Series 946 Vacuum System Controller

Operation and Maintenance Manual

Instruction Manual p/n: 100018121
Rev A, June 2020

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Package Contents

Before unpacking the 946 Controller, check all surfaces of the packing material for shipping damage. Check to be sure that the 946 system contains the following items:

- 1 Series 946 Controller (with selected modules installed)
- 1 female, 25-pin D-sub connector for relay output connection
- 1 male, 37pin D-sub connector for analog output connection
- 1 10-foot power cord (US customer only)

Service and Warranty Guidelines

Some minor problems are readily corrected on site. If the product requires service, contact the MKS Technical Support Department at +1-833-986-1686. If the product must be returned to the factory for service, request a Return Material Authorization (RMA) from MKS. Do not return products without first obtaining an RMA. In some cases a hazardous materials disclosure form may be required. The MKS Customer Service Representative will advise you if the hazardous materials document is required.

When returning products to MKS, be sure to package the products to prevent shipping damage. Shipping damage on returned products due to inadequate packaging is the Buyer's responsibility.

For Customer Service / Technical Support:

MKS Global Headquarters
2 Tech Drive, Suite 201
Andover MA, 01810 USA
Phone: +1-833-986-1686
Email: insidesales@mksinst.com
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Warranty Information

MKS Instruments, Inc. provides an eighteen (18) month warranty from the date of shipment for new MKS products. The MKS Instruments, Inc. general terms and conditions of sale provide the complete and exclusive warranty for MKS products. This document is located on our web site at www.mksinst.com, or may be obtained by a contacting an MKS customer service representative.

1 Safety Information

1.1 Symbols Used in this Manual and their definitions

CAUTION: Risk of electrical shock.

CAUTION: Refer to manual. Failure to read message could result in personal injury or serious damage to the equipment or both.

CAUTION: Hot surface.

Calls attention to important procedure, practice, or conditions.

Failure to read message could result in damage to the equipment.

1.2 Safety Precautions

1.2.1 Safety Procedures and Precautions

The following general safety precautions must be observed during all phases of operation of this instrument. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards for the intended use of the instrument and may impair the protection provided by the equipment. MKS Instruments, Inc. assumes no liability for the customer’s failure to comply with these requirements.

Properly Ground the Controller.

This product is grounded through the grounding conductor of the power cord. To avoid electrical shock, plug the power cord into a properly wired receptacle before connecting it to the product input terminals. A protective ground connection through the grounding conductor in the power cord is essential for safe operation.

Upon loss of the protective-ground connection, all accessible conductive parts (including knobs and controls that may appear to be insulating) can render an electrical shock.

All components of a vacuum system used with this or any similar high voltage product must be maintained at Earth ground for safe operation. Be aware, however, that grounding this product does not guarantee that other components of the vacuum system are maintained at earth ground. Connecting the power cable only to a properly grounded outlet is necessary but not sufficient for safe operation of a vacuum system with this or any similar high voltage producing product. Verify that the vacuum port to which the sensors are mounted is electrically grounded.

⚠ Some of the sensors operated by the 946 Controller are highly gas sensitive and were calibrated with a specific gas. When used with other gases, the true pressure could be much higher than the indicated pressure. Read and understand the information provided in this manual about setting up, installing and operating each sensor type with different gases.

⚠ Do not substitute parts or modify the instrument.

Do not install substitute parts or perform any unauthorized modification to the instrument. Return the instrument to an MKS Calibration and Service Center for service and repair to ensure that all safety features are maintained.

⚠ Use proper electrical fittings.

Dangerous voltages are contained within this instrument. All electrical fittings and cables must be of the type specified, and in good condition. All electrical fittings must be properly connected and grounded.

⚠ The Series 946 Controller contains lethal voltages when on.

High voltage is present in the cable and a Cold Cathode sensor when the Controller is turned on.

⚠ Use the proper power source.

This product is intended to operate from a power source that applies a voltage between the supply conductors, or between either of the supply conductors and ground, not more than that specified in the manual.

⚠ Use the proper fuse.

Only use a fuse of the type, voltage rating, and current rating specified for your product.

⚠ Do not operate in explosive environment.

To avoid explosion, do not operate this product in an explosive environment unless it has been specially certified for such operation.

⚠ Service by qualified personnel only.

Operating personnel must not remove instrument covers. Component replacement and internal adjustments must only be made by qualified service personnel.

⚠ Use proper power cord.

Only use a power cord that is in good condition and that meets the input power requirements specified in the manual.

Only use a detachable cord set with conductors having a cross-sectional area equal to or greater than 0.75 mm^2. The power cable should be approved by a qualified agency such as VDE, Semko, or SEV.

2 Specifications[1]

2.1 Controller

Pressure measuring range[2]	1×10^{-11} to $1.0 \times 10^{+4}$ Torr 1×10^{-11} to $1.3 \times 10^{+4}$ mbar 1×10^{-9} to $1.3 \times 10^{+6}$ Pa
Relay set point range[3]	
CC (Cold Cathode)	2.0×10^{-10} to 5.0×10^{-3} Torr 2.7×10^{-10} to 6.5×10^{-3} mbar 2.7×10^{-8} to 6.5×10^{-1} Pa
HC (Hot Cathode)	5.0×10^{-10} to 5.0×10^{-3} Torr 6.5×10^{-10} to 6.5×10^{-3} mbar 6.5×10^{-8} to 6.5×10^{-1} Pa
Pirani	2.0×10^{-3} to $9.5 \times 10^{+1}$ Torr 2.7×10^{-3} to $1.2 \times 10^{+2}$ mbar 2.7×10^{-1} to $1.2 \times 10^{+4}$ Pa
CP (Convection Pirani)	2.0×10^{-3} to $9.5 \times 10^{+2}$ Torr 2.7×10^{-3} to $1.2 \times 10^{+3}$ mbar 2.7×10^{-1} to $1.2 \times 10^{+5}$ Pa
CM (Absolute Manometer)	0.2% to 100% of the measurement range of the head (e.g. 1 Torr head is 2.0×10^{-3} to $1.0 \times 10^{+0}$ Torr)
FC (Mass Flow Controller)	0.2% to 100% of the measurement range of the MFC (e.g. 1000 SCCM MFC is $2.0 \times 10^{+0}$ to $1.0 \times 10^{+3}$ SCCM)
Allowed range within which a control sensor may switch on a Cold or Hot Cathode	
Pirani	5.0×10^{-4} to 9.5×10^{-1} Torr 6.5×10^{-4} to 1.3×10^{-1} mbar 6.5×10^{-2} to 1.3×10^{1} Pa
CP (Convection Pirani)	2.0×10^{-3} to 1.0×10^{-2} Torr 2.7×10^{-3} to 1.3×10^{-1} mbar 2.7×10^{-1} to 1.3×10^{1} Pa
CM (≤2T head)	1.0×10^{-1} to 0.2% of FS Torr 1.3×10^{-1} to 0.2% of FS mbar $1.3 \times 10^{+1}$ to 0.2% of FS Pa
Protection set point[4]	
CC & HC	1.0×10^{-5} to 1.0×10^{-2} Torr, default setting: 5.0×10^{-3} Torr
Operating temperature range	5° to 40°C (41° to 104°F)

[1] Specifications subject to change without notice.
[2] The measurement range depends upon the sensor options selected.
[3] Relay set point values are automatically adjusted when pressure unit is changed.
[4] The protection set point is always enabled in 946.

Storage temperature range	-10° to 55°C (14° to 131°F)
Relative humidity	80% maximum for temperatures less than 31°C, decreasing linearly to 50% maximum at 40°C
Altitude	2000 m (6561 ft) maximum
Insulation coordination	Installation (Over-voltage) Category II, Pollution Degree 2
Power requirement (nominal)	100 - 240 VAC, 50/60 Hz
Mains voltage	Fluctuations not to exceed ±10% of nominal
Power consumption	150 W maximum
Fuse rating, size	2X2A, 250V, Ø 5 mm x 20 mm
Process control relay	12 nonvolatile relays, (4 for each sensor module)
Relay rating	SPDT, 2 A @ 30 V resistive
Relay response	150 msec maximum
Analog outputs[5]	One Buffered and one Logarithmic ($V = A \times Lg(p) + B$) or Linear ($V = A \times p$) for each channel, up to two (2) wide-range combination logarithmic outputs. Output impedance = 100 ohms
Number of channels	Up to 6
Front panel controls	Power ON-OFF switch, keypad for setup and operational commands.
Display	320x240 color LCD with back lighting.
Pressure units	Torr, mbar, Pascal or microns
Flow units	SCCM (≤10,000 SCCM) and slm (>10 slm)
Update rate	LCD display is updated 3 times per second. The pressure/flow signals are updated every 50 msec.
Sensor module slots	3
Sensor modules	**channels/module**
Cold Cathode	single
Hot Cathode	single
Pirani/Convection Pirani	dual
Capacitance Manometer	dual
MFC	dual
COMM/Control modules	
Pressure Control	
Computer interface	*Serial* – RS-232 and RS-485; 9600, 19200, 38400, 57600,115200 baud rate selectable
Electronic casing	Aluminum

[5] Logarithmic/linear and combined logarithmic analog outputs can be customized using the system setup menu.

Dimensions (W x D x H)	9½" x 12¼" x 3½" (241 mm x 311 mm x 88 mm)
Size	½ rack, 2U high
Typical weight	8.0 lb (3.6 kg)
CE certification	EMC Directive: 2004/108/EEC Low Voltage Directive: 73/23/EEC

2.2 Pressure, Flow Sensors, & Valves

Sensor type

CC (Cold Cathode)	Series 431 and 422 inverted magnetron Series 423 I-Mag
HC (Hot Cathode)	Bayard-Alpert (BA) type ionization sensors including MKS MIG (Miniature Ionization Gauge), or LPN (Low Power Nude)
Pirani	Series 345 Pirani
CP (Convection Pirani)	Series 317 Convection Pirani Series 275 Convectron®
CM (Capacitance Manometer)	MKS unheated Baratron® or MKS 45 C heated Baratron, with suitable cable connections and full-scale ranges. Each CM module operates up to two Capacitance Manometers, and the total current requirement of operating sensor(s) must be 1 amp or less.
FC (Mass Flow Controller)	MKS G, I, P Series and legacy products with tied internal grounds, MFCs requiring ±15 VDC or +15 to +24 VDC, 0 - 5 VDC set point and standard 15 pin or 9 pin D-sub cable connection
Valve	Pressure Control Valves: MKS 248A, 148J, 154A (Solenoid Control Valve), 153D and T3Bi (Exhaust Throttle Valves)

Pressure & Flow measurement ranges

CC (Cold Cathode)	1.0×10^{-11} to 1.0×10^{-2} Torr 1.3×10^{-11} to 1.3×10^{-2} mbar 1.3×10^{-9} to $1.3 \times 10^{+0}$ Pa
HC (Hot Cathode)	1 .0x 10^{-10} to 1.0×10^{-2} Torr 1.3×10^{-10} to 1.3×10^{-2} mbar 1.3×10^{-8} to $1.3 \times 10^{+0}$ Pa
Pirani	5.0×10^{-4} to $4.0 \times 10^{+2}$ Torr 6.5×10^{-4} to $5.2 \times 10^{+2}$ mbar 6.5×10^{-2} to $5.2 \times 10^{+4}$ Pa
CP (Convection Pirani)	1.0×10^{-3} to $1.0 \times 10^{+3}$ Torr 1.3×10^{-3} to $1.3 \times 10^{+3}$ mbar 1.3×10^{-1} to $1.3 \times 10^{+5}$ Pa
CM (Capacitance Manometer)	Three decades below full scale of head, (e.g., 10 Torr head is 1.0×10^{-2} to $1.0 \times 10^{+1}$ Torr)
Flow Range (MFC)	1 SCCM to 1,000 SLM

Response time (Buffered analog output)

CC	<40 msec[6]
HC	<50 msec
Pirani, CP	<80 msec
CM	<40 msec

Response time (Log/Lin analog output)

CC	<50 msec
HC	<50 msec
Pirani, CP	<80 msec
CM	<80 msec

Resolution[7]

CC	2 significant digits between 10^{-10} and 10^{-2} Torr, 1 significant digit in 10^{-11} Torr decade
HC	2 significant digits between 10^{-9} and 10^{-2} Torr; 1 significant digit in 10^{-10} Torr decade
Pirani	1 significant digit from 450 to 100 Torr; 2 significant digits between 10^{-4} and 100 Torr
CP, Convectron	2 significant digits over the entire range.
CM & FC	4 significant digits from 10 to 100% FS, 3 significant digits from 1 to 10% FS, 2 significant digits from 0.1 to 1% FS, 1 significant digit from 0.01 to 0.1% FS.

Repeatability

CC, HC, Pirani, CP	5% of indicated pressure at constant temperature
CM	0.25% of indicated pressure at constant temperature
FC	0.2% of full scale

Calibration gas

CC, HC	Nitrogen, Argon
Pirani, CP	Air/nitrogen, Argon, Helium
CM	Any (gas independent)
FC	Nitrogen

[6] A fast response (<3 msec) Cold Cathode board is also available. Consult MKS for details.
[7] Trailing zeros displayed on LCD screen do not reflect the resolution of the pressure reading.

Installation orientation

CC, HC, CM, Pirani, FC	Any (port down suggested for pressure sensor)
CP	Body horizontal only

Materials exposed to vacuum may include

CC	Series 431 and 422 – SS 304, Al 6061, silver-copper brazing alloy, alumina ceramic, Elgiloy®, OFHC® copper Series 423– SS 302, SS 304, glass, Al, Inconel X-750®, alumina ceramic
HC	304 SS, Inconel® X750, glass, tungsten, platinum clad molybdenum, tantalum, nickel, braze alloy, either yttria coated iridium or tungsten filament
Pirani	300 series stainless, platinum, glass, alumina ceramic, silver brazing alloy, nickel 200
CP	300 series stainless, nickel, glass, platinum
Convectron	304 stainless steel, borosilicate glass, Kovar®, Alumina, NiFe alloy, polyimide
CM	Inconel®
FC	316 series stainless, nickel, Elgiloy®, elastomer seal.

Internal volume[8]

CC	Series 431 and 422 - 1.8 in^3 (30 cm^3) Series 423 - 0.9 in^3 (15 cm^3)
HC	Low power nude tube - zero Mini BA - 1.4 in^3 (23 cm^3)
Pirani	0.5 in^3 (8 cm^3)
CP	2.0 in^3 (33 cm^3)
Convectron	304 stainless steel, borosilicate glass, Kovar®, Alumina, NiFe alloy, polyimide
CM	Type 622A/623A/626A - 0.38 $in.^3$ (6.3 cm^3) Type 722A -0.3 $in.^3$ (4.9 cm^3)
FC	0.27 in^3 (4.43 cm^3)

Operating temperature range

CC	Series 431 - 0° to 70°C (32° to 158°F) Series 422--Versions available that operate up to 250°C. Series 423 - 0° to 70°C (32° to 158°F)
Pirani & HC	0° to 50°C (32° to 122°F)

[8] Volume will vary with the type of vacuum connection selected

CP	10° to 50°C (50° to 122°F)
CM & FC	0° to 50°C (32° to 122°F)

Maximum Sensor bakeout temperature (without cables)

CC	Series 431 – 250°C (482°F) when backshell subassembly removed, 125°C (257°F) otherwise Series 423 – 400°C (752°F) CF flange version only with magnet removed Series 422-versions bakable and operable to 250°C are available.
HC	60^{o}C (104°F) with cable attached 300^{o}C (572°F) max, with CF, cable removed 150^{o}C (302°F), with KF and Viton® seal, cable removed
Pirani	50°C (122°F)
CP	100°C (212°F) plastic shell internally coated for RF shielding 250°C (482°F) on aluminum housing for RF shielding version.
Convectron	150°C (302°F)
CM & FC	N/A

Hot cathode sensitivity

LPN	9 Torr^{-1} (±20%)
Mini BA	12 Torr^{-1} (±20%)

Hot Cathode filament type

LPN	*Tungsten (*W) or Yttria (Y_2O_3) coated iridium
Mini BA	Yttria (Y_2O_3) coated iridium

Hot Cathode degas power (E-beam, at grid)

LPN	20 W max
Mini BA	5 W max

Operating voltages

HC	Grid: 180 VDC (normal operation); up to 600 V during degas Filament bias: 30 VDC Filament: 1.8 VDC @ 2A
CC	4.0 kVDC

Hot Cathode X-ray limit

LPN & Mini BA	3x10^{-10} Torr

Dimensions

CC	Series 431 and 422 – ∅2.2×6.3 in (∅56×160 mm) Series 423 – ∅2.6×3.4 in (∅66×86 mm)

Mini BA	∅1.12X2.37 in (∅28×60 mm) with 2-3/4” CF flange
LPN	∅3.3X1.0 in (∅83 mm×25) with 2-3/4 CF flange, can insert into NW40 tube.
Pirani	∅1.3X4.4 in (∅34×112 mm)
CP	∅1.6X4.4 in (∅41×112 mm)
CM	Types 622A, 623A and 626A - ∅2.6×4.8 in. (∅66×121 mm) Type 722A- ∅1.5×3.9 in (∅38×99 mm)
FC (H×W×L)	1179A -<5.5×<1.5×3 in (<14.0×<3.8×7.6 mm)

Typical Weight

CC (with 2-3/4” CF flange)	Series 431 and 422 - 2.4 lb (1.1 kg) Series423 - 1.8 lb (0.8 kg)
LPN	0.9 lb (0.40 kg) with CF flange
Mini BA	0.816 lb (0.36 kg) with CF flange
Pirani	0.5 lb (0.2 kg)
CP (w/ KF Flange)	0.5 lb (0.2 kg)
FC	<1.9 lb (0.86 kg)

2.3 Controller Display

2.3.1 Display Message

X.X0E±ee	Normal pressure for the Pirani, CP, CC, and HC
X.XXXE±e	Normal pressure for the Baratron, flow rate for MFC
OVER	The pressure is over upper limit (for CC and HC when p > $1x10^{-2}$ Torr)
ATM	Atmospheric pressure for the Pirani sensor
>1.100E±e	CM pressure is over 10% of the full scale
LO<E-11	The CC pressure is below its lower limit, or no CC sensor is connected
LO<E-10	The HC pressure is below its lower limit
LO<E-04	The Pirani pressure is below its lower limit
LO<E-03	The CP pressure is below its lower limit
OFF	Power is OFF to HC/CC/CP/PR sensor.
WAIT	CC and HC startup delay
Low EMIS	The HC OFF due to low emission current
CTRL OFF	The HC or CC are turned OFF by the control channel
PROT OFF	The HC or CC are in a protected state

RP OFF	The sensor power is turned OFF remotely
REDETECT	Detecting the sensor type for PR/CP
_ _ _ _	No Pirani/CP/HC/MFC sensor is detected on the inserted Pirani/CP board
NOBOARD	No board is detected in the slot, display only last 5 secs
N2, AR, He	Gas type
U	User calibration
SPn	Activated relay channel (n=1 to 12)
_ _	A relay is enabled, but not activated.
Ctrl	The CC/HC is controlled by another gauge (PR/CP)
AZ	PR/CP/BR may be auto-zeroed by its control sensor
F1, F2	Active filament
DG	The HC is degassing
An, Bn, Cn	The channel where the control sensor is installed (n=1, 2)

2.3.2 Display Resolutions

Resolution of the pressure values displayed on a 946 Vacuum System Controller front panel varies with the type of sensor connected, and range of measurement. In addition, three display formats are available: Default, HighR[9] (high resolution), and PatchZ (patch zero) and can be selected based on preference.

	PatchZ	**Default/HighR**
Percentage of Full-Scale	Displayed Resolution	Displayed Resolution
>110% FS	>(110%*FS value)	>(110%*FS value)
110% to 10%	X.XXXE+X	X.XXXE+X
10% to 1%	X.XX0E+X	X.XXE+X
1% to 0.1%	X.X00E+X	X.XE+X
<0.1%	X.000E+X	XE+X

Table 2-1 Capacitance Manometer with Exponential Display Format

Table 2-1 shows the exponential display format for Capacitance Manometer. If a Capacitance Manometer measurement range is between 10^4 and 10 (regardless of pressure unit), it is possible to toggle between the decimal and exponential formats. To do this, select the desired CM channel with the up down keys until the LED indicator on the front panel is opposite the channel and press the Degas On/off button.

[9] When HighR mode is selected, the controller displays extra digit for ion gauge pressure to assist the monitoring of pressure changes.

Pressure Range	Convection Pirani		Pirani		Hot Cathode			Cold Cathode		
Torr	PatchZ	Default HighR	PatchZ	Default HighR	PatchZ	Default	HighR	PatchZ	Default	HighR
10^{3}	X.X0E+03	X.XE+03	ATM	ATM						
10^{2}	X.X0E+02	X.XE+02	X.00E+02 (X=1,2,3,4)	X.XE+02						
10	X.X0E+01	X.XE+01	X.X0E+01	X.XE+01						
1	X.X0E+00	X.XE+00	X.X0E+00	X.XE+00						
10^{-1}	X.X0E-01	X.XE-01	X.X0E-01	X.XE-01						
10^{-2}	X.X0E-02	X.XE-02	X.X0E-02	X.XE-02	X.X0E-02	XE-02	X.XE-02	X.X0E-02	XE-02	X.XE-02
10^{-3}	X.X0E-03	X.XE-03	X.X0E-03	X.XE-03	X.X0E-03	X.XE-03	X.XXE-03	X.X0E-03	X.XE-03	X.XXE-03
10^{-4}	LO<E-03	LO<E-03	X.X0E-04 (X.X down to 1.3)	X.XE-04 (>5.0E-04)	X.X0E-04	X.XE-04	X.XXE-04	X.X0E-04	X.XE-04	X.XXE-04
10^{-5}			LO<E-04	LO<E-04	X.X0E-05	X.XE-05	X.XXE-05	X.X0E-05	X.XE-05	X.XXE-05
10^{-6}					X.X0E-06	X.XE-06	X.XXE-06	X.X0E-06	X.XE-06	X.XXE-06
10^{-7}					X.X0E-07	X.XE-07	X.XXE-07	X.X0E-07	X.XE-07	X.XXE-07
10^{-8}					X.X0E-08	X.XE-08	X.XXE-08	X.X0E-08	X.XE-08	X.XXE-08
10^{-9}					X.X0E-09	X.XE-09	X.XE-09	X.X0E-09	X.XE-09	X.XXE-09
10^{-10}					X.00E-10	XE-10	XE-10	X.X0E-10	X.XE-10	X.XE-10
10^{-11}								X.00E-11	XE-11	XE-11

Table 2-2 946 Pressure Display Format for Indirect Gauges including CP, PR, CC and HC

Table 2-2 shows that display format for indirect gauge including Pirani, Convectional Pirani, Cold Cathode and Hot Cathode sensors.

2.3.3 Serial Communication Response Format

CM and Piezo	Diff Baratron	Pirani	Convection	Hot Cathode	Cold Cathode
X.XXXE+X	X.XXXE+X	X.XXE-XX	X.XXE-XX	X.XXE-XX	X.XXE-XX
	-X.XXE+X				

Table 2-3 946 Serial Communication Response Format

Table 2-3 shows the serial communication (RS232/485) response format. In order to keep the communication response string length consistent, 0 will be added or patched to the end if needed.

3 Feature, Control Locations and Dimensions

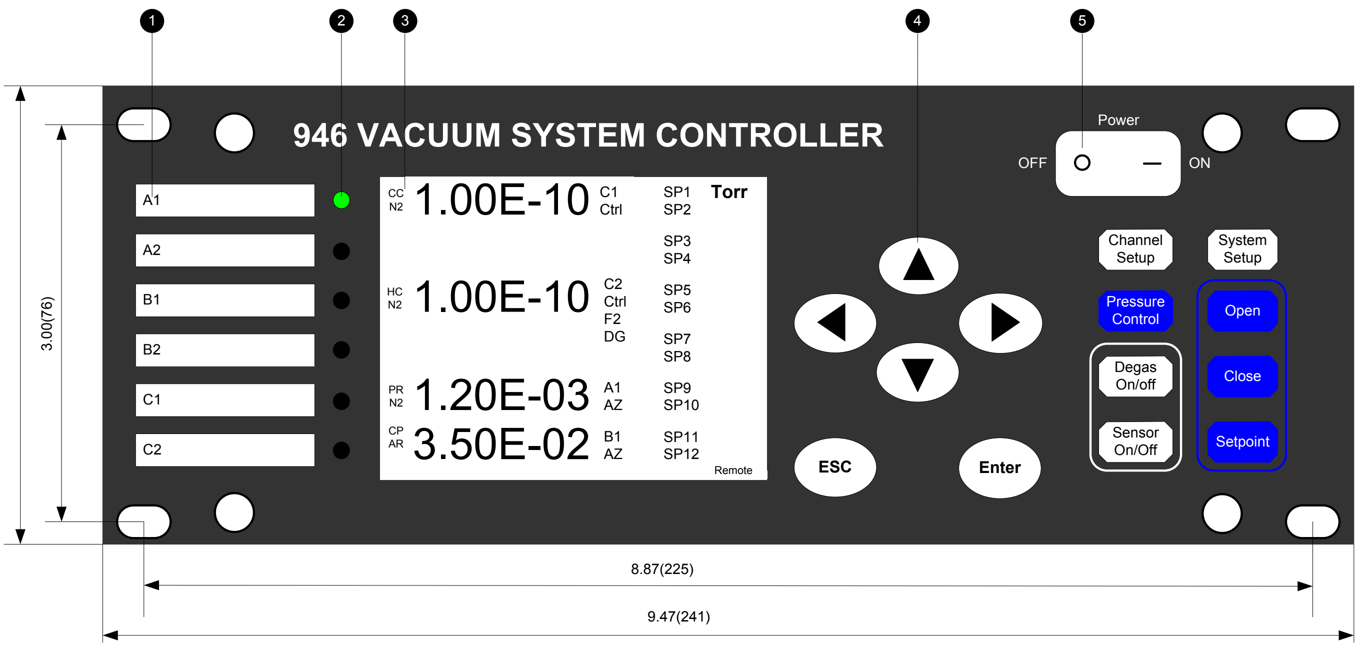


Figure 3-1 946 Front Panel

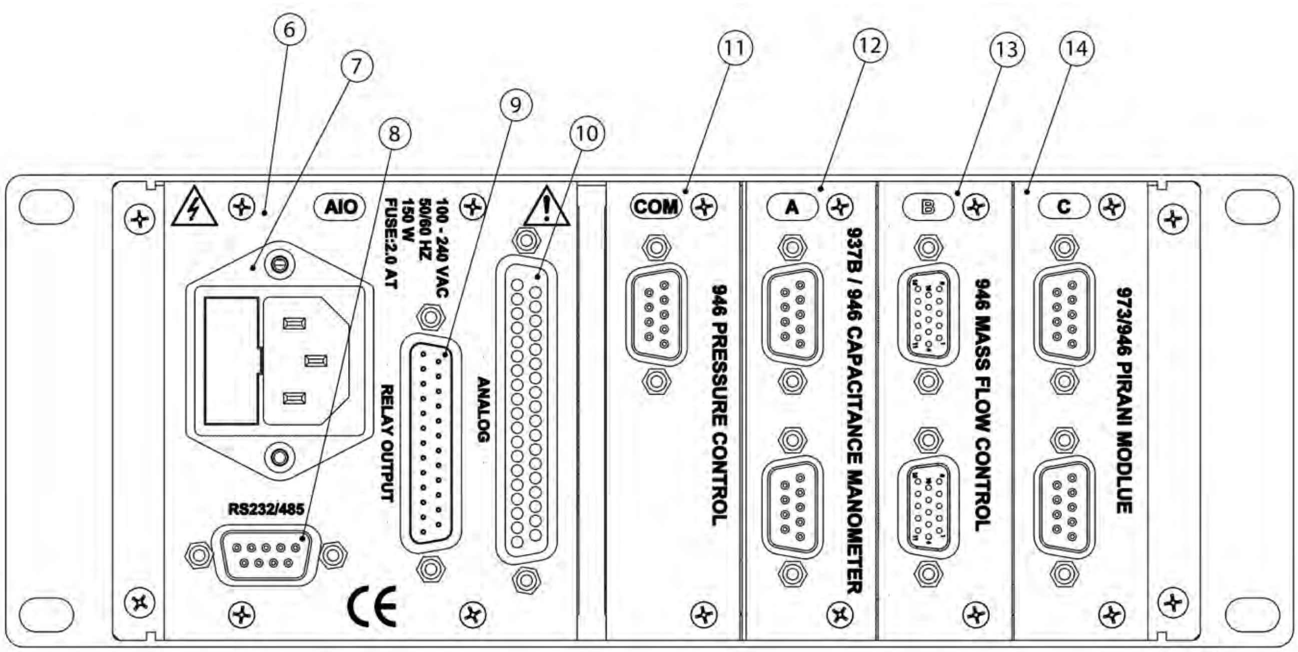


Figure 3-2 946 Rear Panel Example

1	Channel Label
2	LED, Indicating Active Channel
3	Liquid Crystal Display
4	Push Buttons for Menu Navigation
5	Power Switch
6	AIO Module
7	AC Power Inlet
8	RS232/485 Communication Port
9	Relay Output Port
10	Analog Output Port
11	Pressure Control Module
12	Capacitance Manometer Module
13	Mass Flow Control Module
14	Pirani Module

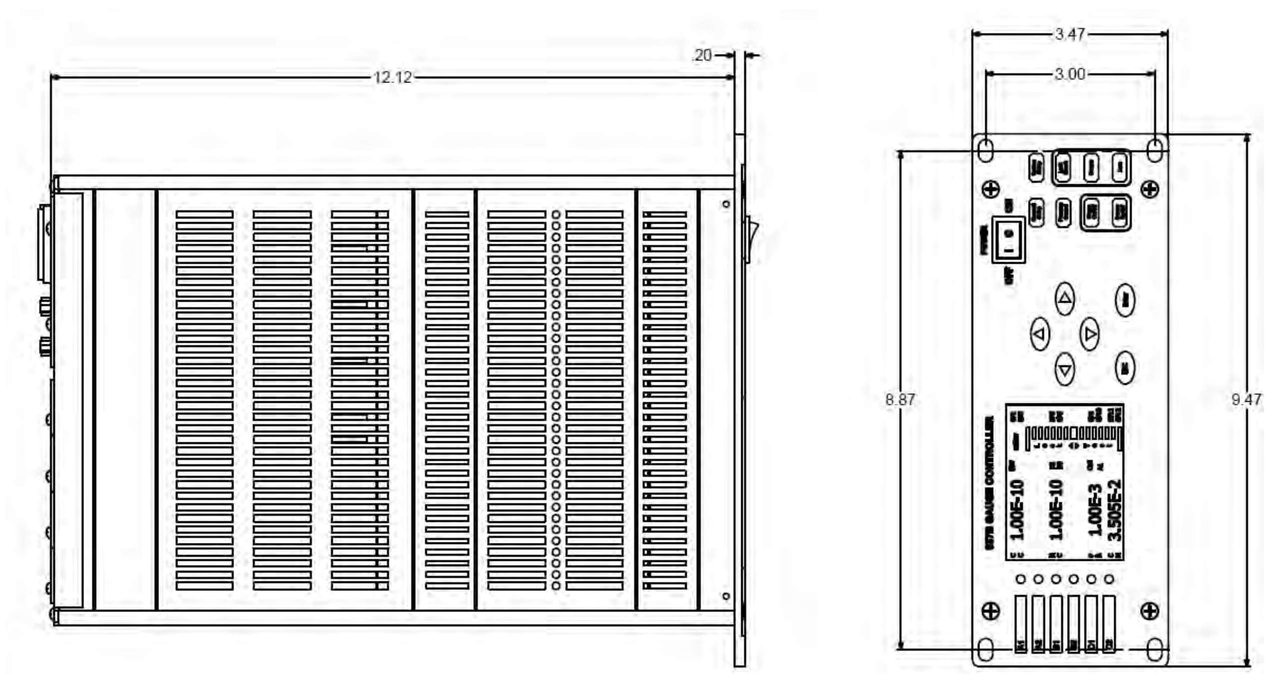


Figure 3-3 946 External Dimensions (inches)

4 Typical Applications for the Series 946 Controller

- Wide pressure measurement range in vacuum chambers.
- Integrated vacuum process control with simultaneous flow, pressure, and valve control.
- Pressure control in vacuum systems and process sequencing using relay set points.
- Sensing abnormal pressure events and initiating and controlling appropriate security measures using the relay set points.
- Controlling system pressure by using the analog output as the input to an automatic pressure controller.
- Starting or stopping system processes using relay set points.
- Measuring backfill pressures.
- Controlling accelerator and light source vacuum systems.
- Displaying the flow rates from MFCs and providing an interface for MFC setup.
- Control of gas flow into vacuum/process chamber.
- Maintaining accurate system pressure by controlling an upstream solenoid valve.
- Maintaining accurate system pressure by controlling a downstream throttle valve.
- Maintaining accurate system pressure by regulating a single MFC flow rate (single MFC PID control), or multiple MFC flow rates with fixed ratio (ratio control).
- Maintaining smooth control of a wide range of pressures through the use of the combined analog outputs of up to 3 sensors.
- Using averaged analog output from up to 3 Capacitance Manometers with the same range for critical process control.
- Fast relay control by a Cold Cathode sensor for high vacuum protection.

5 MKS Series 946 Vacuum System Controller

The MKS Series 946 Vacuum System Controller provides accurate and reliable pressure measurement between 1×10^{-11} Torr to $1\times10^{+5}$ Torr, measurement and control of mass flow rate, and control of system pressure with MFC or pressure control valves. A number of different MKS pressure sensors, mass flow controller/meters and control valves can be connected to the 946.

- MKS Baratron Capacitance Manometers with heads from 0.02 to 10,000 Torr (up to 6)
- MKS 423 I-Mag or Series 431/422 Cold Cathode sensors (up to 3)
- MKS Low Power Nude gauge or Mini BA Hot Cathode sensors (up to 3)
- MKS Series 317 Convection Pirani sensors (up to 6)
- MKS Series 275 Convectron sensors (up to 6)
- MKS Mass Flow controllers (up to 6), Types G, I, P Series with tied grounds and legacy products, requiring +/- 15 to + 24VDC, 0-5 VDC set point and standard 15 pin or 9 pin D-sub cable connection MKS 179A, M100MB Mass Flow Meters (up to 6)
- MKS 148, 248, and 154 upstream Solenoid Control Valves (1)
- MKS 153/T3B downstream Throttle Valves (1)

Figure 5-1 946 Front View

With 3 module slots available and the ability to configure a variety of sensor combinations, the Series 946 Vacuum System Controller can accommodate many unique requirements and applications. It is designed with versatility and ease-of-use in mind, with a large LCD screen that displays:

- Pressure readings for all sensors connected to the controller (up to 6)
- Operational status of MFCs and pressure control valve via the front panel
- The type of pressure and flow sensor in operation
- Mass flow rates for all MFCs connected to the controller (up to 6)
- Relay status (enabled and activated relays are displayed)
- Pressure control status, including the control valve position opening
- The operating status of Hot Cathode sensor (active filament, degas)
- The control status of hot and cold cathode pressure sensors
- The auto zero channel for Pirani/CP/CM sensors
- Open position in percent of a pressure control valve
- System self-checking information (board status, sensor status, pressure range, and etc.)
- Front panel control lock out is possible to prevent unintended set up changes

Controller operation is straightforward. For example, to access the system setup screen, simply push the System Setup button and many system parameters can be viewed or changed. The settings of a specific channel can be viewed or changed by first selecting the channel with the up and down keys until the green front panel LED on the desired channel is illuminated and then pushing the Channel Setup button.

In addition to the pressure and flow values displayed on the screen, three types of analog signals are available on the back panel:

- Buffered analog outputs for each sensor (up to 6). These buffered analog signals respond immediately to sensor signal changes and can be used in critical fast control applications.
- Logarithmic/linear analog outputs for each pressure sensor (up to 6) ranging from 0 to 10 V. The scale for these analog outputs can be adjusted as desired. While these linear signals are somewhat simpler to deal with than the sensor-dependent buffered analog signals, there is a longer time delay (<100 msec) due to the signal processing by the microprocessor.
- There are also combined logarithmic analog outputs available. By combining the sensors with different measurement ranges (such as Convection Pirani and Cold Cathode sensors), analog signals with much wider range are available. This eliminates the requirement for switching/selecting the sensor. The time delay for these analog outputs is around 100 msec.

Twelve (12) mechanical relays with independently adjustable set points allow the 946 to control the operation of critical components in a vacuum system such as valves or a pump. The set point parameters are nonvolatile, remaining unchanged after powering down or during a power failure. They may be set or disabled from either the front panel or RS232/485 communication.

The Controller also has control set points to turn OFF either hot or cold cathode sensors at higher pressures, extending the operating lifetime before maintenance is required.

Direct computer communication is available to change set up configurations or read pressure and other information remotely. A RS232/485 serial port is standard, and the communication protocol can be selected from the System Setup panel.

6 Operating the Series 946 Controller

6.1 Power

946 Vacuum System Controller can be powered by universal AC voltage (100 to 240 V, 50/60 Hz). The power can be switched ON and OFF using the *Power* switch on the front panel. It is recommended to power OFF the controller when not in use.

6.2 Front Panel Control Lock

All front panel keys can be made inactive when the controller's front panel controls are locked. **REMOTE** is then displayed at bottom right corner of the LCD display.

Simultaneously press ◀ and ▶ to lock or unlock the front panel controls or to display the lock status.

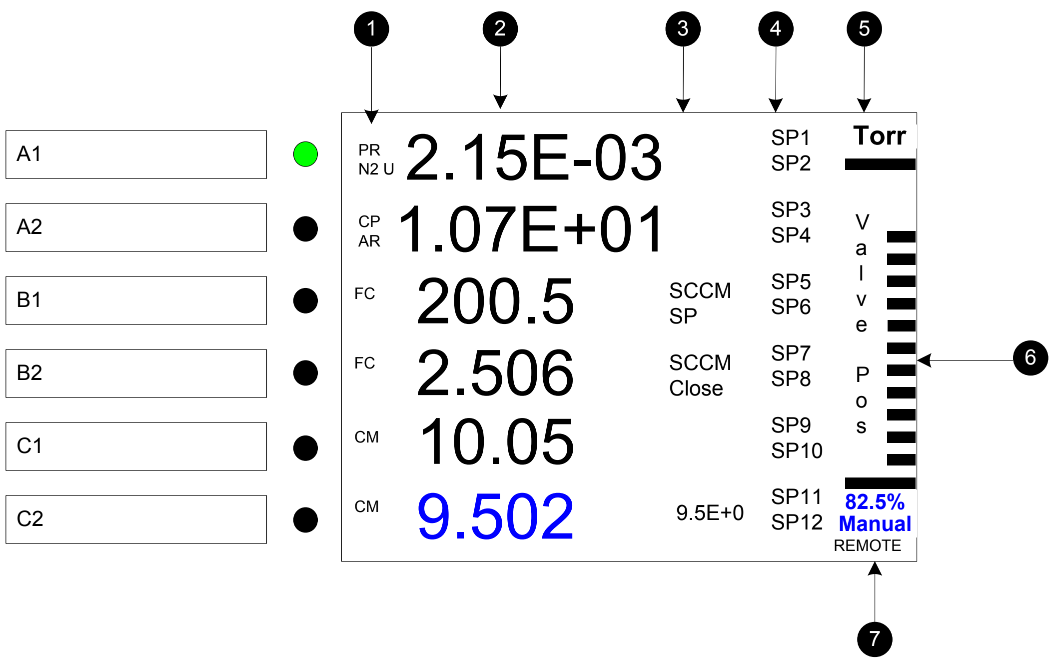
The front panel can also be locked or unlocked with serial communications commands. See *RS232/RS485 Communications Commands* for more information.

6.3 Front Panel Display

6.3.1 Standard Front Panel Display

A 3.6 inch 320x240 pixel color LCD displays the pressure, relay information, sensor type, and other operational and set up information.

A label on the left-hand side of the front displays identifies the name of the channel (A1, A2, B1, B2, C1, C2). An illuminated green LED shows the active channel for channel setting purpose. A front panel display for the 946 is shown in Figure 6-1.



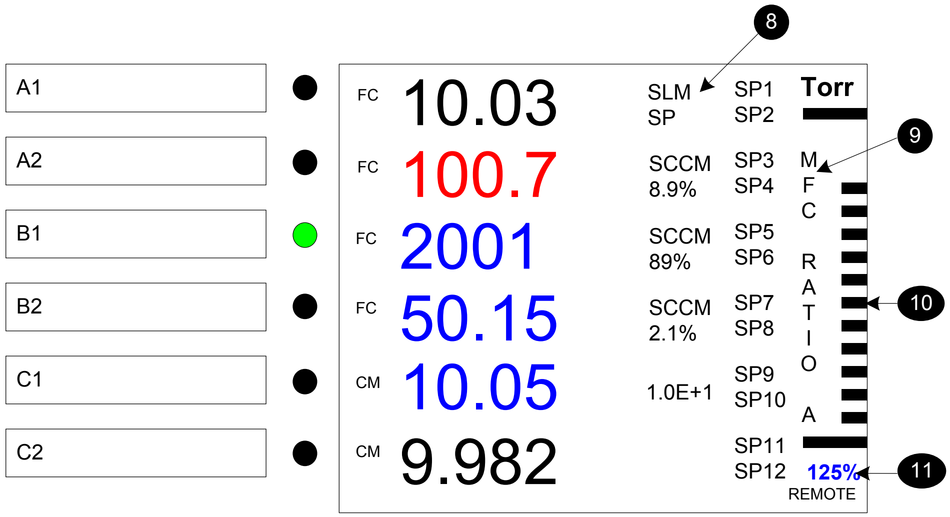


Figure 6-1 946 LCD Front Panel Display for Pressure Measurement with either Valve Pressure Control Mode (upper) and MFC Ratio Control Mode (lower).

1. Type of sensor detected (CC = Cold Cathode, HC = Hot Cathode, PR = Pirani, CP = Convection Pirani or Convectron, CM = Capacitance Manometer or 902B Piezo, FC = Mass Flow Controller); N_2, AR, He = Gas type; U = User Calibrated or Zeroed
2. Pressure/flow readings for all of the detected sensors.
3. Control information which includes:
   - For a Cold or Hot Cathode sensor, Cx Ctrl means the sensor is controlled by channel Cx.
   - For a Hot Cathode sensor, F2 means filament 2 is the active filament, DG means the HC is degassing.
   - For PR/CP/CM, Ax AZ means the PR/CP/CM will be auto-zeroed by the gauge on Channel Ax (typically, a CC or HC).
   - For MFC, SCCM/SLM indicates the flow units, Open/Close/SP is the MFC status or mode. For valve pressure control the set point is displayed--9.5E+0 in the example of 6-1-b.
4. Relay status: displayed channel = activated relay; ---- = enabled, but, not activated relay; blank = relay is not yet set.
5. Pressure units (Torr, Pascal, mBar, Microns)
6. Valve position while using valve for pressure control.
7. Front screen is locked when REMOTE is displayed
8. Unit of flow rate, either SCCM or SLM. The unit switches to SLM automatically when the flow full scale is greater than 10SLM.
9. Control mode: MFC Ratio A, MFC Ratio M, or Valve Position when optional valve control module is installed. When in ratio mode, the pressure set point is also displayed--1.0E+1 in the example of 6-1-b, as well as the flow percentages of each MFC.
10. Graphic indication of Ratio control status for ratio control using multiple MFCs.
11. Digital indication of control parameter

6.3.2 Large Font Display

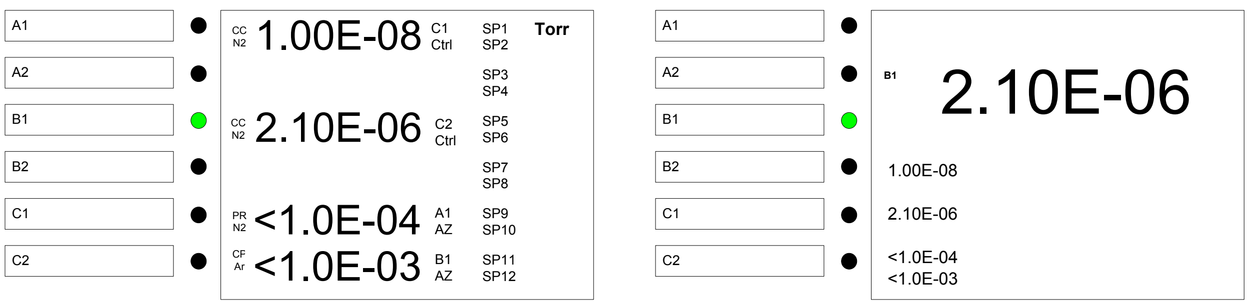
A special large font pressure display of a single channel is also available to ensure the pressure readings can be seen at a distance. To enter this mode:

1. While in the standard display mode, press either the ▲ or the ▼ key to select the desired channel, as indicated by the green LED.

2. Enter the large font display mode by pressing the Enter key.

3. To exit the large font display mode, press the ESC key or the Enter key again.

Figure 6-2 shows a comparison between pressure measurement display in the standard mode and in the large font mode. When the large font display is selected, one channel is displayed as large font (B1 as shown in the figure) and the pressure readings for all the detected sensors are displayed in smaller font of the left side of the LCD.



Standard Display **Large Font Display**

Figure 6-2 A Comparison between Standard Display Mode and Large Font Display Mode for the 946 LCD Display During Pressure Measurement.

6.4 System Setup

6.4.1 Overview of 946 System Setup

An overview of the 946 system setup parameters is shown in Figure 6-3 with the default values and the selection ranges.

The system setup allows settings of parameters such as pressure unit, communication protocol, communication address, disable/enable set parameter, user calibration, define PID control and MFC ratio control recipes, and view firmware versions for the controller and modules.

In addition, the logarithmic/linear analog output for individual channels and combined logarithmic analog output can be scaled by setting the DAC parameters.

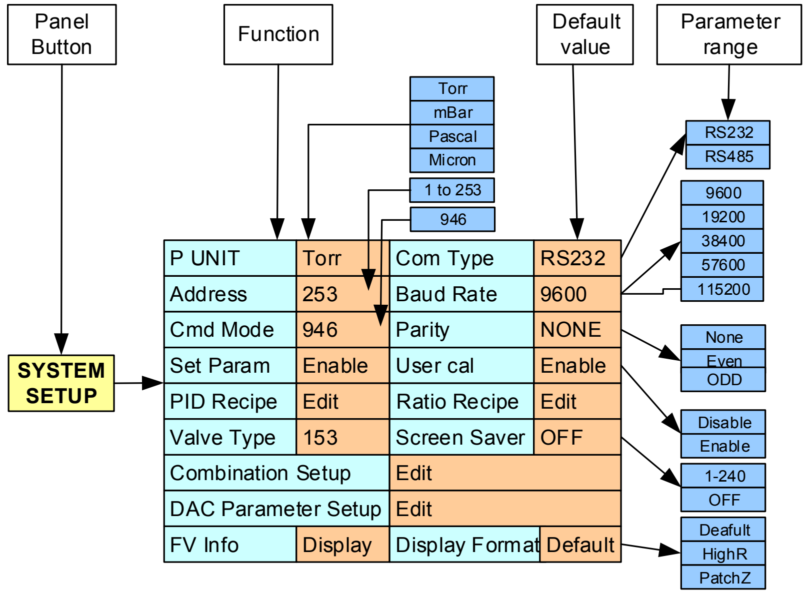


Figure 6-3 946 System Setup Parameters, their Default Values and Ranges

6.4.2 Display System Setup Parameters

To display the 946 system setup, press the [System Setup] key; the LCD display will switch to the system setup mode, as shown in Figure 6-4. The shaded area in the figure shows the cursor position. The cursor position is controlled by the arrow keys on the front panel. A parameter indicated in red indicates that the value has been modified, but not yet saved.

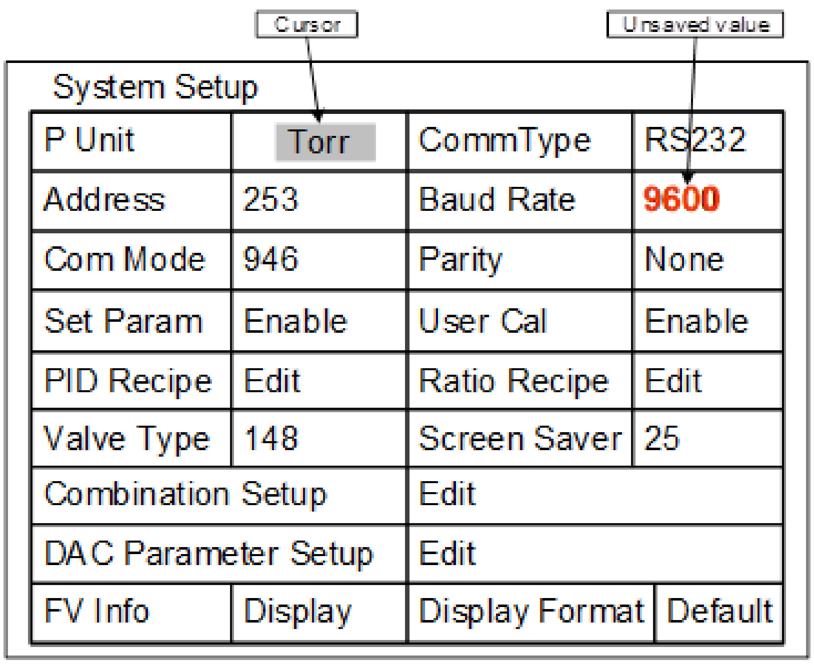


Figure 6-4 System Setup Information Displayed

When a parameter value is indicated in red, it means the value has been changed, but not yet saved. If the setup mode is exited without performing a save, the previous unchanged parameter will be used.

6.4.3 Change and Save a Parameter Value

To change and save a system setup parameter value, use the following procedure:

1. Press any of the ◄ ► ▲ ▼ keys to move the cursor to the parameter to be changed.

2. Press the (Enter) key to highlight this parameter value. For example, Torr will change to Torr.

3. Press either ▲ or ▼ key to change the parameter value (i.e. to change Pascal to mBar).

4. Pressing the (ESC) key at this point will restore the original parameter. If the cursor is moved away from the parameter with the ◄ or ► keys, the color of the parameter value will change to red, and it will not be saved. When either (ESC) or (Enter) is next pushed, the original value will again be displayed and used.

5. To save an updated value, press the (Enter) key while the background of the parameter value is black (i.e. Pascal in this example). After (Enter) is pressed, the background of the selected parameter will turn gray (Pascal in this example). This indicates that the new value has been saved.

6. To return to the normal front panel display mode, press the (ESC) key once after the parameter values have been changed.

The above procedure for changing a pressure unit applies equally to changing all other parameters.

6.4.4 Description of the System Setup Parameters

1. Pressure Unit

   This determines the units used for the pressure displayed on the front panel, the pressure queried from serial communication, and the pressure set point. There are four choices: Torr, mBar, Pascal, and Microns.

2. Communication Type

   This sets the Serial communication protocol, either RS232 or RS485. Default value is RS232.

   When the serial communication protocol is changed, the power of the 946 Controller must be reset for the change to take effect.

3. Address

   This is the address for RS485 and RS232 communication. The valid range is from 1 to 253. The default value is 253. 254 is reserved for broadcasting only.

4. Baud Rate

   This sets the baud rate for serial communication. Valid values are 9600, 19200, 38400, 57600, 115200. The default value is 9600.

5. Command Mode

   Display the command mode for the controller. 946 will be the only choice.

6. Parity

   Define the parity for serial communication protocol. Valid values are NONE, EVEN and ODD. The default setting is NONE.

   ☞ When the serial communication protocol is changed, the power of the 946 Controller must be reset for the change to take effect.

7. Set Parameter

   When Set Parameter is disabled, none of the system or channel setup change commands can be executed. However, parameter values can still be viewed from the display, or queried using serial communication.

8. User Calibration

   When User Calibration is disabled, the following commands cannot be executed through the keypad or through serial communications:

CC	User Calibration
HC	User Calibration and Sensitivity
PR/CP	Factory Default, Manual Zero, and Manual ATM
CM & FC	Factory Default and Manual Zero

9. PID Recipe

   This is used to define the recipe for PID pressure control with a single MFC, ratio control using multiple MFCs and upstream pressure control using Solenoid Control Valve or downstream pressure control using Throttle Valve. Up to 8 recipes can be defined for PID control. See section 6.7 and 6.8 for more detailed instructions on PID recipe setup.

10. Ratio Recipe

    This is used to define the ratio recipe for ratio PID control of multiple MFCs. Up to 4 ratio recipes can be defined for 946. See section 6.7 for more detailed ratio recipe setup.

11. Valve type

    Several types of MKS valves can be operated by the 946 to control the system pressure. Valve type allows selection of the valve type.

12. Screen Saver

    Screen saver turns OFF the front panel display. The front panel display can be re-activated by pressing any button on the front panel. The value of the screen saver is the time in minutes (1 to 254) for time of inactivity after which the screen saver is activated. To disable this function, set the value to zero. Remote operations are not affected by the Screen Saver setting. Default setting is OFF (0).

13. Combination Setup

Two analog output combination channels are available on the 946. Up to 3 vacuum pressure sensors can be assigned to each combination channel. Refer to section 8.4 for a more detailed discussion of the settings for the combination channels.

14. Set DAC Parameter

Scaling of the Log/Linear analog output for each individual channel, as well as the combination analog output can be changed by adjusting the DAC parameter. To view or modify the DAC parameter, press [System Setup] and move the cursor to Set DAC Parameter. Select Edit and press [Enter] and the DAC parameters used in scaling the logarithmic/linear analog output are displayed as shown in Figure 6-5.

Both values for slope A and offset B must be selected when a logarithmic linear equation is used. The slope A is the voltage per decade, and the offset B is the voltage when the pressure is 1 Torr. The valid range for A is from 0.5 to 5, while the valid range for B is from –20 to +20 V. The default settings are 0.6 and 7.2 for A and B, respectively, which provides for a 0.6 to 9.6 Volt output over the maximum pressure range covered by the Controller. If a single channel module is present in (HC or CC), only one equation is displayed (Channel A example in Figure 6.6).

Linearized analog output can be used when high analog output resolution is required over a narrow pressure range. When a linear equation is used, the parameter B is always set to zero as it indicates zero voltage output at high vacuum. The A value can be calculated using the equation:

$$A = \frac{10}{P_{max}}$$

Here, P_{max} is the maximum pressure (or the flow rate for an MFC) when analog output voltage is 10 V. For a Capacitance Manometer, the full range of the Manometer is normally selected for P_{max}. For example, if a 1000 Torr manometer is connected (P_{max}=1000), 1×10^{-2} should be selected for A, while for a 20 SCCM MFC (P_{max}=20), 5×10^{-1} should be used. For other types of gauges (such as CC, HC, PR, CP), linear analog output can be used to magnify the analog out over a special range. For example, if the pressure range from 10 to 10^{-1} Torr needs higher resolution, (P_{max}=10), a value of 1 can be selected for A which results in 10 V analog output at 10 Torr.

Set DAC Parameter (P unit is torr in Eq)

	Equation	A	B
Channel A1	V=AlogP+B	6.00E-1	7.20E+0
Channel A2			
Channel B1	V=AP	1.00E+2	
Channel B2	V=AlogP+B	6.00E-1	7.20E+0
Channel C1	V=AlogP+B	6.00E-1	7.20E+0
Channel C2	V=AP	1.00E+3	
Combined	V=AlogP+B	6.00E-1	7.20E+0

Figure 6-5 Setting DAC Logarithmic and Linear Analog Output [10]

[10] To keep the analog output unaffected by the pressure unit change, the pressure unit in these equations is fixed to Torr.

When selecting A from the front panel, only multiples of 1, 2, and 5 are allowed. Following are some examples for A corresponding to P_{max}.

P_{max}	1×10^{-3}	2×10^{-3}	5×10^{-3}	1×10^{-2}	1×10^{2}	2×10^{2}	5×10^{2}	1×10^{3}	1.5×10^{3}
A	1E+4	5E+3	2E+3	1E+3	1E-1	5E-2	2E-2	1E-2	8.4E-3

If a 10V linear output is needed at a pressure different from that given above, it can be entered via serial communication using the DLAn and DLT commands outlined in Section. 9.14.

15. FV (firmware version) Information

    The firmware version for all of the modules installed in the 946 is displayed when Display is selected. The serial numbers for all detected boards are also displayed, as shown in Figure 6-6.

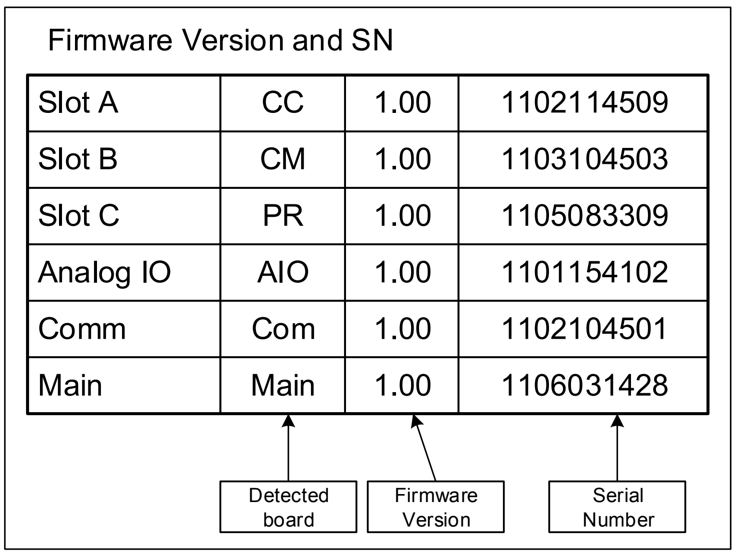


Figure 6-6 System Firmware and Serial Number Information Displayed

16. Display format

    Display format allows selection of the front panel display format. There are three options: Default, PatchZ, and HighR.

    Default format: only significant digits are displayed.

    PatchZ format: Zero(s) will be patched to enable 4-digit display for CM, and 3 digit display for CC or HC and Pirani or Convection Pirani.

    HighR format will display extra digit for CC and HC which may assist to identify pressure changes.

6.5 Channel Setup for Pressure Measurement

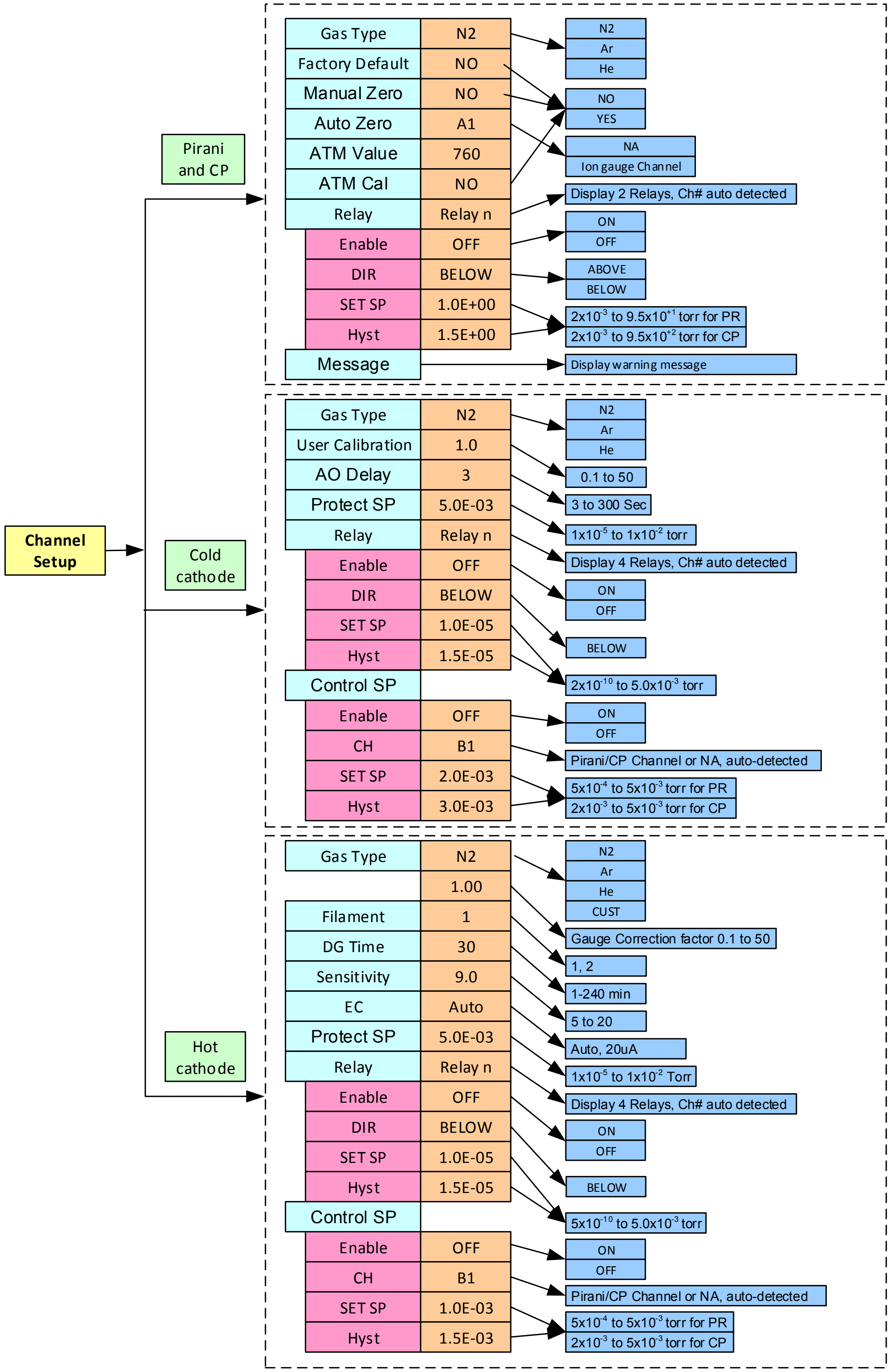
6.5.1 Overview of 946 Channel Setup

Front panel setting of the parameters associated with devices connected to the 946 Controller such as calibration, gas selection, relay set point, control set point, and control channel selection are accomplished using Channel Setup.

Figure 6-7 shows the channel setup parameters for all of the sensors and devices operated by the 946 controller. The default values are shown in the brown boxes while the ranges for setup are shown in the blue boxes. The 946 automatically shows the parameters available for the sensor in operation on the channel selected.

To perform a Channel Setup:

- Select the desired channel by pressing either ▲ or ▼ on the front panel until the green LED on the left side of the display is aligned with the desired channel.
- Once the channel (sensor) is selected, the setup panel is displayed by pressing Channel Setup. The ◀ ▶ ▲ ▼ keys are used to select the parameter to be changed.
- Press Enter to highlight the parameter value, then press either ▲ or ▼ to change the parameter value.
- Press Enter to save the new value.



Channel Setup
Pirani and CP
Gas Type
N2
Factory Default
NO
Manual Zero
NO
Auto Zero
A1
ATM Value
760
ATM Cal
NO
Relay
Relay n
Enable
OFF
DIR
BELOW
SET SP
1.0E+00
Hyst
1.5E+00
Message
N2
Ar
He
NO
YES
NA
Ion gauge Channel
Display 2 Relays, Ch# auto detected
ON
OFF
ABOVE
BELOW
2x10-3 to 9.5x10+1 torr for PR
2x10-3 to 9.5x10+2 torr for CP
Display warning message
Cold cathode
Gas Type
N2
User Calibration
1.0
AO Delay
3
Protect SP
5.0E-03
Relay
Relay n
Enable
OFF
DIR
BELOW
SET SP
1.0E-05
Hyst
1.5E-05
Control SP
Enable
OFF
CH
B1
SET SP
2.0E-03
Hyst
3.0E-03
N2
Ar
He
0.1 to 50
3 to 300 Sec
1x10-5 to 1x10-2 torr
Display 4 Relays, Ch# auto detected
ON
OFF
BELOW
2x10-10 to 5.0x10-3 torr
ON
OFF
Pirani/CP Channel or NA, auto-detected
5x10-4 to 5x10-3 torr for PR
2x10-3 to 5x10-3 torr for CP
Hot cathode
Gas Type
N2
1.00
Filament
1
DG Time
30
Sensitivity
9.0
EC
Auto
Protect SP
5.0E-03
Relay
Relay n
Enable
OFF
DIR
BELOW
SET SP
1.0E-05
Hyst
1.5E-05
Control SP
Enable
OFF
CH
B1
SET SP
1.0E-03
Hyst
1.5E-03
N2
Ar
He
CUST
Gauge Correction factor 0.1 to 50
1, 2
1-240 min
5 to 20
Auto, 20uA
1x10-5 to 1x10-2 Torr
Display 4 Relays, Ch# auto detected
ON
OFF
BELOW
5x10-10 to 5.0x10-3 torr
ON
OFF
Pirani/CP Channel or NA, auto-detected
5x10-4 to 5x10-3 torr for PR
2x10-3 to 5x10-3 torr for CP

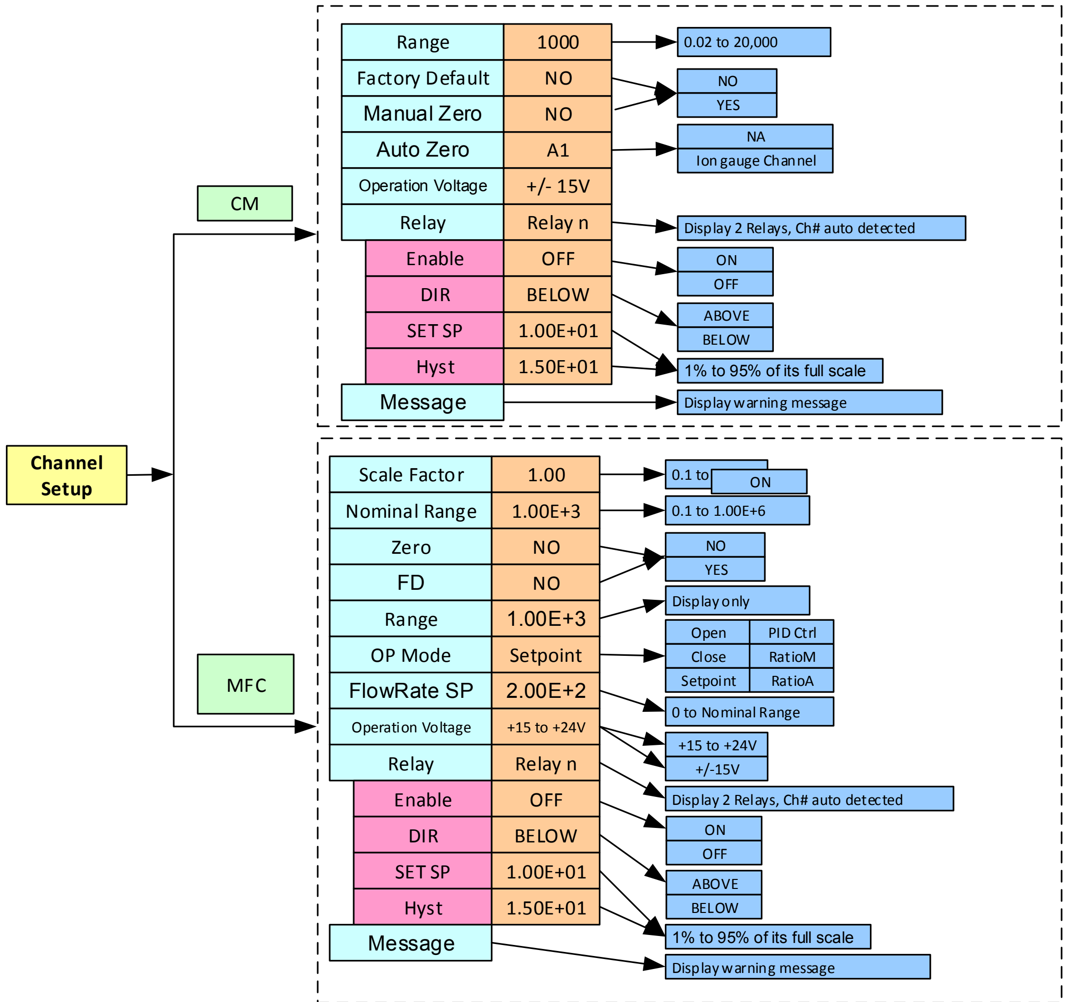


Figure 6-7 946 Channel Setup Setting Parameters, their Default Values and Ranges

6.5.2 Setup for a Capacitance Manometer

A capacitance manometer module will be automatically detected on power-up. At the same time, the connection of the capacitance manometer to the module will be checked. If no capacitance manometer is connected, - - - - will be displayed. A CM module operates up to two Capacitance Manometers, and the total combined current requirement of operating sensor(s) must be 1 amp or less.

Refer to Figure 6-8 in setting up a capacitance manometer.

1. CM Type

   ABS (absolute) can be selected.

2. Input Voltage

   The Input Voltage for the controller is same as the maximum analog output voltage of the capacitance manometer. To select, move the cursor to the Input Voltage box, press (Enter), and to highlight the parameter. Use either (▲) or (▼) to select the correct voltage. Press (Enter) to save the setting, either 10 or 5 V.

3. Range

The full-scale pressure range of the capacitance manometer in use needs to be set. Capacitance manometers with full scale (ranges) from $1x10^{-2}$ to $1x10^{+4}$ Torr can be operated. Only 3 selections are available in each decade (1, 2, and 5), except between 1,000 to 10,000 Torr where 1500 Torr is allowed.

For a Manometer with pressure unit other than Torr (such as 1000 mBar full scale), change the controller pressure unit to match the pressure unit of the manometer (such as mBar) before selecting the appropriate range.

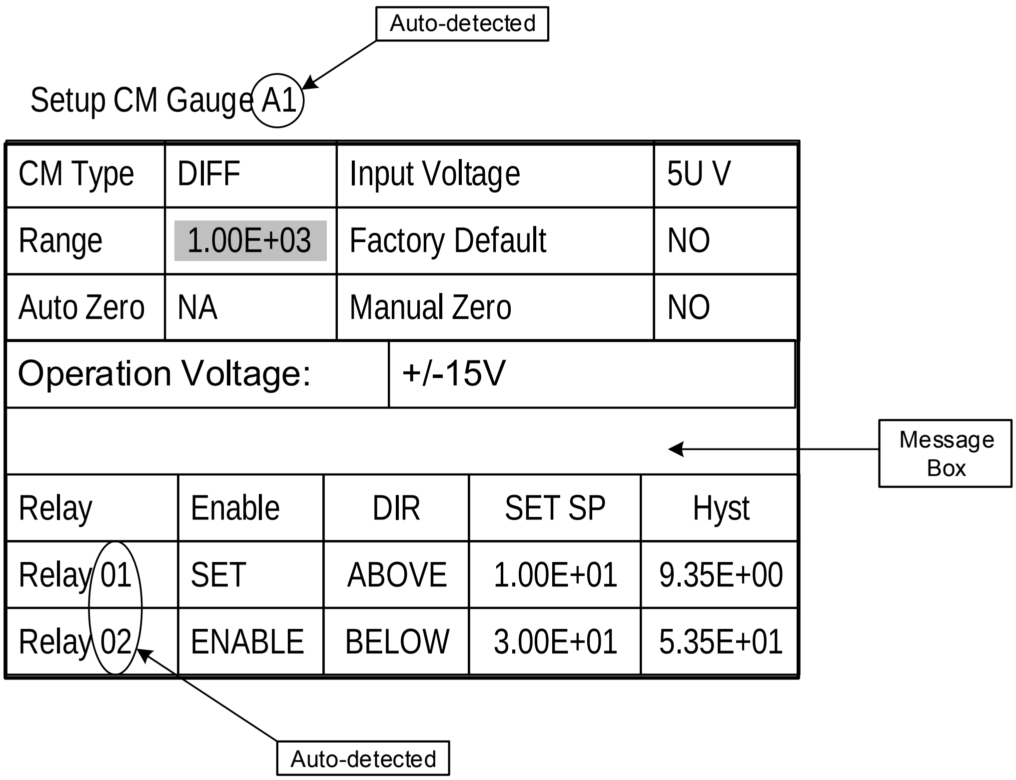


Figure 6-8 Capacitance Manometer Setup Information Screen

4. Factory Default

When YES is selected and entered for Factory Default, any Manual Zero data is removed.

5. Auto Zero

This selects a sensor for autozeroing of the capacitance manometer. Suitable sensors and their channels are autodetected. NA which can be selected if Auto Zero is not required.

The Auto Zero will be executed only when:

(1) System pressure is less than $10^{-5}xP_{FS}$ (5 decades lower than the full scale)

(2) The CM reading is between $5x10^{-4}xP_{FS}$ and $0.05xP_{FS}$ (0.05% to 5% of the full scale)

When a Capacitance Manometer has been zeroed, a U will be displayed under the gauge type indicator (CM) of the zeroed channel to indicate this.

Table 6-1 shows the valid gauges that can be used for autozeroing based on the full-scale rating of the capacitance manometer.

Full scale of CM	CP	PR	CC	HC
≥ 1000 Torr	Yes	Yes	Yes	Yes
100 Torr	No	Yes	Yes	Yes
≤ 20 Torr	No	No	Yes	Yes

Table 6-1 Valid Gauges for Autozeroing Capacitance Manometers

☞ **The Capacitance Manometer and the reference auto-zero sensor must be connected to the same chamber at all times.**

6. Manual Zero

   This allows for manual zeroing of the CM from the front panel. To perform a manual zero, highlight the 'NO' in the box after Manual Zero, and then change to 'YES' with the up/down keys and push ENTER. The indicator will change to 'NO', but a U will be displayed under the gauge type indicator (CM) to indicate that it is user zeroed.

   For accurate zeroing, the system pressure must be less than $10^{-5}xP_{FS}$ (5 decades less than the full scale). The Manual Zero function will abort if the overall offset is greater than 5% of the full-scale.

7. Operation Voltage

   The operation voltage from the 946 is fixed at +/-15 Volts. This limits the selection of capacitance manometers to only those requiring +/-15 Volts operating power.

8. Relay

   Each capacitance manometer channel has two preassigned relays as shown below. The controller auto-detects the correct relays corresponding to where the sensor module is installed.

Sensor location	A1	A2	B1	B2	C1	C2
Relay assigned	1 & 2	3 & 4	5 & 6	7 & 8	9 &10	11 & 12

9. Enable

   There are three 'ENABLE' settings available for a relay:

   a. SET: forces the relay to stay in the activated (closed) state regardless of pressure and set point values

   b. CLEAR: forces the relay to stay in the deactivated (open) state regardless of pressure and set point values.

   c. ENABLE: the relay status is determined by the pressure, set point value, and direction.

10. DIR

   DIR determines when the relay is activated. If ABOVE is selected, the relay will be activated when the pressure is above (greater than) the set point. If BELOW is selected, the relay will be activated when the pressure is below (less than) the set point. The default setting for DIR is BELOW.

   See Figure 8-1 and Section 8.2 for a more detailed description of the DIR setting.

11. SET SP displays the entered and saved setpoint trip value. To change the value, scroll to the value to be changed, highlight by pressing **Enter**, and then adjust to the desired value with the ▲ or ▼ keys. Confirm the change by pressing **Enter**. The range is 1% to 95% of the manometer's full scale. When entering the value, the speed of the value change can be increased by continuously pressing the ▲ or ▼ key.

12. Hyst

    When a set point value is changed, the hysteresis value will be changed automatically. If DIR is set to ABOVE, the hysteresis is automatically set to 0.9xSet point; if DIR is set to BELOW, the hysteresis is automatically set to 1.1xSet point.

    To modify the hysteresis, move the cursor to the hysteresis value and press Enter. Use the ▲ or ▼ key to change the value, then press Enter again to set the value. When DIR has been set to ABOVE, the maximum hysteresis value permitted for a Capacitance Manometer is 0.99xSet point; when DIR is set to BELOW, the minimum hysteresis value is 1.01xSet point.

6.5.3 Setup for a CP (Convection Pirani), Convectron, or PR Sensor

⚠ Do not use Convection Pirani or Convectron gauges above 1000 Torr true pressure. Series 946 Controllers are furnished calibrated for N_2. They also measure the pressure of air correctly within the accuracy of the instrument. Do not attempt to use a Convection Pirani or Convectron gauge calibrated for N_2 to measure or control the pressure of other gases such as argon or CO_2, unless the gas type setting or accurate conversion data for N_2 to the other gas is properly used. If accurate conversion data is not used or improperly used, a potential overpressure explosion hazard can be created under certain conditions.

For example, at 760 Torr of argon gas pressure, the indicated pressure on a Convection Pirani or Convectron gauge calibrated for N_2 is 24 Torr. At an indicated pressure of 50 Torr, the true pressure of argon is considerably above atmospheric pressure. Thus if the indicated pressure is not accurately converted to true pressure, it is possible to overpressure the vacuum system. Overpressure may cause glass components to shatter dangerously, and if high enough may cause metal parts to rupture thus damaging the system and possibly injuring personnel. Read this Section for proper use of conversion data.

A pressure relief valve should be installed in the system if the possibility of exceeding 1000 Torr exists. For some gases, be aware the indicated pressure will be higher than the true pressure. For example, at a true pressure of 9 Torr for helium the indicated pressure on a Convectron gauge calibrated for N_2 is 760 Torr. The safe way to operate the gauge is to properly use accurate conversion data.

Refer to Figure 6-9 for setting up a Pirani or Convection Pirani sensor.

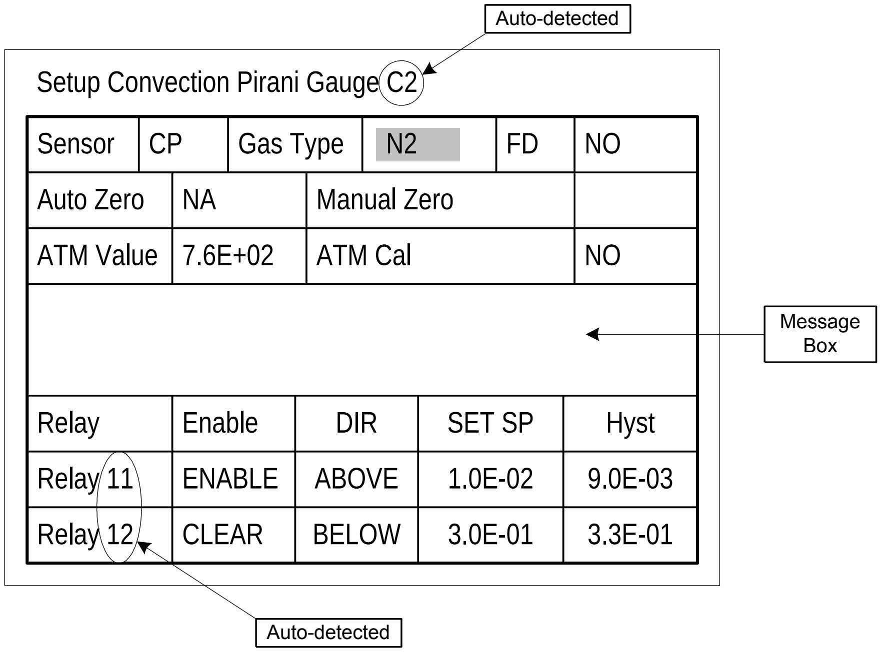


Figure 6-9 Pirani/Convention Pirani Setup Information Screen

1. Sensor

   The Sensor Type (Convection Pirani or Pirani) is often auto-detected during the initial power up. If the sensor type is auto-detected, the sensor type cannot be changed from the front panel. Should the auto-detect fail, the sensor type can be selected manually, and stored in the memory. This information will be used as the default sensor type if sensor power is cycled.

   Note that a Sensor ON/OFF sequence should be performed after manually entering the gauge type.

2. Gas Type

   Select the gas type by moving the cursor to the Gas Type box and pressing (Enter) key. Use the (▲) or the (▼) keys to select the gas type being used with the sensor. Three gas types (N_2, Ar and He) can be selected. The default setting is N_2 which is also used for air.

3. FD (Factory Default)

   When YES is selected and entered for Factory Default, any Manual Zero and ATM Cal values are removed and the Zero and ATM values restored to the factory default ones.

   A small **U** under the sensor type indicator (PR or CP) on the front panel LCD display will be removed when default values are restored.

4. Auto Zero

   Use the (▲) or the (▼) keys to select a valid gauge for autozeroing the Pirani (PR) or Convection Pirani (CP). Only cold or hot cathode sensors can be used as the zero reference.

   The zero will be executed only when:

   (1) The system pressure per the CC/HC is less than $1X10^{-5}$ Torr ($1x10^{-6}$ Torr for the PR).

   (2) The Convection Pirani (or PR) reading is lower than $1x10^{-2}$ Torr.

☞ **Ensure that the Convection Pirani/PR and the reference auto-zero CC/HC sensor are connected to the same chamber at all times.**

5. Manual Zero

   The Convection Pirani or Pirani sensor can be manually zeroed. To do this, select YES in the box next to Manual Zero and then push **ENTER**. A small **U** will appear under the sensor identifier on the main display. Ensure that the system pressure is less than$1x10^{-5}$ Torr ($1x10^{-6}$ Torr for PR) before executing a Manual Zero. The Manual Zero function will abort if the overall offset is over $1x10^{-2}$ Torr.

6. ATM Value

   The entered value is used for the atmospheric reading of the Pirani/CP when an ATM Cal is performed. The default value is 760 Torr. Recall that elevation and weather will affect local atmospheric pressures.

7. ATM Cal

   To perform an ATM Cal, after entering the ATM Value above, select YES in the box next to ATM Cal and then push **ENTER**. The ATM Value will be used as the reference pressure for the ATM reading. A small **U** will appear under the sensor identifier on the main display.

8. Relay

   Each CP/Convectron/Pirani channel has two preassigned relays as shown below. The controller auto-detects the correct relays corresponding to where the sensor module is installed.

Module location	A1	A2	B1	B2	C1	C2
Relay assigned	1 & 2	3 & 4	5 & 6	7 & 8	9 &10	11 & 12

9. Enable

   There are three ‘ENABLE’ settings available for a relay:

   - SET: forces the relay to stay in the activated (closed) state regardless of pressure and set point values
   - CLEAR: forces the relay to stay in the deactivated (open) state regardless of pressure and set point values.
   - ENABLE: the relay status is determined by the pressure, set point value, and direction.

10. DIR

    DIR determines when the relay is activated. If ABOVE is selected, the relay will be activated when the pressure is above (greater than) the set point. If BELOW is selected, the relay will be activated when the pressure is below (less than) the set point. The default setting for DIR is BELOW.

    See Figure 8-1 and Section 8.1.2 for more a detailed description of the DIR setting.

11. SET SP

    SET SP displays the entered and saved setpoint trip value. To change the value, scroll to the value to be changed, highlight by pressing **Enter**, and then adjust to the desired value with the ▲ or ▼ keys. Confirm the change by pressing **Enter**. The set point pressure can be between $2x10^{-3}$ to $9.5x10^{+2}$ Torr for Convection Pirani sensors and $2x10^{-3}$ to $9.5x10^{+1}$ Torr for Pirani sensors. The speed of the value change can be increased by continuously pressing the ▲ or ▼ key.

12. Hyst

    When a set point value is changed, the hysteresis value will be changed automatically. If DIR is set to ABOVE, the hysteresis will automatically be set to 0.5xSet point; if DIR is set to BELOW, the hysteresis is automatically set to 1.5xSet point.

    To modify the hysteresis, move the cursor to the hysteresis value, press **Enter** and use the ▲ or ▼ keys to change the value, then press **Enter** again to set the value. The maximum hysteresis value permitted for PR/CP gauges is 0.9xSetpoint when DIR is set to ABOVE; the minimum hysteresis is 1.1xSet point when DIR is set to BELOW.

13. Power Control of a Convection Pirani or Pirani Sensor

    Pirani or Convection Pirani gauges can be turned ON or OFF using the Power ON/OFF key.

    Note that when a pyrophoric gas is encountered (such as during the degeneration of a cryo pump), it is strongly recommended that the power of the Pirani, CP or Convectron be turned OFF to avoid any potential for ignition of the gas.

    The power to these sensors should also be turned OFF when the sensor's cables are disconnected to avoid any potential for sensor damage. "Hot Swaps" should be avoided.

    If the power for a Pirani or Convection Pirani is turned OFF while it is controlling (in either AUTO or SAFE) a hot or cold cathode sensor, the HC or CC will be switched OFF immediately. To avoid this it is recommended to disable the control of the HC or CC sensor first before powering OFF a Convection Pirani or Pirani sensor.

    When the power to a CP, Convectron, or Pirani sensor is turned ON, a time delay is added before activating control or relay setpoints. This helps to avoid turning ON a controlled hot or cold cathode sensor at high pressure due to any transient and inaccurate pressure indication that may occur during the power-up.

6.5.4 Setup a Cold Cathode Sensor

Refer to Figure 6-10 for the Cold Cathode Sensor set up screen.

1. Gas Type (GT)

   To change the gas type, move the cursor to the **GT** box, press **Enter**, then use the ▲ or ▼ keys to select the gas type in use with the sensor. Three gas types (N_2, Ar, and He) can be selected.

2. User Input Calibration Gas Correction Factor (U Cal)

   This allows the entering of different correction factors for Cold Cathode sensors. This is useful, when the calibration gas used is not one of these listed above (N_2, Ar or He). The valid range is 0.1 to 50, and the default setting is 1.0.

   To change the Gas correction factor, scroll to the box after UCal and highlight the value by pressing **Enter.** Use the up and down keys to select the desired value. Then press **Enter** to save the new value.

Setup CC Gauge A1

GT	N2	U Cal	1.0E+00	AO Delay	3
Fast Relay SP		1.0E-05		Prot SP	5.0E-03
Relay	Enable	Dir/Ch	SET SP	Hyst	
Relay 01	SET	BELOW	1.0E-06	9.0E-07	
Relay 02	CLEAR	BELOW	3.0E-05	3.3E-05	
Relay 03	ENABLE	BELOW	2.0E-08	1.8E-09	
Relay 04	CLEAR	BELOW	5.0E-07	5.5E-07	
Control SP	AUTO	B1	1.0E-03	1.2E-03	

Figure 6-10 Cold Cathode Setup Information Screen

3. AO Delay

The Analog Out (**AO**) Delay function prevents the activation of the Cold Cathode sensor's set point relays on sensor power up, maintaining their outputs in the OFF state, until the delay has expired. The delay can be adjusted from 3 to 300 seconds and the default value is 3 seconds. When the AO delay is active, WAIT will be displayed on the front panel rather than a pressure reading.

To change the AO Delay scroll to the box after AO Delay and highlight the value by pressing **Enter**. Use the up and down keys to select the desired value. Then press **Enter** to save the new value.

4. Fast Relay SP

Note: FAST relay SP is available only when the special cold cathode module with fast control output (CL) is installed.

For fast protection of a vacuum system such as closing a valve rapidly, a special cold cathode control module with a fast logic output is available. The response time is typically less than 15 msec. This fast control is achieved by comparing the buffered analog output signal with an internal DAC output determined by the Fast Relay SP value entered or set via a serial command. The comparator controls an opto-isolated solid state relay, which enables the fast control of an external device. When installed, the control set point for this fast relay is set via the Fast Relay SP parameter. The hysteresis is approximately 15% of the set point value. The relay will be re-energized when the system pressure is 15% below the set point.

5. Protect SP

The Protect Set Point feature will turn OFF the Cold Cathode high voltage at the specified pressure. The Protect Set point range for a Cold Cathode is 1.0×10^{-5} Torr to 1.0×10^{-2} Torr. The default value is 5.0×10^{-3} Torr. It can be disabled by continuing to press ▲ key when the set point value reaches 1.0×10^{-2} Torr.

Once the Protect Set Point is triggered and the sensor turned OFF, the auto control via the Control SP is disabled. The gauge can only be turned back on manually or by serial command. When control mode is used, the Control SP should be set to a pressure lower than the Protect Setpoint to ensure the cold cathode is controlled by the higher pressure sensor. Tripping of the Protect Set Point may indicate that the control set point is not functioning properly, such as due to a control sensor malfunction or both sensors not being connected to the same volume.

6. Relay

   Each Cold Cathode module has four preassigned relays as shown below. The controller auto-detects the correct relays corresponding to where the CC module is installed.

Module location	A1	B1	C1
Relay assigned	1 & 2 & 3 & 4	5 & 6 & 7 & 8	9 &10 & 11 & 12

7. Enable

   There are three ways to set a relay:

   - SET: forces the relay to stay in the activated (closed) state regardless of pressure and set point values
   - CLEAR: forces the relay to stay in the deactivated (open) state regardless of pressure and set point values.
   - ENABLE: the relay status is determined by the pressure, set point value, and direction.

8. DIR

   The DIR (Direction) for relays actuated by a cold cathode are permanently set to BELOW. Thus the relays are closed whenever the pressure is below the set point.

   See Figure 8-1 and Section 8.1.2 for more a detailed description of the direction setting.

9. SET SP

   SET SP displays the entered and saved setpoint trip value. To change the value, scroll to the value to be changed, highlight by pressing **Enter**, and then adjust to the desired value with the ▲ or ▼ keys. Confirm the change by pressing **Enter**. The set point pressure can be between $2x10^{-10}$ to $5x10^{-3}$ Torr. When entering the value, the speed of the value change can be increased by holding the ▲ or ▼ arrow key.

10. Hyst

    When a set point value is changed, the hysteresis value will automatically be changed. Since the direction is always set to BELOW for Cold Cathode sensors, the hysteresis will be automatically set to 1.5x setpoint.

    To modify the hysteresis, move the cursor to the hysteresis value and press **Enter**. Use the ▲ or ▼ key to change the value, then press **Enter** again to set the value. The minimum hysteresis value for a Cold Cathode is 1.1xSet point; DIR is set to BELOW at all times.

11. Control SP

    The Control Setpoint is used to turn the Cold Cathode sensor on or off with a higher pressure sensor, typically a Convention Pirani, Convectron or a Capacitance Manometer (must be ≤2 Torr full scale). This prevents the cold cathode from operating at high pressure, extending the service life. The adjustable Control SP range depends upon the sensor used for control.

2×10^{-3} to 1×10^{-2} Torr for a Convection Pirani or Convectron sensor
5×10^{-4} to 1×10^{-2} Torr for a Pirani
0.2% of full scale to 2×10^{-2} Torr for capacitance manometer (must be ≤2T f.s.)

The default Control Set Point value is 5×10^{-3} Torr. Extended operation of the cold cathode at higher pressures will shorten the CC sensor's lifetime.

☞ **When the power to a PR/CP used as a control sensor is turned off, or the cable is unplugged, the CC will be turned off if the control setpoint is enabled.**

☞ **When a capacitance manometer (must be ≤2T f.s.) is used to control a cold cathode sensor, it is recommended to enable the AUTOZERO of capacitance manometer as a zero shift of the manometer may cause the control function to occur a higher actual pressure, possibly damaging sensor.**

☞ **The 1×10^{-2} Torr upper limit can be extended to 9.5×10^{-1} Torr by using a @254XCS!ON;FF serial command in special situations such as when the PR/CP/CM and CC are installed at different locations. For example, when the PR/CP/CM is installed on the foreline between the mechanical and turbo pumps monitoring the mechanical pump pressure, and the CC is installed on the high vacuum chamber.**

To set the Control SP, first select the control channel in the box under the Dir/Ch heading. Once an allowed channel has been selected, the Control SP can be enabled. There are three choices:

- AUTO: The high voltage for a cold cathode is controlled solely and automatically by the controlling sensor. In **AUTO** it will be tuned both ON and OFF by the control sensor as appropriate. However, if the protection set point is triggered, the auto control will be disabled, and the CC sensor can then only be turned ON manually.
- SAFE: The high voltage for a cold cathode sensor will be automatically turned off by the controlling sensor and remain **OFF** until the CC is turned ON manually.
- OFF: The Cold Cathode must be turned ON/OFF manually. Even if a control channel is selected, the CC will not be turned ON or OFF.

6.5.5 Setup a Hot Cathode Sensor

Refer to Figure 6-11 in setting up a Hot Cathode Sensor.

1. Gas Type

To change the gas type, move the cursor to the **GT** box, press **ENTER**, and use the ▲ or ▼ key to select the gas type in use with the sensor. Four gas types (N_2, Ar, He and **Custom**) can be selected.

When N_2, Ar, and He are selected, the corresponding gas correction factor is displayed on the right-hand side of the **Gas Type** box, and this value cannot be modified. However, when **Custom** is selected, a customized gas factor can be entered, ranging is from 0.1 to 50.

Relative sensitivities shown in Table 6-2 may be used to determine the gas factor if the type of gas inside the vacuum chamber is known.

The gas factor G_f is given by $G_f = 1/R_S$

2. Filament

Indicates the filament in use. The choices are 1 or 2.

Setup HC Gauge A1

Gas Type	N2	1.0	Filament	1
DG Time	30	Sensitivity		9.0
EC	20 uA	Protect Setpoint		5.0E-03
Relay	Enable	Dir/Ch	SET SP	Hyst
Relay 01	SET	BELOW	1.0E-06	9.0E-07
Relay 02	CLEAR	BELOW	3.0E-05	3.3E-05
Relay 03	ENABLE	BELOW	2.0E-08	1.8E-09
Relay 04	CLEAR	BELOW	5.0E-07	5.5E-07
Control SP	SAFE	B1	1.0E-03	1.2E-03

Figure 6-11 Hot Cathode Setup Information Screen

Gas	*Symbol*	*Relative correction factor to N_2*
Air		1.00
Argon	Ar	1.29
Carbon Dioxide	CO_2	1.42
Deuterium	D_2	0.35
Helium	He	0.18
Hydrogen	H_2	0.46
Krypton	Kr	1.94
Neon	Ne	0.30
Nitrogen	N_2	1.00
Nitrogen Oxide	NO	1.16
Oxygen	O_2	1.01
Sulfur Hexafluoride	SF_6	2.50
Water	H_2O	1.12
Xenon	Xe	2.87

Table 6-2 Relative Sensitivities (to N_2) for Different Gases

3. DG Time

Length of time for a degas cycle of a hot cathode sensor. The value can be set from 5 to 240 minutes in 1 minute increments. The default value is 30 min.

4. Sensitivity

The sensitivity value in use with the hot cathode is displayed. For a definition of sensitivity, see section 11.3.1.

Nominal Sensitivity values are 9 $Torr^{-1}$ for the MKS Low Power Nude sensor, and 12 $Torr^{-1}$ for the Mini BA sensor. These values will be automatically selected based on the type of sensor detected on power up, if no user-defined sensitivity value has been stored. Sensitivity values from 1 to 50 $Torr^{-1}$ can be entered from the front panel or over communications.

Once a user-defined sensitivity is saved, this value will become the default value when powering up the same type of hot cathode.

If a sensitivity is entered without a hot cathode being connected, this user-defined sensitivity value will be saved as the default sensitivity for all the HC sensor types.

5. EC

The Emission Current can be set to 20 uA, 100 uA, Auto20, or Auto100. When Auto 20 or Auto100 is selected, the emission current is either 20 uA or 100 uA when the pressure is higher than $1x10^{-4}$ Torr, and automatically switched to 1 mA when pressure is below $1x10^{-4}$ Torr.

6. Protect SP

The Protect Set Point is turns off the hot cathode operating voltages based on its own pressure readings. The Protect Setpoint is always enabled on the 946, but can be set within the range $1.0x10^{-5}$ Torr to $1.0x10^{-2}$ Torr.

☞ **Once the Protect Set Point is triggered and the sensor turned OFF, the auto control via the Control SP is disabled. The gauge can only be turned back ON manually or by serial command. When control mode is used, the Control SP should be set to a pressure lower than the Protect Setpoint to ensure the hot cathode is controlled by the higher pressure sensor. Tripping of the Protect Set Point may indicate that the control set point is not functioning properly, such as due to a control sensor malfunction or both sensors not being connected to the same volume.**

7. Relay

Each Hot Cathode module has four preassigned relays as shown below. The controller auto-detects the correct relays corresponding to where the HC module is installed.

Module location	A1	B1	C1
Relay assigned	1 & 2 & 3 & 4	5 & 6 & 7 & 8	9 &10 & 11 & 12

8. Enable

There are three ways to enable a relay:

- SET: force the relay to activate (close) regardless of pressure and set point values
- CLEAR: force the relay to deactivate (open) regardless of pressure and set point values.
- ENABLE: relay status is determined by the pressure, set point value, and direction.

9. DIR

To prevent the Hot Cathode from being turned ON at high pressure, the DIR for a Hot Cathode is permanently set to BELOW.

Refer to Figure 8-1 and Section 8.1.2 for a more detailed description of the direction setting.

10. SET SP

SET SP displays the entered and saved setpoint trip value. To change the value, scroll to the value to be changed, highlight by pressing **Enter**, and then adjust to the desired value with the ▲ or ▼ keys. Confirm the change by pressing **Enter**. The set point pressure can be between $5x10^{-10}$ to $5x10^{-3}$ Torr. When entering the value, the speed of the value change can be increased by holding the ▲ or ▼ arrow key while changing the value.

11. Hyst

When a set point value is changed, the hysteresis value will be changed automatically. Since the direction is set to BELOW for the Hot Cathode sensor only, the hysteresis will automatically be set to 1.5x Set point.

To modify the hysteresis, move the cursor to the hysteresis value, press **Enter**, use the ▲ or ▼ key to change the value, and press **Enter**. to set the value. The minimum allowed hysteresis for the Hot Cathode is1.1xSet point when direction is set to BELOW.

12. Control SP

The Control set point is used to turn the Hot Cathode ON or OFF with a higher pressure sensor, typically a Convention Pirani, Convectron, or a Capacitance Manometer (must be ≤2 Torr full scale). This prevents the hot cathode from operating at high pressure, extending the service life. The adjustable Control SP range depends upon the sensor used for control:

- $2x10^{-3}$ to $1x10^{-2}$ Torr for a Convection Pirani or Convectron
- $5x10^{-4}$ to $1x10^{-2}$ Torr for a Pirani
- 0.2% of full scale to $2x10^{-2}$ Torr for a Capacitance Manometer (≤2T full scale)
- The default control set point value is $5x10^{-3}$ Torr. Extended operation of the Hot Cathode at higher pressures will shorten the HC sensor's lifetime

When the power to a PR/CP used as a control sensor is turned OFF, or the cable is unplugged, the HC will be turned off if the control setpoint is enabled.

The $1x10^{-2}$ Torr upper limit can be extended to $9.5x10^{-1}$ Torr by using a @254XCS!ON;FF serial command in special situations such as when the PR/CP/CM and HC are installed at different locations. For example, when the PR/CP/CM is installed on the foreline between the mechanical and turbo pumps monitoring the mechanical pump pressure, and the HC is installed on the high vacuum chamber.

When a capacitance manometer (must be ≤2T f.s.) is used to control a Hot Cathode, it is recommended to enable the AUTOZERO of capacitance manometer as a zero shift of the manometer may cause the control function to occur a higher actual pressure, possibly damaging the sensor.

To set the Control SP, first select the control channel in the box under the Dir/Ch heading. Once an allowed channel has been selected, the Control SP can be enabled. There are three choices. Three choices are available:

- AUTO: The filament for a hot cathode is controlled solely and automatically by the controlling sensor. In **AUTO** it will be tuned both ON and OFF by the control sensor as appropriate. However, if the protection set point is triggered, the auto control will be disabled, and the HC sensor can then only be turned ON manually.

- SAFE: The filament for a Hot Cathode sensor will be automatically turned OFF by the controlling sensor, but the HC can be turned ON manually.
- OFF: The Hot Cathode must be turned ON/OFF manually. Even if a control channel is selected, the HC will not be turned ON or OFF.

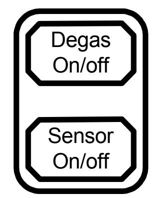
6.6 Power Control of a Pressure Sensor

If flammable or explosive gas is used or present (such as during a regeneration of a LN_2 cooled cold trap), the Convection Pirani, Convectron or Pirani sensor must be turned OFF to avoid potential explosion.

Only the Pirani (PR), the Convectional Pirani (CP), the Cold cathode (CC) and the Hot Cathode (HC) can be turned off from the front panel.

6.6.1 Power (including degas) Control of a Sensor using Front Panel Control Button

To turn ON or OFF a sensor (PR/CP/CC/HC) using the front panel button:



1. Use the ▲ or the ▼ keys to select the desired sensor (PR/CP/CC/HC) to be turned ON or OFF. The active channel (sensor) is indicted by the illuminated green LED to the left of the sensor's displayed pressure.
2. For either a cold or Hot Cathode sensor, make sure it is not controlled automatically by another sensor. If it is in the AUTO control mode, disable the control set point before using the front panel key to switch the sensor.
3. The **Sensor ON/OFF** key switches the corresponding sensor ON and OFF.

☞ **When a Hot Cathode is turned ON, the filament power may turn OFF automatically if the pressure is higher than the protection set point.**

When Cold Cathode sensors are turned on at very low pressures, the sensor may take time to start as the discharge current does not build up immediately.

Prolonged operation of cold cathode sensors at higher pressures will degrade their performance due to sputtering inside the cell reducing the operating service time before cleaning. Additionally, operation at pressures above $5x10^{-1}$ Torr can result in the sensor falsely indicating a much lower pressure. This phenomenon is called rollback, and is due to high concentrations of charge particles making gas conductive at high pressure. With the protect set point feature, the possibility of operating in 'rollback' is minimized.

Operation of Hot Cathode sensors at high pressure may lead to filament burnout. For this reason, the Protection Set Point is always enabled for HC sensor so they are automatically turned OFF once pressure exceeds the protection set point.

To turn ON/OFF the degas for a hot cathode gauge; the procedure is almost identical to the sensor power control, except that the [Degas On/off] button is used. When a HC is in degas, a small **DG** indicator will appear on the display line of the HC. Below the **DG** will be a timer indicating the remaining time for the degas.

☞ **Up to 3 MKS low power nude or Mini BA sensors can be degassed simultaneously.**

☞ **The pressure must be below 1x10^{-5} Torr in order for the degas cycle to begin. If degas is attempted at a higher pressure, the Controller will display HIGH PRES for 10 seconds and will not start a degas.**

6.6.2 Power (including degas) Control of a Sensor via 37 pin AIO D-sub Connector

A connected pressure sensor can also be turned ON/OFF by sending a control signal to pins on the 37pin D-sub connector located on the back of the AIO module as shown in Table 6-3.

To turn OFF a sensor, pull the appropriate pin per Table 6-3 to the ground. The sensor power is turned OFF when the microprocessor detects a falling edge on the input pin. Cycling gauge channel power, controller power or removing ground from the pin turns the gauge power back ON--sensor power is turned on when a rising edge is detected.

☞ **Any of the three turn ON/OFF methods can be over ridden by the other. For instance, front panel ON/OFF can control a sensor last turned ON/OFF at the rear panel or via serial commands**.

Since a Hot Cathode modules operate a single sensor, pins 16, 18, 20 are used to control degas power.

	Description	Pin	Description
1	Buffered Aout A1	11	Log/Lin Aout C1
2	Buffered Aout A2	12	Log/Lin Aout C2
3	Buffered Aout B1	13	Combination Aout 1
4	Buffered Aout B2	14	Combination Aout 2
5	Buffered Aout C1	15	Power A1
6	Buffered Aout C2	16	Power A2/Degas A1
7	Log/Lin Aout A1	17	Power B1
8	Log/Lin Aout A2	18	Power B2/Degas B1
9	Log/Lin Aout B1	19	Power C1
10	Log/Lin Aout B2	20	Power C2/Degas C1
		21 to 37	Ground

Table 6-3 Pin Out for Analog Outputs and HC/CC Remote Control

☞ **Control pins 15-20 are pulled up by internal circuitry. No external voltage source is required to pull up the pin.**

6.6.3 Power (including degas) Control of a Sensor using Serial Communication Commands

Power to sensors can also be turned ON/OFF via serial communications. Commands for this are given in Section 9 under the each gauge type.

Degas of a HC sensor can also be controlled via serial commands. The commands are given in Section 9.8.

6.7 Channel Setup for Flow Measurement and MFC Based Pressure Control

When an MFC module is installed, the 946 Controller can operate MKS Mass Flow Controllers to control the mass flow rate or operate a mass flow meter to monitor the mass flow rate. Up to six MFCs can be simultaneously operated by one 946. When both MFC and pressure (CM, PR, CC, HC) modules are installed, the pressure and flow can dynamically be controlled.

Figure 6-12 946 Front Panel.

6.7.1 Simple Operation of a Mass Flow Controller

An MFC can set to Open, Closed or Set Point from the front panel.

- Open: To set an MFC with integral control valve to fully open:
  - Move the green LED on the front panel to the desired MFC channel by pressing either the ▲ or the ▼ key;
  - Press the Open key, and an "Open" will appear in the display line for the selected channel on the front panel and start blinking;
  - Press Enter key to confirm the operation, and the "Open" indicator will stop blinking.

☞ **When an MFC is set to Open mode, the flow rate is often significantly higher than the full-scale flow rate of the mass flow controller and is too high to be measured by MFC. In this situation, the display would Indicate " > [110% of the f.s. flow rate]", for example >1100 for a 1000 SCCM MFC.**

- Close: To set an MFC to fully closed:
  - Move the green LED on the front panel to the desired MFC channel by pressing either the ▲ or the ▼ key
  - Press the Close key, and "Close" will appear and start blinking in the display line for the selected channel
  - Press Enter key to confirm the operation, and the "Close" indicator will stop blinking.

- Setpoint: to flow gas at the rate specified by the MFC's set point::
  - Move the green LED on the front panel to the desired MFC channel by pressing either the ▲ or the ▼ key;
  - Press the Setpoint key, and "SP" and flow set point value will be displayed alternatively in the display line for the selected channel.
  - Press Enter key to confirm the operation and the "SP" indicator will change to black and remain on.

The flow set point should be set via the MFC Channel Setup screen as described in section 6.7.2. Due to the limited space, only 3 digit resolution is displayed (for example, a set point of 1350 sccm will be displayed as 1.35E+3).

6.7.2 Setup MFC Controlling Parameters for Flow Control

When an MFC is connected to the 946 controller, parameters must be entered and set in order to ensure the proper operation.

The Mass Flow Controller setup screen can be accessed by moving the green LED indicator to the desired MFC channel first, then press the Channel Setup button on the 946 front panel. See Figure 6-13.

Setup MFC (sccm) C1

Scale Factor		1.40	Nominal Range		1.0E+3
Zero	NO	FD	NO	Range	1.40E+3
OP Mode		Setpoint	FlowRate SP		2.00E+2
Operation Voltage:			+15 to 24v		

Relay	Enable	Dir/Ch	SET SP	Hyst
Relay 01	ON	ABOVE	3.00E+1	2.70E+1
Relay 02	OFF	BELOW	8.00E+2	8.80E+2

Figure 6-13 MFC Setup Information Display

1. Scale Factor

   Scale Factor is the gas correction factor ratio between the operating gas and the factory calibration gas. If the factory calibration gas is nitrogen, the Scale Factor is identical to the gas correction factor. Typical gas correction factor values are listed in Chapter 13.

   Move the cursor to the Scale Factor box, press Enter key to highlight the parameter (dark gray background), use the ▲ and ▼ keys to select desired value, and press Enter key again to save the value. The valid range is 0.1 to 10, with a default setting of 1.00.

2. Nominal Range

   Nominal Range is the flow range in SCCM specified on the MFC with its factory calibration gas. To set the Nominal Range, move the cursor to the Nominal Range box, press Enter key to highlight the text, use the ▲ and ▼ keys to select the full scale flow rate for the MFC, and then press Enter key again to save the value. Note that flow parameters on the 946 set up screen are always in units of SCCM with a valid range of

1.0 to 1.00E+6 SCCM. When MFCs with a flow rate specified in SLM are used, the SLM value needs to be multiplied by a factor of 1000 to convert SLM to SCCM.

3. Zero

Before zeroing the MFC, ensure the gas flow through the MFC is zero. This can be done by equalizing the pressure across the MFC.

Once zero flow rate is confirmed, set the Zero parameter to Yes. When Yes is selected, “Ensure zero flow rate across the MFC!” will be displayed;

Press the **Enter** key to complete the MFC zero process. After **Enter** is pressed, the offset DAC is automatically adjusted to make the display zero for the selected MFC. Also, a **U** is displayed on the front panel under the FC indicator of the channel as shown in Figure 6-1, to indicate a user zero.

The maximum zero offset adjustment is around 3% of the full scale flow rate of an MFC.

4. FD (Factory Default)

If YES is selected and entered for the Factory Default function, any Manual Zero is removed and zero is restored to its factory calibration value.

After an FD command is executed, the user zeroed indicator, U, on the display will disappear.

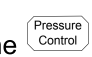
5. Range

This is the actual gas flow range after the Scale Factor is set. It is automatically updated once a new Scale Factor or Nominal Range is entered.

6. OP Mode

There are five control operation modes available for an MFC connected to the 946 Controller. The following three operation modes can be executed from the Setup MFC screen once selected and the **Enter** key is pressed to confirm.

- Open: set the valve inside an MFC to operate at fully open condition quickly. Under this operation mode, the flow rate can be significantly higher than the full range of the MFC. This can be useful for system purge applications where maximum flow rate is desired.
- Close: set an MFC to fully closed.
- Set point: MFC operates at the flow rate specified by the flow set point.
- These modes can also be selected using the buttons on 946 Front Panel as described in Section 6.7.1.

The following two operation modes are activated using the 

button, but when in use, these operation modes will be displayed in the box after OP mod.

- Ratio: indicates that the selected MFCs are operated in either Manual Ratio Control Mode or Auto Ratio Control Modes.
- PID Ctrl: indicates that the selected MFC is operated under the PID Pressure Control Mode, with the 946 Controller dynamically adjusting the flow rate of the MFC to maintain the system pressure.

7. Flow Rate SP

   Flow Rate SP is the entered flow rate set point for MFC set point mode operation. The MFC can be set to close when the set point value is less than 2% of the full scale and to open when the set point value is greater than the full scale (100%). When the MFC is set to run in other control modes (Open, Close, Ratio, PID), this set point value is ignored.

   ☞ **The value for the Flow Rate SP is the actual flow rate after accounting for the scale factor.**

8. Operation Voltage

   The 946 can power both +/-15 Vdc MFCs and +15 to +24 Vdc MFCs. Before selecting the operating voltage, verify the operating voltage of the MFC. Note that the voltage selection applies to both channels of the module, i.e. B1 and B2.

9. Relay

   There are two relays assigned for each MFC. These relays are normally used to provide alarm signals. For example, a relay can be used to report a low flow, such as would be caused by an empty gas cylinder.

6.7.3 Set MFC(s) for Dynamically Controlling System Pressure

MFC(s) can be used for the dynamic control of system pressure such as in process control, calibration and controlled chamber backfilling where a stable chamber pressure is required. The system pressure may be controlled by single MFC (PID Ctrl) or multiple MFCs (Ratio Control).

Several control parameters are involved in dynamic pressure control using MFC(s) and control recipes must be defined before activating the control. For single MFC pressure control, only the PID recipe needs to be defined. However, when multiple MFCs are used for ratio system pressure control, a ratio recipe must be defined in addition to the PID recipe.

In the 946 Controller, only one PID control recipe can be run at a time, but PID and Set Point modes are independent. If one MFC is set to PID control mode, other MFCs can operate simultaneously in the Set point mode. Similarly, if several MFCs are operated under the ratio control mode, the remaining connected MFCs can still operate in Set point mode.

6.7.3.1 Set Single MFC for Controlling System Pressure

PID dynamic control of flow rates allows quicker, more exact attainment and maintaining of a pressure than set point control. Due to variations in pumping speed, chamber outgassing and size, there can be a wide variance in the pressure attained with set point control. At least one pressure control module (e.g., a Capacitance Manometer) is required for measuring the pressure when PID control is used.

For PID operation, an appropriate PID recipe must first be defined. In a 946 Controller, a maximum of 8 recipes (R1 to R8) can be defined as shown in Figure 6-14.

Pressure Control Parameter Setting Recipe							
R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**
B1	B2	C1	C2	Rat	VLV	NA	NA
PID Ch	C1	P Ctrl Ch	A1	P Sp	5.0E+2		
Prop - Kp	1.0E+1	CtrlStart	10s				
Integral - Ti	1.0E+1	Start	0.0%				
Derivative - Td	1.5E+0	End	30.0%				
Base	0.0%	Ceiling	90.0%				
Direction	Upstream	Preset	30%				
GainSchedBand	0%	SchedGainCoeff	1				

Figure 6-14 Single MFC Control Recipe Setup Screen

The Base, Ceiling, Preset, Start and End are the percentage of the full-scale flow rate of the MFC on the assigned PID channel, not the actual flow rate.

6.7.3.1.1 Set the Recipe for Single MFC PID Control

To edit and set a PID recipe, following steps are required to enter the PID recipe editing mode:

1. Press the System Setup button, move the cursor to PID Recipe Edit (see Figure 6-4), then press Enter key to display the Pressure Control Parameters Setting Recipe screen shown in Figure 6-14;

2. Press ◄ or ►keys to select a desired recipe for editing or displaying (highlighted by grey background, such as C1 in Figure 6-14), then, press the **Enter** key to begin the setup or edit mode. Any of the14 PID parameters and settings associated with a recipe may now be entered or changed.

Only 4 parameters (P set point, Prop-Kp, Integral-Ti, and Derivative-Td) can be modified while a PID recipe is actively running. The PID control must be stopped to change any other parameters in an active recipe.

For non-active recipes, all parameters can be changed (either from front panel or serial communication).

See Figure 6-14 for setting up MFC PID control recipe:

- PID Ch: PID Ch: This selects either the channel of the controlling MFC (single MFC control) or method for automatically controlling the system pressure (ratio or valve).

    a) When single MFC is used for pressure control, select and confirm with **Enter** the channel where the MFC is connected.

    b) When multiple MFCs are used for Ratio pressure control, select Rat and confirm with **Enter**.

c) When a valve is used for pressure control, select Vlv and confirm with **Enter**.

d) NA indicates no method of controlling pressure has been selected.

- P Ctrl Ch: This assigns the sensor channel for pressure control and available options are automatically detected.

- P Sp: This is the pressure set point for the system control. Note that the pressure unit is same as the unit set in the 946 Controller.

- Proportional (K_p): This is the proportional control parameter for the PID control of the system pressure. During the pressure control process, the 946 calculates the deviation between the current pressure reading and the set point. The 946 then adjusts the MFC/valve control signal.

  The generic expression of PID control used in the 946 Controller is:

$$Q(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(\tau)\, d\tau + T_d \frac{de(t)}{dt} \right]$$

  Where, *Q(t)* is the control variable (flow rate for MFC, and valve position for valve), and *e* is the control error: ($e = p_{sp} - p$) for upstream control, and ($e = p - p_{sp}$) for downstream control. The range for Proportional gain is 0.002 to 10000. The default setting is 10.0.

  Note that a higher proportional gain results in a larger change in the control signal for a given change in the error. If the proportional value is too high, the system can become unstable. In contrast, a small proportional results in less responsive (sensitive) control.

  The Proportional K_p is pressure unit independent on the 946 due to how the internal calculations are performed.

- Integral (T_i): This is the integral control parameter (time constant) for PID control of system pressure. The integral function considers and corrects for accumulated offset over time, by adjusting the control signal by a term obtained by multiplying the Integral gain and the accumulated error. The valid range for Integral gain is 0.01 to 10000 second. The default setting is 1 sec.

  Note that if the integral time constant is too short (T_i value is to small), the accumulated error may become too large, causing the controlled variable to overshoot the set point.

- Derivative (T_d): This is the derivative control parameter (time constant) for PID control of system pressure. The derivative function creates a control signal based on the rate of change in the sensor's pressure reading (i.e. the first order derivative of the pressure reading with respect to time). The range for Derivative gain is 0 to 1000 second and the default value is 0.2 seconds.

  For MFC, T_d should be set to zero due to its slow response of the flow rate to the corresponding pressure change.

  The derivative term functions to slow the rate of change in the pressure. It reduces the magnitude of the overshoot produced by the integral component and improves the combined control stability. However, differentiation of a

signal amplifies noise, and may cause instability in the process control if the noise and the derivative gain are sufficiently large.

- Ceiling: Ceiling is a control parameter that sets the upper limit of the control signal output. This is expressed as a percent of full scale for a MFC or the percentage of the valve opening for a valve. For example, a ceiling setting of 80% for a MFC with 1000 SCCM full scale means the flow rate should not go above 800 SCCM, while a ceiling setting of 80% for a valve means the valve control signal output should not go above 80% of its opening.

  The valid range is from Base+10% to 100%. The default setting is 100% and it must be 10% larger than the Base parameter value.

  Appropriate setting of ceiling can avoid overshoot of the pressure set point, leading to more stable control.

- Preset: The Preset value is used to set the flow rate for an MFC (as a percent of the MFC full scale) or the position (as the percent of valve opening) of the valve when the PID control is terminated.

  The valid range for Preset is from 0 to 100%. The default value is CLOSE for a MFC, or 0% for a valve. Once a PID control is terminated, the control mode switches to Set point control mode automatically, and the set point value is changed to Preset value.

- Base: Base sets the lower limit of the control signal output. This is expressed as the percent of full scale for a MFC or the percentage of the valve opening for a valve. For example, a Base setting of 20% for an MFC with 1000 SCCM full scale means the flow rate should not go below 200 SCCM, while a Base setting of 20 for a valve means the valve should not go below 20% of its opening.

  The valid range is from 0 to 100%. The default setting is 0 and it must be either equal to less than the Start parameter value.

  A non-zero setting for Base will override the Softstart process, and Base setting will override the Start setting if it is higher than and Start setting.

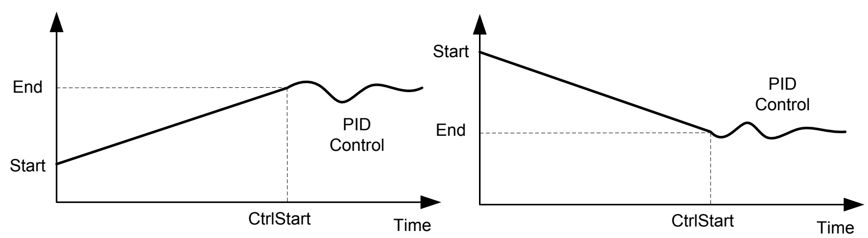


Figure 6-15 Controlled Start Process

The slow start function shown in Figure 6-15 allows a controlled ramping (up or down) process before dynamic PID control starts, providing flexibility for the start of pressure control. When the Start value is set to zero, this becomes a soft start process that can be used to prevent turbulence, reducing the particles in the process chamber during the initial pump down process.

- Start: The Start value is the initial set point value for MFC (or the initial position for a valve) during the slow start control process.

  a) If Base setting is greater than the Start value, the Start will be overridden by Base.

b) If Ceiling setting is less than the Start value, the Start will be overridden by Ceiling.

The range is from 0 to 100% of full scale for a MFC, or from 0 to 100 % for a control valve. The default setting is 0, and it must be equal or larger than Base parameter value.

- End: The End value is the ending set point value for MFC (or the ending position for valve) during the slow start control process (ramp before PID control)

  a) If Base setting is greater the End value, the End will be overridden by Base.

  b) If Ceiling setting is less than the End value, the End will be overridden by Ceiling.

  The range is from 0 to 100% of full scale for a MFC, or from 0 to 100 % for a control valve. The default setting is 0, and it must be equal or larger than Base parameter value.

- CtrlStart: The CtrlStart value is the time period (in seconds) over which the valve drive signal (thus, the valve position) or the MFC flow drive signal goes from the Start to the End. See Figure 6-15..

  There is no ramping of the MFC drive signal if the CtrlStart is set to zero.

- Direction: Direction sets the valve control to either Upstream or Downstream. During Upstream control, higher set point often leads to higher chamber pressure, while it is opposite during Downstream pressure control process. When a Throttle Valve is used, the Direction must be set to Downstream. When MFC is used, it is automatically set to Upstream.

- GainSchedBand: This is the band for gain scheduling PID control, that is, allows different proportional gain K_p at different error band during pressure control. This is often used for maintaining stable control around the set point (within the scheduled PID control zone as shown in Figure 6-16), while ensuring fast approach to the set point in the normal PID control zone where the control error is large (such as at the beginning of the control process).

  The GainSchedBand is defined as $|e|/p_{sp} = |p_{sp} - p|/p_{sp}$, the valid range for GainSchedBand is from 0 to 30%, and default setting is 0.

- GainSchedCoeff: The SchedGainCoeff is the Gain reduction coefficient for PID scheduled control. By reducing the proportional gain K_p in the scheduled PID control zone, more stable control near the set point is achieved, avoiding potential large overshoot during the control. The valid range is from 1 to 200, and the default value is 1 (no scheduled PID).

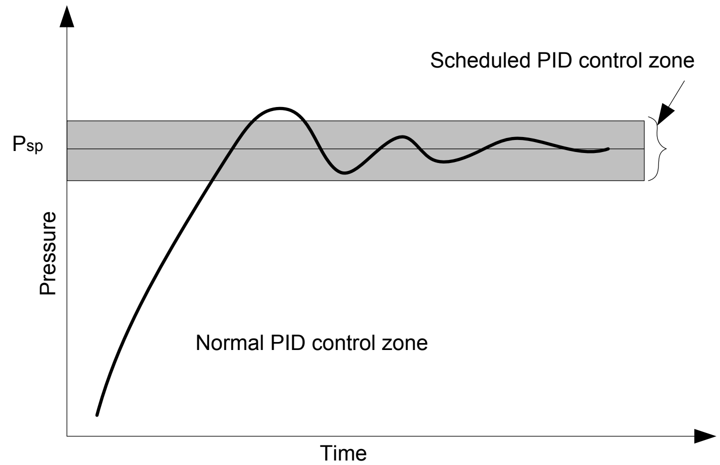


Figure 6-16 Schematic of a Scheduled PID Control

6.7.3.1.2 Activate PID Pressure Control using Single MFC

Once a PID control recipe is properly defined, a PID control can be activated for controlling the system pressure. The steps for activating a PID control using single channel MFC are shown below:

- Press Pressure Control key until the single channel PID Control dialog box is displayed on the right side of the screen as shown in Figure 6-17.
- Select the appropriate control recipe for the PID control. Once a PID recipe is selected, the corresponding PID Ch (such as C1 shown in Figure 6-17) will be displayed. The flow rate of the MFC connected to this PID channel will be varied automatically to control the system pressure. At the same time, the pressure set point value is displayed on the front panel in line with the corresponding channel where the pressure gauge is connected (such as 4.0E+2 for A1 is shown in Figure 6-17). This assists in the identification of the pressure sensor used for control, and the comparison between the real pressure reading and corresponding set point value.

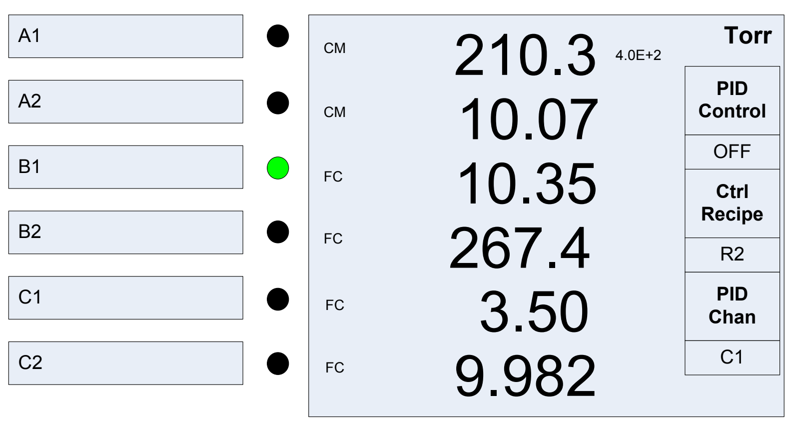


Figure 6-17 Display with the Dialog Box for Single MFC PID Control.

- Change the PID Control parameter from OFF to ON to start the PID control process. The PID control dialog box disappears if ESC is pushed.

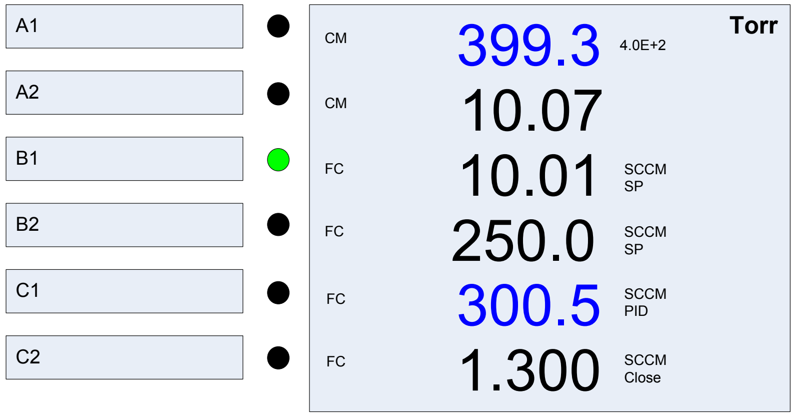


Figure 6-18 Front Panel Display during PID Control using Single MFC

- During PID control process, the active MFC flow reading and corresponding controlling pressure gauge reading are displayed in blue color to identify these channels. PID will be displayed as well to indicate the MFC channel under the PID control (C1 in Figure 6-18).

- The color of the flow rate will turn into red as a warning if the real flow rate is >2% of full scale and 20% off the PID set point value. This might happen, for example, if the gas supply for the MFC is turned OFF accidently during the PID control process.

6.7.3.1.3 Terminate Single MFC PID Control

PID based pressure control with a single MFC can be terminated to any of the following conditions:

1. Close the MFC:
   To close the MFC completely, move the green LED indicator to the MFC in use for the PID, press the Close button on the front panel, and Enter key to confirm.

2. Open the MFC fully:
   To Open the MFC completely, move the green LED indicator to the MFC in use for the PID and press the Open button on the front panel, and Enter key to confirm.

3. Set the MFC to fixed set point defined by the Flowrate SP in Channel setup screen:
   To switch the flow rate to that defined in the channel setup screen, move the green LED indicator to the PID Channel (active MFC channel), and press the Setpoint button on the front panel, and Enter key to confirm the action.

4. Set the MFC to the set point defined in the recipe (Preset)

- Press the Pressure Control to display the PID Control dialog box
- Switch the PID Control parameter from ON to OFF as shown in Figure 6-17. Once the PID control is turned OFF, the flow rate for the MFC will be changed to the Preset set point as defined in the recipe (refer to Figure 6-14).

6.7.3.1.4 Effect of PID Recipe Change While Control is Running

Some of the parameters associated with the active PID control can be changed (via either front panel or serial communication) while the PID control is running. They are pressure set point (P Set point), proportional (Prop-Kp), integral (Integral-Ti), and derivative (Derivative-Td). This allows adjusting and optimizing these parameters without turning ON/OFF the PID control. The remaining PID recipe parameters cannot be changed while the control is running.

When any of these 4 parameters in a PID control recipe is modified while PID control is operating, the new setting will take effect immediately in the running pressure control process. However, the accumulated integral errors will not be reset to zero for the PID control. If resetting of integral error is desired, the PID control must be restarted.

6.7.3.2 Set Ratio Control of System Pressure using Multiple MFCs

In some processes, it is necessary to maintain the system pressure with multiple process gases while keeping the gas compositions unchanged. This can be achieved by utilizing the ratio control function built into the 946 Controller. At least one pressure control module (e.g., a Capacitance Manometer) is required for measuring the pressure when ratio control is used. To operate the 946 in Ratio PID control mode, both PID and Ratio recipes need to be configured before activating the ratio control.

6.7.3.2.1 Set the Recipe for Ratio PID Control using Multiple MFCs

The procedure for setting the recipe for Ratio PID control using multiple MFCs is nearly the same as described in Section 6.7.3.1.1. The only exception is that the PID Ch becomes Rat as shown in Figure 6-19.

In ratio PID control different full range MFCs can be used. To facilitate this, the Base, Preset and Start settings become percentages of the full-scale flow rate of the master channel. The flow rates for rest of the slave channels will follow the master channel to maintain the gas ratio unchanged.

Pressure Control Parameter Setting Recipe							
R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**
B1	B2	C1	C2	Rat	VLV	NA	NA
PID Ch	Rat	P Ctrl Ch	A1	P Sp	5.0E+2		
Prop - Kp	1.0E+1	CtrlStart	10s				
Integral - Ti	1.0E+1	Start	0.0%				
Derivative - Td	1.5E+0	End	30.0%				
Base	0.0%	Ceiling	100.0%				
Direction	Upstream	Preset	30%				
GainSchedBand	0%	SchedGainCoeff	1				

Figure 6-19 Multiple MFC PID Ratio Control Recipe Setup Screen

In Ratio PID, the Base, Ceiling, Preset, Start and End are the percentage of the full-scale flow rate of the master channel, not the actual flow rate.

6.7.3.2.2 Edit the Ratio Recipe for Ratio PID Control using Multiple MFCs

When multiple MFCs are used for ratio control of the system pressure, the Ratio recipe must be defined first. This recipe determines the concentration (ratio) for different gas species, and the starting flow rate for the ratio control. To access Ratio recipe edit screen, and enter the editing mode:

1. Press the [System Setup] button, move the cursor to Ratio Recipe Edit as shown in Figure 6-4, then press [Enter] key to display the MFC Ratio Recipe screen. See Figure 6-20.

2. Press ◀ or ▶ keys to select a desired recipe for editing or displaying (highlighted by grey background), then, press [Enter] key to enter the edit mode as shown in Figure 6-20.

MFC Ratio Recipe

RR1	RR2	RR3	RR4
RR1	RR2	RR3	RR4
Channel	Ref flow	%	Range
A1	NA		NA
A2	NA		NA
B1	1.00E+2	20.0	5.00E+2
B2	0.00E+0	0.0	2.00E+2
C1	0.00E+0	0.0	1.00E+3
C2	4.00E+2	80.0	1.00E+3

Figure 6-20 Ratio Recipe Setup Screen for Multiple MFC Pressure Control

Four (4) ratio recipes (RR1 to RR4) can be defined. While editing a recipe, the ratio recipe is highlighted by the gray background such as the RR2 shown in Figure 6-20. MFC modules are detected automatically, and their effective flow range as slaves in ratio control mode (not the nominal range) will be displayed to assist in setting up the recipe's flow rate(s).

When Ratio PID control is active, parameters associated with the active Ratio recipe cannot be changed. This applies to either manual or auto mode. In order to change the ratio recipe for the active control, the dynamic ratio control must be stopped.

The Ref flow is the reference flow rate for the ratio control. It is used to determine the gas ratio of the control, and also serves as the starting flow set point for the ratio control. If the Ref flow value is set to zero, this MFC will be excluded from the dynamic ratio control. Only a channel with non-zero Ref flow setting will be included in the ratio control automatically. The gas concentration (%) is calculated and displayed after the initial flow rates are entered.

The gas concentration displayed in the ratio Recipe screen may not be true gas concentration in the system as it does not include the gas flows for MFCs that are not included in the ratio control. For example, in Figure 6-20, Channel B2 and C1 are not included in the ratio control, however, they can still be operated under fixed set point operation mode.

MFCs that are set to ratio control operating mode are tied together during the ratio pressure control process. The flow rates for all ratio controlled MFCs vary (either increase or decrease) simultaneously at the same rate. This operating mode can maintain the composition of different gases during the process even though the total flow rate may change to maintain the system pressure at the control set point.

During the ratio control of system pressure, a master channel is assigned, and the flow rates for rest of slave channels will follow the master channel (set point value) to maintain the gas ratio. In order to achieve best control stability, the channel with maximum absolute flow rate is set internally as the master channel for the ratio control. For example, channel C2 is the master channel for the ratio control in Figure 6-20. However, if two MFCs have the same highest flow rate set point, the first channel in the order of A1→A2→B1→B2→C1→C2 will be selected internally as the master channel.

The maximum gas flow rate for an MFC is limited by its full scale and this in turn limits the settings for the ratio control of gas flow. In ratio control, the range for an initial flow control setpoint is limited to be less than 50% of the full scale. This enables a scaling of 0 to 200% in flow rate for all MFCs during ratio control of system pressure. Because of the range limitation (50% of the full scale) of the reference flow set point and scaling limit (200%) for flow control, the maximum gas flow will never surpass the full scale of the MFC during the dynamic ratio pressure control.

6.7.3.2.3 Manual Ratio vs Auto Ratio Control

There are two modes for ratio control using multiple MFCs: Manual or Auto.

During the manual ratio control mode, there is no PID control and the flow rate can be decreased by pressing or increased by pressing key. Since manual ratio is often used for optimizing the initial set point values for an automatic PID ratio control, the PID recipe must be defined before manual ratio control can be used.

During the auto ratio control using multiple MFCs, the flow rates for MFCs will be adjusted automatically based on the system pressure.

6.7.3.2.4 Activate and Terminate the Multiple MFCs Auto/Manual Ratio Control

It is recommended to run a manual ratio control first to determine the optimal starting flow rate. This can help to avoid situations such as an MFC reaching maximum flow, causing an overshoot in flow and pressure. To active either manual or automatic ratio control after PID and ratio recipes are set:

- Press the Pressure Control key until Ratio Control dialog box is displayed as shown in Figure 6-21.

- Select the appropriate Ctrl Recipe for the ratio control. Only valid Ratio control recipes will be displayed.

  When a valid ratio PID control recipe is selected, the pressure set point (P Sp in Figure 6-19) will be displayed on the front panel (4.0E+2 in the example of Figure 6-21) to indicate the sensor being used for pressure control, and assist in the comparison of the real pressure reading and the set point value.

- Select the desired ratio recipe. Once selected, the corresponding gas concentrations (such as 20.0% for B1, and 80.0% for C2 as shown in Figure 6-21) associated with the ratio control channel will be displayed, providing indication of the active ratio channels and ratio settings.

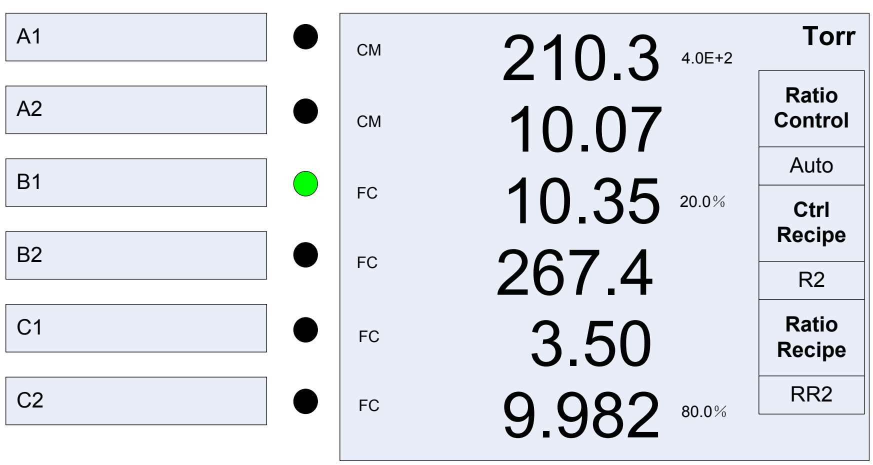


Figure 6-21 Display with the Dialog Box for Ratio Control using Multiple MFCs

- Change the Ratio Control parameter from **OFF** to **Auto** to start the PID auto Ratio control, or to **Manual** to start the manual ratio control. Once ratio control starts, the flow rates with the active ratio channels and pressures associated with the control will be displayed in blue for identification, as shown in Figure 6-22, when the flow rates are within ±20% of the set point value. If the gas flow rate is >2% of full scale and 20% off the target setting, the flow rate readings will be in red as an alarm.

☞ **Both the PID and Ratio recipes (such as R2 and RR2 shown in** Figure 6-**21) cannot be changed when either Auto or Manual ratio control is running.**

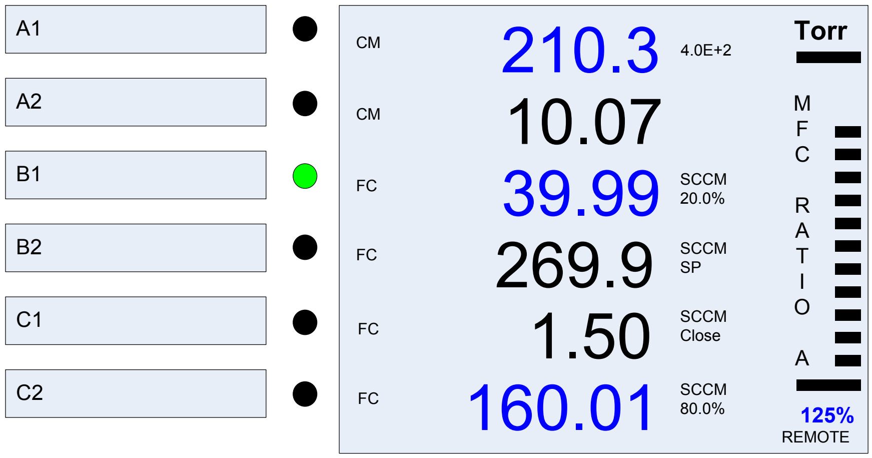


Figure 6-22 Display during Ratio Control using Multiple MFCs

6.7.3.2.5 Terminate a Ratio Control

To terminate a PID ratio control using multiple MFCs, switch either Manual or Auto ratio control to OFF via the dialog box for **Ratio Control** as shown in Figure 6-21.

6.7.3.3 Switching Between Different Control Modes/Recipes

Since many parameters are involved in the dynamic control of the system pressure using MFCs, the PID/Ratio control must be terminated first before switching recipes. Once the control is stopped, all the MFCs will be set to the control mode defined by the Preset in the recipe. If the Preset value is zero for an MFC, this MFC will be set to Close mode when the PID/Ratio control is terminated.

However, switching between Manual Ratio and Auto Ratio is allowed without terminating the control as the same ratio recipe is used.

6.8 Pressure Control using a Control Valve

The system pressure can also be controlled utilizing a control valve. Either an upstream solenoid valve on a delivery line or a downstream throttle valve on the vacuum pumping line can be used for controlling the system pressure.

When upstream control is used, only one valve and thus one gas flow can be adjusted for achieving the desired pressure set point. When downstream control is used, the upstream gas flow rate is fixed, and the pressure is controlled by adjusting the opening of the throttle valve.

Once a valve control module is installed in a 946 controller, it will be detected, and the 946 Front Panel Display will automatically appear as shown in Figure 6-23.

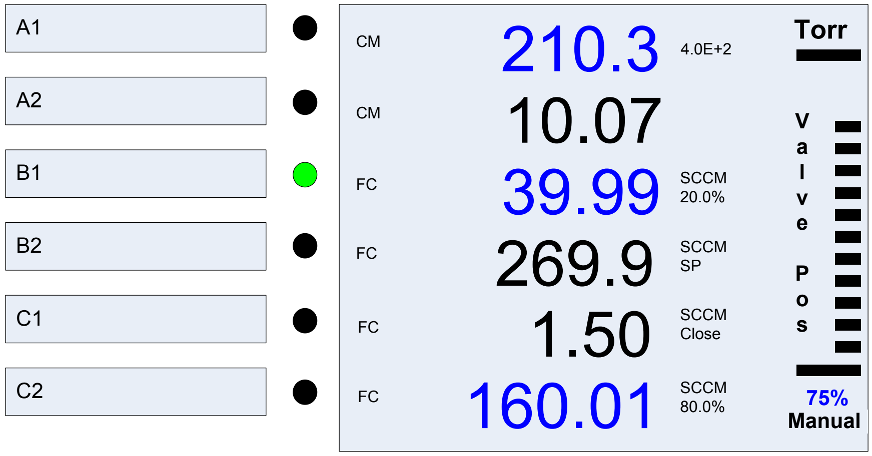


Figure 6-23 946 Display with a Pressure Control Module Installed

The position displayed on the front panel for an upstream solenoid valve is actually the percent of the full scale driving current of the valve, not the true opening position of the valve. Note that 20-40% of the full scale driving current is often required to overcome the sealing force and open the valve and is then the minimum indicated opening position.

6.8.1 Valve Type Selection

Following is list of valves that can be operated by the 946 controller:

- Valves (MKS 153/T3B): This valve is installed on the vacuum pumping line of a process chamber (also called downstream control valve). With these valves, larger valve openings produce lower chamber pressures.
- MKS 148, 154 and 248: These proportional current driven valves are often installed on the delivery line of a process chamber, and are also called upstream control valves. With these valves, larger valve openings produce higher chamber pressure.

When an upstream valve is used to control the vacuum system pressure, the valve inlet pressure should be regulated to ensure stable pressure control. If the control system pressure is low (say, below 10^{-4} Torr), the inlet pressure should be regulated at a similar pressure range, or a small leak valve (orifice) should be installed to avoid a pressure burst during the control, especially if a CC or HC sensor is used.

See Figure 6-24 and use following steps below for setting the valve type on a 946 vacuum system controller:

1. Press System Setup key on the front panel to display the system setup screen as shown in Figure 6-24;
2. Move the cursor with the ▲ or ▼ keys to highlight Valve Type parameter;
3. Press Enter key to enter the edit mode;
4. Select appropriate valve type and press Enter again to save the setting.

System Setup			
P Unit	Torr	CommType	RS232
Address	253	Baud Rate	9600
Com Mode	946	Parity	None
Set Param	Enable	User Cal	Enable
PID Recipe	Edit	Ratio Recipe	Edit
Valve Type		248	
Combination Setup		Edit	
DAC Parameter Setup		Edit	
System FV Infor		Display	

Figure 6-24 Selection of Valve Type using System Setup Screen

6.8.2 Valve Control Recipe Setup

During the process of pressure control using a valve, the opening of the valve is dynamically adjusted based on the feedback of the system pressure. PID control logic is used for the control and all the controlling parameters need to be defined by a recipe, similar to when an MFC is used for PID/Ratio control.

To edit and set a PID recipe for valve control:

1. Press the System Setup button, move the cursor to PID Recipe Edit as shown in Figure 6-4, then press Enter key to display the Pressure Control Parameters Setting Recipes screen as shown in Figure 6-25;

Pressure Control Parameter Setting Recipe							
R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**
B1	B2	C1	C2	Rat	VLV	NA	NA
PID Ch	Vlv	P Ctrl Ch	A1	P Sp	5.0E+2		
Prop - Kp	1.0E+1	CtrlStart	10s				
Integral - Ti	1.0E+1	Start	0.0%				
Derivative - Td	1.5E+0	End	30.0%				
Base	0.0%	Ceiling	100.0%				
Direction	Upstream	Preset	30%				
GainSchedBand	0%	SchedGainCoeff	1				

Figure 6-25 Recipe Setup Screen for PID Control using a Valve

2. Press [◄] or [►] keys to select a desired recipe (R1 to R8) for editing or displaying (highlighted by grey background), then, press [Enter] to enter the edit mode. Note that the cursor automatically highlights the box beside the PID Ch.

3. Move the cursor to the PID Ch, and set its parameter to Vlv.

4. The rest of the parameter settings are identical to that are described in Section 6.7.3.1.1.

Note that the value for Base, Ceiling, Preset, Start and End are the percent of opening of the valve (≤100%).

6.8.3 Activate a Pressure Control with a Valve

6.8.3.1 Simple Valve Operations (Static Valve Control)

Valve control functions for static valve operation are Open, Close, manual, and Set Point.

To active these valve operations:

1. Press the [Pressure Control] button on the front panel until the valve control dialog box shown in Figure 6-26 is displayed. Note that this screen can only be displayed if a pressure control module is inserted in the COMM slot.

2. For Open and Close operation, move the cursor to the box below OP Mode, and change the parameter to either Open or Close, or press the [Open] or the [Close] button on the front panel. In either case, press [Enter] afterward to confirm.

3. For Set Point control of the valve (set the valve opening to specific position), first enter an appropriate Set Point value in the box below Set Point (20.0% in Figure 6-26). Then change the OpMode to Set Point with the up/down keys, or press the [Setpoint] key on the front panel. In either case, press [Enter] key afterward to confirm. Once the valve is in set point operation, the set point value can be adjusted without stopping the Set Point control.

4. Manual operation mode enables the dynamic manual adjusting the valve position. Once the manual operation mode is selected, the dialog box as shown in Figure 6-26 will disappear, the screen shown in Figure 6-23 will appear. The Set Point value can then be increased or decreased with the [◄] or [►] keys. The current opening is shown numerically in blue as a percentage.

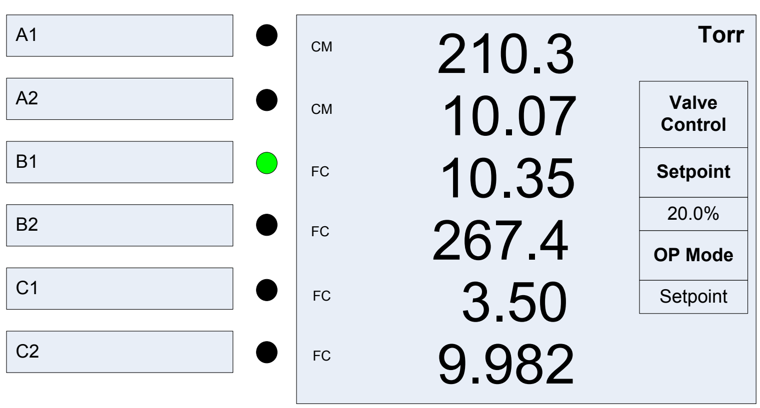


Figure 6-26 Display with Valve Control Dialog Box

6.8.3.2 PID Dynamic Valve Control

Once a valve type is selected, and a recipe is configured, the 946 Vacuum System Controller can dynamically control process pressure using a valve.

The activation of a PID dynamic valve control is identical to activating a PID control using single MFC as described in Section §6.7.3.1.2. The only exception is that **Vlv** needs to be selected for the PID Ch. See Figure 6-27. Once a proper recipe is selected, PID pressure control is activated by changing the PID Control parameter from OFF to ON.

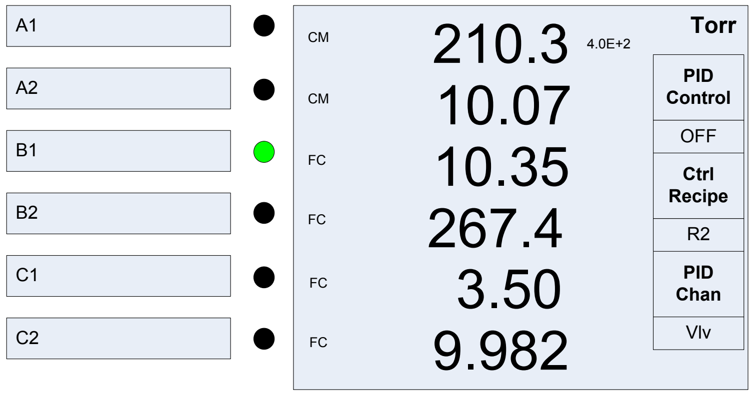


Figure 6-27 Display with the Dialog Box for PID Control using a Valve

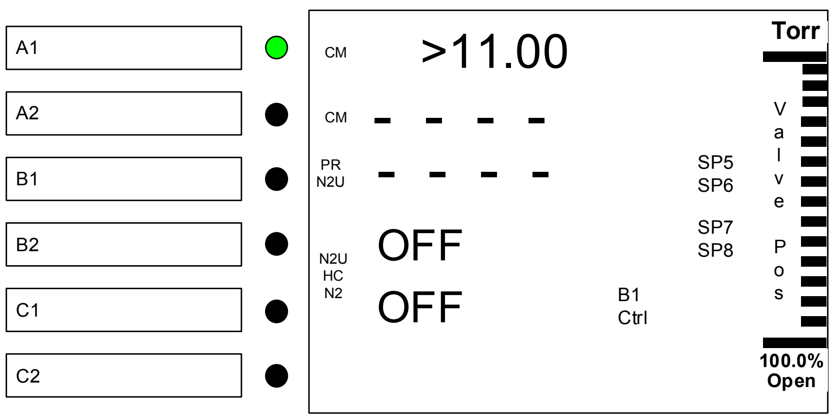


Figure 6-28 Display for PID Control using a Valve

Once the PID control is started, the valve position will be displayed on the front panel both digitally and graphically, as shown in Figure 6-28.

6.8.4 Terminate a PID Pressure Control using a Valve

To terminate a PID dynamic valve pressure control, select one of the following depending upon the desired valve position:

1. Close the valve:

   To close the valve, press the Pressure Control key until the display is as shown in Figure 6-26, move the cursor to the box below OP Mode, and change the parameter to Close, or press the Close button. In either case, press the Enter key afterward to confirm.

2. Open the Valve:

   To Open the valve, press the [Pressure Control] key until the display is as shown in Figure 6-26, move the cursor to the box below OP Mode, and change the parameter to Open, or press the [Close] button. In either case, press the [Enter] key afterward to confirm.

3. Valve in fixed position defined by the set point as shown in valve control dialog box (refer to Figure 6-26).

   To set the valve to fixed position, press the [Pressure Control] key until the display is as shown in Figure 6-26, move the cursor to the box below OP Mode, and change the parameter to Set Point, or press the [Setpoint] button. In either case, press the [Enter] key afterward to confirm.

4. Valve to the set point defined in the recipe (Preset)
   - Press the [Pressure Control] to display the PID Control dialog box as shown in Figure 6-27;
   - Switch the PID Control parameter from ON to OFF as shown in Figure 6-27. Once the PID control is turned OFF, the valve position will be changed to the Preset set point as defined in the recipe(refer to Figure 6-14).

7 Installing Vacuum Sensors

7.1 Installing Cold Cathode Sensors

⚠ Verify that the vacuum port to which the CC sensor is mounted is electrically grounded. It is essential for personnel safety as well as proper operation that the envelope of the sensor be connected to a facility ground.

Be aware that an electrical discharge through a gas may couple dangerous high voltage directly to an ungrounded conductor almost as effectively as would a copper wire connection. Personnel may be seriously injured or even killed by merely touching an exposed ungrounded conductor at high potential. This hazard is not unique to this product.

7.1.1 Locating a Cold Cathode Sensor

Locate Cold Cathode sensors in a position suitable for the measurement of process chamber or manifold pressures. Install the sensor away from pumps, gas sources, and strong magnetic fields to ensure the most representative data. Place and orient the sensor such that contamination is minimized. For example, if a sensor is installed directly above a diffusion pump oil vapor can contaminate the cathode, anode, and other vacuum wetted components, causing calibration drift.

7.1.2 Orienting a Cold Cathode Sensor

A Cold Cathode sensor can be installed with the body set in any direction. The operating position does not affect accuracy. As with any sensor, installation with the vacuum port facing down is preferable since this helps to prevent contaminants from falling into the sensor.

7.1.3 Managing Contamination in a Cold Cathode Sensor

Do not operate a Cold Cathode gauge at pressures above 10^{-3} Torr for extended periods. This will increase the likelihood of contamination due to higher sputtering rates. If pressure readings appear erratic, the sensor may be contaminated. In such a case, the it should be visually inspected and, if contamination is visible, the internal components should be cleaned or replaced using an Internal Rebuild Kit.

7.1.4 Connecting the Series 431/422 Sensor

Mount the sensor to a grounded vacuum system. KF 25 or KF 40 flanged sensors must be attached with a conductive, all-metal clamp to ensure the sensor body is grounded. On sensors with CF flanges, a ground lug on a flange bolt could be used to attach a ground if necessary.

Connect the cables to the sensor and to the Controller before turning ON. Connections on the rear panel of the Controller are H.V. (SHV connector) and Ion Current (BNC connector). The sensors also have H.V. and current connections. Note that some Series 422 sensors have LEMO connectors rather than SHV and BNC connectors.

If there is any potential for strain on the cable, use separate strain relief to avoid damage to the sensor, cable, or the Controller.

Cables are available from the factory in standard lengths of 10, 25, 50, and 100 feet and in custom lengths up to 300 ft.

7.1.5 Connecting the 423 I-Mag Sensor

Mount the sensor to a grounded vacuum system. KF 25 or KF 40 flanged sensors must be attached with a conductive, all-metal clamp to ensure the sensor body is grounded.

If the I-Mag Sensor has a CF flange, remove the magnet first to allow clearance for bolt installation. To remove the magnet, undo the two Phillips head screws in the center of the magnet housing. When replacing the magnet, note that it is keyed to the sensor body to protect the feed-through pins from damage. The pins should be straight and centered.

Connect the cable to the sensor and to the Controller before turning ON. Tighten the thumbscrew on top of the cable to make sure that it is securely in place.

7.2 Installing Hot Cathode Sensors

7.2.1 Over Pressure Conditions

⚠ ***Danger of injury to personnel and damage to equipment exists on all vacuum systems that incorporate gas sources or involve processes capable of pressuring the system above the limits it can safely withstand.***

For example, danger of explosion in a vacuum system exists during backfilling from pressurized gas cylinders because many vacuum devices such as ionization gauge tubes, glass windows, glass belljars, etc., are not designed to be pressurized.

Install suitable devices that will limit the pressure from external gas sources to the level that the vacuum system can safely withstand. In addition, install suitable pressure relief valves or rupture disks that will release pressure at a level considerably below that pressure which the system can safely withstand.

Suppliers of pressure relief valves and pressure relief disks can be located via an online search. ***Confirm that these safety devices are properly installed before installing and operating the product.***

Ensure the following precautions are complied with at all times:

(1) the proper gas cylinders are installed,

(2) the gas cylinder valve positions are correct on manual systems,

(3) and the automation is correct on automated gas delivery systems.

7.2.2 Locating a Hot Cathode Sensor

Locate the sensor in a position appropriate for the measurement of process chamber or manifold pressure. Installing the sensor away from pumps and gas sources gives the most representative pressure measurement. In the case of a nude sensor, ensure that there is nothing in the system or mounting location that could damage the electrode structure. Special consideration should be given to any moving mechanism within the vacuum system to insure the mechanism cannot inadvertently damage the sensor.

7.2.3 Preventing Contamination in a Hot Cathode Sensor

Locate the sensor where contamination is least likely. For example, if the sensor is mounted directly above a source of evaporation, the vapor could contaminate the structure or feed-through and cause calibration shift.

7.2.4 Orienting a Hot Cathode Sensor

A Hot Cathode sensor can be installed and operated in any direction without compromising the gauge accuracy. However, it is recommended that, whenever possible, the sensor be installed with the vacuum port facing down to keep contaminants from falling into the sensor.

7.2.5 Connecting a Hot Cathode Sensor to the Vacuum System

⚠ ***Verify that the vacuum port to which the HC sensor is mounted is electrically grounded. It is essential for personnel safety as well as proper operation that the envelope of the sensor be connected to a facility ground.***

Be aware that an electrical discharge through a gas may couple dangerous high voltage directly to an ungrounded conductor almost as effectively as would a copper wire connection. Personnel may be seriously injured or even killed by merely touching an exposed ungrounded conductor at high potential. This hazard is not unique to this product.

MKS sensors are available with either a CF type metal sealed flange, a KF type flange, or tubulation. Mount the sensor to a grounded vacuum system. KF 25 or KF 40 flanged sensors must be attached with a conductive, all-metal clamp to ensure the sensor body is grounded. On sensors with CF flanges, a ground lug on a flange bolt could be used to attach a ground if necessary.

Note: Attaching tubulated sensors with compression type (quick connect) adaptors is discouraged since in an overpressure condition the gauge could be forced out of the adaptor and thus constitute a safety hazard. Additionally, the use of an elastomer seal is not recommended for high vacuum as outgassing and/or permeation through the elastomer can cause errors in pressure measurement. A sensor with a KF flange and elastomer O-ring seal is suitable only for pressure measurement down to $1x10^{-7}$ Torr.

When inserting a nude sensor into a port, do not bend, damage, move the electrodes or feed-through pins. Do not short the elements to one another, the chamber, or any components inside the chamber. If there is any question of clearance for the electrode structure or of possible damage to the electrode structure, it is recommended that the nude sensor be mounted in a nipple, (i.e. MKS p/n 100883069). The MKS nipple includes a screen that helps to prevent ion coupling. This mounting is also recommended to assure the nominal rated sensitivity.

7.2.6 Connecting a Hot Cathode Sensor to the 946 Controller

A sensor cable with a D-sub connector (Figure 7-1) for the module connections and molded plug for the hot cathode sensor is required for operation.

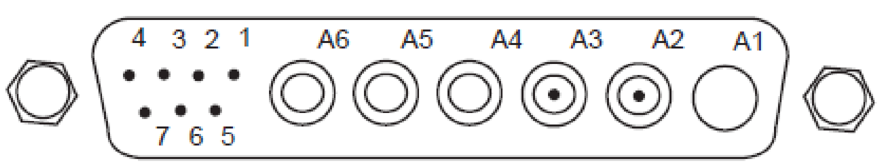


Figure 7-1 Connector on the Back of the HC Module

Pins 5, 6, and 7 are used for sensor identification. The cable needs to be matched to the type of hot cathode so proper operating parameters like maximum degas power will be selected.

Table 7-1 shows the cable pinouts for Low Power Nude and Mini BA sensors.

Since high power is required to operate a Hot Cathode, especially, during degas, the maximum allowed cable length is 50 ft (15 m), significantly shorter than for a cold cathode sensor.

937B Connector End	Low Power Nude (LPN)
A2	C
A3	G (Grid, 2x)
A4	F2
A5	FC (Fil. Comm.)
A6	F1
1--Jumpered to 2	
2--Jumpered to 1	
5--Jumpered to 6	
6--Jumpered to 5	
7--no connect	

937B Connector End	Mini Ionization Gauge (MIG)
A2	7
A3	2, 5
A4	4 (Fil. 2)
A5	3,6 (Fil.Comm.)
A6	1 (Fil. 1)
1--Jumpered to 2	
2--Jumpered to 1	
5	
6--Jumpered to 7	
7--Jumpered to 6	

Table 7-1 Pin Assignments for HC Sensor (LPN on left, MIG on right)

If there is the possibility of forces on the cable, use a separate strain relief to prevent damage to the sensor or controller. Cables are available in standard lengths of 10, 25 & 50 feet only. Tighten the cable jackscrews into the mating screw locks to ensure proper electrical connection and prevent stress on the connector.

☞ **Remove power from the controller before connecting or disconnecting the cable from the sensor or controller.**

7.3 Installing Convection Pirani, Convectron, or Pirani Sensors

7.3.1 Over Pressure Conditions

⚠ ***Danger of injury to personnel and damage to equipment exists on all vacuum systems that incorporate gas sources or involve processes capable of pressuring the system above the limits it can safely withstand.***

For example, danger of explosion in a vacuum system exists during backfilling from pressurized gas cylinders because many vacuum devices such as ionization gauge tubes, glass windows, glass belljars, etc., are not designed to be pressurized.

Install suitable devices that will limit the pressure from external gas sources to the level that the vacuum system can safely withstand. In addition, install suitable pressure relief

valves or rupture disks that will release pressure at a level considerably below that pressure which the system can safely withstand.

Suppliers of pressure relief valves and pressure relief disks can be located via an online search. ***Confirm that these safety devices are properly installed before installing and operating the product.***

Ensure the following precautions are complied with at all times:

(1) the proper gas cylinders are installed,

(2) the gas cylinder valve positions are correct on manual systems,

(3) and the automation is correct on automated gas delivery systems.

7.3.2 Locating the Sensor

Locate a Pirani sensor appropriately for measuring a chamber or manifold pressure. Install the sensor away from pumps and gas sources for the most representative data. Place the sensor in a location with minimal vibration.

7.3.3 Preventing Contamination in a Pirani Sensor

Locate and orient the heat-loss sensor to avoid contaminants that might affect the tube's element. For example, if a sensor is installed directly above a roughing pump oil vapor could contaminate the filament wire and cause incorrect readings.

Install the sensor with the vacuum port facing downward whenever possible. This helps to prevent particulates and liquids from entering the sensor. The use of a screen or porous filter at the port can be helpful, such as MKS seal and centering ring assembly with screen.

7.3.4 Orienting the Series 317Convection Pirani or Convectron Sensor

STOP **When measuring pressures greater than 1 Torr, the Series 317 or Convectron sensors must be mounted with their axis horizontal.**

Measurements below 1 Torr are less affected by position, but readings will be incorrect at higher pressures. The sensors are calibrated with the tube axis horizontal. Incorrect mounting could result in under- or over-pressure, damaging equipment, or injury.

Mount the Sensor with the vacuum port facing downward to reduce particulates and liquids falling or flowing into it. The sensors are calibrated in this position.

7.3.5 Orienting the Series 345 Pirani Sensor

Operating position has no effect on accuracy. The Pirani Sensor was designed to minimize the effects of convection. With a standard Pirani, the output of the sensor changes very little in going from the horizontal to vertical position.

The Series 345 Pirani Sensor exhibits slight convection characteristics near atmospheric pressure. Above 30 Torr the best accuracy can be achieved by performing an **ATM Cal** with the sensor in a vertical position with the port facing down. This can be done at any pressure between 600 and 1000 Torr.

7.3.6 Connecting Convection Pirani, Convectron, or Pirani Sensors

To install the Sensor with a 1/8" NPT, do not apply torque to the case to tighten the connection. The sensor's vacuum tubing has 9/16" hex flats for tightening. Wrap about two turns of Teflon® tape on the threads of the Sensor in the direction of the threading to ensure a leak-free seal. Note: positive pressures can blow the sensor out of a compression fitting, damaging equipment and possibly injuring personnel.

⚠ **Do not use a compression mount (quick connect) to attach the sensor to a system in positive pressure applications.**

⚠ **A solid electrical connection between the sensor and the grounded vacuum system must be provided.**

Use an MKS adaptive centering ring (MKS p/n 100315821) to fit a KF 16 port to a KF 10 port.

In applications where the system may be subject to large voltage fluctuations, a metal centering ring with a screen should be installed. The clamp must be tightened properly so that the flange contacts the centering ring and the sensor port or clamp grounded.

The sensor cable is connected to the Controller with the 9-pin "D" connector. Tighten the cable jackscrews into the mating screw locks on the controller to ensure proper electrical connection and prevent stress on the connector.

Function	937B/946 Module Connector Pin	Series 317: 10, 25 and 50 foot cables; Pin at sensor	Series 317: custom length cables: Pin at sensor	Series 275: 10, 25 and 50 foot cables; Pin at sensor
Bridge Drive +	1	1	1,6	1
Chassis Ground	2	2	No Connect	
Signal +	3	3	3	1
Signal -	4	4	4	3
Bridge Drive -	5	5	5,9	3
Bridge Drive +	6	6	No Connect	1
Bridge Sensor Leg	7	7	7	2
Bridge Ref. Leg	8	8	8	5
Bridge Drive -	9	9	9	3

Table 7-2 Pin Assignments for Convetion Pirani and Convectron Sensor

If excess stress is applied to the cable, use separate strain relief to prevent damage to the sensor, cable or the Controller. Cables are available from MKS in standard lengths of 10, 25, 50, and 100 feet and in custom lengths up to 500 feet.

7.3.7 Preparing the 317 Sensor for Bakeout

The Series 317 Convection Pirani Sensor with a black plastic housing can be baked up to 100°C after the electronics module is removed. A 317 with an aluminum housing can be baked to 250°C after the electronics module is removed.

☞ The **electronics modules are matched to the sensor during manufacturing, and must not be interchanged.**

Prior to removing the module, the Series 317 Sensor should first be turned off. Remove the cable from the Sensor. Using a #1 Phillips screwdriver, remove the two screws at the end of the connector/electronics subassembly and separate it from the sensor. Leaving or replacing the electronics module on the cable connector may help to prevent loss or interchange of the module on reassembly.

7.4 Installing Capacitance Manometers - MKS Baratron

The Series 946 Controller supports a number of Capacitance Manometers, including the MKS unheated Baratrons and MKS 45 C heated Baratrons. They are available in full scale ranges from 0.02 to 10,000 Torr, each with a 3-decade range. A CM module operates up to two Capacitance Manometers, and the total combined current requirement of operating sensor(s) must be 1 amp or less.

See an MKS Baratron instruction manual for complete information on using these capacitance manometers.

The Series 946 Controller also supports the gas-independent Series 902B Piezo resistive gauges. Refer to Section 7.5 for information on this.

⚠ **Do not connect heated Baratrons with controlled temperatures higher than 45°C. It may damage the Capacitance Manometer**.

7.4.1 Installing a Capacitance Manometer

In general Capacitance Manometers may be mounted in any position although the most sensitive units (i.e. those with the lowest full scale value) may require a specific orientation to meet factory calibration specifications. Please consult the information supplied with the Capacitance Manometer, However, it is recommended that capacitance manometers in general be installed with the measuring port facing down to allow contamination to fall away from the pressure sensing diaphragm. The sensor port will easily carry the weight of the transducer.

☞ **Due to the failure of many users to follow the proper tightening procedures for single or double metal ferrule compression vacuum fittings and the resulting damage to the pressure sensor, MKS does not warrant this product when such fittings are used.**

7.4.2 Connecting a Capacitance Manometer

A shielded cable with 9 pin male d-sub on the controller end and a 9 or 15 pin male d-sub end on the Baratron end is required to connect the Baratron to the module on the controller. The pin-outs for the D-Sub connectors on the CM cables is shown in Table 7-4. Part numbers of cables are given in the Accessory Section of this manual.

Function	937B/946 Module Connector Pin	Baratron (CM) Connector Pin (15 pin D-sub)	Baratron (CM) Connector Pin (9 pin D-sub)
-15 V	1	6	
+15 V	5	7	4
Chassis Ground	6		
Signal -	7	12	8
Signal +	8	2	1
+/- 15V Return	9	5	9

Table 7-3 Pin Out of the 9 Pin D-sub Connector on CM Module.

7.5 Series 902B Piezo

The Controller also supports the gas-independent Series 902B Piezo resistive gauges. The 9-pin versions can be operated off the Capacitance Manometer module using the cables listed in the Spare Parts and Accessory section. The CM module needs to simply be set up for an absolute (ABS) gauge with 10V input and 1000 Torr full scale value. The same considerations in mounting and orienting a Capacitance Manometer apply to the 902B.

7.6 Installing Mass Flow Controllers

The 946 Controller can operate up to six mass flow controllers simultaneously. These include MKS G, I, P Series and legacy MFCs with internally tied grounds, requiring ±15 Vdc or +15 to +24 Vdc input.

7.6.1 Environmental requirements

Follow the guidelines listed below when installing and using a mass flow controller.

1. Maintain the normal operating temperature between 0° and 50° C (32° and 122° F).
2. Observe the pressure limits:
    A. Maximum gas inlet pressure is 150 psig.
    B. Operational differential pressure is:
        10 to 40 psid for ≤ 5000 SCCM units
        15 to 40 psid for 10,000 to 30,000 SCCM units
3. Allow 2 minutes for warm-up time.
4. Use high purity gas and filters in line upstream of the MFC.
5. Leave the power to the instrument on at all times, for optimal performance.

7.6.2 Interface Cables

Connect the MFC and 946 Controller using MKS cables. Cables are listed in the Spare Parts and Accessories section. Cables are available with either standard 9 or15 pin D-Sub at one end for connecting to the MFC, and high density 15 pin D-sub at other end for connecting to the 946 MFC module. The MKS mass flow controllers used with these cables must have the signal ground and power grounds connected (tied) internally in the mass flow controller.

Function	946 MFC Module Connector Pin	MFC Connector Pin (15 pin D-sub)	MFC Connector Pin (9 pin D-sub)
No Connection	1	1	9
Signal In+	2	2	2
Valve Close	3	3	1
valve Open	4	4	
Power Common	5	5	4
-15 V	6	6	5
+15 V	7	7	3
Set Point Signal Output	8	8	6
No Connection	9	9	
Zero	10	10	
Signal Common	11	11	7
Signal Common	12	12	8
No Connection	13	13	
No Connection	14	14	
Chassis Ground	15	15	

Table 7-4 Pinout for MFC Cables used on the 946

7.6.3 Setup

1. Set the mass flow controller into position where it will be connected to a gas supply. Placement of flow components in an orientation other than that in which they were calibrated (typically horizontal) may cause a small zero shift. The zero offset can be removed by adjusting the zero potentiometer on the mass flow controller, or via the 946 Controller.
2. Install the flow controller in the gas stream such that the flow will be in the direction of the arrow on the side of the controller.
3. Allow adequate clearance for the cable connector (approximately 3” height) and tubing connections/fittings.
4. Position the flow controller to provide access to the zero potentiometer. The zero potentiometer is located on the inlet side of the flow controller body.

7.6.4 Gas Line Connections

Connect the gas line (via tubing) from the gas supply to the flow controller’s inlet, and from the flow controller’s outlet, to the downstream tubing. Remember to follow all applicable procedures for gas line installation, gas handling and leak testing of gas lines especially when toxic or corrosive gases are used.

7.7 Installing a Pressure Control Valve

Either an upstream solenoid valve or a downstream throttle valve can be connected to the 946 to perform system pressure control. This feature requires the 946 to have the Pressure Control (PC) option installed.

7.7.1 Installing an Upstream Solenoid Valve

Only one upstream valve (148, 248, 154) can be controlled with the 946 Vacuum System Controller. If multiple gases are used for system pressure control, MFC based ratio control is recommended.

7.7.1.1 Mounting the Valve

- Ensure the flow direction arrow on the valve body is pointing towards the vacuum chamber.
- The valve may be installed in any position, although base down is recommended.
- Although ¼” O.D. tubing connections are generally adequate to support the weight of the valve, it is recommended to mount the valve on a base plate with the two 10-24 mounting holes in the valve body.
- Tubing lengths should be kept short throughout the flow control loop. Restrictions and bends should be eliminated wherever possible.

7.7.1.2 Inlet Pressure

- The 148/248/154 valve may be operated with 150 psig maximum inlet pressure, however, the nominal flow rating is established at 1 atmosphere differential across the valve, increasing with the inlet pressure up to the maximum allowed. This extends the maximum flow control range from approximately 3X (10,000 SCCM range) to 250X (10 SCCM range).
- Decreasing the outlet pressure increases the flow range until the choked flow condition is reached. Further lowering of outlet pressure for a fixed inlet pressure will not increase flow because a sonic restriction exists.
- If low flow rate is desired (such as used in control the high vacuum system pressure), the inlet pressure must be regulated at very low pressure to avoid pressure burst inside the chamber during the valve operation, which may cause damage to the turbo pump or a hot cathode sensor.

7.7.1.3 Connecting the Valve to 946 Controller

Cable part number 100018192 can be used to connect an MKS 148/248/154 upstream valve to the 946 Vacuum System Controller.

The pinout for the connector on 946 pressure control module is shown in Table 7-. When the pressure control board is used for controlling an upstream solenoid valve, only pins 6 and 7 are used.

Function	946 Press. Control Module Pin	148/248/154 Valve Connector	153 Valve Connector	T3B Valve Connector
Power Common	1		Supply Common	
+15 V	2		Supply (+)	
Analog Set Point (+)	3			
Analog Set Point (-)	4			
PCS Signal	5		0 - 10 V Analog In	Signal (+)
Valve Drive (+)	6	2		
Valve Drive (-)	7	1		
PCS Common	8		Analog Rtn	Common (-)
Chassis Ground	9	Braid of Cable	Chassis	

Table 7-5 Pinouts for Pressure Control Valves to 946 Pressure Control Module

7.7.2 Installing a Downstream MKS 153 or T3B Throttle Valve

If the inlet gas flow rate and system pumping speed are fixed, the system pressure can be effectively controlled by adjusting the flow conductance using a downstream throttle valve such as MKS 153 or T3B control valve. Because the valve is positioned between the vacuum system and the vacuum pump, larger opening of the valve leads to higher conductance and lower system pressure. This logic is opposite the upstream pressure control where high opening often results in higher system pressure since more gas is fed into the vacuum system.

7.7.2.1 Mounting the Throttle Control Valve

- The 153/T3B unit can be mounted in a vacuum exhaust line with the proper fittings and connectors. The unit consists of a 253 exhaust valve with an electronic housing attached to the motor plate. Although the unit was designed and tested to operate in the most extreme conditions (with no air circulation and a heated valve at 80° C), it will operate cooler if the air slots in the side of the housing are clear to allow convection air circulation. Typically, electronic components last longer in cooler environments.
- For best pressure control, locate the pressure transducer and exhaust control valve as close as practical to the process chamber to minimize the time constants.

7.7.2.2 Connecting the 153/T3B control valve to 946 Controller

- Cable part number 10018191 can be used to connect the 153 control valve to 946 Vacuum System Controller.
- Once the cable is connected, the 946 Controller will provide the power to the 153 valve, and position of the valve is controlled by the PCS signal voltage, as shown in Table 7-.

7.7.2.3 Connecting the T3B Valve to the 946

- Use cable 1053451-001 to connect the T3B to the 946.
- Connect desktop power supply part number 1053192-001 to the T3B or DIN Rail power supply part number 1053456-001 to the T3B.
  Or connect +24 VDC 4 Amps to pins 1 and 2 and +24 VDC Return to pins 3 and 4 of the 9-pin power connector of the T3B.
- Connect the pressure sensor to the 946, not the valve.

7.7.2.4 Setting of 153/T3B Valve and 946 Controller

The 153 or T3B valve and 946 Controller need to be set as follows:

- 153/T3B valve control mode must be switched to Position Control mode.
  For the T3B, connect pin 5 to pin 24 on the Aux I/O connector.
  Additionally, ensure that the interlock signal is satisfied by connecting pins 22 and 24 on the Aux I/O connector.
- Valve type on 946 should be selected as 153 or T3B. See Figure 6-24 Selection of Valve Type using System Setup Screen.
- Direction in PID control recipe must be selected to DOWNSTREAM (see Figure 6-25).

8 Connecting Relay and Analog Outputs

☞ **Relay and analog outputs require 2.5 sec time delay to stabilize after power application.**

8.1 Connecting 946 Relay Outputs

There are twelve relays available in the 946 Controller which can be used to control the operation of devices associated with a vacuum system. Relay contacts can be accessed through the 25 pin “Relay Output” D-sub connector on the back of the AIO module.

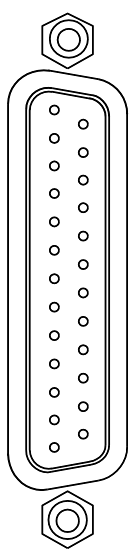
Relays used in the 946 are normally open (NO) SPDT relays. During the 946 power-up process, a 2.5 sec. delay is implemented to ensure that all relays remain in the normally open state until reliable control signals are available.

If normally closed relay outputs are required, an external conversion is required.

The relays are controlled with signals from the main microprocessor in the 946. The time required to process a pressure signal results in a relay activation time delay of between 50 to 100 msec.

8.1.1 Pin Out for the 946 Relay Output

Table 8-1 identifies the pins for the 25-pin "D" connector on the AIO/Power module that provides the connection to the relay outputs. 12 relays are built into the controller and 4 relays are assigned to each sensor module slot. If a single sensor module such as a CC or a HC is present, all four of these relays are assigned to the one sensor. If a dual sensor module such as a Pirani, CP, or Capacitance Manometer is used, 2 relays are assigned to each sensor.



Pin	Description	Pin	Description
1	Relay 1 NO	14	Relay 7 NO
2	Relay 1 Common	15	Relay 7 Common
3	Relay 2 NO	16	Relay 8 NO
4	Relay 2 Common	17	Relay 8 Common
5	Relay 3 NO	18	Relay 9 NO
6	Relay 3 Common	19	Relay 9 Common
7	Relay 4 NO	20	Relay 10 NO
8	Relay 4 Common	21	Relay 10 Common
9	Relay 5 NO	22	Relay 11 NO
10	Relay 5 Common	23	Relay 11 Common
11	Relay 6 NO	24	Relay 12 NO
12	Relay 6 Common	25	Relay 12 Common
13	No Connection		

Table 8-1 Pin Out for the 946 Relay Output

8.1.2 Proper Setting of a Relay

Several parameters need to be correctly set to properly use the relays in a 946 Controller. Figure 8-1 shows that manner in which these parameters are defined.

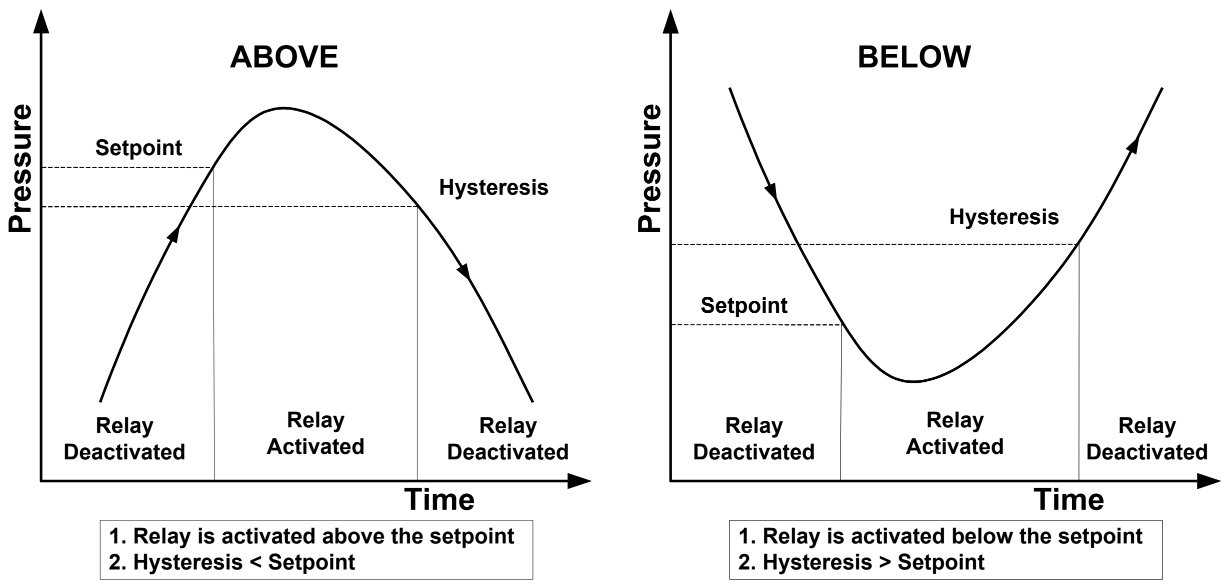


Figure 8-1 Definition of the Parameters used for Relay Control

1. Direction

   Direction indicates the direction relative to the set point when the relay is activated. There are two choices: ABOVE and BELOW.

   When ABOVE is selected, the relay will be activated when the pressure is higher than the set point. All relays in the 946 are normally open so ABOVE must be selected to close a relay when the pressure rises above a defined value. For example, a 946 relay set to ‘above’ can be used to control a normally closed (NC) roughing by-pass valve in a vacuum system. If the pressure is above the setpoint value, a relay can be activated (i.e. closed) so that power is supplied to the solenoid of the NC roughing valve, opening the valve until the setpoint pressure is reached and the valve is then closed.

   When BELOW is selected, the relay will be activated (closed) when the measured pressure is lower than the set point. For example, using relay activation in the BELOW mode, a normally closed isolation valve can be opened only when the pressure is below its set point.

   ☞ **Since a hot or cold cathode sensor is turned OFF when the pressure is above its protection or control set point, only the BELOW direction is permitted for these sensors.**

2. Hysteresis

   Hysteresis is designed to prevent chattering of the relay. System pressure may fluctuate slightly, and if the hysteresis is set too close to the set point value there is a potential for undesired relay activation.

   For example, when a high vacuum isolation valve is opened, a small pressure rise may occur in the vacuum system. If the hysteresis is close to or identical with the pressure set point, the controller will try to shut the valve, then reopen once the pressure drops, causing another rise and the sequence repeating. Such an operation is detrimental to system control and should be avoided.

Thus, when direction is set to ABOVE, the hysteresis must be lower than the set point, while when the direction is set to BELOW, the hysteresis must be higher than the set point.

When Direction is changed, hysteresis is set to a default value (of about 10%). Depending on the application, this value may need to be optimized. Default values depend upon the sensor type. Information on specific defaults is given in Section 6-5 for each sensor.

8.1.3 Relay Inductive Loads and Arc Suppression

If the set point relay is used to switch inductive loads, e.g., solenoids, relays, transformers, etc., arcing of the relay contacts may interfere with the controller operation or reduce relay contact life. In these situations, an arc suppression network, shown schematically in Figure 8-2, is recommended.

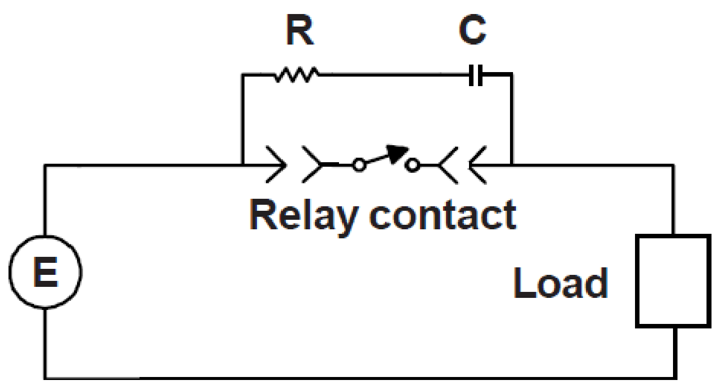


Figure 8-2 The Relay Arc Suppression Network

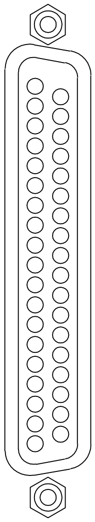
The values of the capacitance *C* and the resistance *R* are calculated using the equations:

$$C = \frac{I^2}{10} \;\; ; \;\; R = \frac{E}{10 \times I^a} \quad and \quad a = 1 + \frac{50}{E}$$

where *C* is in µF, *R* is in Ω, *I* is the DC or AC_{peak} load current in amperes, *E* is the DC or AC_{peak} source voltage in volts. C_{min} = 0.001µF and R_{min} = 0.5 Ω.

8.2 Connecting the 946 Analog Output

Analog output signals, which can be sent to a data acquisition system, are available from each sensor. These signals can be accessed from the 37 pin D-sub analog connector on the back of the controller. They include buffered, logarithmic, and combination logarithmic output. Buffered and logarithmic analog outputs are simultaneously available from all sensors. The detailed assignment for these pins is described in Table 8-2.



Pin	Description	Pin	Description
1	Buffered Aout A1	11	Log/Lin Aout C1
2	Buffered Aout A2	12	Log/Lin Aout C2
3	Buffered Aout B1	13	Combination Aout 1
4	Buffered Aout B2	14	Combination Aout 2
5	Buffered Aout C1	15	Power A1
6	Buffered Aout C2	16	Power A2/Degas A1
7	Log/Lin Aout A1	17	Power B1
8	Log/Lin Aout A2	18	Power B2/Degas B1
9	Log/Lin Aout B1	19	Power C1
10	Log/Lin Aout B2	20	Power C2/Degas C1
		21 to 37	Ground

Table 8-2 Pin Out for 946 Analog Output

8.3 Buffered Analog Output

A buffered analog signal responds immediately to sensor signal changes and is suitable for fast controlling applications.

Buffered analog signals are non-linear and strongly sensor dependent.

For capacitance manometers, Pirani type or cold cathode sensors, the buffered outputs are analog signals without microprocessor processing. However, the buffered output from a hot cathode sensor at pin 1, 3 or 5 in the table 8-2 is a microprocessor formed output. This is because the hot cathode sensor uses different emission currents to cover the pressure range, necessitating microprocessor scaling. The equation for this output is $V = 0.6 * \log(P) + 7.2$. (see Figure 8-4).

Normal buffered output for the 946 is 0 to 10 V. If a negative buffered voltage is observed, it may be caused by:

- No discharge for a Cold Cathode, or a pressure reading of less than $1x10^{-11}$ Torr.
- A reading below zero for a Capacitance Manometer (zero adjustment may be required).

The buffered analog outputs for variety of pressure sensors in an unpowered state are shown in Table 8-3.

Sensor	Buffered Analog Output when power is OFF
Cold Cathode (CC)	> 10 V
Hot Cathode (HC)	> 10V
Pirani (PR)	0
Convection Pirani (CP)	0

Table 8-3 Buffered Analog Output when Sensor Power is OFF.

Buffered analog outputs for the Cold Cathode, Hot Cathode, Pirani, Convection Pirani and Capacitance Manometers are shown in following figures and tables.

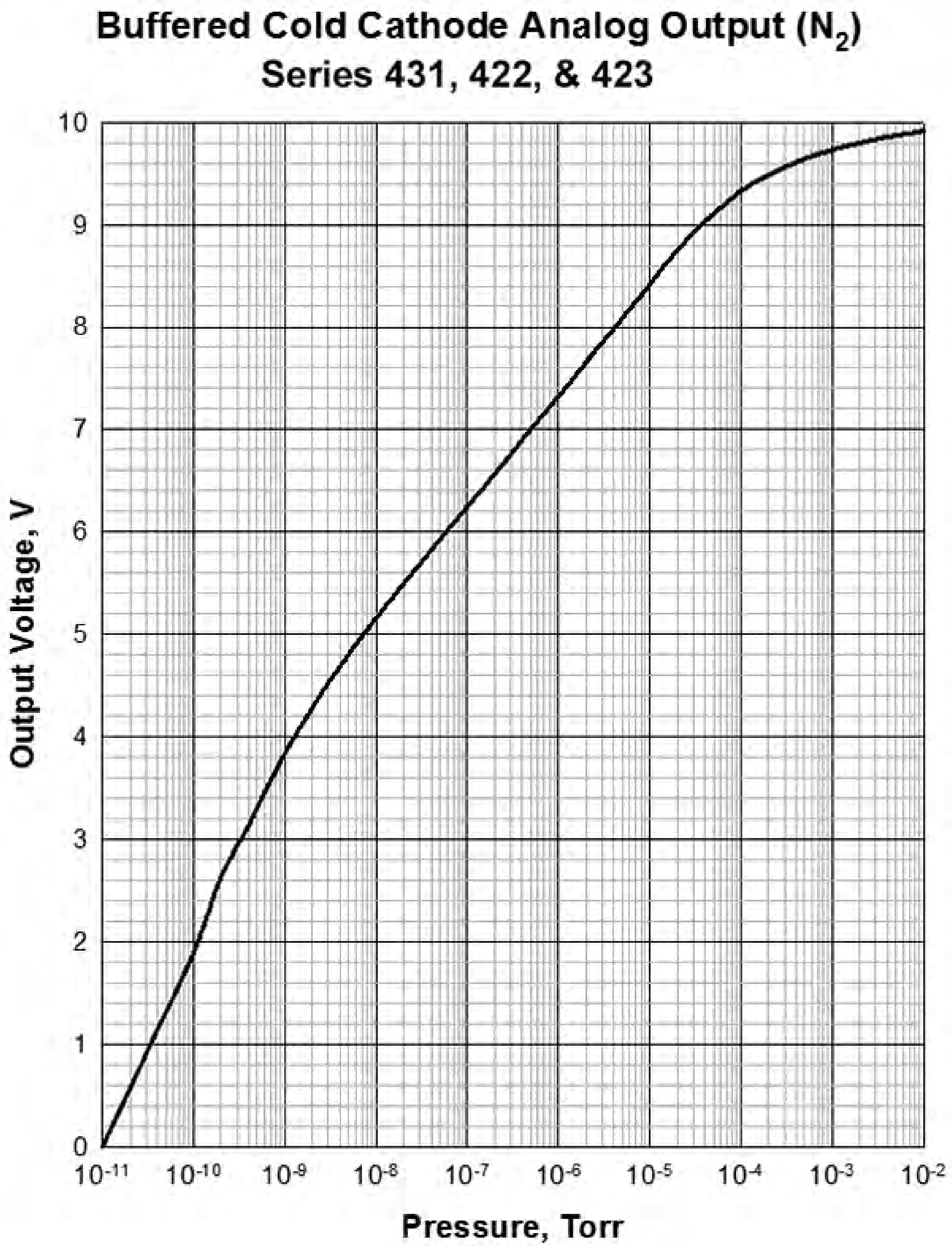


Figure 8-3 Buffered Analog Output for Cold Cathode Sensors (431/422/423) in N_2

Pressure, Torr	Buffered Vout, V	Pressure, Torr	Buffered Vout, V
1.0E-11	0.0000	4.0E-07	6.8993
1.5E-11	0.3286	6.0E-07	7.0871
2.0E-11	0.5634	8.0E-07	7.2222
3.0E-11	0.8994	1.0E-06	7.3247
4.0E-11	1.1416	1.5E-06	7.5140
6.0E-11	1.4585	2.0E-06	7.6551
8.0E-11	1.7035	3.0E-06	7.8469
1.0E-10	1.8882	4.0E-06	7.9769
1.5E-10	2.3241	6.0E-06	8.1714
2.0E-10	2.6299	8.0E-06	8.3064
3.0E-10	2.9358	1.0E-05	8.4136
4.0E-10	3.1342	1.5E-05	8.6166
6.0E-10	3.4587	2.0E-05	8.7446
8.0E-10	3.6700	3.0E-05	8.9177
1.0E-09	3.8409	4.0E-05	9.0275
1.5E-09	4.1006	6.0E-05	9.1665
2.0E-09	4.2838	8.0E-05	9.2614
3.0E-09	4.5248	1.0E-04	9.3297
4.0E-09	4.6807	1.5E-04	9.4255
6.0E-09	4.8991	2.0E-04	9.4826
8.0E-09	5.0452	3.0E-04	9.5605
1.0E-08	5.1579	4.0E-04	9.6076
1.5E-08	5.3563	6.0E-04	9.6708
2.0E-08	5.4924	8.0E-04	9.7034
3.0E-08	5.6809	1.0E-03	9.7325
4.0E-08	5.8185	1.5E-03	9.7703
6.0E-08	6.0096	2.0E-03	9.7975
8.0E-08	6.1423	3.0E-03	9.8340
1.0E-07	6.2431	4.0E-03	9.8575
1.5E-07	6.4281	6.0E-03	9.8823
2.0E-07	6.5683	8.0E-03	9.8997
3.0E-07	6.7570	1.0E-02	9.9178

Table 8-4 Buffered Analog Output for the Cold Cathode Sensors (431/422/423) in N_2.

Range	Equation
V<2.2V	$P = \exp(-25.3546 + 3.3941V - 0.9901V^2 + 0.4259V^3)$
2.2 V< V <3.71 V	$P = \exp\left(\frac{V - 5.7722}{0.1969}\right)$
V>3.71 V	$P = \exp\left(\frac{V - 4.2157}{0.3161 - 0.0721557V}\right)$

Table 8-5 Equations for Cold Cathode Sensors (N_2) Raw Analog Output

NOTE: The analog voltage from the 946 needs to be divided by 2.4 before equations can be used.

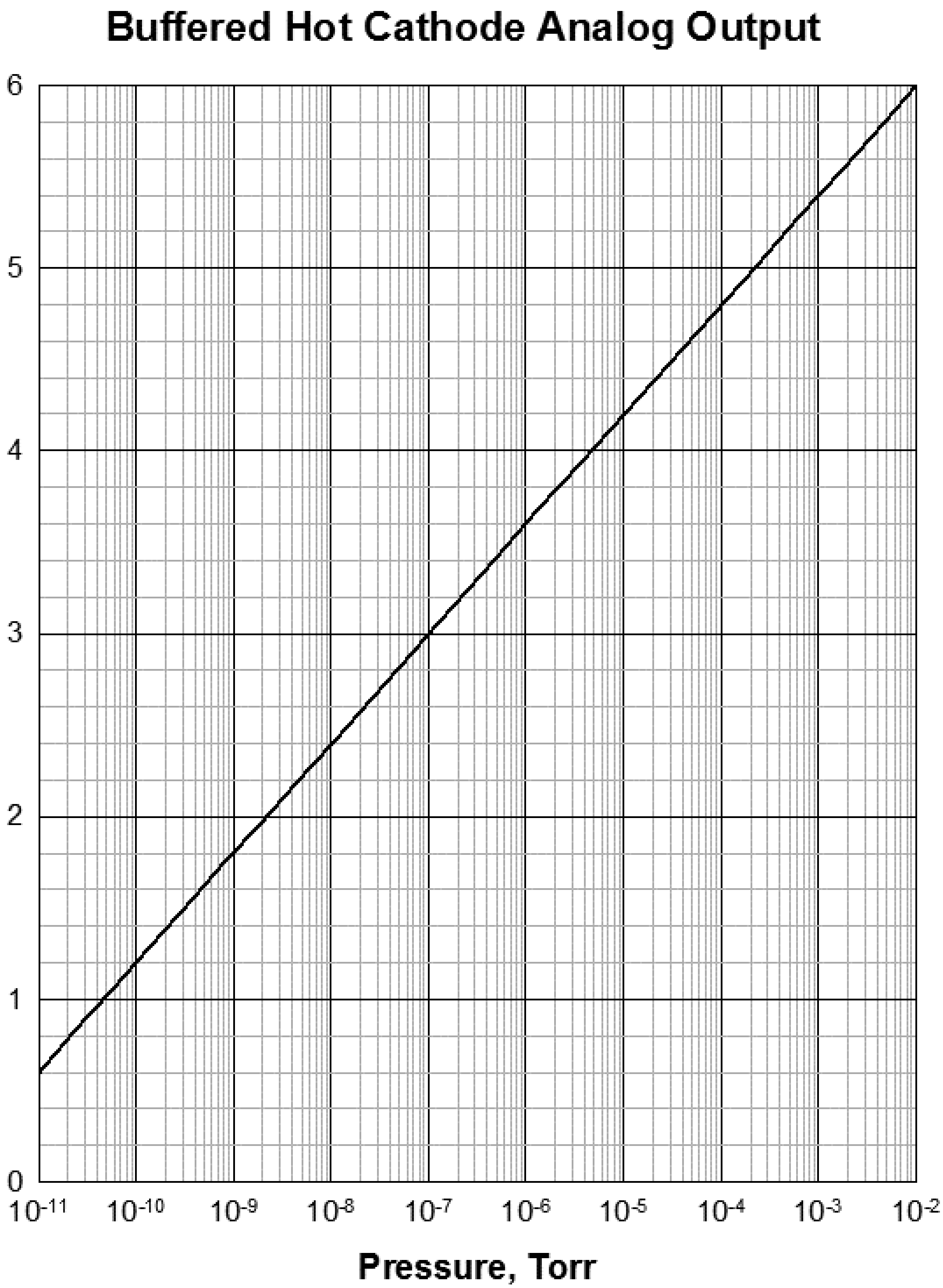


Figure 8-4 Buffered Analog Output for Hot Cathode Sensors

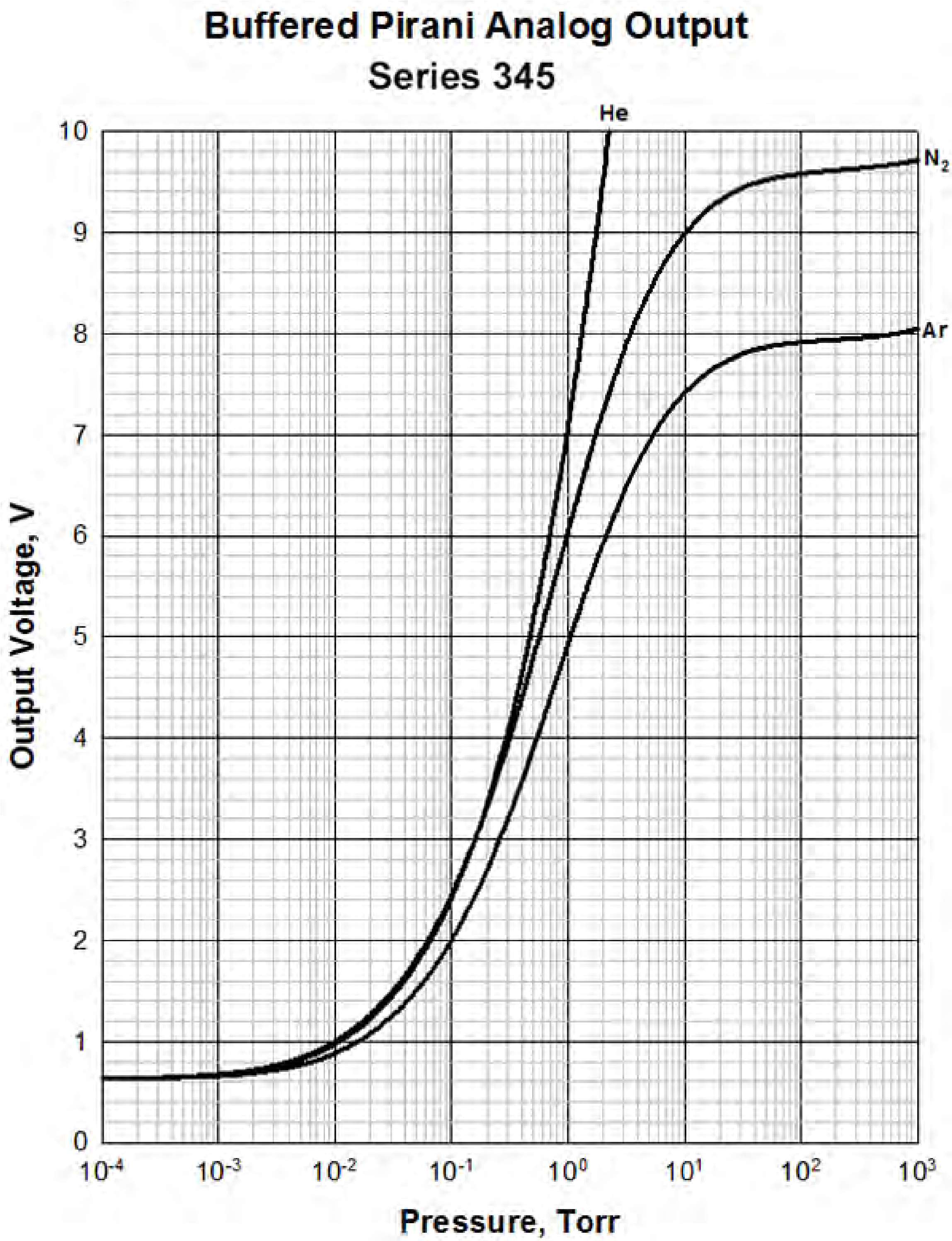


Figure 8-5 Buffered Analog Output for a 345 Pirani Sensor

Pressure, Torr	Buffered N_2 Vout, V	Buffered Ar Vout, V	Buffered He Vout, V
1.0E-04	0.6323	0.6324	0.6340
1.5E-04	0.6347	0.6339	0.6362
2.0E-04	0.6372	0.6355	0.6384
3.0E-04	0.6420	0.6385	0.6426
4.0E-04	0.6468	0.6414	0.6469
6.0E-04	0.6563	0.6474	0.6553
8.0E-04	0.6656	0.6533	0.6636
1.0E-03	0.6747	0.6591	0.6718
1.5E-03	0.6970	0.6734	0.6919
2.0E-03	0.7185	0.6875	0.7115
3.0E-03	0.7597	0.7147	0.7490
4.0E-03	0.7985	0.7408	0.7847
6.0E-03	0.8707	0.7905	0.8517
8.0E-03	0.9371	0.8371	0.9138
1.0E-02	0.9988	0.8812	0.9718
1.5E-02	1.1376	0.9824	1.1036
2.0E-02	1.2602	1.0735	1.2211
3.0E-02	1.4727	1.2344	1.4271
4.0E-02	1.6557	1.3751	1.6066
6.0E-02	1.9652	1.6162	1.9148
8.0E-02	2.2254	1.8213	2.1788
1.0E-01	2.4526	2.0015	2.4131
1.5E-01	2.9255	2.3794	2.9143
2.0E-01	3.3095	2.6885	3.3370
3.0E-01	3.9177	3.1815	4.0419
4.0E-01	4.3922	3.5686	4.6294
6.0E-01	5.1070	4.1556	5.5955
8.0E-01	5.6323	4.5898	6.3873
1.0E+00	6.0405	4.9289	7.0651
1.5E+00	6.7597	5.5295	8.4399
2.0E+00	7.2342	5.9282	9.5215
3.0E+00	7.8281	6.4295	11.1701
4.0E+00	8.1874	6.7340	
6.0E+00	8.6026	7.0869	
8.0E+00	8.8363	7.2858	
1.0E+01	8.9862	7.4136	
1.5E+01	9.1992	7.5950	
2.0E+01	9.3119	7.6909	
3.0E+01	9.4294	7.7908	
4.0E+01	9.4846	7.8398	
6.0E+01	9.5377	7.8835	
8.0E+01	9.5638	7.9034	
1.0E+02	9.5795	7.9149	
1.5E+02	9.6017	7.9306	
2.0E+02	9.6146	7.9400	
3.0E+02	9.6319	7.9539	
4.0E+02	9.6454	7.9664	
6.0E+02	9.6693	7.9922	
8.0E+02	9.6925	8.0200	
1.0E+03	9.7157	8.0502	

Table 8-6 Buffered Analog Output for the 345 Pirani Sensor

Range	Equation
Nitrogen	
0.63<V<9.3 V *1×10^-4^<p <20 Torr*	$p = \left(\dfrac{1.585}{\dfrac{93.303}{V^2 - 0.3935} - 1} \right)^{1.007}$
9.3 V< V <9.72 V *20 <p< 1×10^3^ Torr*	$p = 4123 \times \left[(V - 9.621) + \sqrt{(V - 9.621)^2 + 1.34 \times 10^{-3}} \right]^{0.8696}$
Argon	
0.63<V<7.79 V *1×10^-4^ <p<20 Torr*	$p = \dfrac{1.663}{\dfrac{63.63}{V^2 - 0.3961} - 1}$
7.79 V< V <8.05 V *30 <p< 1×10^3^ Torr*	$p = 2959 \times \left[(V - 7.9386) + \sqrt{(V - 7.9386)^2 + 5.464 \times 10^{-4}} \right]^{0.729}$
Helium	
0.63<V<10 V *1×10^-4^ <3 Torr*	$p = \dfrac{9.287}{\dfrac{509.4}{V^2 - 0.3965} - 1}$

Table 8-7 Equations for the 345 Pirani Sensor

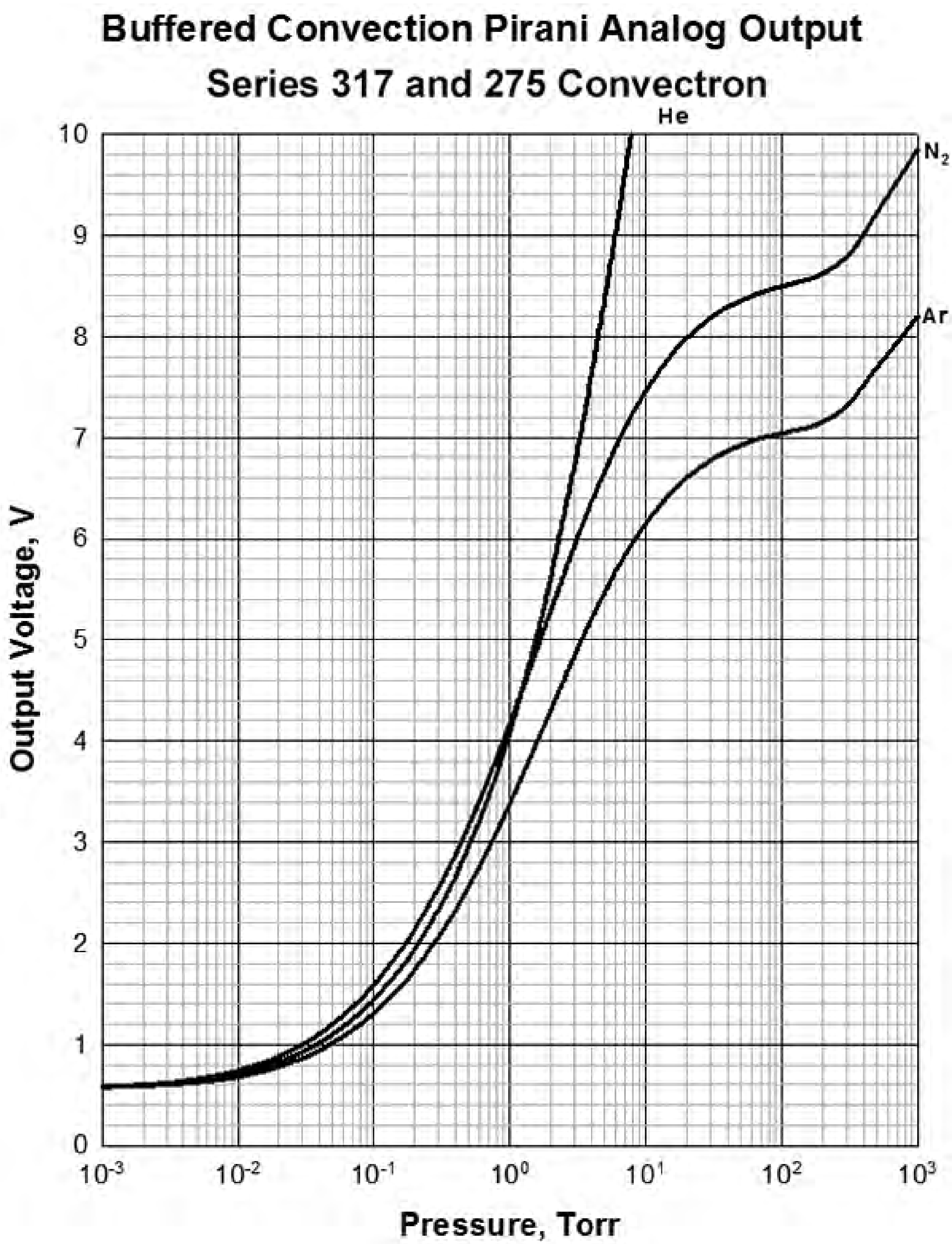


Figure 8-6 Buffered Analog Output for the 317 Convection Pirani Sensor or 275 Convectron Sensor

Pressure, Torr	Buffered N_2 Vout, V	Buffered Ar Vout, V	Buffered He Vout, V
1.0E-04	0.5639	0.5674	0.5654
1.5E-04	0.5650	0.5680	0.5663
2.0E-04	0.5660	0.5687	0.5671
3.0E-04	0.5681	0.5699	0.5688
4.0E-04	0.5702	0.5712	0.5705
6.0E-04	0.5744	0.5737	0.5738
8.0E-04	0.5785	0.5762	0.5771
1.0E-03	0.5825	0.5787	0.5803
1.5E-03	0.5925	0.5849	0.5883
2.0E-03	0.6023	0.5909	0.5961
3.0E-03	0.6213	0.6029	0.6114
4.0E-03	0.6397	0.6147	0.6262
6.0E-03	0.6748	0.6375	0.6547
8.0E-03	0.7081	0.6594	0.6818
1.0E-02	0.7397	0.6807	0.7077
1.5E-02	0.8130	0.7309	0.7685
2.0E-02	0.8799	0.7778	0.8244
3.0E-02	0.9993	0.8635	0.9256
4.0E-02	1.1050	0.9410	1.0161
6.0E-02	1.2884	1.0782	1.1755
8.0E-02	1.4465	1.1985	1.3147
1.0E-01	1.5870	1.3066	1.4398
1.5E-01	1.8866	1.5399	1.7110
2.0E-01	2.1371	1.7370	1.9427
3.0E-01	2.5480	2.0637	2.3341
4.0E-01	2.8825	2.3318	2.6645
6.0E-01	3.4139	2.7612	3.2168
8.0E-01	3.8301	3.1003	3.6784
1.0E+00	4.1716	3.3801	4.0811
1.5E+00	4.8207	3.9161	4.9231
2.0E+00	5.2897	4.3067	5.6142
3.0E+00	5.9352	4.8489	6.7300
4.0E+00	6.3647	5.2126	7.6243
6.0E+00	6.9069	5.6749	9.0227
8.0E+00	7.2375	5.9585	10.0998
1.0E+01	7.4611	6.1510	10.9720
1.5E+01	7.7955	6.4399	
2.0E+01	7.9814	6.6008	
3.0E+01	8.1820	6.7747	
4.0E+01	8.2885	6.8671	
6.0E+01	8.3954	6.9637	
8.0E+01	8.4563	7.0109	
1.0E+02	8.4917	7.0396	
1.5E+02	8.5547	7.0943	
2.0E+02	8.6178	7.1523	
3.0E+02	8.7804	7.3037	
4.0E+02	9.0106	7.5176	
6.0E+02	9.3827	7.8191	
8.0E+02	9.6467	8.0330	
1.0E+03	9.8515	8.1989	

Table 8-8 Buffered Analog Output for the 317 CP & 275 Convectron Sensors

Range	Equation
Nitrogen	
0.56<V<8.3 V *1×10⁻⁴<p <40 Torr*	$$p = \left(\frac{3.35}{\frac{74.327}{V^2 - 0.3156} - 1} \right)^{1.01}$$
8.3 V< V <8.8 V *40 <p< 300 Torr*	$$p = 399.5\sqrt{(V - 8.503) + \sqrt{(V - 8.503)^2 + 5.372 \times 10^{-3}}}$$
p>300 Torr	$$p = \exp\left(\frac{V - 3.512}{0.9177} \right)$$
Argon	
0.56<V<7.00 V *1×10⁻⁴<p <60 Torr*	$$p = \left(\frac{3.6}{\frac{51.083}{V^2 - 0.3205} - 1} \right)^{1.002}$$
7.00 V< V <7.4 V *60 <p< 300 Torr*	$$p = 411.2\sqrt{(V - 7.042) + \sqrt{(V - 7.042)^2 + 3.789 \times 10^{-3}}}$$
P>300 Torr	$$p = \exp\left(\frac{V - 3.063}{0.7436} \right)$$
Helium	
0.63<V<10 V *1×10⁻⁴ <4 Torr*	$$p = \left(\frac{26.93}{\frac{456.3}{V^2 - 0.3177} - 1} \right)^{1.017}$$

Table 8-9 Equations for the 317 CP and 275 Convectron Sensors

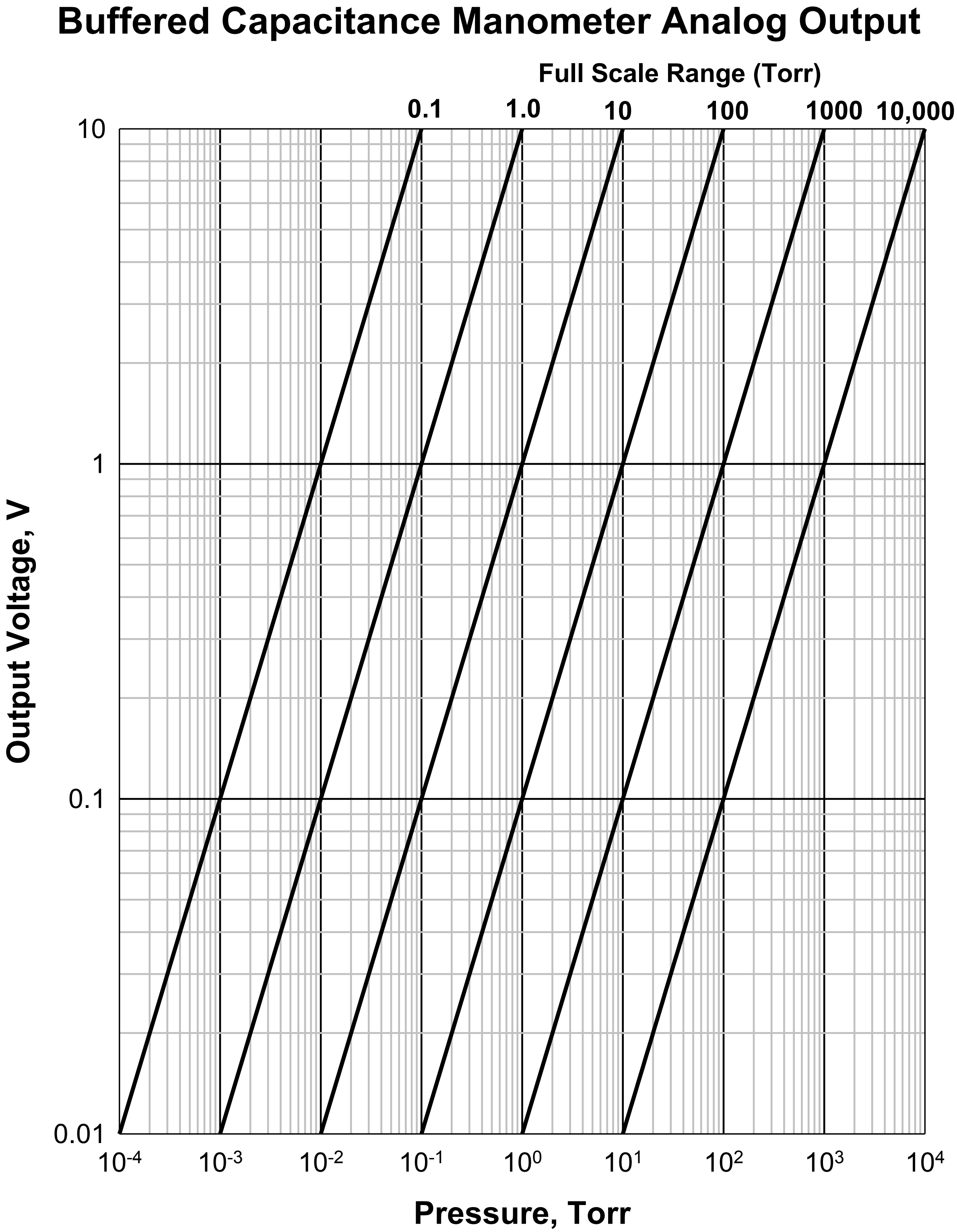


Figure 8-7 Buffered Analog Output for Capacitance Manometers

8.4 Logarithmic/Linear and Combination Analog Output

Since most of the buffered analog outputs are non-linear, logarithmically linearized or linear analog outputs are also provided for each individual sensor. However, since the logarithmic/linear analog outputs are processed by the microprocessor, these are updated only every 50 msec, regardless of the number of sensors being connected to the controller.

In addition to these Log/Lin analog outputs, 2 combination analog outputs are also available. Up to 3 sensors can be selected for a combination analog output.

8.4.1 Logarithmic/Linear Analog Output

There are two types of analog output that can be selected for each channel: logarithmic ($V = A \bullet \log(p) + B$) or linear ($V = A \bullet p$). These analog outputs are determined by the DACs inside the controller, and can be modified by setting appropriate DAC parameters in the System Setup screen shown in Figure 6-6.

The default analog output for the controller is logarithmic having a slope of 0.6V per decade and an offset of 7.2 V ($V = 0.6Log(p) + 7.2$). This provides an analog output ranging from 0.6 to 9.6 V (equivalent to a pressure range from $1X10^{-11}$ to $1X10^{4}$ Torr).

For detailed setting of the DAC parameters, refer to System Setup, Section 6.4.

8.4.2 Combination Analog Output

In addition to the logarithmic analog output for each individual sensor, two combination analog outputs are available. These can provide a wider pressure range coverage since the combination output combines the measurement ranges of multiple gauges.

When Capacitance Manometers are used in combination, no smoothing is provided in the overlap range. The 95% rule is used in switching the Capacitance Manometers. Once the reported pressure on the lower range Manometer is greater than 95% of its full scale, the combined analog output will be off the upper range Manometer.

A Pirani/Convection Pirani and capacitance manometer with a full scale of 500 torr or more, or a 902B piezo sensor, can be used in combination. When the Convection Pirani reading is greater than 5% of the full scale of the capacitance manometer the combined analog output will be based off the capacitance manometer.

When a capacitance manometer and a hot or cold cathode sensor are used in combination, the HC/CC pressure will be used as the combined analog output. The combined output will switch to the capacitance manometer only when the HC/CC is turned OFF.

If a Pirani/Convection Pirani and an HC/CC are used in combination, a smoothing formula is used where sensor ranges overlap (10^{-3} to 10^{-4} Torr). The combination output is 10V when 946 power is ON but the combination option is disabled if a fault is detected when three gauges are used in combination. Possible faults include filament failure or cable disconnected.

To set the combination analog output from the from panel, press the [System Setup] button, then move the cursor to change the Set Combination Ch parameter to ON and press [Enter], a setup screen will appear, as shown in Figure 8-8.

Set Combination Channel Parameter

	High	Middle	Low	Enable
Combo #1	C2	B1	A1	Enable
Combo #2	NA	NA	NA	Disable

Figure 8-8 Setup Screen for Setting Combination Channel Parameters

Once the combination sensors are selected, enable the combined analog output. If invalid channels are selected, the Enable indicator will stay in the Disabled mode.

The following rules may be used to simplify the combination configuration.

- The combination must include at least two pressure sensors.
- NA is when no sensor is assigned
- If either a Cold Cathode or Hot Cathode is included in the combination, it must be assigned as the low-pressure range sensor (“Low” in Figure 8.8).
- If a Pirani or Convection Pirani sensor is included in the combination, it must be assigned as the middle pressure range sensor (“Middle” in Figure 8.8).
- When a Pirani or Convection Pirani is used in combination, only HC/CC can be assigned to the low-pressure range sensor.
- Only capacitance manometer can be assigned as the high-pressure range sensor.
- If two or more capacitance manometers are used in a combination, the full scale (f.s) of the high range CM must be greater than or equal to the f.s. of the middle range CM, which in turn must have a f.s. greater or equal to the f.s. of the CM used for low range.
- When multiple capacitance manometers with same full-scale ranges are set in combination, the output is the average of the outputs from the CMs in combination.
- Only logarithmic analog output is available for combined analog output.

Combination pressure settings can also be accomplished using following serial commands:

- Query the pressure

@254PC1?;FF for corresponding pressure of combined Aout 1 and **@254PC2?;FF** for the pressure of combined Aout 2.

- Set the sensor combination

@254SPC1!HH,MM,LL;FF and **@254SPC2!HH,MM,LL;FF .** Here, **HH, MM** and **LL** are the channels **(A1, A2, B1, B2, C1, C2, NA)** corresponding to the sensor assigned to High, Middle, and Low range segments.

- Query the gauge combination

@254SPC1?;FF and **@254SPC2?;FF .**

- Enable/disable the combined analog output

@254EPC1!Enable;FF and **@254EPC1!Disable;FF .**

8.4.3 Logarithmic/Linear Analog Output when the Sensor Power is Turned OFF

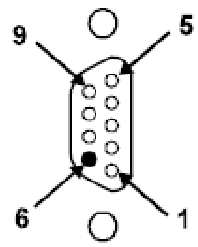
The following table shows the expected logarithmic/linear analog output when the sensor power is turned OFF or the combined analog output is disabled.

	Analog Out (Volts)	**Linear Out (volts)**	**Log-Linear Out (Volts)**
946 Power OFF	0	0	0
CP/Convectron channel OFF incl. gauge OFF via RP	0	10	10
CP/Convectron below range	See Analog Out Chart for CP Sensor	0	0.2
CP/Convectron filament failed	0	10	10
CP/Convectron cable disconnected	0	>10	>10
CC OFF from front panel; rear panel; via 'control' or 'protect'	11.5	10.5	10.5
HC OFF from front panel; rear panel; via 'control', 'protect', disconnected cable, or failed filament	10	10	10
CM (Absolute) below range	0	0	0.2
CM (Absolute) disconnected cable	-11	0	0.2
CM above range	11	10	9.8

Table 8-10 The Expected Logarithmic/Linear Analog Output Values

9 RS232/485 Serial Communication Commands

9.1 Serial Communication Wiring Diagram



Pin	Description
2	RS485(-)/RS232TxD/(B)
3	RS485(+)/RS232RxD/(A)
5	Ground

Table 9-1 946 Serial Communication Wiring Diagram

9.2 Communication Protocols

Cable length with RS232 signals	50 ft (15 m)
Cable length with RS485 signals	4000 ft (1200 m)
Baud rate	9600, 19200, 38400, 57600, 115200
Character format	8 data bits, 1 stop bit, No parity, No hardware handshaking
Query format	**@<aaa><Command>?;FF** The corresponding response is **@<aaa>ACK<Response>;FF** Here, **<aaa>**: Address, 1 to 254 **<Command>**: Commands as described in 9.3 to 9.14 **<Response>** Responses as described in 9.3 to 9.14 For example, to query pressure on channel A1, use **@003PR1?;FF** and the corresponding response is **@003ACK7.602E+2;FF** Here**, <aaa>=003; <Command>=PR1; <Response>=7.602E+2**
Set format	**@<aaa><Command>!<parameter>;FF** The corresponding response is **@<aaa>ACK<Response>;FF** Here, **<aaa>**: address, 1 to 254 **<Command>** Commands as described in 9.3 to 9.13 **<Parameter>** Parameter as described in 9.3 to 9.13 **<Response>** Responses as described in 9.3 to 9.13 For example, to set new baud rate, use **@001BR!19200;FF** and the corresponding response is **@001ACK19200;FF** Here**, <aaa>=001; <Command>=BR; <Parameter>=19200; <Response>=19200**

Table 9-2 946 Serial Communication Command Protocol

9.3 Pressure Reading Commands

<table>
<tr><th>Command</th><th>Function</th><th>Response</th><th colspan="4">Meaning</th></tr>
<tr><td colspan="7">Single Channels</td></tr>
<tr><td rowspan="17">PRn
(n=1 to 6)</td><td rowspan="17">Read pressure on Channel n</td><td>d.d0E±ee
(d,e=0 to 9)</td><td colspan="4">Pressure in selected units for PR, CP, CC & HC</td></tr>
<tr><td>d.dddE±e
(d,e =0 to 9)</td><td colspan="4">Pressure in selected units for CM</td></tr>
<tr><td>-d.ddE±e
(d,e=0 to 9)</td><td colspan="4">CM, when CM output is negative.</td></tr>
<tr><td rowspan="5">LO<E-e</td><td>Sensor</td><td>e(Torr/mbar)</td><td>e(Pascal)</td><td>e(micron)</td></tr>
<tr><td>PR</td><td>4</td><td>2</td><td>1</td></tr>
<tr><td>CP</td><td>3</td><td>1</td><td>0</td></tr>
<tr><td>CC</td><td>11</td><td>9</td><td>8</td></tr>
<tr><td>HC</td><td>10</td><td>8</td><td>7</td></tr>
<tr><td>ATM</td><td colspan="4">PR when p>450 Torr</td></tr>
<tr><td>OFF</td><td colspan="4">Cold cathode HV is OFF, or HC/PR/CP power is OFF.</td></tr>
<tr><td>RP_OFF</td><td colspan="4">HC and CC power is turned OFF from rear panel control</td></tr>
<tr><td>WAIT</td><td colspan="4">CC or HC startup delay</td></tr>
<tr><td>LowEmis</td><td colspan="4">HC OFF due to low emission</td></tr>
<tr><td>CTRL_OFF</td><td colspan="4">CC or HC is OFF in controlled state</td></tr>
<tr><td>PROT_OFF</td><td colspan="4">CC or HC is OFF in protected state</td></tr>
<tr><td>MISCONN</td><td colspan="4">Sensor improperly connected, or broken filament (PR, CP only)</td></tr>
<tr><td>NO_GAUGE</td><td colspan="4">Controller unable to determine sensor connection.</td></tr>
<tr><td>PRZ</td><td>Read pressures on all channel</td><td>6 of above, separated by spaces</td><td colspan="4">Same as above</td></tr>
<tr><td colspan="7">Combination Channels</td></tr>
<tr><td rowspan="2">PCn
(n=1 or 2)</td><td rowspan="2">Read pressure on channel n and its combination sensor</td><td>d.d0E±ee
(d,e=0 to 9)</td><td colspan="4">Combined pressure in selected units</td></tr>
<tr><td>NAK181</td><td colspan="4">Combination disabled</td></tr>
</table>

Table 9-3 946 Pressure Reading Commands

9.4 Relay and Control Setting Commands

Command	Parameter	Response	Function
SPm (m=1 to 12)	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query or set a set point for relay m, response with the current setting value. If 0 is used as the parameter, the set point will be set as its low limit value.
SHm (m=1 to 12)	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query or set a hysteresis for relay m, response with the current setting value.
SDm (m=1 to 12)	**ABOVE** or **BELOW**	**ABOVE** or **BELOW**	Query or set the direction for relay m, response with the current setting value. For CC and HC, only BELOW can be selected.
		NAK162	For CC and HC as the relay direction is fixed to BELOW.
ENm (m=1 to 12)	**SET, ENABLE,** or **CLEAR**	**SET, ENABLE,** or **CLEAR**	Query or set status for relay m. Response with current Enable status. **ENABLE** enables the relay, its status depends on the pressure and set point value, **SET** forces relay activation, regardless of pressure, and **CLEAR** disable relay.
SSm (m=1 to 12)		**SET** or **CLEAR**	Query all the relay setting status, **SET** is activated, and **CLEAR** is disabled.
ENA		**ddd..ddd** **(d=0,1,2)**	Query single relay set point status (relay1 relay 2 …relay 12). 0: clear; 1: set; 2: enable.
SSA		**ddd..ddd** **(d=0,1)**	Query all 12 relay set point status (relay1 relay 2 …relay 12). 0: clear; 1: set.

Table 9-4 946 Relay and Control Serial Setting Commands

9.5 Capacitance Manometer Control Commands

Command	Parameter	Response	Function
RNGn (n=1 to 6)	**d.dd E±ee**	**d.dd E±ee**	Query or set the full-scale pressure measurement range for a capacitance manometer. Valid range is from 0.01 to 10000, and default range is 1000 Torr.
CMTn (n=1 to 6)	**ABS** or **Diff**	**ABS** or **Diff**	**Query or set the Capacitor Manometer type, either absolute or differential.**
BVRn (n=1 to 6)	**5 or 10** for ABS **1B, 5B, 1U, 5U or 10U** for Diff	**5 or 10** for ABS **1B, 5B, 1U, 5U or 10U** for Diff	**Query or set the full scale voltage output range for a capacitance manometer. Default = 10V.**
ATZn (n=1 to 6)		**OK** or **NAK**	Zero a differential Capacitance Manometer on channel n.
VACn (n=1 to 6)		**OK** or **NAK**	Zero a capacitance manometer on channel n. Execute only when the signal is less than 5% of the full scale.
AZn (n=1 to 6)	**A1, B1, A2, B2, C1, C2, NA**	**A1, B1, A2, B2, C1, C2, NA**	Query or set capacitance manometer autozero control channel n, or disable autozero (NA). Execute only when the signal is less than 5% of the full scale.

Table 9-5 946 Capacitance Manometer Serial Commands

9.6 Convection Pirani, Convectron and Pirani Control Commands

Command	Parameter	Response	Function
ATMn (n=1 to 6)	**d.ddE+ee** (ambient pressure)	**d.ddE+ee**	Send an atmospheric pressure to perform ATM calibration. The PR/CP must be at atmospheric pressure when running ATM calibration. Valid range is from 100 to 1000.
VACn (n=1 to 6)		**OK** or **NAK**	Zero a PR/CP on channel n. Execute only when the pressure reading is less than $1X10^{-2}$ Torr.
AZn (n=1 to 6)	**A1, B1, A2, B2, C1, C2, NA**	**A1, B1, A2, B2, C1, C2, NA**	Query or set an autozero (CC or HC) control channel n for a PR/CP, or disable autozero (NA). Execute only when the pressure reading is less than $1X10^{-2}$ Torr.
GTn (n=1 to 6)	**Nitrogen Argon Helium**	**Nitrogen Argon Helium**	Query or set a gas type for PR/CP on channel n.
CPn (n=1 to 6)	**ON** or **OFF**	**ON** or **OFF**	Query the channel power status for PR, CP, HC or high voltage status for CC. Turn ON/OFF the channel power for PR, CP, HC, or high voltage for CC).
PTn (n=1 to 6)	**AUTO PR CP**	**AUTO PR CP AUTO-PR AUTO-CP**	Query or set Pirani sensor type on channel n. If Pirani type is set to PR or CP, the PTn command will respond PR or CP. If the Pirani is set to AUTO, the PTn command will response with the Pirani type it auto detects, i.e. AUTO-PR, when it detects the PR.

Table 9-6 946 Pirani and Convection Pirani Control Commands

9.7 Cold Cathode Control Commands

Command	Parameter	Response	Function
PROn **(n=1, 3, 5)**	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query or set protection set point value for sensor on channel n. The valid PRO range is 1x10^{-5} to 1x10^{-2} Torr. Use 0.0 to disable the protect set point control. Default value is 5x10^{-3} Torr.
CSPn (n=1, 3, 5)	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query and set control set point value for a CC sensor on channel n. Valid CSP range is 5x10^{-4} to 1x10^{-2} Torr for Pirani, 2x10^{-3} to 1x10^{-2} Torr for convention Pirani, and 0.2% of Full scale to 0.02 Torr for Capacitance Manometer. Capacitance Manometer full scale range has to be =< 2 Torr. Control channel (CSE command) needs to be set to a valid channel prior to setting this command.
XCSn (n=1, 3, 5)	**ON** or **OFF**	**ON** or **OFF**	Query or set the upper control set point status. If "ON" the range extended from 1x10^{-2} Torr to 9.5x10^{-1} Torr.
CHPn (n=1, 3, 5)	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query and set control set point hysteresis value for a CC sensor on channel n. Valid CHP range is 1.2×CSP to 1.1x10^{-2} Torr for Convention Pirani and Pirani, and 1.2×CSP to 0.03 Torr for Capacitance Manometer. Default value is 1.5X the control set point value.
CSEn (n=1, 3, 5)	**A1, B1, A2, B2, C1, C2, OFF**	**A1, B1, A2, B2, C1, C2, OFF**	Query, enable/disable the control channel status for a CC gauge on channel n.
CTLn (n=1, 3, 5)	**AUTO, SAFE, OFF**	**AUTO, SAFE, OFF**	AUTO: CC sensor can be turned ON & OFF by the controlling sensor. SAFE, CC sensor can be turned OFF, but, not be turned ON by the controlling sensor.
UCn (n=1,3, 5)	**dd.d** (d=0 to 9)	**dd.d** (d=0 to 9)	Query or set a gas correction factor for a CC on Channel n. Valid range is from 0.1 to 10.0.
CPn (n=1,3, 5)	**ON** or **OFF**	**ON** or **OFF**	Query the channel power status for PR, CP, HC or high voltage status for CC. Turn ON/OFF the channel power for PR, CP, HC, or high voltage for CC).
GTn (n=1,3, 5)	**Nitrogen** **Argon** **Helium**	**Nitrogen** **Argon** **Helium**	Query or set a gas type for HC/CC on channel n.
Tn (n=1,3, 5)		**W, O, G, P, C, R, H, L**	Sensor status query. W = WAIT — P = PROTECT O = OFF — R = Rear panel Ctrl OFF G = GOOD — H = High C = Control — L = LOW
TDCn (n=1,3, 5)	**ddd** (d=0 to 9)	**ddd** (d=0 to 9)	Time delay until relays and output for CG are active, 3 to 300 secs
FRCn (n=1,3,5)	**d.d E±ee** (d,e=0 to 9)	**d.d E±ee** (d,e=0 to 9)	Query or set the pressure to trigger fast relay control output. Only available for special CC board with fast relay, and the set point value needs to be between 5x10^{-5} to 2x10^{-10} Torr.

Table 9-7 946 Cold Cathode Control Commands

9.8 Hot Cathode Control Commands

Command	Parameter	Response	Function
PROn **(n=1, 3, 5)**	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9) **DISABLE**	Query or set protection set point value for sensor on channel n. The valid PRO range is 1x10^{-5} to 1x10^{-2} Torr. Use 0.0 to disable the protect set point control. Default value is 5x10^{-3} Torr.
CSPn (n=1, 3, 5)	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query and set control set point value for a sensor on channel n. Valid CSP range is 5x10^{-4} to 1x10^{-2} Torr for Pirani, 2x10^{-3} to 1x10^{-2} Torr for Convention Pirani, and 0.2% of Full scale to 0.02 Torr for Capacitance Manometer. Capacitance Manometer full scale range has to be =< 2 Torr. Control channel (CSE command) needs to be set to a valid channel prior to setting this command.
XCSn (n=1, 3, 5)	**ON** or **OFF**	**ON** or **OFF**	Query or set the upper control set point status. If "ON" the range extended from 1x10^{-2} Torr to 9.5x10^{-1} Torr.
CHPn (n=1, 3, 5)	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query and set control set point hysteresis value for an HC sensor on channel n. Valid CHP range is 1.2×CSP to 1.1×10^{-2} Torr for Convention Pirani and Pirani, and 1.2×CSP to 0.03 Torr for Capacitance Manometer. Default value is 1.5X the control set point value.
CSEn (n=1, 3, 5)	**A1, B1, A2, B2, C1, C2, OFF**	**A1, B1, A2, B2, C1, C2, OFF**	**Query, enable/disable the control channel status for an HC sensor on channel n.**
CTLn (n=1, 3, 5)	**AUTO, SAFE, OFF**	**AUTO, SAFE, OFF**	AUTO: HC/CC can be turned ON & OFF by the controlling sensor (PR/CP). SAFE Sensor can be turned OFF, but, not be turned ON by the controlling sensor. If no PR/CP exists, this function cannot be enabled.
AFn (n=1,3, 5)	**1 or 2**	**1 or 2**	Query or set active filament for HC.
ECn (n=1,3, 5)	**20UA** **100UA** **AUTO20** **AUTO100**	**20UA** **100UA** **AUTO20** **AUTO100**	Query or set emission current.
GCn (n=1,3, 5)	**d.dd** (d =0 to 9)	**d.dd** (d =0 to 9)	Query or set a gas correction factor for an HC sensor on Channel n. Valid range is from 0.1 to 50.0. GT must be set to CUSTOM.
CPn (n=1,3, 5)	**ON** or **OFF**	**ON** or **OFF**	Query the channel power status for PR, CP, HC or high voltage status for CC. Turn ON/OFF the channel power for PR, CP, HC, or high voltage for CC).
SENn (n=1,3, 5)	**d.dd** (d =0 to 9)	**d.dd** (d =0 to 9)	Query or set a gas sensitivity for an HC sensor on Channel n. Valid range is from 1 to 50.0.
DGn (n=1,3, 5)	**ON** or **OFF**	**ON** or **OFF**	Query the HC degas status Turn ON/OFF degas
DGTn (n=1,3, 5)	**ddd** (d=5-240)	**ddd** (d=5-240)	Query and set the HC degas time.
GTn (n=1,3, 5)	**Nitrogen** **Argon** **Helium** **Custom**	**Nitrogen** **Argon** **Helium** **Custom**	Query or set a gas type for HC/CC on channel n. When Custom is selected, one can select GC value other than N_2, Ar or He.
Tn (n=1,3, 5)		**W, O, P, D, C, R, F, N, H**	HC sensor status query. W = WAIT; C = Control O = OFF; R = Rear panel Ctrl OFF P = PROTECT; F = HC filament fault D = DEGAS; N = No sensor

Table 9-8 946 Hot Cathode Control Commands

9.9 MFC Control Commands

Command	Parameter	Response	Function
FRn (n=1 to 6)	Read flow on Channel n	**d.dd0E±ee** (d,e=0 to 9)	Query flow reading in SCCM for MFC on Channel n.
QSFn (n=1 to 6)	**d.dd** (d =0 to 9	**d.dd** (d =0 to 9	Query or set a scale factor for a MFC on Channel n. Valid range is from 0.1 to 10.
RNGn (n=1 to 6)	**0.1 to 1E+6**	**0.1 to 1E+6**	**Query or set the full scale nominal range for a MFC. Valid ranges are 1.0 to 1000000 SCCM.**
QZn (n=1 to 6)		**OK** or **NAK**	Zero a MFC on channel n. Execute only when flow reading is less than 5% of full scale.
QSPn (n=1 to 6)	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query and set the flow set point for a MFC on channel n. If the channel is set to set point mode, this is the true flow rate set point. If the channel is set to Pctrl mode, this is the starting flow rate for the MFC. If the channel is set to RatioM or RatioA mode, this is the set point for ratio control. The maximum set point value is half of the full scale under the ratio control mode.
QMDn (n=1 to 6)	**Open** **Close** **Setpoint**	**OPEN** **CLOSE** **SETPOINT** **PCTRL** **RATIO** **PRESET**	Query or set the operation mode for a MFC on channel n.

Table 9-9 946 MFC Serial Control Commands

9.10 Pressure (Valve) Control Commands

Command	Parameter	Response	Function
VTP	**148** **248** **153** **154** **T3B**	**148** **248** **153** **154** **T3B**	Query or set the type of valve connected to valve control board.
VMD	**Open** **Close** **Manual**	**OPEN** **CLOSE** **SETPOINT** **AUTO** **MANUAL** **PRESET**	Query or set the operation mode for the valve connected to the pressure control board. *When PID control is turned OFF, valve mode goes to PRESET.*
VSP	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Set and query the position set point for valve.
VPOS	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query the current position of valve.

Table 9-10 946 Pressure (Valve) Serial Control Commands

9.11 PID Recipe Setting Commands

Command	Parameter	Response	Function
RCPn	**n** (n=1 to 8)	**n** (n=1 to 8)	Set or query the active recipe number.
RDCH?n **RDCH!n:**	**A1, B1, A2, B2, C1, C2, Rat, Vlv**	**n:CH** (n=1 to 8, CH=A1, A2, B1, B2, C1, C2, Rat, Vlv, NA)	Set or query the MFC channel for PID pressure control associated with recipe n.
RPCH?n **RPCH!n:**	**A1, B1, A2, B2, C1, C2, PC1, PC2**	**n:CH** (n=1 to 8, CH=A1, A2, B1, B2, C1, C2, NA)	Set or query the pressure channel for PID pressure control associated with recipe n.
RPSP?n **RPSP!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 8) (d,e=0 to 9)	Set or query the pressure set point for PID pressure control associated with recipe n.
RKP?n **RKP!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 8) (d,e=0 to 9)	Set or query the proportional control gain Kp for PID pressure control associated with current n. Valid rage is from 0.00002 to 10000.0, default setting is 10.
RTI?n **RTI!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 8) (d,e=0 to 9)	Set or query the Integral time constant for PID pressure control associated with recipe n. Valid rage is from 0.01 to 10000, default setting is 1.
RTD?n **RTD!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 8) (d,e=0 to 9)	Set or query the derivative time constant for PID pressure control associated with recipe n. Valid rage is from 0 to 1000, default setting is 0.5.
RCEI?n **RCEI!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 8) (d,e=0 to 9)	Set or query the CEILING parameter for PID pressure control associated with recipe n. Valid rage is from 10+BASE to 100 of full scale, default setting is 100.
RBAS?n **RBAS!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 8) (d,e=0 to 9)	Set or query the BASE parameter for PID pressure control associated with recipe n. Valid rage is from 0 to CEILING -10 of full scale, default setting is 0.
RPST?n **RPST!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 8) (d,e=0 to 9)	Set or query the PRESET parameter for PID pressure control associated with current active recipe n. Valid rage is from 0 to 100 of full scale, default setting is 99.
RSTR?n **RSTR!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 8) (d,e=0 to 9)	Set or query the START parameter for PID pressure control associated with recipe n. Valid rage is from 0 to 100 of full scale, default setting is 0.
REND?n **REND!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 8) (d,e=0 to 9)	Set or query the END parameter for PID pressure control associated with recipe n. Valid rage is from 0 to 100 of full scale, default setting is 0.
RCST?n **RCST!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 8) (d,e=0 to 9)	Set or query the CtrlStart parameter for PID pressure control associated with recipe n. Valid rage is from 0 to 1000 seconds, default setting is 0 seconds.
RDIR?n **RDIR!n:**	**Upstream** **Downstream**	**n:UPSTREAM** **n:DOWNSTREAM**	Set or query the DIRECTION parameter for PID pressure control associated with recipe n. Default is Upstream.
RGSB?n **RGSB!n:**	**d** (d=0 to 30)	**n:d** (n=1 to 8) (d=0 to 30)	Set the band for gain scheduled PID control for PID pressure control associated with recipe n. Default is 0.
RGSG?n **RGSG!n:**	**d** (d=1 to 200)	**n:d** (n=1 to 8) (d=1 to 200)	Set the gain for gain scheduled PID control for PID pressure control associated with recipe n. Default is 1.

Table 9-11 946 Recipe Serial Setting Commands

☞ **Example 1: To query the proportional gain Kp for recipe 3: @001RKP?3;FF)**

Example 2: To set control setpoint pressure to 50 Torr for recipe 1: @005RPSP!1:5.0E+1;FF)

☞ **The n: argument in both query and set command may be omitted (@254RPSP!2.5E+2;FF) if you query or set parameters within current active recipe.**

9.12 Ratio Recipe Setting Commands

Command	Parameter	Response	Function
RRCP	**n** (n=1 to 4)	**n** (n=1 to 4)	Set or query the active ratio recipe number.
RRQm?n **RRQm!n:**	**d.dd E±ee** (d,e=0 to 9)	**n:d.dd E±ee** (n=1 to 4) (m=1 to 6) (d,e=0 to 9)	Set or query the flow rate for ratio control channel m associated with ratio recipe n. The ratio channel is disabled if the flow rate is set to zero.

Table 9-12 Ratio Recipe Serial Setting Commands

☞ **Ratio recipe serial commands can only query or set parameters within current active recipe. It is recommended to run @254RRCP!n;FF first to set the active recipe before modifying recipe parameters.**

9.13 PID/Ratio Control Activation Command

PID	**ON, OFF**	**ON, OFF, NAK**	Start or stop the PID pressure control using current active recipe.
RM	**ON, OFF**	**ON, OFF, NAK**	Start or stop the manual pressure control using current active recipe.
RF	**ddd** (0 to 200)	**ddd** (0 to 200)	Set or query the ratio control factor. The RF! Command will also switch the auto ratio to manual ratio control.
RCP	**n** (n=1 to 8)	**n** (n=1 to 8)	Set or query the active recipe number.
RRCP	**n** (n=1 to 4)	**n** (n=1 to 4)	Set or query the active ratio recipe number.

Table 9-13 PID and Ratio Control Activation Commands

9.14 System Commands

Command	Parameter	Response	Function
AD	**aaa** (**aaa**=001 to 253)	**aaa** (**aaa**=001 to 253)	Query or set controller address (1 to 253) 254 is reserved for broadcasting. Default = 253.
BR	**#**	**#**	Query or set baud rate (valid **#** = 9600, 19200, 38400, 57600, 115200), default = 9600.
PAR	**NONE** **EVEN** **ODD**	**NONE** **EVEN** **ODD**	**Query or set the parity for the controller. Default=NONE.**
DLY	**t** msec	**t** msec	485 time delay, t must ≥ 1 for reliable 485 communication. Default = 8 msec.
U	**Unit**	**Unit**	Pressure unit, Unit=Torr, MBAR, PASCAL, Micron
DM	**STD** or **LRG**	**STD or LRG**	Display mode: either standard display, or large font display. Default = STD.
DF	**Default** **PatchZ** **HighR**	**Default** **PatchZ** **HighR**	Display format: either default, patch zero, or high resolution (only for HC and CC). Default = Default.
LOCK	**ON** or **OFF**	**ON** or **OFF**	**Enable (ON) or disable (OFF) front panel lock**
CAL	**Enable** **Disable**	**Enable** **Disable**	**Enable or disable User Calibration, default = Enable.**
SPM	**Enable** **Disable**	**Enable** **Disable**	Enable or disable parameter setting, default = Enable.
MT		**T1,T2,T3,T4**	Display the sensor module type. T1, T2, T3=(CC, HC, CM, PR, FC, NC). NC= no connection. T4=(NA, PF, PC)
STn **(n=A, B, C)**		**S1S2**	Display the connected sensor type on the specified module (A, B, or C). S1,S2=CC,PR,CP,CM,FC,HC, NG. NC=no connection.
MD		**937B** or **946**	Type of controller, either 937B, or 946.
FDn (n=1 to 6)		**OK**	Factory default for sensor module. This will reset the user calibration to factory default.
FDS		**OK**	Factory default for system setup (including address, unit, baud rate, recipes, combination, display format, screen saver)
FVn (n=1 to 6)		**d.dd** (d=0 to 9)	Firmware version n=1=Slot A; n=2=Slot B; n=3=Slot C n=4=AIO; n=5=COMM; n=6=Main
SN		**10 digit SN**	Display the serial number of the unit.
SNn (n=1 to 6)	Read serial number in slot n	**10 digit SN**	Display the serial number of the card in slot A, B, C, CO M, Analog and Main
SPCn (n=1 or 2)	**HH,MM,LL**	**HH,MM,LL**	Set or query the combination channel setting. HH: The channel for HP sensor; MM: The channel for MP sensor; LL: The channel for LP sensor. Valid values for HH, MM, or LL are A1, A2, B1, B2, C1, C2, or NA. Default is NA.
EPCn (n=1 or 2)	**Enable** **Disable**	**Enable** **Disable**	Enable or disable the combination channel. When the combination channel is disabled, the output is 10 V.

DLTn (n=1 to 6)	**LIN** or **LOG**	**LIN** or **LOG**	Query or set the type of DAC linear (LIN, V=A*P) of logarithmic linear (LOG, V=A*LogP+B) output. Default setting is LOG. (Only LOG is allowed for combined output)
DLAn (n=0 to 6)	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query or set the DAC slope parameter A. Default value is 0.6. Use n=0 for combination output. Valid range is from 0.5 to 5 when DLT is set to LOG, and 1E-4 to 1E+8 when DLT is set to LIN.
DLBn (n=0 to 6)	**d.dd E±ee** (d,e=0 to 9)	**d.dd E±ee** (d,e=0 to 9)	Query or set the DAC offset parameter B. Default value is 7.2. Use n=0 for combination output. Valid range is from –20 to 20 when DLT is set to LOG, and always equals to zero when DLT is set to LIN.
IU	**ON** or **OFF**	**ON** or **OFF**	Force the use of international pressure unit (Pascal).
XDL			Erase the first page of the memory for preparing the firmware downloading using Sam-BA after power cycle of the controller.
SEM	**TXT** or **CODE**	**TXT** or **CODE**	Set the NAK error code response. An error text string is returned if it is set to TXT, while an error code is returned if it is set to CODE.
SST	**0** to **240**	**OFF, 1** to **240**	Set and query the screen saver time (in minute) when sleep mode (turn OFF front panel display) is activated. 0 means the screen saver mode is disabled.

Table 9-14 946 System Commands

9.15 Error Codes

When serial commands are used in communicating with 946, an error code will be returned if an invalid command or an invalid parameter is sent. The error code can be displayed in either in TXT or CODE mode, and can be selected by using @254SEM!TXT;FF or @254SEM!CODE;FF command, respectively.

946 Error Code	
CODE	**TXT**
150	WRONG_GAUGE
151	NO_GAUGE
152	NOT_IONGAUGE
153	NOT_HOTCATHODE
154	NOT_COLDCATHODE
155	NOT_CAPACITANCE_MANOMETER
156	NOT_PIRANI_OR_CTP
157	NOT_PR_OR_CM
158	NOT_MFC
159	NOT_VLV
160	UNRECOGNIZED_MSG
161	SET_CMD_LOCK
162	RLY_DIR_FIX_FOR_ION
163	INVALID_CHANNEL
164	DIFF_CM
165	INVALID_PID_PARAM
166	PID_IN_PROGRESS
167	INVALID_RATIO_PARAM
168	NOT_IN_DEGAS
169	INVALID_ARGUMENT
172	VALUE_OUT_OF_RANGE
173	INVALID_CTRL_CHAN
175	CMD_QUERY_BYTE_INVALID
176	NO_GAS_TYPE
177	NOT_485
178	CAL_DISABLED
179	SET_POINT_NOT_ENABLED
181	COMBINATION_DISABLED
182	INTERNATIONAL_UNIT_ONLY
183	GAS_TYPE_DEFINED
191	NOT_RATIO_MODE
195	CONTROL_SET_POINT_ENABLED
199	PRESSURE_TOO_HIGH_FOR_DEGAS

Table 9-15 946 Serial Communication Error Codes

10 Maintenance of Series 946 Controller Modules

Lethal voltages are present in the controller when it is powered. Disconnect the power cable before disassembly. Do not connect or disconnect any electrical connectors while power is applied to the equipment (hot swapping). Doing so may cause damage to the equipment or severe electrical shock to personnel. This hazard is not unique to this product.

The service and repair information in this manual is for the use of Qualified Service Personnel. To avoid shock, do not perform any procedures in this manual or perform any servicing on this product unless you are qualified to do so.

Suitable ESD handling precautions should be followed while installing, configuring or adjusting the instrument or any modules.

There are 3 sensor module slots (A, B, and C) available in the 946 Controller. Sensor module plug-in boards (Pirani/CP, Capacitance Manometer, Cold Cathode, Hot Cathode and Mass Flow) can be inserted into any available slot and the controller will automatically recognize the type of the board in the slot. Typically, 946 Controllers are shipped with customer-specified sensor modules.

The optional Pressure Control (PC) module for operating valves with the 946 Controller can only be used the slot labeled “COM”. The Pressure Control module has a different DIN connector for internal connection to the 946 than the other modules. The controller with automatically recognize when this module is installed.

To change the controller configuration by removing and installing modules, follow the steps shown below.

10.1 Removing and Installing a Sensor Module

To remove a module:

1. Make sure that the 946 power is OFF, and the power cord is disconnected.
2. Use a #1 Phillips screwdriver to remove the two screws on the top and bottom of the rear panel of the module.
3. Use a small, flat-blade screwdriver to gently pry the module away from the rear panel frame until it slides freely.
4. **Carefully** slide the module out.
5. Place the module on a static-protected workbench.

To install a module:

☞ **A pressure or flow sensor module (with 32-pin DIN) can only be inserted into slots A, B or C. It will not fit into the COMM slot!**

1. Make sure that the controller power is OFF and the power cord is disconnected.
2. If there is a blanking panel over the slot, use a #1 Phillips screwdriver to remove the two screws on the top and bottom of the blank panel.

3. Align the module to fit and slide freely in the **card guides**, with the internal 32-pin DIN connector end first.
4. Gently slide the module forward.
5. Use a #1 Phillips screwdriver to tighten two screws on the top and bottom of the rear panel of the module.

10.2 Removing and Installing AIO Module

The power cord receptor, the RS232/485 communication 9-pin D-Sub connector, the 25 pin D-Sub Relay output connector, and the 37-pin D-Sub Analog output connector are all located on the back panel of the AIO module.

To remove the AIO module:

⚠ **Lethal voltages are present in the controller when it is powered. Disconnect the power cable before proceeding.**

⚠ **Suitable ESD handling precautions should be followed while installing, configuring or adjusting the instrument or any modules.**

1. Make sure that the controller power is OFF and the power cord is disconnected.
2. Use a #1 Phillips screwdriver to remove the four (4) screws on the four corner of the rear panel of the AIO module.
3. Place a small, flat-bladed screwdriver at the top right corner of the AIO module (as shown below) and gently pry the AIO module away from the rear panel frame until it slides easily.

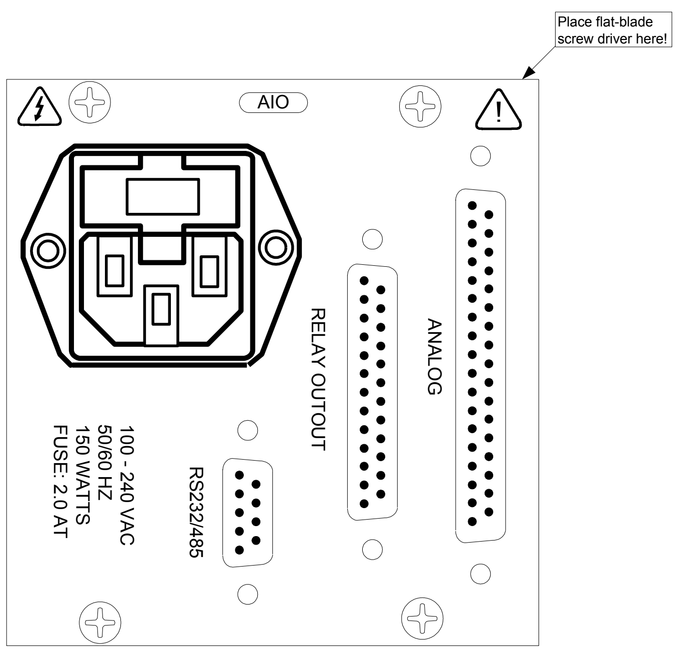


Figure 10-1 Instructions for Removing AIO Module

4. Pull the AIO board out by about 2 inches (5 cm).

5. Use needle-nose pliers to remove the 3 wires (Blue, Brown, and Green/Yellow) connected to the back of the power cord receptor.
6. Carefully slide the module out.
7. Place the module on a static-protected workbench.

To install the AIO module:

1. Make sure that the controller power is OFF and the power cord is disconnected.
2. Align the module to fit and slide freely in the **card guides**, with the internal 48-pin DIN connector end first.
3. Gently slide the module forward until the back panel of the module is about 2 inches (5 cm) away from the back panel frame.
4. Connect 3 wires to the back of the power cord receptor as show below.

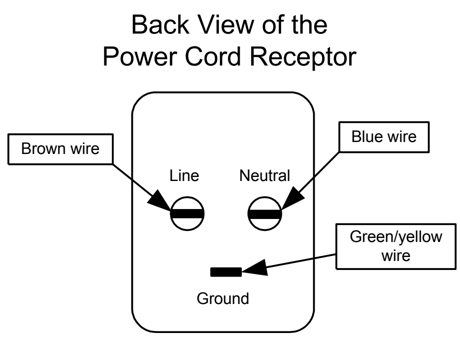


Figure 10-2 Instruction for Connecting Wire on the Back of the Power Cord Receptor

5. Gently slide the module forward and make sure the internal 48-pin DIN connector is engaged.
6. Use a #1 Phillips screwdriver to install and tighten the four (4) screws on the four corners of the rear panel of the module.

10.3 Pressure Control (PC) Module

In the 946 Controller, the slot labeled "COM" can only be used for the Pressure Control (PC) module that operates valves. The Pressure Control module has a different DIN connector for internal connection to the 946 than the other modules.

Lethal voltages are present in the controller when it is powered. Disconnect the power cable before proceeding.

Suitable ESD handling precautions should be followed while installing, configuring or adjusting the instrument or any modules.

To remove a Pressure Control Module:

1. Make sure that the controller power is OFF, and the power cord is disconnected.
2. Use a #1 Phillips screwdriver to remove the two screws on the top and bottom of the rear panel of the Pressure Control module.
3. Use a small, flat-blade screwdriver to gently pry the module away from the rear panel frame until it slides freely.
4. **Carefully** slide the module out.
5. Place the module on a static-protected workbench.

To install a Pressure Control module:

1. Make sure that the controller power is OFF and the power cord is disconnected.
2. If there is a blanking panel over the slot, use a #1 Phillips screwdriver to remove the two screws on the top and bottom of the blank panel.
3. Align the module to fit and slide freely in the card guides, with the internal 48-pin DIN connector end first.
4. Gently slide the module forward.
5. Use a #1 Phillips screwdriver to tighten the two screws on the top and bottom of the rear panel of the module.

10.4 Mounting the 946 Controller

The 946 Controller was designed for both rack mounting and bench top use. In both cases, leave at least 1 inch (25mm) open above the perforated panels to ensure adequate ventilation of the controller. Side clearance is not required.

To accommodate connectors and cables, leave open about 3 inches (75mm) clearance behind the rear panel.

Adhesive backed rubber pads are provided for bench top use. Remove the adhesive backing from each pad and apply one to each corner of the bottom surface.

Optional mounting hardware is available for mounting the 946 Controller in a 19-inch rack.

- Mounting a single 946 Controller into a 19" rack using MKS half-rack mounting kit part number 100005651:
    1. Attach the faceplate (3.5"x5.5") to each side of the 946 front panel using the four 10-32 screws provided. Secure the screws with the nuts included in the kit.
    2. Secure this assembly to the rack using the ¼" screws provided. It may be necessary to loosen the 10-32 screws securing the faceplates to align the holes with the mounting holes on the rack.
- Mounting the 946 Controller with another half-rack instrument using MKS half-rack mounting kit part number 100007700:
    1. Attach the half-rack instrument to the 946 Controller using the small splicing plate and the four 10-32 screws provided. The splicing plate is used to connect the front panel of each instrument together.
    2. Secure this assembly to the rack using the ¼"screws provided. It may be necessary to loosen the 10-32 screws securing the splicing plate to align the holes with the mounting holes on the rack.

☞ **All items in the kit may not be needed, depending on the mounting configuration.**

Contact an MKS Applications Engineer for solutions to other mounting configurations.

10.5 AC Power Cord

The 946 Controller has a standard female IEC 60320 connector for connecting to a 100-240 VAC, 50/60 Hz power source. Use only a harmonized, detachable cord set with conductors having a cross-sectional area equal to or greater than 0.75 mm^2. The power cord should be approved by a qualified agency such as UL, VDE, Semko, or SEV.

⚠ **Properly ground the controller and vacuum system.**

The 946 Controller is grounded through the ground conductor of the power cord. If the protective ground connection is lost, all accessible conductive parts may pose a risk of electrical shock. Plug the cord into a properly grounded outlet only.

⚠ **Do not exceed the manufacturer's specifications when applying voltage. Electrical shock may result.**

11 Maintenance and Service of MKS Vacuum Sensors

11.1 422 and 431 Cold Cathode Sensor

11.1.1 Cold Cathode Theory

Ambient gas molecules are ionized by a high voltage discharge in Cold Cathode sensors and sensitivity is enhanced by the presence of a magnetic field. MKS Cold Cathode sensors utilize an inverted magnetron design that includes an isolated collector, as shown in Figure 11-1. This makes the sensor less susceptible to contamination and allows a wider range of pressure measurement.

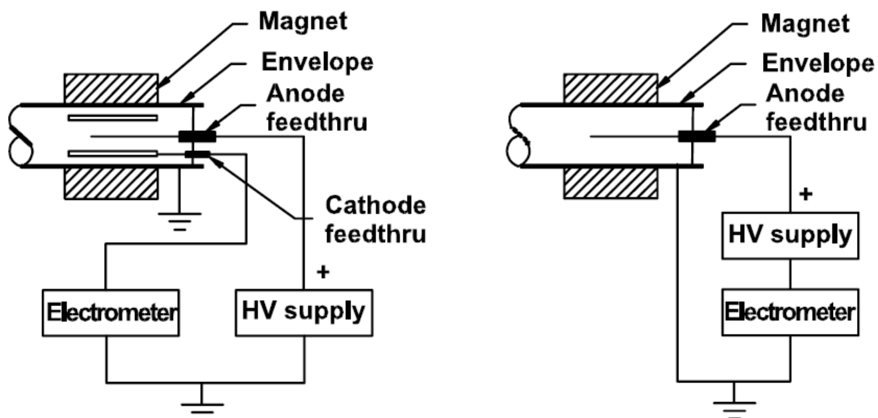


Figure 11-1 A comparison of Inverted Magnetron Cold Cathode Geometries. Isolated collector design is shown on the left.

Cold Cathode ionization sensors have inherent advantages over Hot Cathode sensors. These include:

- No filament to break or burn out, which makes the gauge immune to inrushes of air. It is also relatively insensitive to damage due to vibration.
- No X-ray limit for lower pressure measurements.
- No adjustment for emission current or filament voltage is needed.
- Degassing is not needed.
- Sensor tubes can often be cleaned and reused almost indefinitely.
- The control circuit is simple and reliable, having only one current loop, as compared with a Hot Cathode sensor which has three.
- Less power consumption enables the use of significantly longer cables between the controller and the sensor.

A Cold Cathode sensor consists of a cathode and an anode with a potential difference of several kilovolts between them. The electrodes are surrounded by a magnet, arranged so the magnetic field is perpendicular to the electric field. The crossed electric and magnetic fields cause electrons to follow long spiral trajectories within the sensor, increasing the chance of collisions with gas molecules, thereby providing a significant increase in ionization efficiency over a Hot Cathode sensor.

In operation, a near constant circulating electrical current is trapped by the crossed fields in which the collisions between electrons and residual gas molecules produce ions that are collected by the cathode. The relationship between sensor current and pressure is $i = kP^n$, where i is the sensor ion current, k is a constant, P is the pressure, and n is a constant (in the range of 1.00 to 1.15). This equation is valid for pressures ranging from 10^{-3} to 10^{-8} Torr, depending on the series resistor used. At pressures around 10^{-6} Torr, the sensitivities of 1 to 10A/Torr are not unusual.

The initiation of electron impact events within a Cold Cathode sensor depends upon certain chance events such as field emission or cosmic ray production of the first free electron. Electron-molecule collisions thereafter produce additional electron/ion pairs during the electrons' transit between the electrodes. The discharge rapidly builds to a stable value. Start of the discharge normally requires a very short time at 10^{-6} Torr or above, a few minutes at 10^{-8} Torr, and longer times at lower pressures.

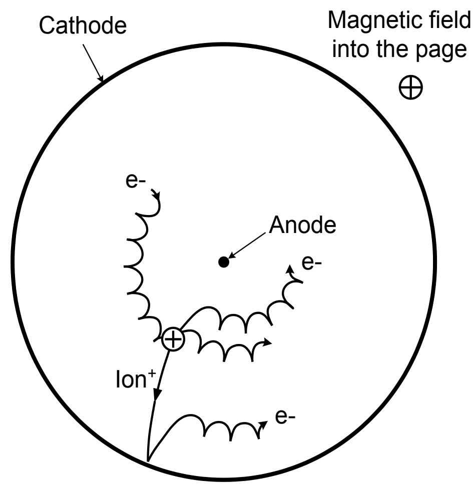


Figure 11-2 Electron Orbits and Ion Production in an Inverted Magnetron

MKS Cold Cathode sensors use an inverted magnetron with separate feed-throughs for the anode high voltage and the cathode current. This configuration has a cylindrical cathode, a central wire anode, and an external cylindrical magnet which provides an axial field. The cathode is isolated from the grounded metal housing. The inverted magnetron geometry produces more stable signal output, and also works well to low pressure without risk of extinguishing the discharge. The range of the MKS Instrument's cold cathode sensors is extended to 10^{-2} Torr by using a large series resistor to decrease sputtering within the sensor. Additionally, the voltage across the tube is pressure dependent in the range between 10^{-4} to 10^{-2} Torr and this is used in determining the pressure reading.

11.1.2 Maintenance of Series 431/422 Cold Cathode Sensor

11.1.2.1 Disassemble the Series 431/422 Sensor

The Series 431/422 sensor consists of three subassemblies – the backshell; the internal; and the body. Only the internal and body subassemblies are exposed to vacuum.

To disassemble the sensor, remove the backshell subassembly as follows (Steps 1 through 4 are not necessary when replacing internal parts):

1. Remove the two *4-40 x ¼" Phillips head SEMS screws* ❷ and slide the *backshell* ❾ off the sensor.

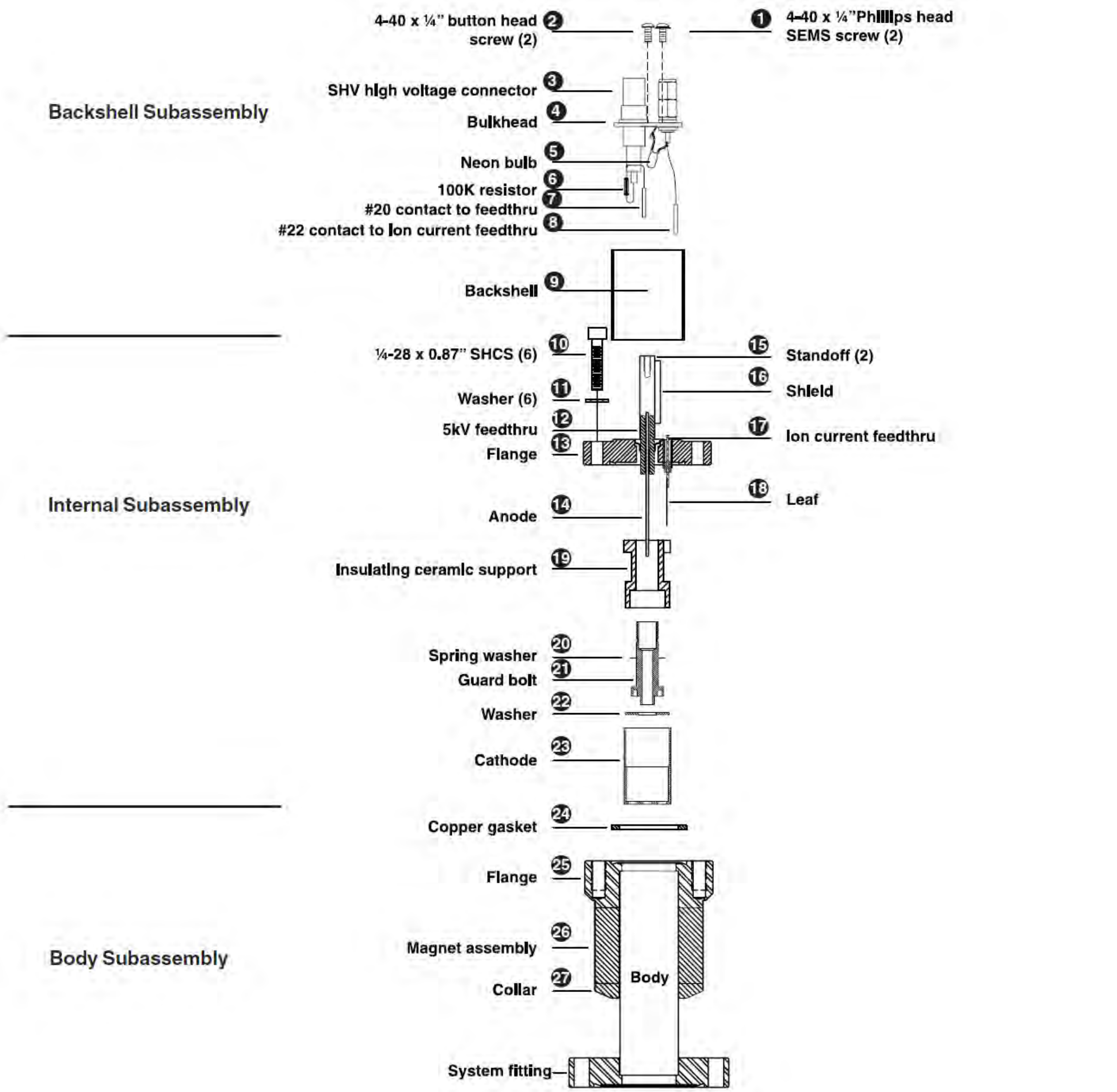


Figure 11-3 Exploded View of the 431/422 Cold Cathode Gauge Assembly

2. Remove the two 4-40 x ¼" button head screws (1).

3. Use needle nose pliers to pull the #22 contact (8) carefully off the ion current feed-through (17).

4. Pull the #20 contact (7) off the 5kV feed-through (12) taking the entire bulkhead (4) with it (do not remove the SHV and BNC connectors from the bulkhead).

5. Remove the six 1/4-28 x 0.875" socket head cap screws (10) and pull the back flange (13) free. Note that these screws are silver-plated for lubricity and should be used only once. They may be re-lubricated with a dry lubricant such as molybdenum disulfide, though new silver-plated screws are recommended. The copper gasket (24) must be replaced with a standard 2-1/8" CF flange gasket.

☞ **The cathode and anode assemblies are attached to the flange. Disassembly should proceed from the bottom to the top of the internal assembly drawing.**

6. To remove the cathode (23), release the two integral, spring-loaded ears that are hooked over the shoulder of the ceramic insulating support (19).
7. Gently pull up on the ear until it just clears the outer diameter of the ceramic insulating support (19).

☞ **Note the small Elgiloy® leaf (18) used to connect the ion current feed-through (17) to the *cathode* and its position. The rotational position of the *cathode* with respect to the *leaf* is not critical, however, be careful not to bend the *leaf*.**

8. Slide the cathode (23) and washer (22) off the insulating support.
9. The insulating support is captured by the guard bolt (21). Remove this using a spanner wrench (see accessory section) and unscrew the guard bolt from the flange (13).

☞ **There is a small curved spring washer (20) under the head of the guard bolt. This spring washer holds the insulating support tight, preloads the guard bolt to resist unscrewing due to possible vibration, and provides compliance for differential thermal expansion during bakeout.**

11.1.2.2 Cleaning the Series 431/422 Sensor

Depending on the degree of contamination and application of the sensor, the internal parts may be cleaned — either ultrasonically, with mild abrasives, or chemically.

☞ **Do not touch any vacuum exposed part after cleaning unless wearing gloves.**

Ultrasonic cleaning should use only high-quality detergents compatible with aluminum (e. g. ALCONOX®). Scrub surfaces with a mild abrasive to remove most contamination. Scotch-Brite™ or fine emery cloth may be effective. Rinse with alcohol.

Clean aluminum and ceramic parts chemically in a wash (not recommended for semiconductor processing), such as a 5 to 20% sodium hydroxide solution, at room temperature (20°C) for one minute. Follow with a preliminary rinse of deionized water. Remove smut (the black residue left on aluminum parts) in a 50 to 70% nitric acid dip for about 5 minutes.

Each of the cleaning methods described above should be followed with multiple rinses of deionized water. Dry all internal components in a clean oven set at 150°C. The ceramic parts are slightly porous and will require longer drying time in the oven to drive off the absorbed water.

11.1.2.3 Assemble the Series 431/422 Sensor

To reassemble the sensor, reverse the order of procedures used during disassembly. Note the following tightening procedure for the guard bolt. The bolt has a 3/8-40 thread design that is delicate.

1. Finger tighten the guard bolt to compress the spring washer and then back off one turn. Do not over tighten as this will remove all compliance from the spring washer and possibly damage the aluminum 3/8-40 thread.
2. Verify that the anode 14 is well-centered within the bore of the guard bolt.
3. If it is off center, carefully bend it back into position and continue with the assembly.

11.1.2.4 Preparing the Sensor for Bakeout

To prepare a Series 431 sensor for bakeout up to 125°C, remove the high voltage and ion current cables only. Series 431 sensors can be baked up to 250 C after the backshell subassembly is removed. Refer to section 11.1.2.1 above, and follow steps 1 to 4 for the backshell subassembly removal.

The bakeout temperature of a fully assembled Series 422 sensor depends upon the exact catalog part number of the sensor. Some versions are limited to 100°C with the backshell attached, others 250°C. Series 422 sensors with high temperature connectors may be operated during bakeout if cables and connectors with appropriate temperature ratings are used. Cables or connectors rated to temperatures less than the bakeout temperature need to be disconnected from the sensor for bakeout.

11.1.2.5 Testing a Cold Cathode Sensor

MKS cold cathode sensors contain anode and cathode (collector) electrodes. Test the sensor with an ohmmeter. There should be no shorts between the electrodes or from the electrodes to the sensor body.

11.2 Maintenance of Series 423 I-Mag Cold Cathode Sensor

11.2.1 Disassemble the I-Mag Sensor

1. Clean tweezers and clean smooth-jaw, needle-nose pliers are required.
2. Turn OFF the power to the 946 Controller.
3. Loosen the thumbscrew on top of the sensor cable and remove the cable. After safely venting/backfilling the vacuum system, remove the sensor from the system.
4. Loosen the two flat head screws 15. *See Figure 11-4.*
5. Remove the magnet 14.
6. Using the smooth-jaw, needle-nose pliers, firmly grab the compression spring 3 at the tip closest to the flange.
7. Pull on the compression spring 3 while rotating it to free it from the formed groove of the sensor body 9. Continue to pull until the compression spring 3 is completely free.
8. With the vacuum port facing up, carefully remove the remaining components (4 through 8) from the sensor body.

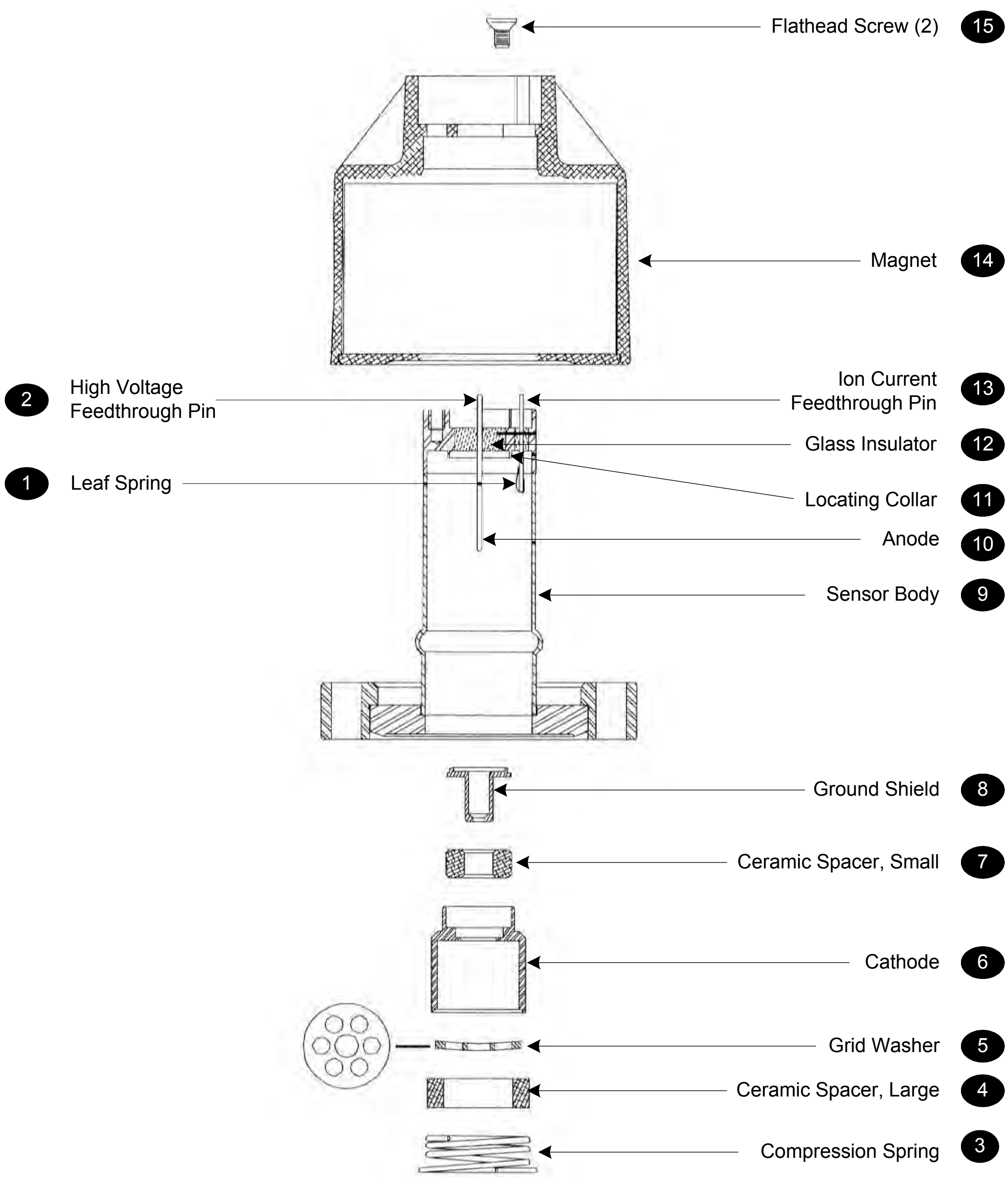


Figure 11-4 Exploded View of the Series 423 I-Mag Cold Cathode Gauge Sensor

STOP Do not bend the anode (10) or the leaf spring (1) on the ion current feed-through pin when assembling or disassembling the sensor.

11.2.2 Clean the I-Mag Sensor

Depending on the degree of contamination and the application of the sensor, the internal parts may be cleaned — either ultrasonically, with mild abrasives, or chemically.

Do not touch any vacuum-exposed part after cleaning unless wearing gloves.

Ultrasonically clean surfaces using only high quality detergents compatible with aluminum (i.e. ALCONOX®).

Scrub with a mild abrasive to remove most contamination. Scotch-Brite™ or fine emery cloth may be effective. Rinse with alcohol.

Clean aluminum and ceramic parts chemically in a wash (not recommended for semiconductor processing), such as a 5 to 20% sodium hydroxide solution, at room temperature (20°C) for one minute. Follow with a preliminary rinse of deionized water. Remove the black residue left on aluminum parts in a 50 to 70% nitric acid dip for about 5 minutes.

Chemical cleaning should not be used to clean the anode; mild abrasives or ultrasonic cleaning are acceptable.

STOP **Do not damage the leaf spring (1) while cleaning or assembling the sensor.**

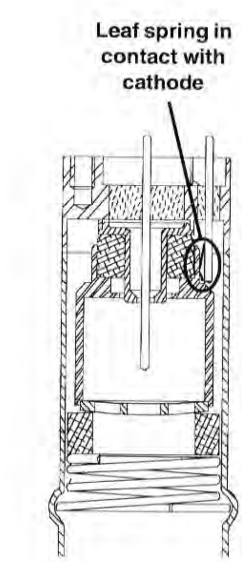
Each of the cleaning methods described above should be followed with multiple rinses of deionized water.

Dry all internal components and the sensor body (9) in a clean oven set at 150°C. The two ceramic spacers, (4) and (7), are slightly porous and will require longer drying time in the oven to drive off the absorbed water.

11.2.3 Assemble the I-Mag Sensor

Wear gloves and assemble with clean tools.

1. Roll the sensor body (9) on a flat surface and, looking down the port, check the anode (10) for any radial runout motion. It should be straight and centered with the sensor body (9) for proper operation.
2. Install the ground shield (8) using tweezers. Make sure that the ground shield (8) drops into the locating collar (11).
3. Slide the small ceramic spacer (7) over the small end of the ground shield (8).
4. Check that the leaf spring (1) will contact the base of the cathode (6), as shown to the right. If not, remove the small ceramic spacer (7) and the ground shield (8), and gently bend the leaf spring (1) towards the anode (10) and then replace the ground shield (8) and ceramic spacer (7).



5. Slide the cathode 6, the grid washer 5, and the large ceramic spacer 4 into place. The grid washer 5 has a concave shape. Refer to the figures to see its installation orientation.
6. Insert the small end of the compression spring 3 into the sensor body 9.
7. Using your thumbs, push the larger end of the spring into the sensor body 9 until it is contained within the tube's inside diameter.
8. Using the smooth-jaw, needle-nose pliers, work the compression spring 3 down into the sensor body 9 until it is fully seated in the formed groove.
9. Inspect the ground shield 8 and the grid washer 5 to verify they are centered with respect to the anode 10.
10. If adjustment is needed, gently reposition the grid washer/cathode assembly, taking care not to scratch the grid washer 5.

It is recommended that the resistance between the ion current feed-through pin 13 and the grid washer 5 be measured to verify that the leaf spring 1 is in contact with the cathode 6. The measurement should indicate a short circuit between them. There should be an open circuit between the ion current feed-through pin 13 and both the high voltage feed-through pin 2 and the sensor body 9.

Once this procedure is complete, the I-Mag Sensor is ready for installation. If it is not to be installed immediately, cover the flange with clean, vacuum grade aluminum foil and cap with a flange protector.

11.2.4 Preparing the Sensor for Bakeout

To prepare the sensor for bakeout at up to 400°C (when the sensor has a CF flange and is sealed with a metal seal), remove the sensor cable and magnet assembly as described in "Disassemble the I-Mag sensor".

11.3 Maintenance of Low Power Nude and Mini BA Hot Cathode Sensors

11.3.1 Hot Cathode Theory

Hot Cathode Ionization sensors use the electrons emitted from a hot filament (thermionic electrons) to create ions in a surrounding gas. The ion numbers are in proportion to the ambient gas pressure. Electrons are accelerated through the structure by a potential difference between the hot, emitting filament and a positively charged surrounding grid (anode). The energy acquired by the electrons as they are accelerated by the electric field is sufficient to ionize resident ambient gas molecules. The positively charged ions created by this collision ionization are attracted to the negatively biased ion collector where they are neutralized by an electron current. The gas molecules are singly ionized and there is a one–to-one correspondence between the number of ions neutralized and the magnitude of the neutralizing electron current. Hence the electron current is often called the “ion current” and this is proportional to the pressure in the sensor. The “ion current” is measured by the electrometer and converted to a pressure indication on 946 display.

The Bayard Alpert (BA) geometry is one of the most popular types of hot cathodes sensors. The main advantage of the BA configuration is its reduced susceptibility to X-ray induced errors. This is achieved through the adoption of a small diameter ion collector that minimizes the area exposed to the soft X-ray emitted from the grid. X-ray emission from the grid is an undesirable side effect of electron impact upon the grid surface. Some of these emitted X-rays strike the ion collector, releasing electrons by the photoelectric effect. This photoelectric current is not related to the pressure but is nevertheless added to the measurement of current determined by the electrometer. The photoelectric current can fully mask the ion current at low pressure (around $1x10^{-10}$ Torr) which limits the pressure measurement capabilities.

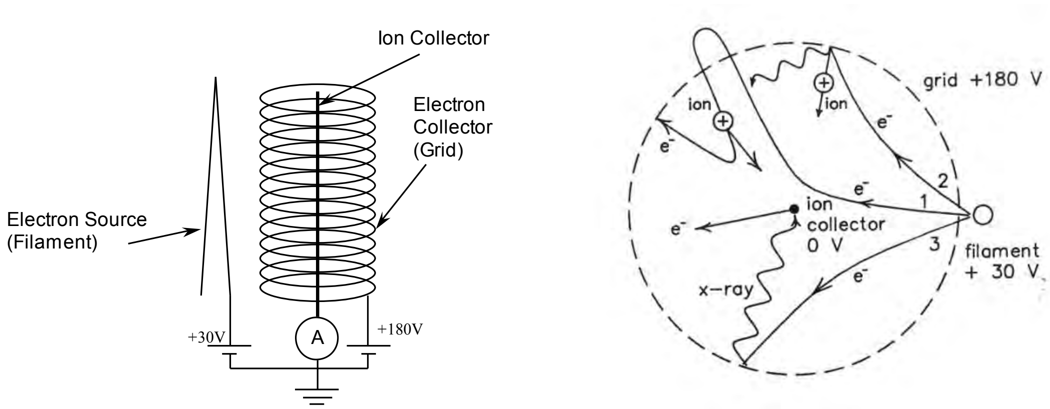


Figure 11-5 Bayard Alpert Gauge Structure and Electron Processes

The collection ion current i_+ is related to the pressure P and emission current i_- by the equation $i_+ = kPi_-$ where, k is the sensitivity factor which depends strongly upon the electron accelerating structure and operating condition. Typical sensitivity factor for nitrogen is around 7.5 to 15 $Torr^{-1}$.

To reduce the outgassing within the hot cathode to a negligible level and minimize the effect of ESD (electron stimulated desorption) on high vacuum measurement, high temperature degassing techniques are used to drive off any adsorbed gas molecules from the surface of the anode grid. Electrode heating during the degas process is accomplished either by electron bombardment (EB degas) or by passing a high current through the grid (I^2R degas). EB degas technique is accomplished in the 946 Controller by increasing the emission current from the filament.

11.3.2 Cleaning the Hot Cathode Sensor

Pump oils and other fluids that condense and/or decompose on surfaces such as the grid and collector, contaminate the sensor and can cause calibration shift. Degassing of the electrode structure can remove surface contamination on the grid and collector. Severe contamination of the grid structure may require a replacement of the sensor.

Although the feed-through insulators are shielded, in some applications conducting films or other forms of electrically conductive pathways may be formed on insulator surfaces. When this happens, it creates a leakage path on the insulator that can produce false low pressure reading. In these cases, the sensor may have to be replaced.

Unlike with Cold Cathode Sensors, it is not advisable to the clean the Hot Cathode sensor. Attempts to clean the sensor it may either deform or break the gauge structure.

11.3.3 Testing the Hot Cathode Sensor

This test will only identify a non-functional sensor. It will not detect damage from contamination, misuse or rough handling that can affect the calibration of a Hot Cathode gauge.

The most common cause of sensor failure is filament failure. To check for this, test the sensor using an ohmmeter with less than 5 mA of current. The resistance readings of a normal hot cathode sensor are show in Table 11-1. The resistance between the two pins of each filament is important.

Pin Numbers	Resistance (Ohm) for a good sensor	Resistance (Ohm) for a bad sensor
Between F1 pins	0 - 5	Open (>100 Ohm)
Between F2 pins	0 - 5	Open (>100 Ohm)
Any pin to ground/shell	$>10^6$ Ohm	$<10^6$ Ohm

Table 11-1 Resistance Readings of a Normal HC Sensor

F1 and F2 are identified on the Low Power Nude sensor (HC). For a Mini BA, use the drawing in Figure 11-6 to locate F1 and F2.

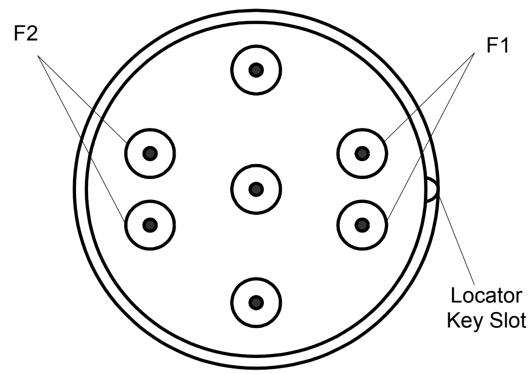


Figure 11-6 Filament Pin Locator for LPN and Mini BA Hot Cathodes

11.4 Maintenance of a Pirani Sensor

11.4.1 Theory of a Pirani Pressure Sensor

Measurement of pressure with any type Pirani sensor is based on the thermal conductivity of the gas type and amount in the vacuum environment. A wire, sometimes referred to as a filament, suspended from supports (see Figure 11-7) is heated and maintained at a constant temperature during the measurement process.

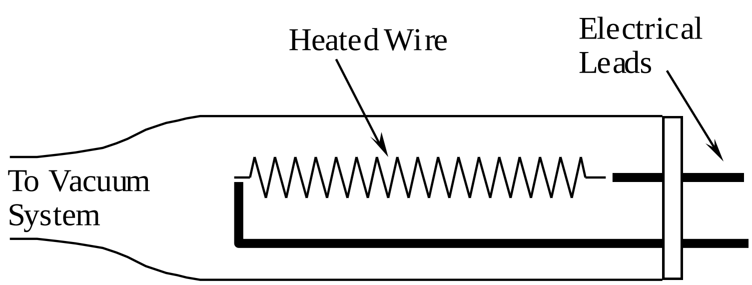


Figure 11-7 Schematic of a Pirani Thermal Conductivity Sensor

The amount of heat exchanged between the hot wire and a colder environment (wall of the sensor) is a function of the pressure when the distance between the hot wire and the cold (cooler) environment is comparable to, or less than, the mean free path of the gas molecules. When gas pressure is higher, the gas thermal conductivity becomes pressure insensitive and natural convective heat transfer must be employed to improve the sensitivity. This demands the horizontal placement of the sensor tube (see Figure 11-8) for a convention enhanced Pirani used to measure pressures greater than 100 Torr.

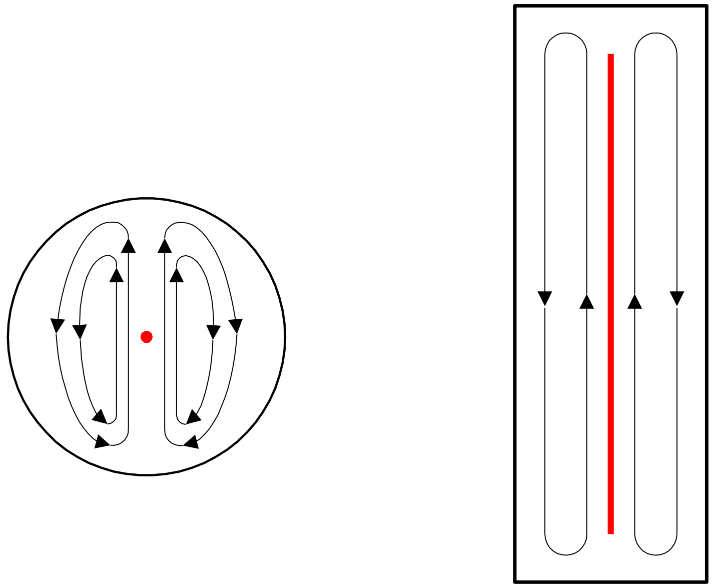


Figure 11-8 Natural Convection Heater Transfer in Horizontal (left) and Vertical (right) Sensor Tubes.

The size of gas molecules has significant impact on the Pirani sensor. Since smaller molecules (such as helium) move faster in the gas, this gas can transfer more heat energy under the same pressure as compared with a gas composed of heavy molecules (e.g. Argon). This explains the gas sensitivity of these sensors shown in Figures 8-5 and 8-6.

The standard Pirani sensor will read continuously between 5 x 10^{-4} to 100 Torr, and, with lower resolution, up to atmospheric pressure.

The Convection Pirani and Convectron sensor design enhances heat transfer at higher pressures through convection. This sensor will read continuously with full resolution from 1.0 x 10^{-3} to 1000 Torr.

11.4.2 Cleaning the Series 345 Sensor

Roughing pump oils and other fluids condensing or decomposing on the heated filament can contaminate the sensor. This changes the emissivity of the filament, which in turn can cause the calibration to change, especially at low pressure.

> **It is not advisable to clean the sensor. Attempts to clean it may either deform or break the filament. The deformed filament can further shift the sensor's output, increasing the errors in reading.**

Replace the sensor if it becomes contaminated.

11.4.2.1 Testing the Series 345 Sensor

> **This procedure tests function only. Lower levels of sensor damage that are due to contamination or rough handling can affect calibration, but the tube may still be functional.**

The most common cause of sensor failure is a broken filament.

Test the sensor using an ohmmeter with less than 5 mA of current. The resistance readings of a normal Series 345 Sensor measured at atmospheric pressure and at room temperature (20°C) are shown in Table 11-2.

345 D-sub Pin #	Resistance (Ω)
4 to 7	39
4 to 8	114
6 to 7	31
6 to 8	114
5 to 6	62
3 to 5	345

Table 11-2 Bridge Resistance Value for a Normal 345 Pirani Sensor

11.4.3 Cleaning the Series 317 Sensor

Roughing pump oils and other fluids condensing or decomposing on the heated filament can contaminate the sensor. This changes the emissivity of the filament, which in turn can cause the calibration to change, especially at low pressure.

It is not advisable to clean the Sensor. Attempts to clean it may either deform or break the filament wire. The deformed filament wire can further shift the sensor's output, increasing the errors in reading.

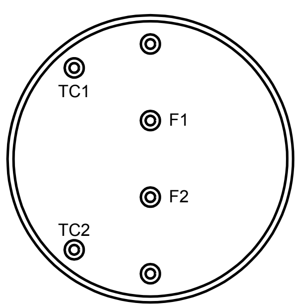
Replace the sensor if it becomes contaminated.

11.4.3.1 Testing the Series 317 Sensor

The most common cause of sensor failure is a broken filament. This might be caused by physical abuse or sudden venting of the sensor to atmosphere at the inlet port.

1. Using a #1 Phillips head screwdriver, remove the two screws to separate the connector/electronics subassembly from the end of the sensor.

2. Check the resistance on the sensor's pins listed in the first column in Table 11-3. Test the sensor using an ohmmeter with less than 5 mA of current. The resistance readings for a normal sensor measured at atmospheric pressure and at room temperature (20°C) are listed in the middle column. If the condition shown in the right column exists, the sensor should be replaced.



Sensor Tube

Check	Resistance (Ω)	Results
F1 to F2	20	If higher, filament is broken or burned out.
F1 to sensor port F2 to sensor port	>20x10^6	If lower, sensor is damaged or contaminated.
TC1 to TC2	27	If higher, temperature compensation winding is broken.
TC1 to sensor port TC2 to sensor port	>20x10^6	If Lower, temperature compensation winding is broken.

Table 11-3 Resistance Values for a Normal 317 Convection Enhanced Pirani Sensor

11.4.3.2 Testing the Series 275 Convectron Sensor

Even a small amount of voltage can damage the small diameter sensing or filament wire inside the Convectron sensor. To determine if the sensing wire inside a Convectron has been damaged, use a low-voltage (maximum 0.1 V) ohmmeter to check resistance values across the pins on the base of the sensor. Pin numbers are embossed on the base. The resistance across the pins should be within the ranges listed in Figure 11-4. If resistance across pins 1 and 2 is not approximately 20 to 30 Ω or if other listed resistance values are greater than the listed values, the sensor tube is defective.

- Pins 1 to 2: 19 to 22 ohms
- Pins 2 to 3: 50 to 60 ohms
- Pins 1 to 5: 180 to 185 ohms

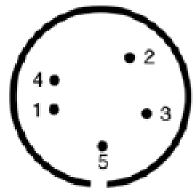


Figure 11-9 Series 275 Convectron Sensor Base Pinout

11.5 Maintenance of a Capacitance Manometer

11.5.1 Theory of a Capacitance Manometer

The MKS Capacitance Manometer head contains a sensor and signal conditioner. The sensor is made up of a tensioned metal diaphragm, one side of which is exposed to the media whose pressure is to be measured. The other (reference) side contains an electrode assembly placed in a reference cavity (see Figure 11-9). Absolute transducers have the reference side factory-sealed under high vacuum (10^{-7} Torr). The diaphragm deflects with changing pressure — force per unit area — causing a capacitance change between the diaphragm and the adjacent electrode assembly. The high level output signal, current, or DC voltage is linear with pressure, amplified, and self-compensated for thermal stability with ambient temperature changes. Capacitance Manometers should be zeroed on installation. This zero adjustment has no effect on the internal calibration.

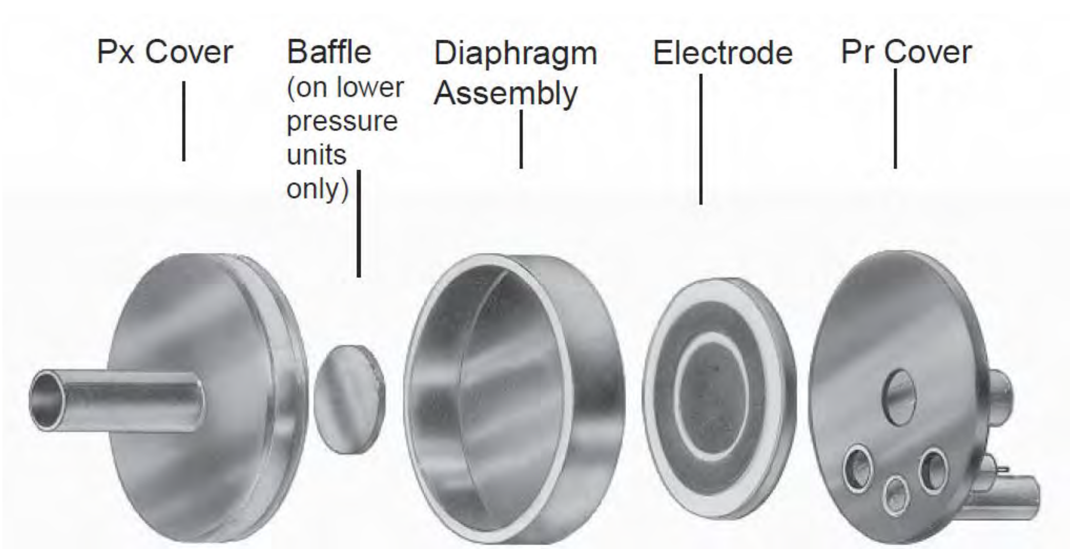


Figure 11-10 Exploded View of a MKS Capacitance Manometer Sensor

11.5.2 Repairing the Baratron Capacitance Manometer

Repair by the user is not recommended since replacement or movement of PC board components may require complete calibration of the unit. Return the product to MKS for repair.

12 Spare Parts and Accessories

	Part #
Accessories	
USA power cable	103150001
Half rack mounting kit	100005651
Full rack mounting kit	100007700
946 Instruction Manual	100016467
Rebuild kit for Series 431 or 422	100006734
Spanner Wrench for 431 or 422 tube rebuild	100005279
Rebuild kit for Series 423 I-Mag	100002353
Adapter, SMA-F to BNC-M	100016120
Adapter, Connector, SMA-M to BNC-F	100016121
Fuse (2X) inside the inlet power connector	100015755
Module, plug-in	
Cold Cathode	100018446
Cold Cathode with TTL	100018448
Hot Cathode (MIG/LPN)	100015641
Dual Capacitance Manometer/Piezo	100015267
Dual Standard Convection Pirani or Convectron	100015132
MFC	100016529
Pressure control	100016609
Cable for Capacitance Manometer, Type 722B	
10 ft (3.0 m)	100016951
25 ft (7.6 m)	100016952
50 ft (15.2 m)	100016953
Cable for Capacitance Manometer, Type 626B/627D	
10 ft (3.0 m)	100007555
25 ft (7.6 m)	100007556
50 ft (15.2 m)	100007557
Custom to 50 ft (15.2 m)	100007558
Cable for Capacitance Manometer, Type AA09A	
10 ft (3.0 m)	RCB121S-1-10
Cable for Series 902B Piezo with 9-oin D-sub connector only	
10 ft (3.0 m)	100011869
25 ft (7.6 m)	100011870
50 ft (15.2 m)	100011871
Custom (maximum length 50 ft)	100011872
Cable for Cold Cathode Sensor, Series 431	
10 ft (3.0 m)	100016217
25 ft (7.6 m)	100016218
50 ft (15.2 m)	100016219
100 ft (30.5 m)	100016220
Custom to 300 ft (91.4 m)	100016221
Cable for Cold Cathode Sensor, Series 423 I-Mag	
2 ft (0.6 m)	100016295
10 ft (3.0 m)	100016296
25 ft (7.6 m)	100016297
50 ft (15.2 m)	100016298
Custom to 300 ft (91.4 m)	100016299
Cable for Hot Cathode, Mini BA Gauge	
10 ft (3.0 m)	100011106
25 ft (7.6 m)	100011107
50 ft (15.2 m)	100011108

Cable for Hot Cathode, Low Power Nude

10 ft (3.0 m)	100010909
25 ft (7.6 m)	100010910
50 ft (15.2 m)	100010911

Cable for 317 Convection Pirani & 345 Pirani Sensor

10 ft (3.0 m)	103170006SH
25 ft (7.6 m)	103170007SH
50 ft (15.2 m)	103170008SH
100 ft (30.5 m)	103170017SH
Custom to 500 ft (152.4 m)	103170009SH

Cable for 275 Convectron Sensor

10 ft (3.0 m)	100016890
25 ft (7.6 m)	100016891
50 ft (15.2 m)	100016892

Cable for Mass flow controller (15 pin connector)

10 ft (3.0 m)	100016744
25 ft (7.6 m)	100016745
50 ft (15.2 m)	100016746

Cable for Mass flow controller (9 pin connector)

10 ft (3.0 m)	100019087
25 ft (7.6 m)	100019088
50 ft (15.2 m)	100019089

NOTE: The above cables are for use with MKS mass flow controllers having tied grounds.

Cable for 148/248/154 solenoid valve

10 ft (3.0 m)	100018192
XX ft	100018191-XX

Cable for 153/T3B throttle valve

10 ft (3.0 m)	100018191
XX ft	100019191-XX

Cable for T3B

T3B to 946	1053451-001
Din Rail Power Supply	1053456-001
Desktop Power Supply	1053192-001

Contact the MKS Customer Service Department to order any of these parts or for technical support.

13 Appendix

13.1 MFC Gas Conversion Factors for Selected Gases

***Note**: Standard pressure is defined as 760 Torr (mmHg). Standard temperature is defined as 0 °C.*

Gas	Symbol	Cp Cal/g K)	Density g/l @ 0 °C	Conversion Factor
Air		0.240	1.293	1.00
Ammonia	NH_3	0.492	0.760	0.73
Argon	Ar	0.1244	1.782	1.39
Arsine	AsH_3	0.1167	3.478	0.67
Boron Trichloride	BCl_3	0.1279	5.227	0.41
Bromine	Br_2	0.0539	7.130	0.81
Carbon Dioxide	CO_2	0.2016	1.964	0.70
Carbon Monoxide	CO	0.2488	1.250	1.00
Carbon Tetrachloride	CCl_4	0.1655	6.86	0.31
Carbon Tetrafluoride (Freon 14)	CF_4	0.1654	3.926	0.42
Chlorine	Cl_2	0.1144	3.163	0.86
Chlorodifluoromethane (Freon 22)	$CHClF_2$	0.1544	3.858	0.46
Chloropentafluoroethane (Freon 115)	C_2ClF_5	0.164	6.892	0.24
Chlorotrifluoromethane (Freon 13)	$CClF_3$	0.153	4.660	0.38
Cyanogen	C_2N_2	0.2613	2.322	0.61
Deuterium	D_2	1.722	0.1799	1.00
Diborane	B_2H_6	0.508	1.235	0.44
Dibromodifluoromethane	CBr_2F_2	0.15	9.362	0.19
Dichlorodifluoromethane (Freon 12)	CCl_2F_2	0.1432	5.395	0.35
Dichlorofluromethane (Freon 21)	$CHCl_2F$	0.140	4.592	0.42
Dichloromethysilane	$(CH_3)_2SiCl_2$	0.1882	5.785	0.25
Dichlorosilane	SiH_2Cl_2	0.150	4.506	0.40
1,2-Dichlorotetrafluoroethane (Freon 114)	$C_2Cl_2F_4$	0.160	7.626	0.22
1,1-Difluoroethylene (Freon 1132A)	$C_2H_2F_2$	0.224	2.857	0.43
2,2-Dimethylpropane	C_5H_{12}	0.3914	3.219	0.22
Ethane	C_2H_6	0.4097	1.342	0.50
Fluorine	F_2	0.1873	1.695	0.98
Fluoroform (Freon 23)	CHF_3	0.176	3.127	0.50
Freon 11	CCl_3F	0.1357	6.129	0.33
Freon 12	CCl_2F_2	0.1432	5.395	0.35
Freon 13	$CClF_3$	0.153	4.660	0.38
Freon 13B1	$CBrF_3$	0.1113	6.644	0.37
Freon 14	CF_4	0.1654	3.926	0.42
Freon 21	$CHCl_2F$	0.140	4.592	0.42
Freon 22	$CHClF_2$	0.1544	3.858	0.46
Freon 23	CHF_3	0.176	3.127	0.50
Freon 113	$C_2Cl_2F_3$	0.161	8.360	0.20

Freon 114	$C_2Cl_2F_4$	0.160	7.626	0.22
Freon 115	C_2ClF_5	0.164	6.892	0.24
Freon 116	C_2F_6	0.1843	6.157	0.24
Freon C318	C_4F_8	0.1866	8.93	0.164
Freon 1132A	$C_2H_2F_2$	0.224	2.857	0.43
Helium	He	1.241	0.1786	1.45
Hexafluoroethane (Freon 116)	C_2F_6	0.1843	6.157	0.24
Hydrogen	H_2	3.419	0.0899	1.01
Hydrogen Bromide	HBr	0.0861	3.610	1.00
Hydrogen Chloride	HCl	0.1912	1.627	1.00
Hydrogen Fluoride	HF	0.3479	0.893	1.00
Isobutylene	C_4H_8	0.3701	2.503	0.29
Krypton	Kr	0.0593	3.739	1.543
Methane	CH_4	0.5328	0.715	0.72
Methyl Fluoride	CH_3F	0.3221	1.518	0.56
Molybdenum Hexafluoride	MoF_6	0.1373	9.366	0.21
Neon	Ne	0.246	0.900	1.46
Nitric Oxide	NO	0.2328	1.339	0.99
Nitrogen	N_2	0.2485	1.250	1.00
Nitrogen Dioxide	NO_2	0.1933	2.052	**
Nitrogen Trifluoride	NF_3	0.1797	3.168	0.48
Nitrous Oxide	N_2O	0.2088	1.964	0.71
Octafluorocyclobutane (Freon C318)	C_4F_8	0.1866	8.93	0.164
Oxygen	O_2	0.2193	1.427	0.993
Pentane	C_5H_{12}	0.398	3.219	0.21
Perfluoropropane	C_3F_8	0.194	8.388	0.17
Phosgene	$COCl_2$	0.1394	4.418	0.44
Phosphine	PH_3	0.2374	1.517	0.76
Propane	C_3H_8	0.3885	1.967	0.36
Propylene	C_3H_6	0.3541	1.877	0.41
Silane	SiH_4	0.3189	1.433	0.60
Silicon Tetrachloride	$SiCl_4$	0.1270	7.580	0.28
Silicon Tetrafluoride	SiF_4	0.1691	4.643	0.35
Sulfur Dioxide	SO_2	0.1488	2.858	0.69
Sulfur Hexafluoride	SF_6	0.1592	6.516	0.26
Trichlorofluoromethane (Freon 11)	CCl_3F	0.1357	6.129	0.33
Trichlorosilane	$SiHCl_3$	0.1380	6.043	0.33
1,1,2 Trichloro-1,2,2,-Trifluoroethane (Freon 113)	$C_2Cl_3F_3$	0.161	8.360	0.20
Tungsten Hexafluoride	WF_6	0.0810	13.28	0.25
Xenon	Xe	0.0378	5.858	1.32

Series 946 Vacuum System Controller

Operation and Maintenance Manual

Instruction Manual p/n: 100018121
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