determined for every gas which may be a component of the system. Each gas component in the sample will fragment differently and will have slightly different sensitivities.
- Correct calibration of the mass scale is essential during qualitative analysis for the correct assignment of mass numbers to the different peaks. The mass scale will affect the peak height if it is more than 0.3 amu out of calibration.
- The mass resolution of the quadrupole mass filter,  $\Delta m_{10\%}$  must be kept at or under 1 amu to avoid overlap between adjacent peaks. Changes in  $\Delta m_{10\%}$  during the measurements (caused by aging, severe contamination and large temperature changes) will cause variations in the sensitivity of the instrument and the shapes of the fragmentation patterns of the molecules, affecting all quantitative measurements.
- The gain of the electron multiplier is mass dependent and needs to be determined prior to performing measurements with the device. The gain characteristics of the multiplier change with time and periodic recalibrations are very important.

The following sections of this chapter describe several procedures designed to assure that all the calibration conditions described above are satisfied prior to a set of partial pressure measurements. All tuning procedures can be executed from RGA Windows software. Users writing their own programs can implement the procedures themselves, using the RGA Command Set and the instructions in the RGA manual.

All the tuning procedures require the ability to introduce pure gases (or a mixture of gases of known composition) into the system and a reference pressure gauge. All pressures are absolute; it is possible to make measurements in gauge pressure.

**Important:** Tuning should only be attempted after the unit has been warmed up (with the filament on and under typical operating conditions) for at least one hour.

### 5.1.6 Effect of Total Pressure

Increasing the total pressure at the inlet of the capillary will increase the flow through the capillary. The higher flowrate in turn will increase the pressure at the RGA. This effect is not linear and in applications where the inlet pressure varies, the user needs to understand the flow at the inlet. The flowrate or throughput of the capillary is characterized by

$$Q = C(P_{in} - P_{out}),$$

where  $Q$  is the throughput (a mass flowrate),  $C$  is the conductivity of the capillary, and  $P_{in}$  &  $P_{out}$  are the pressures at the inlet and outlet of the capillary. The inlet pressure is much larger than the outlet pressure, which allows  $P_{out}$  to be approximated as zero. The conductivity is a function of the capillary dimensions, the viscosity of the gas, and the pressure drop across the capillary. This results in the throughput,  $Q$ , being proportional to the square of the inlet pressure. The diaphragm pump dictates the pressure at the outlet of the capillary according to

$$P_{out} = \frac{Q}{S_{DP}}$$

where  $S_{DP}$  is the speed of the pump. The speed of the diaphragm pump varies with throughput according to its characteristic curve, referred to as a speed curve. The speed curve is not linear. Because the pump has an ultimate vacuum it can achieve, the intercept of the curve is not even zero. The aperture and turbo pump respond linearly to  $P_{out}$ . Although all these factors can be modeled, the overall response of the UGA to total pressure is best characterized experimentally. A short experiment with the specific gas of interest, equipment and operating conditions will yield a curve describing how the pressure at the RGA varies with  $P_{in}$ .

### 5.1.7 Operating Off the Design Pressure

Each system is specified for one inlet pressure, the design point, which is atmospheric pressure for the standard capillary. The capillary accomplishes the first stage of the pressure reduction from the chosen design point to about 1 mbar. The aperture in the UGA is fixed, and designed to reduce the pressure from 2 mbar to about  $5 \times 10^{-6}$  mbar at the RGA. Each capillary is designed for the specific inlet pressure; mainly by choosing length and bore diameter. The inlet pressure to the capillary can be applied up to 10 mbar. Because the UGA has a separated bypass pump, the inlet pressure can go as high as turbo pump could hold the proper pressure for the RGA (below  $1 \times 10^{-4}$  mbar). Operating the inlet at high pressures would cause two unacceptable effects: First, the turbo pump exhaust pressure would be excessive and slow the pump. The high pressure would increase the work load and cause excessive heating of the pump bearings. In the UGA, these fault conditions are prevented. The turbo pump contains a thermocouple which monitors the bearing temperature and shuts down the pump before it overheats. Also, the system microcontroller will shutoff the turbo pump and will give the error message. The second effect is excessive pressure at the RGA, which can degrade the filament if it occurs for long periods. This fault condition is also prevented by two means. The RGA will shut off the filament when it senses the pressure is high and the system microcontroller will close the sample valve. These operating limits restrict the dynamic range of the UGA with respect to increasing the inlet pressure above the design point. The instrument has little "head-room" and the capillary should be designed for the maximum expected pressure.

Below the design point, the UGA can tolerate large decreases in the inlet pressure. The ultimate vacuum of the diaphragm pump lim-

its the lowest pressure at the outlet of the capillary, typically to 0.5 mbar. This pressure is the only operating limit; below it gas would flow out of the RGA. With respect to measurements, operating the outlet of the capillary near the ultimate vacuum of the diaphragm pump is inadvisable. At the ultimate vacuum, the flow through the pump is effectively zero. Operating the UGA with zero flow obliterates the fast response time of the instrument. While there are no physically harmful effects to operating below the design point, the ability to make measurements is lost at very low inlet pressures. Best performance of the system requires that the outlet of the capillary is between 1 to 3 mbar. The later section of this manual discusses in greater detail the design of capillaries.

### 5.1.8 Total Pressure and Composition

The RGA measures **partial pressure** of the components in a gas stream. For ideal gases, the partial pressure is related to composition by

$$P_i = x_i P^T$$

where  $P_i$  is the partial pressure of the  $i$ -th component,  $x_i$  is the mole fraction of the  $i$ -th component and  $P^T$  is the total pressure. It is evident from this equation that a measurement of  $P_i$  cannot determine both  $x_i$  and  $P^T$ . To determine the composition,  $x_i$ , a value for  $P^T$  must be known. In many applications total pressure is constant and therefore partial pressure is proportional to mole fraction. When total pressure is not constant, a method of determining its value must be employed to allow composition to be determined.

In theory, the sum of the partial pressures determines the total pressure, i.e.

$$P^T = \sum_i P_i$$

In practice, this summation requires care. For example, when using the P vs. t mode to acquire data, make sure to record all the major components of the gas being analyzed. Beware of overlapping peaks; these complicate the analysis. For example, consider a 50/50 mixture of nitrogen and carbon dioxide. The parent peaks

for these gasses are at 44 and 28. Referring to the library in the software shows that nitrogen produces a peak at masses 28 and 14 that are 93% and 6% of the partial pressure and that carbon dioxide produces peaks at masses 44 & 28 that are 78% & 9% of the partial pressure. For a 1000 mbar total pressure, the spectrum would show peaks at 28 & 44 with heights of 510 and 390 mbar. An error can be demonstrated by using these peak heights and reversing the calculation, while ignoring the interference. The carbon dioxide partial pressure would be correctly calculated as 500 mbar ( $=390/0.78$ ), but the nitrogen would be erroneously calculated as 548 mbar ( $=510/0.93$ ) mixture. The mixture appears to be present at a total pressure of 1048 mbar and a composition of 52/48. The correct calculation would first subtract the component of the peak at mass 28 which was caused by carbon dioxide, before calculating the nitrogen partial pressure. More discussion of the quantitative analysis of complex mixtures can be found in the texts listed in the Reference section.

## 5.2 Calibration of Partial Pressure

All quantitative calculations performed with the RGA rely on the assumption that there is a linear relation between the partial pressure and the corresponding RGA signals of the gases. Each gas ionizes differently, and its ions make it through the mass filter with different efficiencies. As a result the proportionality constant relating the ion current of a gas to its partial pressure is dependent on the specific gas.

Two calibration factors are used in the UGA system: the RGA sensitivity and the pressure reduction factor. The RGA sensitivity is the factor which converts the ion current that is measured by the electrometer to partial pressure at the ionizer. The pressure reduction factor accounts for the large pressure reduction performed by the two stage inlet (capillary and aperture). Determination of these factors requires comparing the system with a known-accurate pressure gauge and calculating the factor that makes the UGA agree with the standard. Calibration is not necessary on a frequent interval, but is required whenever operating conditions change.

The RGA intrinsically measures an ion current, which is proportional to the partial pressure at its ionizer. While the software can be set to report ion currents, most users will need to measure par-

tial pressure at the inlet of the capillary. To convert between the two, the partial pressure reported by the software is calculated by the formula:

$$P_i = \text{ion current (A)} \times \frac{\text{pressure reduction factor}}{\text{sensitivity factor (A Torr}^{-1}\text{)}} = \text{ion current (A)} \times \text{overall factor (Torr A}^{-1}\text{)}$$

The pressure reduction factor is a function of the capillary dimensions, the performance curve of the pumps, and the dimensions of the aperture. The sensitivity factor is a function of the precise dimensions of quadrupole and ion optics, the state of the detector, the ionizer filament, and the four parameters which control the filter (electron energy, focus voltage, ionizer current, and ion energy). In the equation above, the two factors are unknown. During calibration only the standard partial pressure and measured ion current are known. Therefore, both factors cannot be determined; only the overall factor can be determined. Both factors can be determined if a second reference pressure gauge is introduced into the RGA chamber. While this approach would yield another reference pressure and allow both factors to be accurately determined, it has no practical benefit.

Because only the ratio of the two factors is relevant, strictly speaking, one of the factors could be chosen to be any number. An obvious choice is to make one of the factors equal to one and use only the other. Because the sensitivity factor is stored in the RGA, this choice causes practical problems. The RGA firmware limits the sensitivity factor to reasonable values. The sensitivity factor must be on the order of  $10^{-4}$  to  $10^{-5}$  A Torr<sup>-1</sup>, which are typical values. The pressure reduction factor is stored by the software in each .RGA file. With the two values stored in different locations, there are benefits for using each to account for various components of the overall calibration factor.

Both factors cannot be determined; therefore, each time the instrument is calibrated, one of the factors will be assumed to be correct, and the other will be adjusted to make the measured and reference values agree. The strategies for using each value are discussed in the following sections, starting with the basic technique that was performed at the factory.

## 5.2.1 Initial Calibration

Initially, a default value is stored in the RGA for its sensitivity factor. This factor is displayed by selecting the “Head|Get Head Info...” menu item in the software. This value was determined at the factory using a reference ion pressure gauge. Users can resort to this default value when they wish to completely recalibrate the instrument. The pressure reduction factor is calibrated using the partial pressure of nitrogen present in air using the following steps:

1. Determine the barometric pressure, which is typically reported in “in Hg”. Example: on a typical clear day the pressure is 29.95 in Hg or 761 Torr (1 in Hg = 25.4 Torr).
2. Nitrogen is naturally present at 78.1% of total pressure. Multiply by this factor to yield the partial pressure. Example: on that day nitrogen is present at 594 Torr.
3. Gases break into molecular fragments in the ionizer. For common gases, fragmentation factors exist that indicate what fraction of the molecules remain intact. For nitrogen 92.6% of the molecules will remain intact and will be measured at mass 28. Multiply the partial pressure by this fraction to determine the reference value. Example: the reference value would be 550 Torr.
4. With the pressure reduction factor disabled (or set to 1), measure the peak at mass 28. Example: the system indicates  $1.3 \times 10^{-6}$  Torr at mass 28.
5. The pressure reduction factor is the reference value divided by the measured value. Example: the factor is calculated to be  $4.2 \times 10^8$  for this instrument.
6. Enter this number in the pressure reduction factor dialog box and check the enable box.

This completes the calibration. All modes of the software will now report partial pressure at the inlet to the capillary. Be sure to record these values as they can be used to diagnose system performance. The pressure reduction factor is saved in the .RGA file; make sure to select File|Save to record the new pressure reduction factor.

## 5.2.2 Basic Recalibration

Some situations will require recalibration of the instrument. For example:

- aging of the diaphragm pump and ionizer filament
- small changes in the total pressure at the capillary inlet
- small dimensional changes to capillary and aperture

For users of one capillary and one input stream, an easy method of making small changes to the calibration values is available with the Sensitivity Tuning feature of the software. Under this method, we assume that the pressure reduction factor is correct and change the RGA sensitivity factor.

Nitrogen is the most common recalibration gas, and in this example, we assume that the partial pressure of nitrogen in air is used as a reference. While air is convenient, the recalibration can be performed with any test gas as a reference. Follow these steps to recalibrate the UGA:

1. Make sure that the pressure reduction factor is enabled and correct in the dialog box that appears under the “Utilities | Pressure Reduction...” menu item.
2. Setup the UGA to sample the reference gas.
3. Choose the “Head | Sensitivity Tuning...” menu item to make the Sensitivity Tuning dialog box appear. Make sure the Measurement Mode is set to Partial Pressure and that the Mass Selection is set to the parent peak of the reference gas.
4. Enter a value in the Reference Pressure Reading edit box that is the expected value for the pressure at the capillary inlet. This value should be adjusted for the fragmentation factor as done above (92.6% for peak 28 from nitrogen). As in the example in the previous section, the reference reading is 550 Torr for nitrogen in air at a barometric pressure of 29.95 in Hg.
5. Observe the value in the Sensitivity Factor text box and then press the Measure button. A new value will be displayed in the text box, which should be close to the old value.
6. Press the Accept button to store the newly calculated value into the RGA or the Undo button to restore the previous button.

The instrument is now recalibrated. Note that the new sensitivity factor is only correct when used with .RGA files that contain the matching pressure reduction factor. This procedure can be repeated frequently to make minor adjustments to the overall sensitivity factor. Because the range of the RGA sensitivity factor is limited by firmware, this procedure cannot be used to account for large changes in the overall sensitivity factor.

### 5.2.3 Calibration for Multiple Operating Conditions

The UGA capable of being used over a variety of operating conditions, which in turn require different overall sensitivity factors. Examples are:

- one UGA system used with multiple capillaries
- measurements of gas streams at different total pressure, temperature, or composition
- measurements at multiple ionizer conditions

The RGA sensitivity factor is not meant to be directly adjusted by the user. The software only allows this value to be changed via the Sensitivity Tuning dialog box using a reference gauge reading. Users cannot type a new value into the Sensitivity Factor text box. Instead, the Pressure Reduction Factor feature is provided to account for widely varying operating conditions.

The Pressure Reduction Factor is stored in the .RGA files. When using the UGA with various operating conditions, one .RGA file can be made for each set of conditions. Each of these files will contain a different pressure reduction factor. The procedure to determine the pressure reduction factor is the same as used in the Initial Calibration section above. Briefly: disable the pressure reduction factor, compare the measured value with a reference, and calculate a new pressure reduction factor. When determining the pressure reduction factor for each set of conditions, make sure that the RGA sensitivity factor has not been changed.

To use the UGA at one of the multiple conditions, simply open the appropriate .RGA file and connect the window to the ECU (if the

ECU is already connected to another window, disconnect from that window first). The software will now be ready to make measurements.

It is worth restating that the pressure reduction factor is only accurate when used with the matching RGA sensitivity factor. The value in the RGA electronics can be changed by other users, so the RGA sensitivity factor should be recorded or locked using the security feature of the software.

## 5.2.4 Calibration with Fixed Reservoir

Air is a convenient calibrant gas for the UGA, but only provides nitrogen as a useful reference. The other major components, e.g. oxygen, water, and carbon dioxide, are not present at reliable concentrations. For more precise calibrations a reservoir and pressure gauge can be used as a calibrant. When using this method, be aware that the UGA continuously draws 1-5 milliliter per minute of gas, depending on the capillary. The reservoir should be large or the total pressure will change quickly.

## 5.2.5 Corrections

### 5.2.5.1 Correcting for the Chamber Background

Even with the sample flow and bypass flow valves closed, there will be a noticeable background in the mass spectrum. This background in the analyzer chamber is caused by outgassing from the chamber surfaces and gas production from the ionizer of the RGA. These two processes account for the ever present background of hydrogen, water, nitrogen, oxygen, and carbon dioxide seen in high vacuum. The outgassing of water can be minimized by extensive pumping with both valves closed; typically the system can achieve water partial pressures around  $1 \times 10^{-8}$  mbar. The other process (ionizer) is fundamental and cannot be reduced. The ultimate vacuum of the turbo pump causes nitrogen to be present at no lower than  $2 \times 10^{-9}$  mbar and oxygen at 1/4 of that level. Carbon dioxide from the ionizer will be present at levels from  $10^{-9}$  to  $10^{-7}$  mbar. The software contains a background subtraction feature that allows the chamber background to be removed from the mass spectrum.

The background spectrum is correctly measured with the sample valve closed and the bypass valve closed. When the bypass valve is open, the background pressure at the chamber is rising due to the backstreaming through the bypass valve. However, the backstreaming components will be flushed out when the sample valve is open. Therefore, the background spectrum should be obtained with both valves closed. The software can only subtract two spectra when they cover the same mass range. Set the software to acquire the spectrum (either histogram or analog) at the speed, range, and schedule you require. To obtain a background subtracted spectrum, follow these steps:

1. Measure one complete analog or histogram mode spectrum with the sample valve closed. If the software was set to scan on a continuous schedule, you can select "Stop at End" from the "Scan" menu to stop when the current scan in progress is complete. The data displayed must be a complete scan, and be measured with the same parameters as the scans to follow.
2. Under the Utilities menu, select "Background" and select "Scan Data - Background" from the dialog box. Check the box next to "Enable" and select "OK" to close the dialog box. This makes the current spectrum the background and all spectra displayed subsequently will have this spectrum subtracted from it.
3. Open the sample flow valve and start the scan with the "GO" button. The newly acquired spectra are the background corrected result.

The ability to subtract background is limited by signal proportional noise, which is typically present at between 1-10% of the signal magnitude. Because this noise originates in the ionizer of the RGA, subtraction cannot remove much more than 90% of the background. This limits the ability to see small changes of less than 1% at the same mass as peaks present in the background.

#### **5.2.5.2 Correcting for Multiple Species**

As discussed above, the UGA is calibrated at one mass number. Because every gas behaves differently, analog scans can only show peak heights that are correct at the one mass number. It is not possible to correct the analog and histograms at every mass number.

The RGA would have to know what species was causing the ion current at each mass. As an example: is ion current at a  $m/z$  of 16 caused by a fragment of  $H_2O$  ( $O^{+1}$ ), a fragment of  $O_2$  ( $O_2^{+2}$ , or  $O^{+1}$ ), or  $CH_4^{+1}$ . Many of the peaks in a mass spectrum have multiple sources. To demonstrate this to yourself, use the library search on almost any single mass number. Except for a few values, the search will retrieve multiple species for almost all the low mass peaks. Without knowledge of what species is causing what peak, the correction cannot be made automatically. Practically, this is not a problem; the histogram and analog modes are intended to show qualitative composition.

The table modes (table, P vs. t, and annunciator) contain a calibration factor for each species. These factors are provided to resolve the problem with the mass spectrum just discussed. The user can use these factors to tell the software how to correct for each peak. To determine the correct calibration factor to use, you must know (or assume) what species is causing each peak and choose masses that are not complicated by other species. Choosing the correct peaks is complicated and requires understanding of the mass spectrum. For instance in a 50/50 mixture of nitrogen and carbon dioxide, you cannot use mass 28 to measure the nitrogen. With this mixture, about 10% of the peak at 28 would be caused by a fragment. A better choice would be to use the peak at 14 to measure nitrogen. Once you have chosen a mass that is representative of each species of interest, you then refer to published fragmentation factors (see references) to determine how to correct back to the parent peak. Even if the instrument was calibrated for nitrogen, it was likely calibrated on the peak at 28. The peak at 14 will not be correct; it will be about 7% of the correct value. Entering 14.2 (1/0.07) as a calibration value in the table parameters allows the software to correct the partial pressure reading. Similar calibration factors are entered for each species being measured. A calibration gas of known composition makes process of determining factors easy. First make a measurement of the standard with all the factors set to 1. From this measurement, a correction for each species can be calculated and entered into the tables. The references listed at the end of this manual contain discussions about how to interpret mass spectra from RGA's.

### 5.2.6 Operation with Condensable Gases

The UGA is designed to sample gases that are nominally at room temperature. Under these conditions, any species that is a gas in

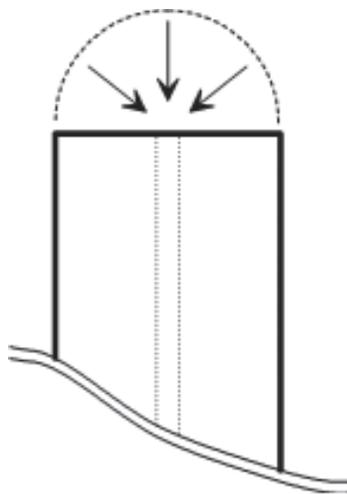
at inlet conditions can be expected to travel through the instrument without condensing. Without a heat input, a gas will cool as it expands through a capillary and pressure reduction aperture (according to its Joule-Thompson coefficient). In the UGA system, the absolute pressure difference across the aperture is small and the flow rate is small; under these circumstances the interior metal surfaces can provide sufficient heat to the expanding gas to keep it from condensing. If problems due to condensation are suspected, the capillary with the heater can be used (Option#3). The goal of heating the capillary is to increase the heat transfer rate to the sample gas.

When the gas being measured is significantly hotter than the UGA system, condensation is likely and presents a problem. If the species at the inlet are gases only at temperatures above room temperature, they can condense when they reach the UGA. The condensed material will continually build up in the UGA and cover the valve seats and aperture. Two approaches can prevent this problem: control the location of condensation or prevent condensation. The first approach can be very simple: place screens or metal plates before the inlet to provide sacrificial surfaces for condensation. The sacrificial surfaces should have good thermal connections to the outer walls so that they stay at room temperature. These surfaces will act like a trap and prevent the unwanted materials from passing into the UGA. The second approach involves operating the entire UGA inlet above the condensation temperature of the condensable material. This may be feasible if the operating temperature is below 100 °C. All the tubing components in the inlet can be heated to 100 °C or more. The electronics and pumps cannot operate at elevated temperatures. This approach (keeping the tubing hot and electronics cool) is a difficult task and therefore is not recommended.

### 5.3 Pressure Reducing Inlet

The gas handling subsystem is designed to achieve several goals:

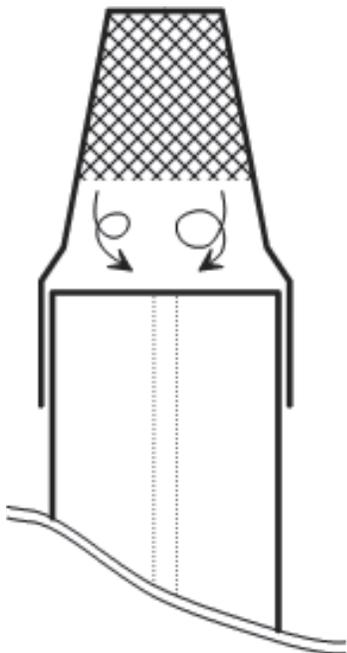
- reduce the pressure of the sample gas to the operating range of the mass spectrometer (<10<sup>-5</sup> mbar)
- provide a quick response time to changes of sample composition at the inlet
- allow for easy connection to system being measured
- use conventional materials



If only the first goal were important a single stage pressure reduction would be suitable.

For example, about 50 cm of 50  $\mu\text{m}$  capillary would perform the required pressure reduction. In a single stage design, all the gas that enters the capillary is delivered to the spectrometer chamber. For a  $80 \text{ l s}^{-1}$  pump, the flowrate at the capillary inlet is  $80 \text{ nl s}^{-1}$ ! The velocity of the gas near the capillary inlet is very small. To demonstrate, the figure at the right shows the end of a 1/16 OD capillary and a hemi-spherical boundary of the same diameter. The time it would take to drain the volume inside the boundary is a measure of the response. For the small volumetric flowrate in this example, it would take 30 seconds to drain the tiny volume. This low speed implies that the capillary relies on diffusion or forced convection to respond to concentration changes.

The effect of a low flowrate on leak detection is catastrophic. Imagine trying to locate a leak by moving the capillary tip around a fitting on a gas line. With the capillary in the example above, you could be 1/16 of an inch away from the leak source and not detect it for 30 seconds. To locate the leak, you would either have to move incredibly slow, or be exactly at the leak.



Low flowrates also severely restrict the inlet. At the left is shown a capillary with a syringe tip filter installed. The gap between the filter element and the end of the capillary (about 1/16 inch in this example) creates a dead volume. If this volume is approximated to be well mixed, the time constant is over 5 seconds. The time constant relates to the rate at which a system responds to a step change and

is characterized by the familiar  $1 - \exp[-t/t_c]$  response. In this example, a sudden change outside the filter would not be completely detected for over 15 seconds.

To achieve fast response, the UGA uses a bypass flow configuration, which draws 200-1000 times larger flowrates through the capillary. The same amount of sample is delivered to the spectrometer. As the name implies, most of flow is bypassed around the spectrometer. Also the pressure drop across the capillary is now only a factor of 1000 (as opposed to 1 billion). This means the capillary can either have a larger bore or be shorter than in a single stage system. The

lower pressure drop makes feasible many capillary materials commonly used in gas chromatography. The following sections discuss details of the flow of the sample gas within the instrument.

### 5.3.1 Flow Calculations

The pressure and flowrates of the sampled gas can be calculated with simple formulas. The calculations here assume that gases behave ideally, which is a reasonable approximation at the temperatures and pressures involved. Actual system performance compares well with these simple calculations.

The pressure drop across a length of tube is related to the flowrate and dimensions by:

$$Q = C(P_{in} - P_{out}) = C \Delta P \quad (1)$$

where  $Q$  is the throughput,  $C$  is the conductivity, and  $\Delta P$  is the pressure drop. Throughput is a measure of mass flowrate commonly used in vacuum systems. Typical units for  $Q$  are mbar liter  $s^{-1}$ , which unless stated otherwise, implies a standard temperature. At STP (273.15 K and 1013.25 mbar) 1 mbar liter  $s^{-1}$  is equal to 1.013  $cm^3 s^{-1}$  (sometimes abbreviated sccs). The conductivity of various geometries is calculated with the standard formulas available in texts discussing vacuum (see References).

The pressures and flow at every point in the system is determined by applying equation 1 to each section of tube. A simplified flow schematic of the UGA is shown below.

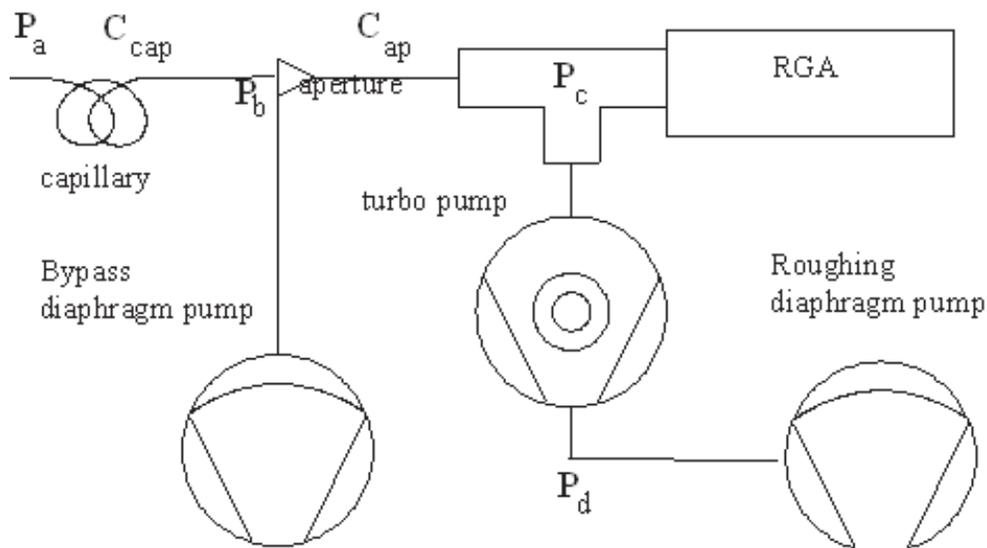


Fig. 5-1. Schematic of key components of system.

For this example there are four points at which the pressure is unknown,  $P_a$ ,  $P_b$ ,  $P_c$ , and  $P_d$ . Applying equation 1 between each pair of points will yield a set of equations to solve. First all the sampled gas flows through the capillary:

$$Q_{total} = C_{cap} (P_a - P_b) \cong C_{cap} P_a \quad (2)$$

Because  $P_a \gg P_b$ , the approximation can be made. When the flow reaches the aperture it is split into two streams, bypass and sample. The sample flow is a small fraction of the total flow, so we can assume that the bypass flow is equal the total and write the equation from the tee to the diaphragm pump as:

$$Q_{total} = S_B \times P_b \quad (3)$$

where  $S_B$  is the speed of the Bypass diaphragm pump and has the same units as conductivity ( $\text{liter s}^{-1}$ ). The flow through the aperture is:

$$Q_{sample} = C_{ap} (P_b - P_c) \cong C_{ap} P_b \quad (4)$$

where again the large pressure drop allows the approximation to be used. Lastly, the turbo pump is an active component that is characterized by

$$P_c = Q_{sample} / S \quad (5)$$

where  $S$  is the speed of the pump and has the same units as conductivity ( $\text{liter s}^{-1}$ ). For the pump in the UGA, the speed is a constant at  $80 \text{ liter s}^{-1}$  (except for He and  $\text{H}_2$ ).

The speed of the diaphragm pump is not a constant; it is a function of the inlet pressure. A typical speed curve is shown in the graph below.

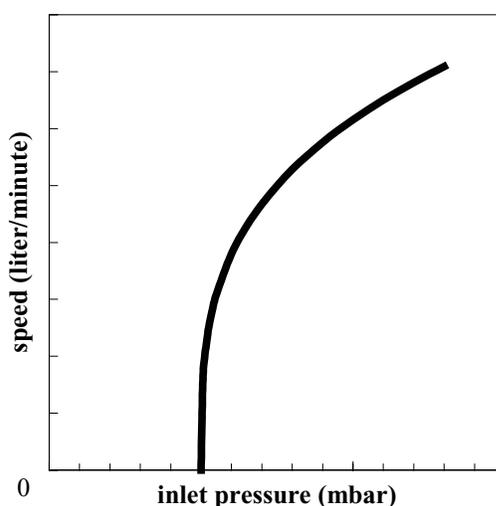


Fig. 5-2. Speed curve for a diaphragm pump.

The curve shows an important feature: the speed goes to zero at a finite pressure. This pressure is the ultimate pressure of the pump. At this pressure, gas travels backward through the pump at the same speed at which it is being pumped forward. Therefore, even though the pump is still operating, it effectively has no speed.

Equations 2 to 5 completely describe the system. Solution of the

entire set would determine all the unknowns, except that there are more unknowns than equations. Typically, the inlet pressure is known and the desired pressure at the spectrometer is known leaving 5 unknowns. To simplify the calculations,  $P_b$  is chosen to be an acceptable value and the remaining values are solved for.

These equations demonstrate some important characteristics of the UGA.

- The pressure in the spectrometer chamber is directly proportional to the pressure at the exit of the capillary and largely controlled by the aperture. Choosing a different aperture has insignificant effect on the remainder of the system.
- The mass flowrate through the capillary is insensitive to changes in pressure at the exit of the capillary. This characteristic is very helpful to predicting the performance of different capillaries. If this were not true, the exit pressure of the capillary would be complexly related to the speed curve of the diaphragm pump. (This can happen when designing capillaries for low pressure).
- The pressure at the exit of the capillary is dominated by the speed curve of the diaphragm pump and the mass flowrate through the capillary.

These last two characteristics greatly simplify the selection of alternate capillaries and is discussed later in this chapter.

### 5.3.2 Diaphragm Pump

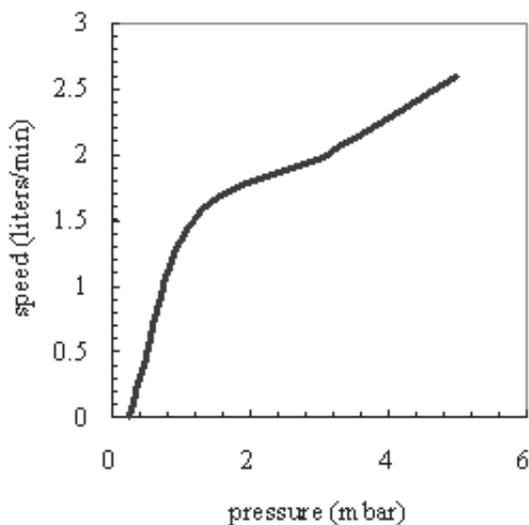


Fig. 5-3. Measured pumping speed vs. the pressure at the pump inlet for the pump in the UGA.

A measured speed curve for the diaphragm pump is shown in the Figure 5-3. The speed is the volumetric flowrate at that pressure. Because mechanical pumps have much lower flowrates than turbo pumps, the speed is usually expressed in volume per minute. A pressure of 2 mbar is a typical operating point for the UGA, which means the pump speed is 1.8 liter min<sup>-1</sup>. The mass flowrate at the diaphragm pump and capillary inlet are the same. At the higher pressure of the capillary inlet, 1000 mbar, the corresponding volumetric flowrate is 3.6 milliliter min<sup>-1</sup>. The simple relation

$$P_1 V_1 = P_2 V_2$$

is a good approximation as long as temperature is constant. The speed is 2.6 liter min<sup>-1</sup> at 5 mbar, which corresponds to 13 milliliter min<sup>-1</sup> at 1000 mbar. The turbo pump only operates with exhaust pressures up to approximately 5 mbar, which limits the useful range to that shown in Fig. 5-3. Thereby, capillaries are always chosen to draw volumetric flowrates of 1-10 ml min<sup>-1</sup>. The complete speed curve would keep increasing up to the pumps specification of 13 liter min<sup>-1</sup> at atmospheric pressure.

The ultimate pressure of the diaphragm pump can age, mainly by degradation of the valve seats. This aging will shift the zero intercept of the speed curve (Fig. 5-3) to higher pressures. For many operating pressures the effect is minimal, but pressures near the ultimate pressure will show drastic speed changes. The implication is that operating the UGA near the ultimate pressure of the diaphragm pump requires careful monitoring and should be avoided when feasible.

### 5.3.3 Turbo Pump

The pump attached to the spectrometer chamber is hybrid turbomolecular/drag pump. The hybrid design of this pump allows it to exhaust at high pressure (relative to conventional turbomolecular pumps). The pumping speed is constant at the nominal value of 80 l s<sup>-1</sup> over a large range of exhaust pressures. As the exhaust pressure approaches the maximum value, the speed begins to drop. Fig.5-4 shows a representative turbo pump speed curve, overlaid with the speed curve of the diaphragm pump. The two curves overlap for a small region of pressures, which determine the operating range of

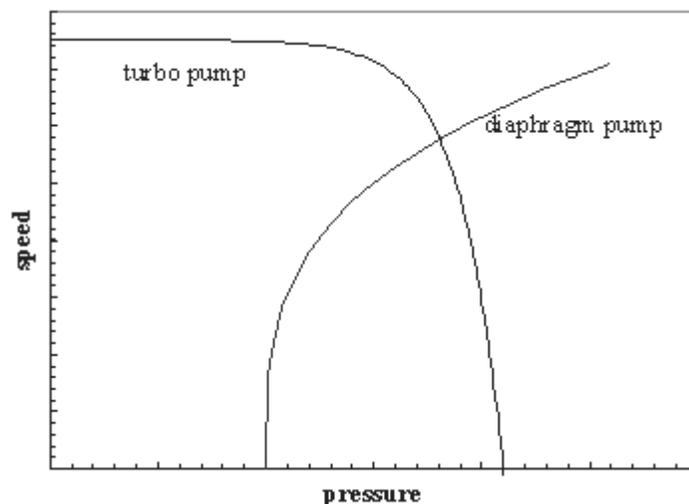


Fig. 5-4. Representative speed curves for two pumps. The speed values have been scaled to show both pumps on the same graph. The pressure is the exhaust of turbo and the inlet of the diaphragm pump.

the system.

In the case the UGA, the overlapping region is 1-5 mbar. As the turbo pump exhaust pressure increases approaches 5 mbar, the work it performs will increase. The current monitor display on the front panel is a good indicator of the power consumed by the pump. Running the pump near its limit mainly causes the bearing temperature to increase. The turbo pump controller will detect if the bearings are overheating and avoid damage by shutting down the pump. Long term operation near the temperature limit mainly will age the bearings more quickly. The only advantage to operating the turbo pump at higher exhaust pressures is an increase in the flow rate through the capillary. The higher flowrate can help response time, but given the cost of a turbo pump rebuild, response time is better addressed through capillary design.

### 5.3.4 Capillary Design

The inlet uses a bypass configuration that results in a fast response time. A large flow is drawn through the capillary tube, which drops the pressure 3 decades. The typical capillary used at atmospheric pressure has a bore diameter of 0.175 mm and a length of 0.9 m. Any number of combinations of length and bore diameter can achieve the same flowrate and pressure drop. Capillaries are

available in several materials. The factors affecting the choice of capillary are:

- inlet pressure
- required response time
- distance to sample point
- material restrictions
- cost

The possibilities for capillary choice are numerous, and SRS offers only a few types. The standard capillary shipped with the UGA is mainly provided to test the system and provide a reference. The following sections contain some guidelines to designing a capillary suited to the users application.

### 5.3.5 Length & Bore

To choose the dimensions of the capillary, three parameters must be fixed: the inlet pressure, exit pressure, and flowrate. These three values allow the conductivity to be determined (equation 1). A typical design point is an exit pressure of 1-2 mbar and a corresponding flow rate of 1.5 to 3.5 milliliter  $\text{min}^{-1}$  (see Fig. 5-3). The inlet pressure is determined by the users application. The capillary conductivity is a function of the geometry, pressure, temperature, and gas properties. A common formula for air flowing through a tube at 20 °C is

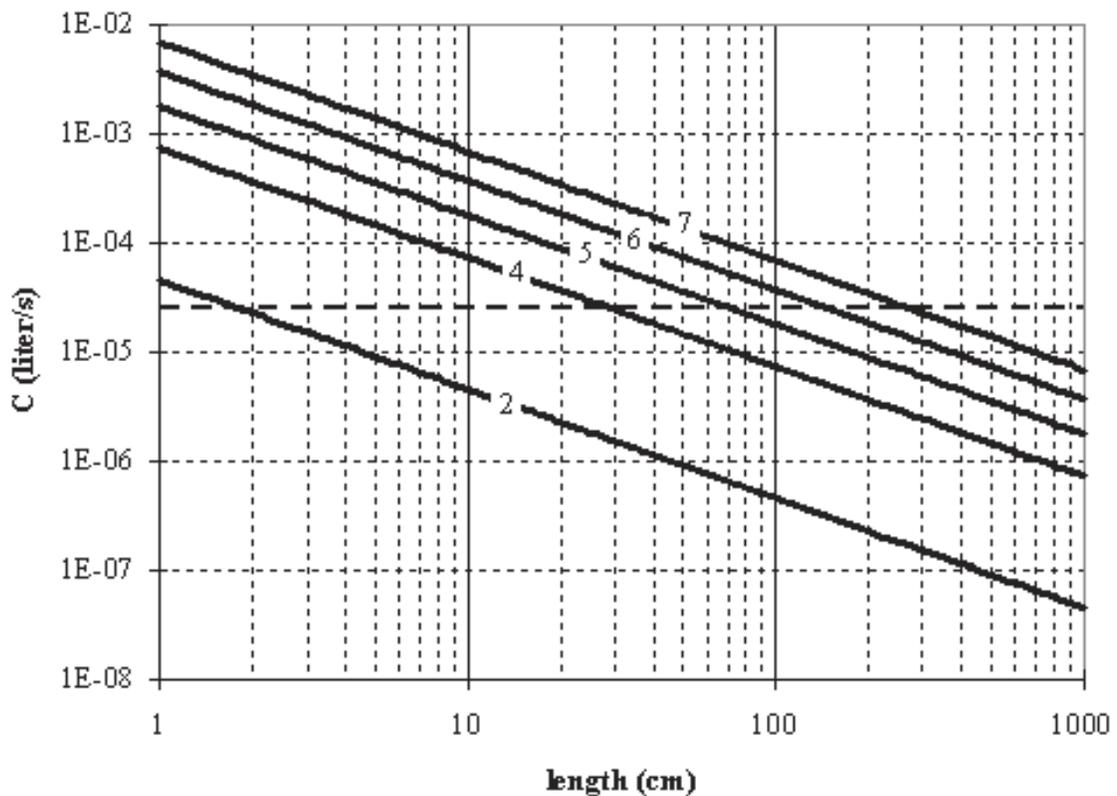
$$C = 135 \frac{d^4}{L} \frac{P_1 + P_2}{2} \quad (6)$$

where C is the conductivity in  $\text{l s}^{-1}$ , d and L are in cm, and the pressures are in mbar. More general formulas including temperature and viscosity are contained in the texts listed in the references. This formula also assumes laminar flow.

There are many approximations used in equation 6 and users may be concerned about its accuracy. The formula shows that the conductivity is a strong function of diameter. As a practical consequence, this strong dependence means the standard manufactur-

ing tolerances on bore diameters will cause more uncertainty than the formula itself. A typical 0.005 inch bore capillary might have a  $\pm 10\%$  tolerance. While it is reasonable that the bore could vary from 0.0045 to 0.0055 inch, this uncertainty causes the conductivity to vary by about  $\pm 40\%$ . Use the standard formulas as a guide, but cut the capillary long to begin with. Measure the actual performance and trim as necessary.

The chromatography industry uses a large variety of capillaries, from which we can select capillaries for the UGA. The figure below shows the conductivity for several commonly available bore diameters.



As an example, consider a capillary for atmospheric pressure and an capillary exit pressure of 1 mbar. From the speed curve for the diaphragm pump, the throughput,  $Q$ , is  $2.5 \times 10^{-2}$  mbar liter  $s^{-1}$  ( $Q = P S$ ) and the required conductivity is  $2.5 \times 10^{-5}$  liter  $s^{-1}$ . The horizontal dotted line in Fig. 5-5 shows that for each capillary diam-

eter there is an appropriate length. The application dictates which bore diameter is appropriate. If the system being measured was far away from the UGA, 3 meters of the 7/1000 capillary would be best. On the other hand, for something close 0.7 meters of 5/1000 would be less expensive. The gas velocity through the capillary quickly reaches the speed of sound. Thereby, until the capillary becomes **very** long, it is not an important contributor to the response time of the UGA.

### 5.3.6 Materials and Fittings

Users will find vendors of gas chromatography supplies a good source for capillaries and fittings. Capillaries are available in many materials. No material is ideal for all applications. The following table list features of several materials

material	min. bore diameter	advantages	disadvantages
stainless steel	0.005 in	<ul style="list-style-type: none"> <li>• rugged</li> <li>• high temperature</li> <li>• durable connections</li> </ul>	<ul style="list-style-type: none"> <li>• difficult to cut without clogging the bore</li> <li>• marginal flexibility</li> </ul>
PEEK	0.005 in	<ul style="list-style-type: none"> <li>• highly flexible</li> <li>• can be cut by user</li> </ul>	<ul style="list-style-type: none"> <li>• weaker connections</li> </ul>
glass lined plastic	0.002 in	<ul style="list-style-type: none"> <li>• smallest bore</li> </ul>	<ul style="list-style-type: none"> <li>• cost</li> <li>• not flexible</li> <li>• low temperature</li> </ul>

Three conventional methods are available for making connections to the capillaries: metal compression fittings, graphite seals, and o-ring seals. Metal compression fittings are suitable for stainless steel tube. The steel is capable of deforming to make the seal. The outside diameter of plastic capillaries is not round enough to make a good seal to metal ferrule. Graphite ferrules in a metal fitting are a better choice. The graphite will conform to any irregularities in the surface of the capillary. In addition, the graphite ferrule does not

permanently deform the capillary as a steel ferrule would. O-ring seals, e.g. Ultra-Torr, make good seals. They only lack in the ability to operate at high temperature.

### 5.3.7 Extensions

As discussed in the previous section, the capillary can be designed to any length necessary by choosing an appropriate bore diameter. The cost of material might warrant the use of an extension of another material, e.g. common vinyl tubing. This can be accomplished as long as the extension is added to the vacuum side of the capillary:

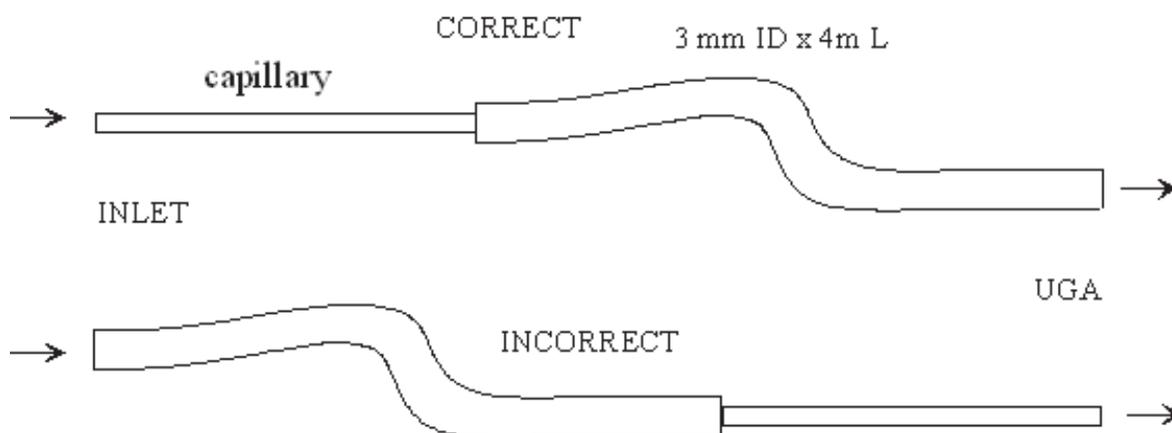


Fig. 5-6. Good and bad methods of adding an extension of vinyl tubing to the capillary.

The incorrect approach above will destroy the response time of the instrument. At 1 ml per minute, it would take 33 minute for gas to travel from the inlet to the UGA. The correct approach would take less than 2 seconds. The decrease in pressure causes the volumetric flowrate to increase 1000 times as the gas travels through the capillary. The flow in the extension is viscous, which implies that only diffusion will cause mixing in the axial direction. Sudden changes in composition at the inlet will be detected as sudden changes at the UGA. The response is simply delayed by the amount of time it takes to traverse the extension. Only very long extensions should show any mixing. For extensions, the general rule is to get the beginning of the capillary as close to the sampling point as possible.

## 5.4 References

### General RGA information

Dawson, "Quadrupole Mass Spectrometry and Its Applications", AIP Press, NY, 1995.

Drinkwine and D. Lichtman, "Partial Pressure Analyzers and Analysis", AVS Monograph Series published by the Education Committee of the American Vacuum Society

Basford et. al., J. Vac. Sci. Technol., A 11(3) (1993) A22-40: "Recommended Practice for the Calibration of Mass Spectrometers for Partial Pressure Analysis. Update to AVS Standard 2.3".

Batey, Vacuum, 37 (1987) 659-668: "Quadrupole Gas Analyzers"

Fu Ming Mao et. al., Vacuum, 37 (1987) 669-675: "The quadrupole mass spectrometer in practical operation"

Dawson, Mass Spectrometry Reviews, 5 (1986) 1-37: "Quadrupole mass analyzers: Performance, design, and some recent applications"

### Vacuum Diagnosis

Studd, R&D Magazine, October 1991, p. 104: "Design Away Those Tough Vacuum System Riddles"

Applications of RGAs to process control

O'Hanlon, J. Vac. Sci. Technol. A 12 (4), Jul/Aug 1994: "Ultrahigh vacuum in the semiconductor industry"

Vic Comello, R&D Magazine, September 1993, p. 65: "Process Monitoring with "Smart" RGAs"

Waits, et. al., Semiconductor International, May 1994, p. 79: "Controlling your Vacuum Process: Effective Use of a QMA"

Rosenberg, Semiconductor International, October 1995, p. 149: "The Advantages of Continuous On-line RGA Monitoring".

Lakeman, Semiconductor International. October 1995, p. 127: "Increase overall Equipment Effectiveness with In Situ Mass Spectrometry".

### Quantitative measurements

Bley, Vacuum, 38 (1988) 103-109: "Quantitative measurements with quadrupole mass spectrometers: important specifications for reliable measurements"

Cowen, et. al., J. Vac. Sci. Technol. A 12(1), Jan/Feb 1994: "Non-linearities in sensitivity of quadrupole partial pressure analyzers operating at higher pressures"

Multiple linear regression analysis algorithms

William H. Press, et. al., 1992, *Numerical Recipes in C, The Art of Scientific Computing*, Second Edition, Cambridge Univ. Press, section 15.4, page 671.

Bevington, P.R., 1969, *Data Reduction and Error Analysis for the Physical Sciences*, New York, McGraw-Hill, Chapters 8-9.

## Appendix A

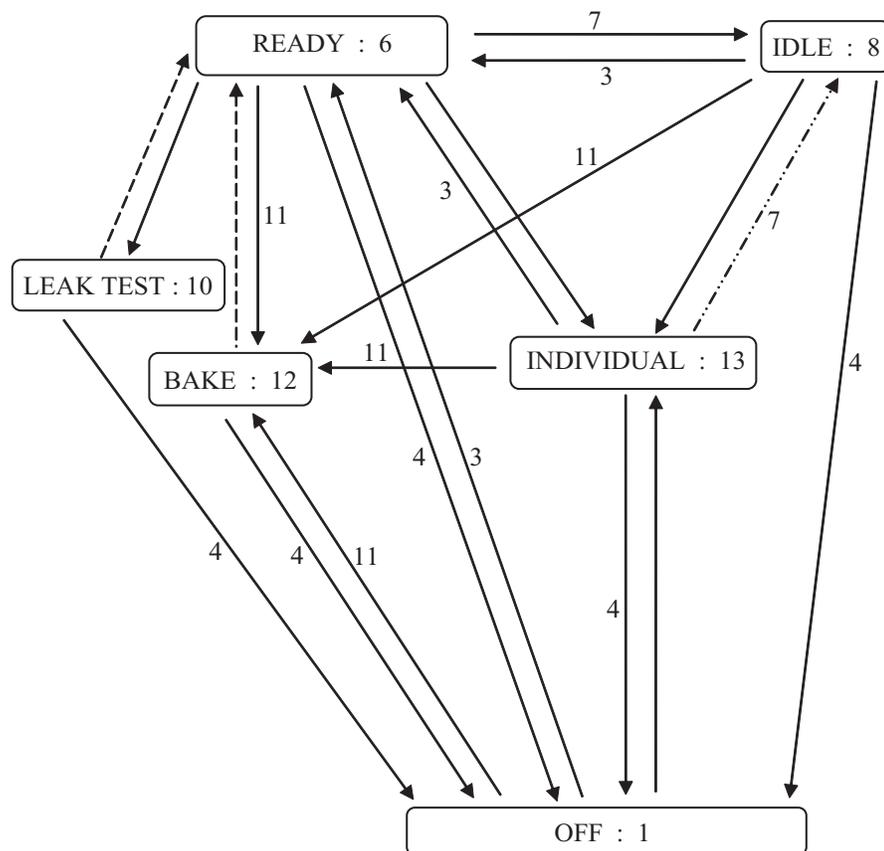
UGA Menu Table						
(* The <b>bold value</b> is the factory default value.)						
Top level	2nd level	3rd level	4th level	5th level	6th level	
Leak Test	<b>Off</b> : Stop Leak test & go to the selected display					
	On : Start Leak test & go to the Leak Test display					
	Mass Selection	Input data ( <b>4 amu</b> , 1 - 100) & one level up				
	Audio Volume	Select a state (Off, <b>Low</b> , Medium, High) & one level up				
	ElectronMultiplier	Select a state ( <b>Off</b> , On) & one level up				
System Bake	<b>Off</b> : Stop System baking & go to the selected display					
	On : Start System baking & go to the System Bake display					
	Bake Time	Input data ( <b>8 hr</b> , 2 - 100) & one level up				
	Bake Temperature	Elbow	Input data ( <b>105</b> , Off - 120) & one level up			
Chamber		Input data ( <b>105</b> , Off - 120) & one level up				
Communication	RS232 Baud rate	Select a parameter (28800, <b>38400</b> ) & one level up				
	IP Address	Input data ( <b>0.0.0.0</b> ) & one level up				
	Subnet Mask	Input data ( <b>255.255.255.0</b> ) & one level up				
	Gateway	Input data ( <b>0.0.0.0</b> ) & one level up				
	Login Name	Input data ( <b>SRSUGA</b> ) & one level up				
	Password	Input data ( <b>SRSUGA</b> ) & one level up				
Display	Pressure	Select a unit ( <b>Torr</b> , Pascal, mbar, bar) & go to Pressure Display ( <b>default during the operation</b> )				
	Turbo Pump : Go to Turbo Pump Display					
	Temperature : Go to Temperature Display					
	Leak Test : Go to Leak Test Display					
	System Bake : Go to System Bake Display					
	About UGA : Go to Introduction Display ( <b>default for the Off state</b> )					
Controls	Roughing Pump	<b>Off</b> : Turn off RP & go to the selected display				
		On : Turn on RP & go to the selected display				
		Idle : Set RP idle & go to the selected display				
		Tune On-Power	Input data ( <b>60 %</b> , 30 - 100) & one level up			
		Tune Idle-Power	Input data ( <b>45 %</b> , 30 - 100) & one level up			
		Vent Valve	<b>Close</b> : Close the vent valve & go to the selected display			
			Open : Open the vent valve & go to the selected display			
	Auto Vent Valve	Select a state (Off, <b>On</b> ) & one level up				
	Bypass Pump	<b>Off</b> : Turn off BP & go to the selected display				
		On : Turn on BP & go to the selected display				
		Tune On-Power	Input data ( <b>60 %</b> , 30 - 100) & one level up			
	Turbo Pump	Select a state ( <b>Off</b> , On, Idle) & go to the selected display				
Bypass Valve	Select a state ( <b>Close</b> , Open) & go to the selected display					

Top level	2nd level	3rd level	4th level	5th level	6th level	
Controls (continue...)	Sample Valve	<b>Close</b> : Close the vent valve & go to the selected display				
		<b>Open</b> : Open the vent valve & go to the selected display				
		Auto Sample Valve	Select a state ( <b>Off</b> , <b>On</b> ) & one level up			
	RGA	Select a state ( <b>Off</b> , <b>On</b> ) & go to the selected display				
	Ion Gauge	<b>Off</b> : Turn off IG & go to the selected display				
		<b>On</b> : Turn on IG & go to the selected display				
		<b>Degas</b> : Start degassing IG & go to the selected display				
		IG Fil Select	Select a parameter ( <b>Fil 1</b> , <b>Fil 2</b> ) & one level up			
	Heaters	<b>Off</b> : Turn off all the heaters & go to the selected display				
		<b>Bake</b> : Turn on Baking heaters & go to the selected display				
		<b>Heat Sample</b> : Turn on Sample heaters if installed & go to the selected display				
		Set Temperatures	Bake Temperature	Elbow	Input data ( <b>105</b> , <b>Off</b> , 40-120) & one level up	
				Chamber	Input data ( <b>105</b> , <b>Off</b> , 40-120) & one level up	
		Sample Temperature		Elbow	Input data ( <b>Off</b> , 40-120) & one level up	
				Chamber	Input data ( <b>Off</b> , 40-120) & one level up	
Sample Line				Input data ( <b>80</b> , <b>Off</b> , 40-80) & one level up		
Capillary				Input data ( <b>80</b> , <b>Off</b> , 40-80) & one level up		
MultiInlet Channel		Select a channel (Not Installed for no Option#1, present Channel # for Option #1) & go to the selected display				
Pressure Interlock	Select a state ( <b>Off</b> , <b>On</b> ) & one level up					
Auto	<b>Start</b> : Perform the Start sequence & go to the selected display					
	<b>Sleep</b> : Perform the Sleep sequence & go to the selected display					
	<b>Stop</b> : Perform the Stop sequence & go to the selected display					

## Appendix B

### UGA State Diagram

The state diagram is shown below. Each arrow means a state can be reached from the state which an arrow starts. For example, BAKE state (12) can be reached from READY, IDLE, INDIVIDUAL, and OFF. And LEAK TEST function can be reached only from READY, not from any other states. But during LEAK TEST, the system can go to STOP. As can be seen below, all fundamental modes can be reached from another. The UGA can be stopped from any condition. The stop command is handled on an emergency basis.



-----> : Changes to READY state when the mode ends.

-.-.-.-.-> : Change to IDLE from INDIVIDUAL only when TP is at full speed

3 : Starting (Preparing for Ready state)

4 : Stopping

7 : Sleeping

11 : Going to the Bake state

Refer to Chapter 3 for the other state numbers.

