O P E R A T I N G   M A N U A L

Cygnus®

Thin Film Deposition Monitor

IPN 074-379-P1K

INFICON

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Cygnus®

Thin Film Deposition Monitor

IPN 074-379-P1K

INFICON Instruments for Intelligent Control™

www.inficon.com   reachus@inficon.com

Due to our continuing program of product improvements, specifications are subject to change without notice.

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DECLARATION OF CONFORMITY

This is to certify that this equipment, designed and manufactured by:

INFICON Inc.
Two Technology Place
East Syracuse, NY 13057
USA

meets the essential safety requirements of the European Union and is placed on the market accordingly. It has been constructed in accordance with good engineering practice in safety matters in force in the Community and does not endanger the safety of persons, domestic animals or property when properly installed and maintained and used in applications for which it was made.

Equipment Description:	Cygnus Thin Film Deposition Controllers, including Oscillators and Crystal Sensors as properly installed.
Applicable Directives:	73/23/EEC as amended by 93/68/EEC 89/336/EEC as amended by 93/68/EEC
Applicable Standards:	EN 61010-1:2001 EN 61326:1997 (Industrial Use) EN 61000-3-2:1995/A14:2000 EN 61000-3-3:1995
CE Implementation Date:	August 22, 2003
Authorized Representative:	Gary W. Lewis Vice President - Quality Assurance INFICON Inc.

ANY QUESTIONS RELATIVE TO THIS DECLARATION OR TO THE SAFETY OF LEYBOLD INFICON'S PRODUCTS SHOULD BE DIRECTED, IN WRITING, TO THE QUALITY ASSURANCE DEPARTMENT AT THE ABOVE ADDRESS.

01-22-04

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NOTE: These instructions do not provide for every contingency that may arise in connection with the installation, operation or maintenance of this equipment. Should you require further assistance, please contact INFICON.

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Chapter 1
Introduction and Specifications

1.1 Introduction

Cygnus is a closed loop process controller designed for use primarily in physical vapor deposition. The unit monitors and/or controls the rate and thickness of the deposition of thin films. Deposition rate and thickness are inferred from the frequency change induced by mass added to a quartz crystal. This technique positions sensors in the path between or to the side of the source of the vaporized material and the target substrate. The sensor incorporates an exposed oscillating quartz crystal whose frequency decreases as material accumulates. The change in frequency provides information to determine rate and thickness and to continually control the evaporation power source. With user supplied time, thickness and power limits and with desired rates and material characteristics, the unit is capable of automatically controlling the process in a precise and repeatable manner. User interaction is accomplished via the unit's front panel and consists of selection or entry of parameters to define the process.

The complete system consists of a main electronics unit, the Cygnus, sensor heads and a crystal interface unit (XIU) for each attached sensor. These items are generally bundled at the factory and are also sold separately.

The Cygnus Manual provides user information for installing, programming, calibrating and operating the main electronics unit.

When reading the Cygnus Manual, please pay particular attention to the NOTES, CAUTIONS, and WARNINGS found throughout the text. The Notes, Cautions, and Warnings are defined in section 1.2.1 on page 1-2.

You are invited to comment on the usefulness and accuracy of this manual by filling out the registration card and returning it.

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1.1.1 Related Manuals

Sensors are covered in separate manuals.

- 074-154 - Bakeable
- 074-155 - CrystalSix
- 074-156 - Single/Dual
- 074-157 - Sputtering
- 074-398 - Crystal12

1.2 Instrument Safety

1.2.1 Definition of Notes, Cautions and Warnings

When using this manual, please pay attention to the NOTES, CAUTIONS and WARNINGS found throughout. For the purposes of this manual they are defined as follows:

NOTE: Pertinent information that is useful in achieving maximum instrument efficiency when followed.

CAUTION

Failure to heed these messages could result in damage to the instrument.

WARNING

Failure to heed these messages could result in personal injury.

WARNING - Risk Of Electric Shock

Dangerous voltages are present which could result in personal injury.

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1.2.2 General Safety Information

WARNING - Risk Of Electric Shock

Do not open the instrument case! There are no user-serviceable components within the instrument case.

Dangerous voltages may be present whenever the power cord or external input/relay connectors are present.

Refer all maintenance to qualified personnel.

CAUTION

This instrument contains delicate circuitry which is susceptible to transient power line voltages. Disconnect the line cord whenever making any interface connections. Refer all maintenance to qualified personnel.

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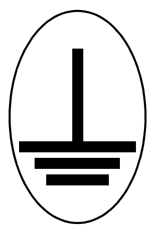
1.2.3 Earth Ground

Cygnus is connected to earth ground through a sealed three-core (three-conductor) power cable, which must be plugged into a socket outlet with a protective earth terminal. Extension cables must always have three conductors including a protective earth terminal.

WARNING - Risk Of Electric Shock

Never interrupt the protective earth circuit.

Any interruption of the protective earth circuit inside or outside the instrument, or disconnection of the protective earth terminal is likely to make the instrument dangerous.



This symbol indicates where the protective earth ground is connected inside the instrument. Never unscrew or loosen this connection.

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1.2.4 Main Power Connection

WARNING - Risk Of Electric Shock

This instrument has line voltage present on the primary circuits whenever it is plugged into a main power source.

Never remove the covers from the instrument during normal operation.

There are no operator-serviceable items within this instrument.

Removal of the top or bottom covers must be done only by a technically qualified person.

In order to comply with accepted safety standards, this instrument must be installed into a rack system which contains a mains switch. This switch must break both sides of the line when it is open and it must not disconnect the safety ground.

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1.3 How To Contact Customer Support

Worldwide support information regarding:

- Technical Support, to contact an applications engineer with questions regarding INFICON products and applications, or
- Sales and Customer Service, to contact the INFICON Sales office nearest you, or
- Repair Service, to contact the INFICON Service Center nearest you,

is available at www.inficon.com.

If you are experiencing a problem with your instrument, please have the following information readily available:

- the serial number for your instrument,
- a description of your problem,
- an explanation of any corrective action that you may have already attempted,
- and the exact wording of any error messages that you may have received.

To contact Customer Support, see Support at www.inficon.com.

1.3.1 Returning Your Cygnus to INFICON

Do not return any component of your Cygnus to INFICON without first speaking with a Customer Support Representative. You must obtain a Return Material Authorization (RMA) number from the Customer Support Representative.

If you deliver a package to INFICON without an RMA number, your package will be held and you will be contacted. This will result in delays in servicing your instrument.

Prior to being given an RMA number, you may be required to complete a Declaration Of Contamination (DOC) form if your instrument has been exposed to process materials. DOC forms must be approved by INFICON before an RMA number is issued. INFICON may require that the instrument be sent to a designated decontamination facility, not to the factory. Failure to follow these procedures will delay the repair of your instrument.

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1.4 Cygnus Specifications

1.4.1 Measurement

Crystal Frequency	6.0 MHz (new crystal) to 4.5 MHz
Internal Precision	± 0.004657 Hz over 100 ms sample for fundamental and anharmonic frequencies
Thickness & Rate Resolution	0.00577 Å (new crystal); 0.01016 Å (crystal @ 4.5 MHz) over 100 ms sample for material density = 1.0, Z-ratio = 1.0
Thickness Accuracy	0.5% typical, (dependent on process conditions, especially sensor location, material stress, temperature and density)
Frequency Accuracy	± 2 ppm 0-50 °C
Measurement Frequency	10 Hz
Measurement Technique	ModeLock
User Interface	CRT and limited membrane keypad. All parameters accessible through computer communications. Multiple message areas for indication of states and detailed indication of abnormal and stop conditions.

1.4.2 Screens and Parameters

Navigation	Six soft keys
Structure	Separate screens dedicated to 1) All Channel Data Display, 2) Individual Channel Data, 3) Channel Parameters, 4) Channel Hardware Parameters, 5) General Parameters, 6) Logic, 7) Maintenance, 8) Communications.
# of Source / Sensor Channels	6, Sources can be started or stopped individually or in any combination.

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1.4.2.1 *Instrument Set Up Parameters*

Test On. . . . . Yes / No

Time Compressed . . . . Yes / No

Audio Feedback . . . . Yes / No

RS232 Baud Rate 2400, 4800, 9600, 19200

IEEE Address. 1-30

Data Logging Path . . . . 0 = No Data Logging
2 = File, Page Format
3 = File, Comma Format

Data Log XTAL History. . . . . Yes / No

Print Screen Path . . . . 2 = Floppy Disk

Print Screen Number . . . . 0 to 999

DAC Output Option . . . . 0 = Power/Rate for 6 channels
1 = Power/Thickness for 6 channels
2 = Power/Rate/Thickness for 4 channels
3 = Rate/Thickness for 6 channels

Thickness Equation 1. . . . . Up to 6 channel numbers can be specified, each channel number can be used only once.

Thickness Equation 2. . . . . Up to 6 channel numbers can be specified, each channel number can be used only once.

Thickness Equation 3. . . . . Up to 6 channel numbers can be specified, each channel number can be used only once.

1.4.2.2 *Set Up Parameters for Each Source*

Source States. . . . . Film template defines state sequence. Flexible sequencing is a done by skipping states or vectoring to a different state.

Power Ramps. . . . . 2 per Source

Power Level . . . . 0.00 to 99.99%

Rise Time . . . . 00:00 to 99:59 min:sec

Soak Time . . . . 00:00 to 99:59 min:sec

Rate Filter Time . . . . 0.1, 0.4, 1.0, 4.0, 10.0, 20.0, or 30.0 sec

Rate & Thickness Control with Shutter open	0.001 to 999.9 Å/sec
Rate Control with Shutter closed	0.001 to 999.9 Å/sec
Idle Ramp	1 per Source
Idle Power	0.00 to 99.99%
Idle Ramp Time	00:00 to 99:59 min:sec
Deposit After Pre-Deposit	Yes / No Yes = go to Deposit No = go to Non-Deposit Rate Control
Density	0.100 to 99.999 gm/cc
Z-ratio	0.100 to 15.000
Control Loop types	0 / 1 / 2 Non-PID, PI, PID
PID Control Mode	Fast or Slow Source
Process Gain	0.01 to 999.99 Å/sec/%Power
Primary Time Constant	0.010 to 9999.99 seconds
System Dead Time	0.010 to 9999.99 seconds
Tooling Factor	1.0 to 999.9%
Secondary Tooling	1.0 to 999.9%
Sensors	2 standard, 4 additional w/optional hardware
Sensor Type	1 / 2 / 6 / 7 / 12 (Single, CrystalTwo, CrystalSix, Rotary, Crystal12)
CrystalSix Position Select	Indexes to next good crystal
Sensor Switch Output	0 to 38
Sensor Shutter Output	0 to 38
Sensor Shutter Output Type	0 / 1 Normally Open, Normally Closed
Maximum Source Power	0.01 to 99.99%
Minimum Source Power	0.00 to 99.98%
Maximum Power Option	Stop / Idle Ramp / Continue — can be selected for each source individually.
Averaging Time	0 to 30 minutes
Final Thickness	0.000 to 999.9 kÅ

ON Final Thickness . . . . 0 / 1 / 2
0 = Go to Non-Deposit Control
1 = Go to Idle Ramp
2 = Continue

Cross Talk Percent . . . . 0.00 to 99.99%, Correction for 2 sensors, multiple instances of 2 sensor correction is allowed (maximum of 3 instances of 2 sensor correction).

Crucible Selection . . . . Turret is indexed to selected position on a start. Turret feedback is checked whenever a source is started. Range is from 1 to number of crucibles.

Number of Crucibles. . . . . 1, 4, 8, 16, 32 or 64

Crucible Output . . . . 0 to 37

Crucible Output Type . . . . 0 / 1
0 = Normally Open, 1 = Normally Closed.

Turret Feedback . . . . Yes / No

Turret Input . . . . 0 to 28

Turret Delay . . . . 1 to 60 secs.

RateWatcher® . . . . Sample and Hold Feature

RateWatcher Option . . . . 0 = None, 1 = Non-deposit,
2 = Non-deposit and Deposit

RateWatcher Time . . . . 00:01 to 99:59 min:sec

RateWatcher . . . . Accuracy 1 to 99%

Source Voltage Range . . . . 0 to 10 V, 0 to 5 V, 0 to 2.5 V, 0 to -10 V,
0 to -5 V, 0 to -2.5 V

DAC Rate Range . . . . 0 = 10 Å/sec, 1 = 50 Å/sec, 2 = 100 Å/sec,
3 = 1000 Å/sec, 4 = 1 Å/sec

DAC Thickness Range . . . . 0 = 100 Å, 1 = 1000 Å, 2 = 2000 Å,
3 = 3000 Å, 4 = 5000 Å

Substrate Shutter Output . . . . 0 to 38

Substrate Shutter Output Type. . . . . 0 / 1
0 = Normally Open, 1 = Normally Closed

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Crystal Fail Option . . . . 0 / 1 / 2
0 = Time Power,
1 = Idle Ramp
2 = Stop
Can be selected for each source individually.

Crystal Quality . . . . 0 to 9

Crystal Stability . . . . 0 to 9

Auto-Z. . . . . Yes / No

1.4.3 User Interface

Front Panel / CRT. . . . . Parameters can be programmed through Cygnus front panel. There is a display for each source with graphical and text / number information. There is also a display showing text and number information for all sources.

Remote Communications . . . . Parameters can be programmed through computer communications. Complete control of source state sequencing available by remote communications.

I/O. . . . . Control of state sequencing, starting / stopping each source, is available using Inputs and Outputs.

PC Applications Software . . . . Optional, Compatible with RS232 communications or National Instruments PCI-GPIB Controller and NI-488.2 protocol.

Operating System. . . . . Windows 2000

Function . . . . Complete Cygnus programming, Monitoring of sources.

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1.4.4 Display

Type / Color / Size . . . . CRT / Amber /
5" H x 9" W (127 mm x 228.6 mm)

Format . . . . 23 kHz Horizontal Scan Rate

Resolution . . . . 750 W x 350 H Monochrome

Vertical Scan Rate . . . . 50/60 Hz automatically detected

Thickness Display Range. . . . . 0.000 to 999.9 kÅ

Thickness Display Resolution . . . . . 1 Å

Rate Display Range . . . . 0.000 to 9999 Å/sec

Rate Display Resolution. . . . . 0.001 Å/sec for 0 to 9.999 Å/sec
0.01 Å/sec for 10.00 to 99.99 Å/sec
0.1 Å/sec for 100.0 to 999.9 Å/sec
1 Å/sec for 1000 to 9999 Å/sec

Power Display Range. . . . . 0.00 to 99.99%

Graphic Display Functions . . . . Rate Deviation at ±10 or ±20 Å/sec or Power at 0 to 100%

Graphic Scan Rate. . . . . 0 = Auto, 1 = Slow, 2 = Med, 3 = Fast

Display Data Update Rate . . . . 1 Hz

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1.4.5 Source / Recorder Outputs

Quantity	6 standard, an additional 6 are optional with 2nd DAC board.
Type	6 standard with BNC Connectors for Source control. 6 optional with 15 pin miniature D-sub providing analog outputs for Rate and Thickness.
Source control voltage range (BNC connectors)	0 to 10V, 0 to 5V, 0 to 2.5V, 0 to -10V, 0 to -5V, 0 to -2.5V.
Recorder Voltage Range	0 to 10V
Current rating	20 mA per channel
Resolution	15 bits over full range (10 V)
Update Rate	10 Hz, maximum, (dependent on source characteristics).
Accuracy	± 3% full scale
Zero Adjust	Individual potentiometer

1.4.6 Logic Processing

Type	If/Then statements
Logical Functions	And; Or; Not; Parentheses
Depth	5 "If" conditions and 5 "Then" results/actions per statement
# of Statements	100 If/Then
Selectable events	Deposition monitor events, states, external inputs, relays, timers, and counters.
Hierarchy	Statements evaluated in numerical order at 10 Hz any time the unit is on.
Partitioning	None
Initialization	All outputs transition to their normal states as early as possible during power-on initialization sequence.

1.4.7 Relays / Inputs

Relays	SPST 2.5 A relays rated @ 30 V(dc) or 30 V(ac) RMS or 42 V(peak) maximum; (8 standard, up to 16 optional with 2 additional I/O cards); D sub connector; relays are normally open in the power off state, but may be programmed to normally open or normally closed during operation.
Relay Ratings	100 VA inductive; 2.5A maximum.
# of TTL Compatible Outputs	14 with optional I/O card. Internally pulled up to 5 V(dc). May be pulled up externally to 24 V(dc) through 2.4k resistor. minimum high level 0.5mA load @3.75 V maximum low level 10mA load @1.1 V
Inputs (TTL Compatible)	(14 standard, 14 additional optional)
Input Levels	
maximum high	24 V
minimum high	2.5 V
maximum low	1.1 V
Scan/Update Rate	10 Hz

1.4.8 Remote Communications

RS232C Serial Port . . . . Standard

Baud Rates. 19,200; 9,600; 4,800; 2,400

IEEE488 Parallel Port. . . . . Optional

IEEE Service Requests . . . . Supported with RQS and MAV status bits

1.4.9 Accessories

Manual Power
Control Connection. . . . . Front panel

Function . . . . Handheld, increase/decrease/stop

Floppy (Optional) . . . . 3.5', 1.44 MByte for process and datalog storage

Connector Kit . . . . Connectors for inputs and relays

Operating Manual. . . . . PDF format on CD

1.4.10 Power

Power . . . . 100 +10%, -15% V(ac) 50/60 Hz
120 +10%, -10% V(ac) 50/60 Hz
230 +10%, -10% V(ac) 50/60 Hz
240 +10%, -15% V(ac) 50/60 Hz

Maximum apparent power . . . . 300 VA

Fuse . . . . 100 V(ac), 120 V(ac) use 4 Amp IEC 127 approved type T
230 V(ac), 240 V(ac) use 2 Amp IEC 127 approved type T

1.4.11 Operating Environment

Usage . . . . Indoor only

Temperature . . . . 0 to 50 °C (32-122 °F)

Humidity . . . . Up to 85%RH, non-condensing

Altitude . . . . Up to 2000 meters

Installation (Overvoltage) . . . . Category II per IEC 664

Pollution Degree. . . . . 1 per IEC 664

1.4.12 Storage Temperature

Storage Temperature . . . . -10 to 60 °C (14 to 140 °F)

1.4.13 Warm Up Period

Warm Up Period. . . . . None required;
For maximum stability allow 5 minutes.

1.4.14 Size

Not including mounts or user connectors

5.25" H x 17.625" W x 17.3" D
(133.4 mm H x 447.7 mm W x 435.1 mm D)

Including mounts, but no user connectors

5.25" H x 18.85" W x 17.3" D
(133.4 mm H x 478.8 mm W x 435.1 mm D)

1.4.15 Connector Clearance Requirements

Front. . . . . Minimum 1.0" (25.4 mm)

Rear . . . . Minimum 4.0" (101.6 mm)

1.4.16 Weight

With all options. . . . . 13.2 kg / 29 lb

1.4.17 Cleaning

Use a mild, nonabrasive cleaner or detergent taking care to prevent cleaner from entering the unit.

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1.5 Unpacking and Inspection

1. If the Cygnus control unit has not been removed from its shipping container, do so now.
2. Carefully examine the unit for damage that may have occurred during shipping. This is especially important if you notice obvious rough handling on the outside of the container. *Immediately report any damage to the carrier and to INFICON.*
3. Do not discard the packing materials until you have taken inventory and have at least performed a power on verification.
4. Take an inventory of your order by referring to your order invoice and the information contained in section 1.6 on page 1-17.
5. To perform a power-on verification, see section 1.7 on page 1-20.
6. For additional information or technical assistance, contact your nearest INFICON Inc. sales office.

1.6 Parts and Options Overview

1.6.1 Base Configurations

Cygnus Control Unit	779-700-G1 (100 V(ac) 50/60 Hz) 779-700-G2 (120 V(ac) 50/60 Hz) 779-700-G3 (230 V(ac) 50/60 Hz) 779 -700 -G4 (240 V(ac) 50/60 Hz)
Technical Manual	074-379
Hand Controller	755-262-G1
I/O Relay Ship Kit	760-024-G1
Power Cord	068-0433 (shielded power cord - North America) 068-0434 (shielded power cord - European)
Ship Kit	779-610-G1 (100 V(ac), 120 V(ac)) 779-610-G2 (230 V(ac), 240 V(ac))

1.6.2 Pre-Installed Options or Spares

Additional Sensor Module (std.) . . . . 760-1132-G1 (up to 2 extra)

Relay Card 760-162-G1
(8 relay outputs, 14 TTL inputs)

Relay Card 760-162-G2
(8 relay outputs, 14 TTL outputs)

I/O Relay Ship Kit. 760-024-G1
(8 relay outputs, 14 TTL inputs)
760-024-G2
(8 relay outputs, 14 TTL outputs)

IEEE488 Parallel Communications 760-142-G1

Floppy disk 760-023-G1

Optional DAC Card 760-1112-G2

1.6.3 Oscillator Packages, Optional Accessories, and Sensors

IC/5 XIU (Oscillator) 760-600-G1

Oscillator to vacuum feedthrough cable, 6" (152.4 mm) 755-257-G6

IC/5 Unit to Oscillator Cable 15' (4.6 m). 600-1039-G15

IC/5 Unit to Oscillator Cable, 30' (9.2 m) 600-1039-G30

IC/5 Unit to Oscillator Cable, 50' (15.3 m) 600-1039-G50

IC/5 Unit to Oscillator Cable, 100' (30.5 m) 600-1039-6100

Pneumatic Shutter Actuator Control Valve 750-420-G1

Sensor Emulator 760-601-G2

Cygnus Editor Applications Software 779-030-G1

IC/5 Oscillator, 15' and 6" cable pkg. 760-025-G15

IC/5 Oscillator, 30' and 6" cable pkg. 760-025-G30

IC/5 Oscillator, 50' and 6" cable pkg. 760-025-G50

IC/5 Oscillator, 100' and 6" cable pkg. 760-025-G100

4 Meter Oscillator Kit 4XI5-nnn

NOTE: For operation with 3 m to 4 m long in-vacuum cable, contact INFICON for part the number.

Standard Sensor	750-211-G1
Standard Sensor with Shutter	750-211-G2
Compact Sensor	750-213-G1
Compact Sensor with Shutter	750-213-G2
Sputtering Sensor	750-618-G1
UHV Bakeable Sensor, 12" (304.8 mm)	007-219
UHV Bakeable Sensor, 20" (508 mm)	007-220
UHV Bakeable Sensor, 30" (762 mm)	007-221
UHV Bakeable Sensor with Shutter, 12" (304.8 mm)	750-012-G1
UHV Bakeable Sensor with Shutter, 20" (508 mm)	750-012-G2
UHV Bakeable Sensor with Shutter, 30" (762 mm)	750-012-G3
Dual Sensor	750-212-G2
CrystalSix Sensor	750-446-G1
Crystal12 Sensor	750-667-G1
CrystalTwo Switch with two 6" (152.4 mm) BNC cables	779-220-G1
CrystalTwo Switch with two 20" (508 mm) BNC cables	779-220-G2

NOTE: Contact INFICON for a complete listing of oscillators and sensors.

1.7 Initial Power-On Verification

A preliminary functional check of the instrument can be made before formal installation. It is not necessary to have sensors, source controls, inputs or relays connected to do this. For more complete installation information, see Chapter 6, Installation and Interfaces and Chapter 7, Calibration Procedures.

WARNING - Risk Of Electric Shock

There are no user-serviceable components within the instrument case.

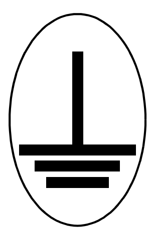
Dangerous voltages may be present whenever the power cord or external input/relay connectors are present.

Refer all maintenance to qualified personnel.

WARNING - Risk Of Electric Shock

Never interrupt the protective earth circuit.

Any interruption of the protective earth circuit inside or outside the instrument, or disconnection of the protective earth terminal is likely to make the instrument dangerous.



This symbol indicates where the protective earth ground is connected inside the instrument. Never unscrew or loosen this connection.

1 Confirm that AC line voltage is supplied and proper for the instrument. Line voltage should be indicated on the instrument back label.

2 Press the power button on the front panel. A green pilot light should be seen next to the power switch.

3 The fan at the back of the instrument should be exhausting air.

4 Video monitor will display an image similar to the one shown in Figure 1-1.

5 Compare the configuration information on the screen against the unit configuration ordered.

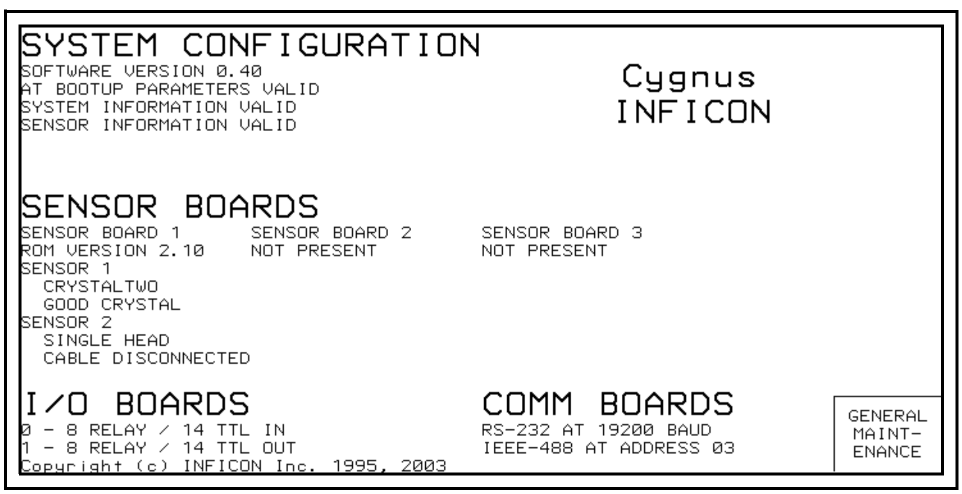
6 Status of parameter information will be displayed. If information was valid prior to this power up, it should stay valid.

7 After a delay, the instrument will enter the OPERATE display.

8 In the OPERATE display, confirm that the display is centered vertically. Lines between the function keys (F1...F6) should align with the lines between the panels on the right side of the display.

9 Using a non-conducting alignment tool, verify that the brightness pot is operative. Adjust for the desired brightness. Access to the brightness pot is at the bottom-center of the face panel, see Figure 2-1 on page 2-1.

Figure 1-1 Cygnus System Status Screen
(Display will vary depending on options present)



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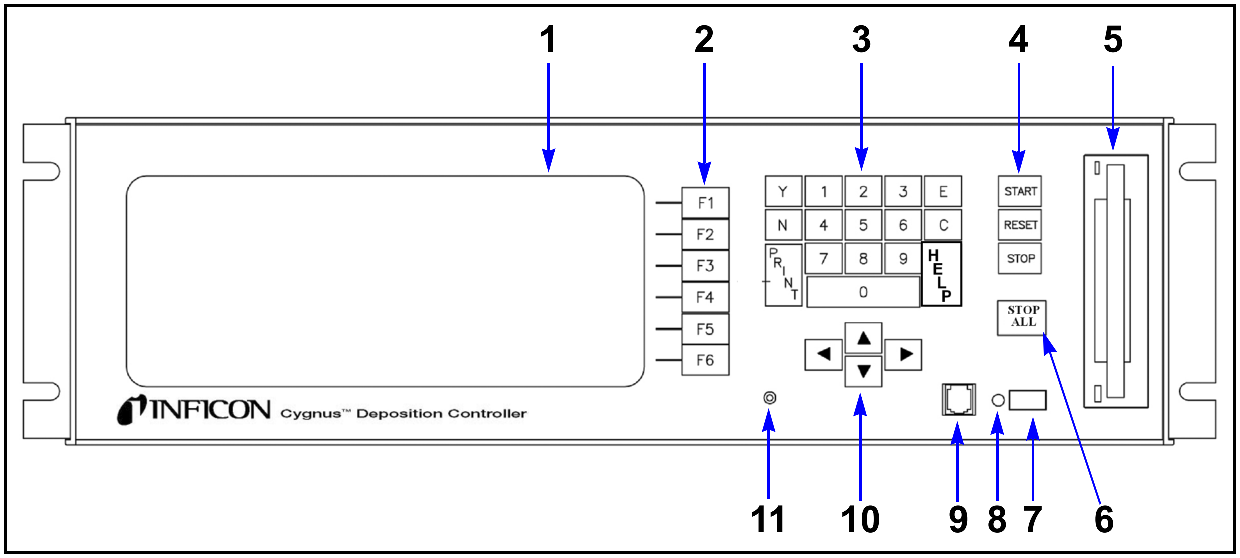
Chapter 2
Operation

2.1 Front Panel Controls

Operational controls for Cygnus are located on the front panel of the instrument, as depicted in Figure 2-1.

Figure 2-1 Cygnus Front Panel



1 CRT Screen

Provides graphical displays, set-up menus, status and error messages.

2 Function Keys

An array of function keys are located adjacent to the screen. These keys are labeled F1 through F6. They are used to select displays or menu items. Their function is indicated on the display and is described in subsequent sections.

3 Data Entry Keys

A keypad array with numerics 0 through 9 and keys for Yes (Y), No (N), Enter (E), Clear (C), Print, and Help used for selection and parameter entry. All numeric and Yes/No entries need to be followed by Enter. Clear is used to erase data entry errors. If an illegal value has been entered, Clear will erase the error message and re-display the last valid data. The Print Screen key is used to send the display information to the floppy drive. The Help key displays parameter information and the parameter's value range on the upper portion of the display, replacing the screen name area.

4 System Switches

An array of four keys that provide START, STOP, RESET and STOP ALL functions, for process control.

5 3.5" Floppy Disk Access Port

Receptacle for the optional 3.5", 1.44 MB floppy disk.

6 Stop ALL Key

A key which when pressed will place all channels in a STOP state regardless of the screen display.

7 Power

This switch controls secondary power to the instrument between ON and STANDBY. Power is provided when the button is in its depressed position. The instrument is initialized for approximately 5 seconds before providing an operational screen.

8 Pilot Light

A green pilot light, adjacent to the power switch, is illuminated when power is on.

9 Remote Control Jack

Receptacle for the wired hand-held remote controller.

10 Cursor Keys

An array of four keys that are used to move the display cursor either up, down, left or right. The keys auto-repeat; the cursor will continue to move as long as the key is held down or until a display field boundary is met.

11 Brightness Adjustment

An access hole for the display’s brightness adjustment potentiometer. Use a nonconductive TV adjustment tool to increase the brightness by turning the potentiometer clockwise.

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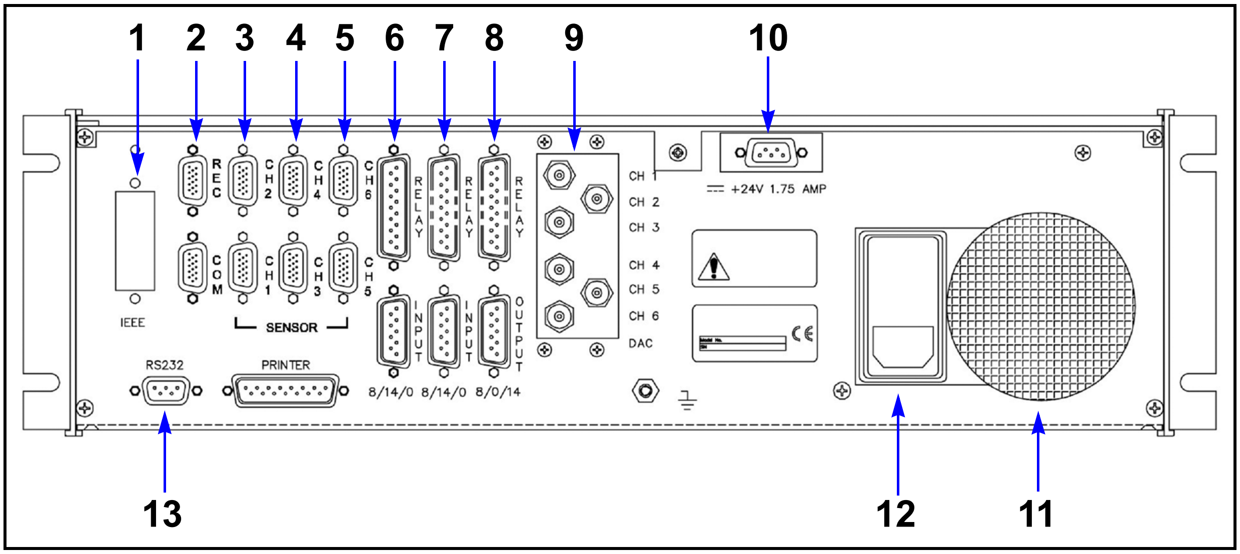
2.2 Rear Panel Interfaces

Interfaces for Cygnus are located on the rear panel of the instrument as depicted in Figure 2-2.

Figure 2-2 Cygnus Rear Panel



1 IEEE488 Connector (Optional)

Provides connections for IEEE-GPIB interface.

2 Digital to Analog Converter (optional)

Provides recorder output for six channels (15 pin miniature D-sub connector). Outputs are programmable for recorder function.

3 Sensor Connectors - Channels 1 & 2 (standard)

Provides connection for the units two standard sensor channels.

4 Sensor Connectors - Channels 3 & 4 (optional)

Expansion panel to accommodate the optional addition of two more sensors, sensors 3 & 4.

5 Sensor Connectors - Channels 5 & 6 (optional)

Expansion panel to accommodate the optional addition of two more sensors, sensors 5 & 6.

6 8 Relay x 14 Input I/O Card (standard)

Provides pin connection for 8 Relays rated for 30 V(dc) or 30 V(ac) RMS or 42 V(peak) maximum, and 14 TTL Inputs.

7 8 Relay x 14 Input I/O Card (optional)

Provides pin connection for 8 relays rated for 30 V(dc) or 30 V(ac) RMS or 42 V(peak) maximum, and 14 TTL inputs.

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8 8 Relay x 14 Output I/O Card (optional)

Provides pin connection for 8 relays rated for 30 V(dc) or 30 V(ac) RMS or 42 V(peak) maximum, and 14 open collector type outputs.

9 6-Channel DAC (standard)

Provides source control voltage or recorder output for 6 channels (BNC connectors). Outputs are programmable for Source Control or Recorder function.

10 24-Volt Supply (standard)

Provides one 24 V(dc) supply rated at 1.75 Amps.

11 Fan Outlet

Exhaust opening for the unit's miniature fan. A grill is attached for safety.

12 AC Power Inlet

Provides a common connector for various international plug sets. The unit is factory set for 100 V(ac), 120 V(ac), 230 V(ac) or 240 V(ac) service.

13 RS-232C Remote Communication Connector (standard)

Provides a 9-pin RS-232C communications port.

2.3 Displays

Cygnus has many display screens for monitoring and programming processes. At the top of the hierarchy is the ALL CHANNELS display. The ALL CHANNELS display allows the user to simultaneously monitor process information for up to six channels. Three main types of displays, GENERAL PARMS; GENERAL MAINTENANCE and CHANNEL are accessible from the ALL CHANNELS DISPLAY: To move from one display to another, use the function keys to the right of the screen. Figure 2-4 provides an overview of the Cygnus display hierarchy.

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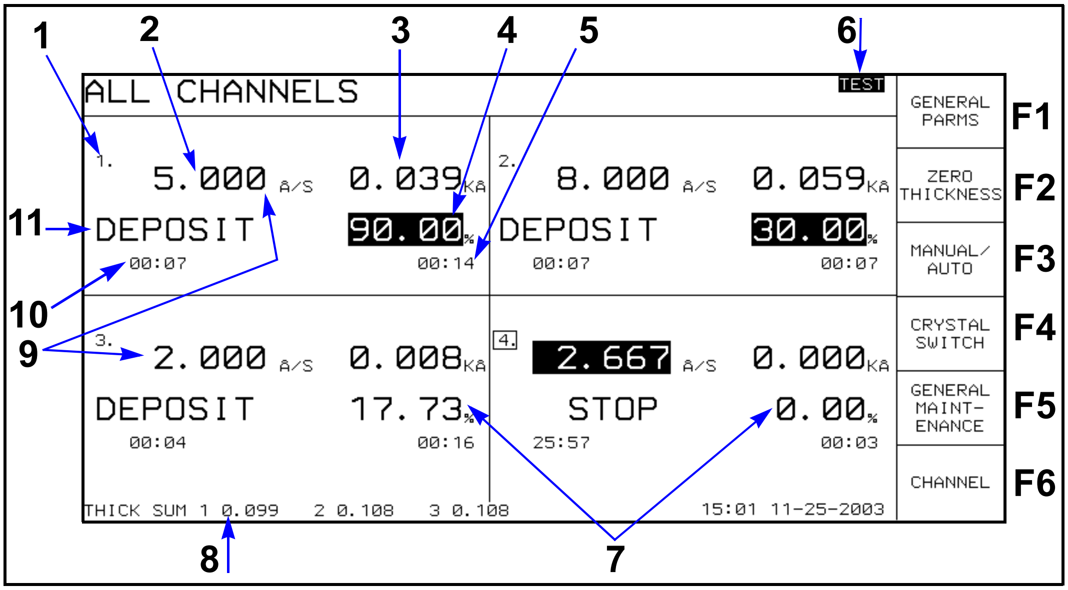
2.3.1 ALL CHANNELS Display

Figure 2-3 All Channels Display



NOTE: The four channel ALL CHANNELS display is shown when one or two measurement boards are installed. If three measurement boards are installed, a six channel ALL CHANNELS display is shown.

<u>ALL CHANNELS Display Description</u>

1 Identifies the channel number associated with the displayed information.

2 Deposition Rate of the channel

3 Accumulated Channel thickness

4 Percent power of individual channel

5 Run time

6 General message area for Test and Lock

7 Power — normal video = level is OK, inverse video = power is at max/min level and channel is in control.

8 Cumulative thickness for the individual THICK SUM equations defined in the GENERAL PARAMETER display

9 Rate — normal video = good crystal, inverse video = failed crystal

10 State timer

11 State of individual channel

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ALL CHANNELS Display Function Keys

F1 GENERAL PARMS

To view the GENERAL PARAMETERS display, press function key F1.

F2 ZERO THICKNESS

To zero the accumulated thickness for the channel indicated by the cursor, press function key F2.

F3 MANUAL / AUTO

To toggle between the MANUAL and RATE control states for the channel indicated by the cursor, press function key F3. When in MANUAL, the source power is controlled by the handheld controller.

F4 CRYSTAL SWITCH

To initiate a crystal switch for the channel indicated by the cursor, press function key F4.

F5 GENERAL MAINTENANCE

To view the GENERAL MAINTENANCE display, press function key F5.

F6 CHANNEL

To go to the CHANNEL display associated with the current cursor position, press function key F6.

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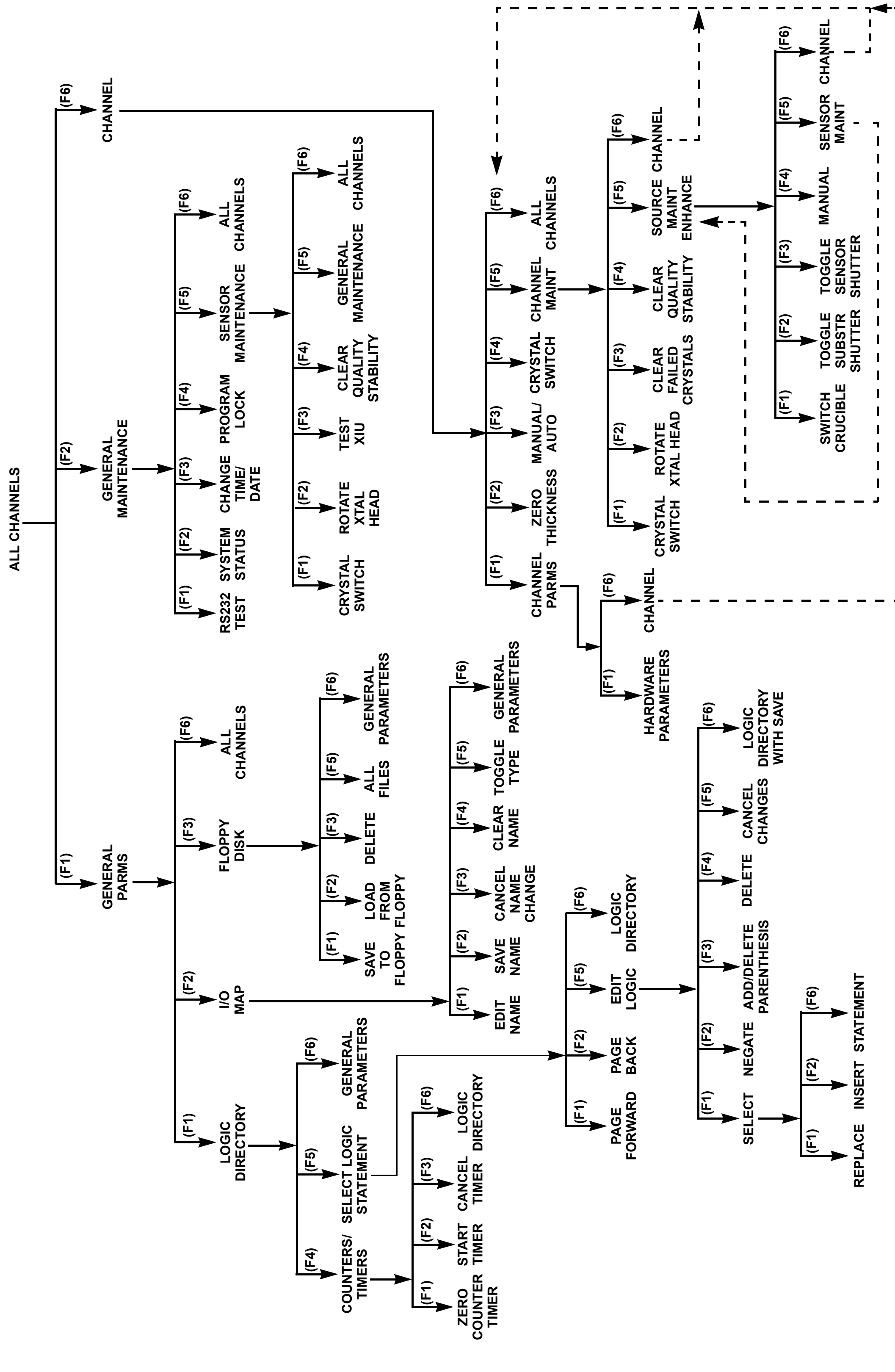

Figure 2-4 Cygnus Display Hierarchy

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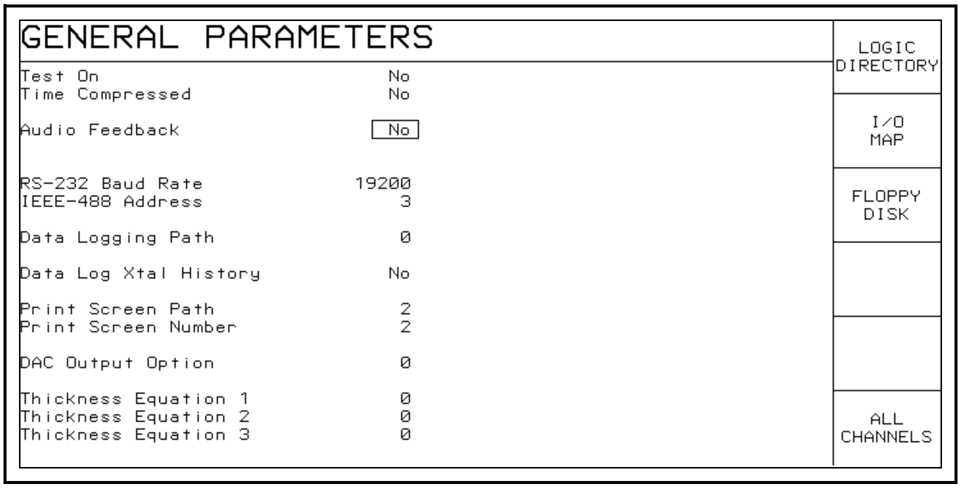
2.3.1.1 GENERAL PARAMETERS Display

Figure 2-5 GENERAL PARMATERS Display



See Chapter 4 for a detailed description for programming the General Parameters.

GENERAL PARAMETER Display Function Keys

F1 LOGIC DIRECTORY

For a display that facilitates selection of Logic Statements for editing, press function key F1.

F2 I/O MAP

To view the I/O MAP display, press function key F2. Provides access to a display where inputs or outputs may be assigned names and where the output type may be designated as normally open or normally closed.

F3 FLOPPY DISK

To view the files currently stored on the floppy disk, press function key F3. Saves or retrieves parameters to or from floppy disk.

F6 ALL CHANNELS

To return to the ALL CHANNELS display, press function key F6.

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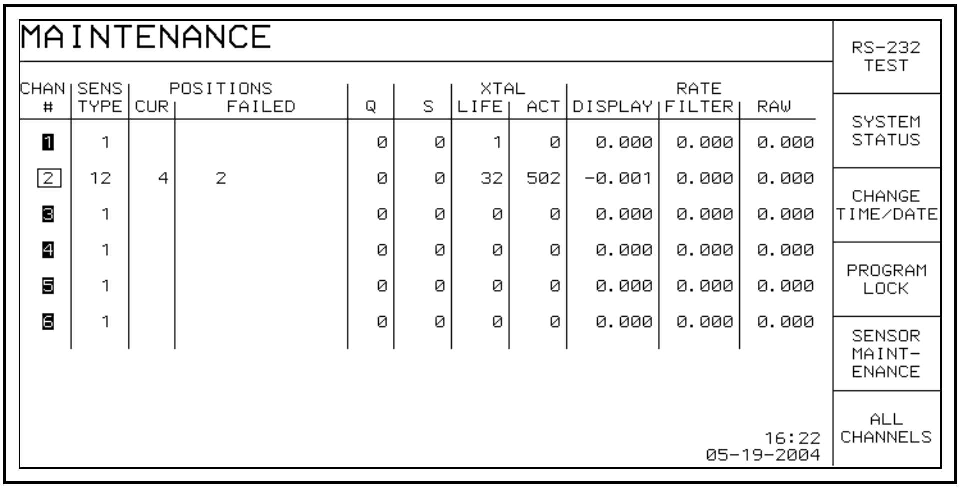
2.3.1.2 *General MAINTENANCE Display*

These displays provide a simple method for system maintenance and diagnostics. To access the MAINTENANCE display, press the GENERAL MAINTENANCE function key (F2) on the ALL CHANNELS display.

Figure 2-6 General MAINTENANCE Display



General MAINTENANCE Display Description

CHAN #

These numbers correspond to the measurement channel numbers on the Cygnus rear panel. The cursor keys are used to position the box cursor over the desired channel number. When either the Crystal Switch, Rotate Crystal Head, Test XIU, or Clear Quality / Stability function key is pressed, the function will be performed on the channel indicated by the box cursor. It is not allowed to cursor to channel numbers that do not have the corresponding measurement card installed. If a crystal fail has occurred for a particular channel this condition is indicated by displaying the channel number in reverse video.

SENS TYPE

This field indicates the Sensor Type chosen for each channel number. A “1” indicates a single crystal head, a “2” indicates a CrystalTwo head, a “6” indicates a CrystalSix sensor head, a “7” indicates a Rotary sensor and a “12” indicates a Crystal12.

POSITIONS

This field is subdivided into two categories; current position (CUR), and FAILED. Information is displayed in these fields if the sensor has more than one position. For a single sensor type, the CUR and FAILED fields have no meaning. For a multi-position sensor type, the CUR field indicates the current position of the sensor head. The FAILED field indicates the sensor head positions containing failed crystals.

Q (Crystal Quality value field)

This field displays the value currently accumulated in the Crystal Quality counter when active. The Crystal Quality counter will become active five seconds after entering DEPOSIT and if the Crystal Quality parameter is non-zero. The function of the Crystal Quality counter is described in section 3.2.1 on page 3-2.

S (Crystal Stability value field)

This field displays the value currently accumulated in the Crystal Stability counter. The function of the Crystal Stability counter is described in section 3.2.1 on page 3-2.

XTAL

This field is subdivided into two categories. The first category, LIFE displays the crystal life. The second category is a measurement of the crystal activity, ACT. For a detailed explanation of LIFE and ACT, see section 2.4 on page 2-21.

RATE

This field is subdivided into three categories. These fields are useful in identifying if a sensor's rate measurements are becoming erratic. 0.000 will be displayed in these fields for channels not in use. All values are refreshed at the display's one second update rate.

The first category is **DISPLAY**. The value displayed here is the channel's average rate. This average is calculated based on a 1 second average.

The second field labeled **FILTER** is based on the average of the RAW rate (100 msec) measurements over the Rate Filter Time selected in the Channel Parms screen for that particular channel.

The third field is **RAW** representing the instantaneous 100 msec frequency change measurement restated in Angstrom/second units.

General MAINTENANCE Display Function Keys

F1 RS232 TEST

To initiate the RS-232C COMM PORT self test, press function key F1. Upon completion of the test, the unit will display a message indicating the test was successful and the COMM PORT is okay; or the test failed and the COMM PORT is bad.

NOTE: The RS-232C Loop Back connector, IPN 760-406-P1 must be installed on the Cygnus RS-232C port for the self-test to work properly.

F2 SYSTEM STATUS

To access the SYSTEM STATUS display (refer to Figure 1-1 on page 1-21), press function key F2.

F3 CHANGE TIME/DATE

To access the display to edit the time and date for the instrument, press function key F3.

F4 PROGRAM LOCK

To access a display for setting a program lock code, press function key F4.

F5 SENSOR MAINTENANCE

To access the All Channels Sensor MAINTENANCE display, see Figure 2-7, press function key F5.

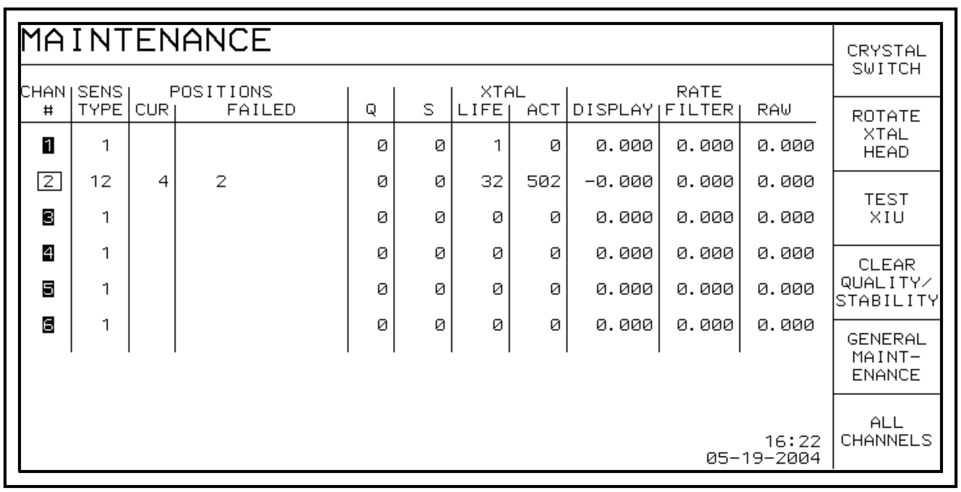
F6 ALL CHANNELS

To return to the ALL CHANNELS display, press function key F6.

2.3.1.2.1 All Channels Sensor MAINTENANCE Display

This display provides a simple way to view sensor information for all the sensors as well as providing general sensor maintenance functions.

Figure 2-7 All Channels Sensor MAINTENANCE Display



CHAN #	SENS TYPE	POSITIONS CUR	FAILED	Q	S	XTAL LIFE	ACT	DISPLAY	RATE FILTER	RAW
1	1			0	0	1	0	0.000	0.000	0.000
2	12	4	2	0	0	32	502	-0.000	0.000	0.000
3	1			0	0	0	0	0.000	0.000	0.000
4	1			0	0	0	0	0.000	0.000	0.000
5	1			0	0	0	0	0.000	0.000	0.000
6	1			0	0	0	0	0.000	0.000	0.000

<u>**All Channels Sensor Maintenance Display Function Keys**</u>

F1 CRYSTAL SWITCH

To initiate a crystal switch for the sensor indicated by the cursor position, press function key F1.

F2 ROTATE XTAL HEAD

If the sensor number indicated by the cursor position is a CrystalSix, Crystal12, or Rotary sensor, pressing F2 will sequentially rotate the sensor head through all positions. This is useful to initialize a CrystalSix, Crystal12, or Rotary sensor after replacing failed crystals.

F3 TEST XIU

To initiate the XIU Self Test, press function key F3. The XIU Self Test determines whether the Crystal Interface Unit (XIU) and Measurement Card pair is operating properly.

NOTE: For the XIU Self Test to work properly, the XIU must have the 6" (152.4 mm) BNC cable (IPN 755-257-G6) attached and must be disconnected from the sensor feedthrough.

F4 CLEAR QUALITY / STABILITY

To clear the Quality and Stability counters, press function key F4.

F5 GENERAL MAINTENANCE

To access the General MAINTENANCE display, press function key F5.

F6 ALL CHANNELS

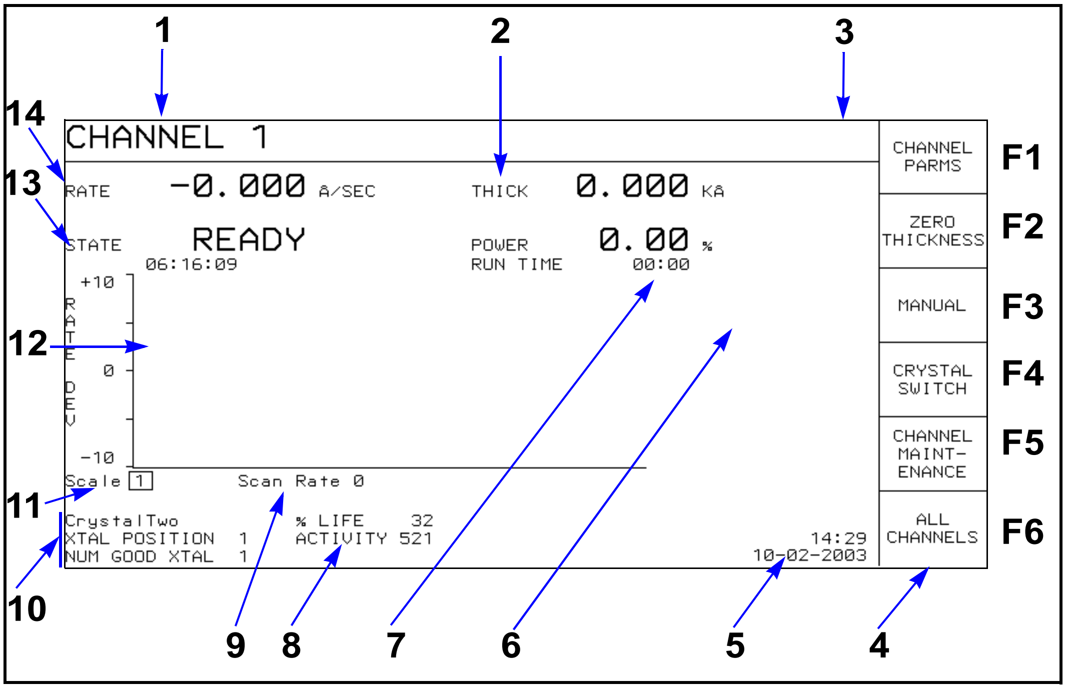
To access the ALL CHANNELS display, press function key F6.

2.3.1.3 CHANNEL Display

The CHANNEL display (shown in Figure 2-8) provides information about the specified channel. The rate, thickness, power level, state, state time, and run time are all updated once a second. Near the bottom of the display is a graph that provides an analog display of the rate deviation from the desired rate, while the channel is in a Rate Control state. Alternatively, the graph can display the percent power being output during a process. The SCALE and SCAN RATE parameters control the meaning, scaling and speed of the graph.

On the top right of the display is a general message area. This area displays information that is not channel specific, such as indicating that the instrument is in TEST mode The region adjacent to the graph displays channel specific status information,. For a complete list of error and status messages, see Chapter 8.

Figure 2-8 CHANNEL Display



CHANNEL Display Description

1 Identifies the channel number associated with the displayed information.

2 Accumulated Channel thickness

3 General instrument information message area

4 Function key definitions

5 Date and Time

6 Status area

Displays channel specific status information

7 Run time

This timer represents the elapsed time since the last READY state.

8 Crystal life and activity values (see section 2.4 on page 2-21)

9 Scan rate 0 / 1 / 2 / 3

This parameter determines the horizontal axis for the channel graphic display. Permissible values are 0, 1, 2 and 3. A 0 places the scan rate into the Auto mode. A 3 sets the scale to three measurements per horizontal pixel, a 2 sets the scale to 10 measurements per horizontal pixel, while a 1 sets the scale to 40 measurements per horizontal pixel. The default value is zero. When the plot reaches the right edge it will wrap and erase the plot from the left edge. Auto mode starts plotting at 3, then compresses and plots at 2, then compresses and plots at 1's rate.

10 Channel sensor information

This region of the Channel identifies the sensor type currently defined in the Channel hardware configuration (see section 2.3.1.3.1.1 on page 2-17). If a value of 2, 6, 7 or 12 is selected for the sensor type, the current crystal position as well as the quantity of good crystals remaining is displayed.

11 Scale 0 / 1 / 2

Establishes the vertical scale for the channel graphics display. Permissible values are 0, 1 and 2. A 0 sets the vertical scale to % Power, 1 sets the vertical scale to ±10 Å/sec, while a 2 sets the vertical scale to ±20 Å/sec. The default value is 1.

12 Graphical display of rate deviation or power

13 State of channel

14 Rate of the channel

CHANNEL Display Function Keys

F1 CHANNEL PARMS

To access the PROCESS (see Figure 2-9) and HARDWARE (see Figure 2-10) related channel parameters, press function key F1.

F2 ZERO THICKNESS

To resets the channel thickness and zero the channel’s contribution to the thickness sum equations, press function key F2.

F3 MANUAL

To put the channel in manual control, (so that the power level is controlled by the hand-held controller), press function key F3. When in manual, the F3 panel reads AUTO, and pressing it will remove the channel from the manual state and place it into a rate control state. See State Descriptions (see section 2.6 on page 2-23) for a more complete description of manual operation.

F4 CRYSTAL SWITCH

To initiate a crystal switch, press function key F4.

F5 CHANNEL MAINTENANCE

To move to the Channel Sensor and Source Maintenance displays, press function key F5.

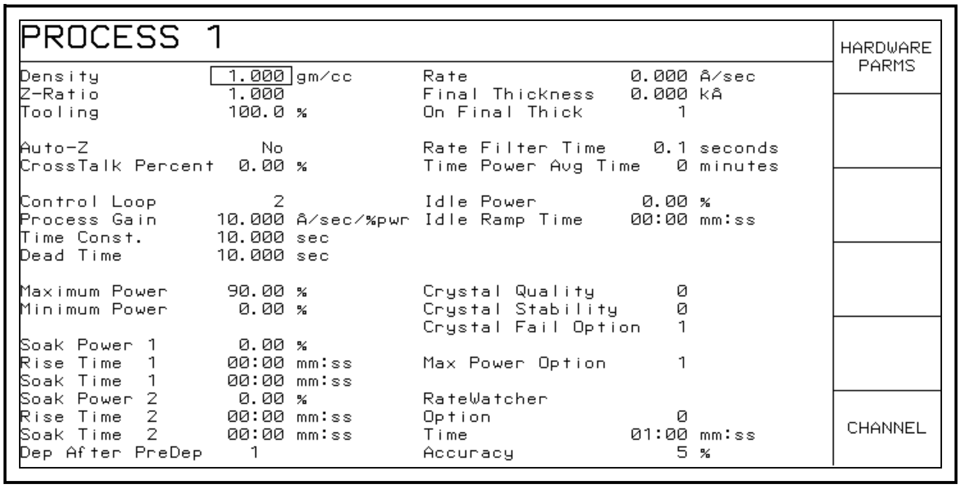
F6 ALL CHANNELS

To return to the ALL CHANNELS display, press function key F6.

2.3.1.3.1 Channel Parameters Display

The Channel Parameters Display contains CHANNEL specific material and process related parameters. This display is accessed by selecting the CHANNEL PARMS function key (F1) from the CHANNEL display. See Chapter 3 for a detailed description for programming of these parameters.

Figure 2-9 Channel Parameters Display



PROCESS Display Function Keys

F1 HARDWARE PARMS

To access the Channel HARDWARE parameters (see Figure 2-10), press function key F1.

F6 CHANNEL

To return to the CHANNEL display, press function key F6.

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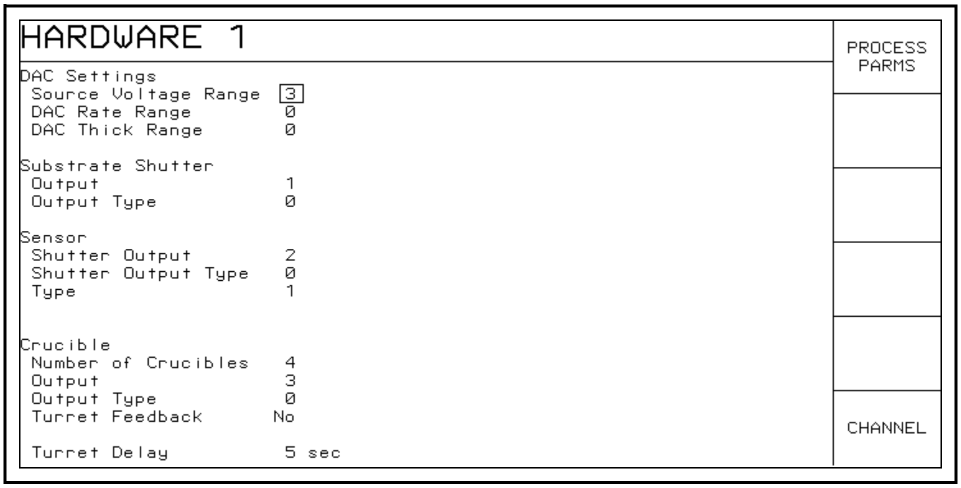
2.3.1.3.1.1 HARDWARE PROCESS Display

The Channel HARDWARE display contains channel specific hardware related parameters. This display is accessed by selecting the HARDWARE PARMS function key (F1) from the PROCESS display. See section 3.3 on page 3-12 for a detailed description for programming of these parameters.

Figure 2-10 HARDWARE Display



<u>HARDWARE Display Function Keys</u>

F1 PROCESS PARMS

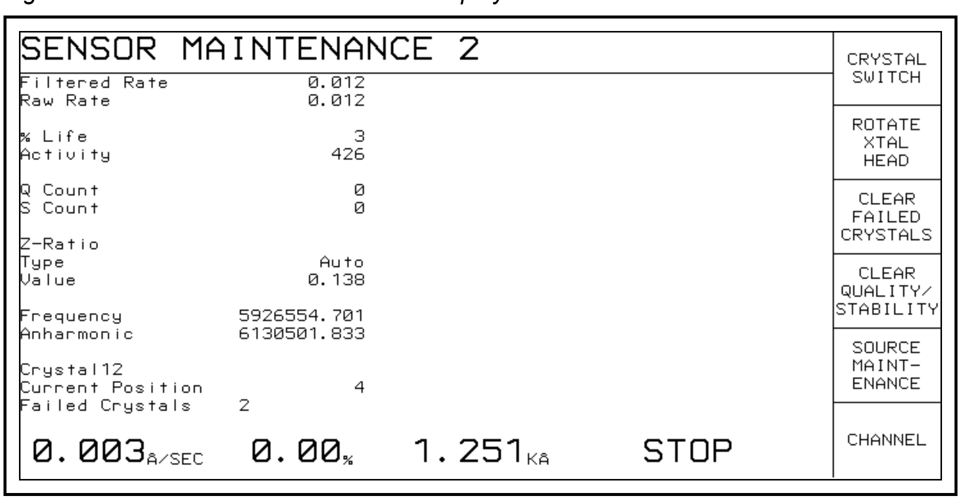
To access the PROCESS (see Figure 2-9) related channel information, press function key F1.

F6 CHANNEL

To return to the CHANNEL display, press function key F6.

2.3.1.3.2 Channel SENSOR MAINTENANCE Display

Figure 2-11 SENSOR MAINTENANCE Display



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SENSOR MAINTENANCE Display Description (refer to Figure 2-11)

Sensor Type

Indicates the Sensor Type as defined on the Channel Hardware display (refer to Figure 2-10).

XTAL Readings

The values of percent life and activity for the channel sensor crystal

Crystal Status

Depending upon the type of sensor used, this field may be empty (Single), may identify the current crystal position in addition to the quantity of good crystals (CrystalTwo); may identify the current crystal position and the position number(s) of the failed crystal (CrystalSix, Crystal12) or the quantity of good crystals (Rotary).

Q Count (Crystal Quality value field)

This field displays the value currently accumulated in the Crystal Quality counter when active. DLY indicates the Crystal Quality counter is not active. The Crystal Quality counter will become active five seconds after entering DEPOSIT and if the Crystal Quality parameter value is non-zero.

S Count (Crystal Stability value field)

This field displays the value currently accumulated in the Crystal Stability counter.

Z-Ratio

Type Material or Auto-Z, value in use.

Frequency

Crystal Fund — normal video = good crystal, inverse video = bad crystal

Anharmonic

Crystal Anharmonic — normal video = good crystal, inverse video = unable to Auto-Z.

Rate, Power, and Thickness display area

The lower portion of this display shows the Rate, %Power, and Thickness for the channel.

SENSOR MAINTENANCE Display Function Keys

F1 CRYSTAL SWITCH

To initiate a crystal switch, press function key F1.

F2 ROTATE XTAL HEAD

If the channel sensor type is a CrystalSix, Crystal12, or Rotary, press function key F2 to sequentially rotate the sensor head through all positions. This is useful to initialize a CrystalSix, Crystal12 or Rotary sensor after replacing failed crystals, or changing Sensor Type parameter.

F3 CLEAR FAILED CRYSTALS

If the channel sensor type is a CrystalTwo, CrystalSix or Crystal12, press function key F3 to clear all non current failed crystal position numbers (CrystalSix, Crystal12) or to increment the number of good crystals (CrystalTwo), if applicable.

F4 CLEAR QUALITY / STABILITY

To clear the Quality and Stability counters, press function key F4.

F5 SOURCE MAINTENANCE

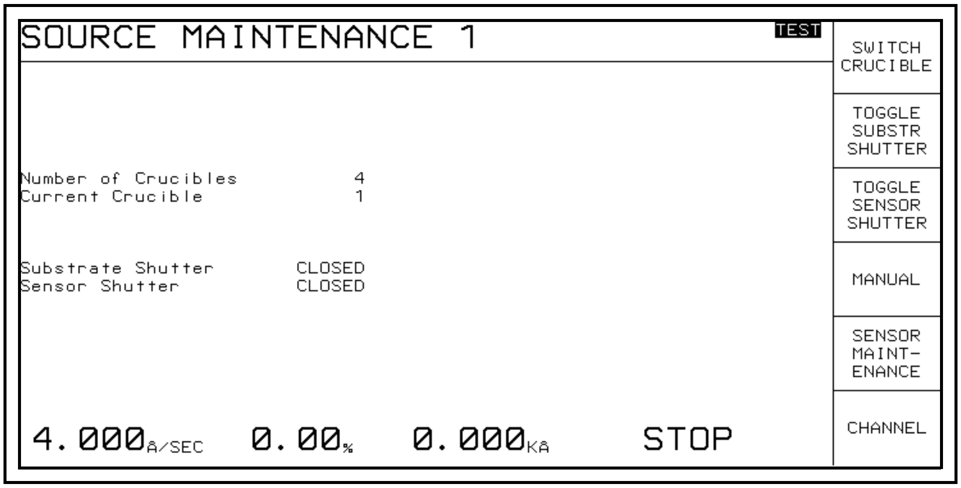
To access the channel source maintenance display press function key F5.

F6 CHANNEL

To return to the Operate display, press function key F6.

2.3.1.3.2.1 Channel SOURCE MAINTENANCE Display

Figure 2-12 Channel SOURCE MAINTENANCE Display



<u>Channel SOURCE MAINTENANCE Display Function Keys</u>

F1 SWITCH CRUCIBLE

To switch the source turret to the crucible position designated by the crucible parameter, press function key F1. When power is at 0.00% only.

F2 TOGGLE SUBSTRATE SHUTTER

To activate the relay for the substrate shutter, press function key F2. A second pressing of this key deactivates the substrate shutter relay.

F3 TOGGLE SENSOR SHUTTERS

To activate the sensor shutter relay, press function key F3. Pressing this key a second time deactivates the sensor shutter relays.

F4 START MANUAL POWER

To enable the hand-held controller to effect power changes to the source output associated with the channel, press function key F4.

F5 SENSOR MAINTENANCE

To access the channel sensor maintenance display press function key F5.

F6 CHANNEL

To return to the Channel display, press function key F6.

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2.4 Crystal Life, Starting Frequency and Activity

On the CHANNEL display, crystal life is shown as a percentage of the monitor crystal's frequency shift, relative to the 1.50 MHz frequency shift allowed by the instrument. This quantity is useful as an indicator of when to change the monitor crystal to safeguard against crystal failures during deposition. It is normal to change a crystal after a specific amount of crystal life (% change) is consumed. It is not always possible to use a monitor crystal to 100% of crystal life. Useful crystal life is highly dependent on the type of material being deposited and the resulting influence of this material on the quartz monitor crystal. For well-behaved materials, such as copper, at about 100% crystal life the inherent quality, Q, of the monitor crystal degrades to a point where it is difficult to maintain a sharp resonance and therefore the ability to measure the monitor crystal's frequency deteriorates.

When depositing dielectric or optical materials, the life of a gold, aluminum or silver quartz monitor crystal is much shorter — as much as 10 to 20%. This is due to thermal and intrinsic stresses at the quartz-dielectric film interface, which are usually exacerbated by the poor mechanical strength of the film. For these materials, the inherent quality of the quartz has very little to do with the monitor crystal's failure.

It is normal for a brand new quartz monitor crystal to display a crystal life anywhere from 0 to 5% due to process variations in producing the crystal. Naturally, this invites the question, "Is a brand new crystal indicating 5% life spent inferior to a crystal indicating 1% life spent?"

If a new crystal indicates 5% life spent, it means that either the quartz blank is slightly thicker than normal (more mechanical robustness), or the gold electrode is slightly thicker than normal (better thermal and electrical properties), or both. In either case, its useful life with regard to material deposition should not be adversely affected. To verify this assertion, laboratory testing was performed on crystals that covered the crystal life range in question. Results indicate that a brand new crystal that indicates 3 to 5% life spent is just as good as, if not better than, a crystal indicating 0 to 2% life spent. As a consequence, it is important to consider the change in crystal life (%), not just the absolute crystal life (%) indicated.

The activity value is useful for predicting when a crystal needs to be replaced. If a crystal is about to fail, its series resistance will increase, allowing less current to flow through the crystal and hence the activity value will decrease. The closer the activity value is to zero the more imminent a crystal failure.

It also can be used to gauge the health of the sensor head electrical contacts. Activity values range from a maximum of 650 (healthiest) to a minimum of 0 (least healthy). For example, if a new monitor crystal is placed into the sensor head and has a crystal life of near 0%, but the activity value for this crystal is lower than 400, the sensor head or in-vacuum cable is in need of repair.

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2.5 Defining a Process

The following procedure is used to define a process. (All steps do not necessarily have to be followed in the given order.)

1 Make sure the instrument is in READY.

Some configuration and process parameters can be changed only while the channel is in READY. Therefore, before setting parameters, make sure READY appears as the state on the CHANNEL display. If it does not, press STOP then RESET.

2 Configure the sensor.

Configuring the sensor involves designating whether the sensor is a single, CrystalTwo, CrystalSix, Crystal12 or Rotary sensor, and what output relays are connected to the sensor shutter and crystal switcher, if any. These parameters are on the Channel HARDWARE display.

3 Configure the sources.

Configuring the sources involves selecting, the output voltage range and polarity, and selecting the output relay for the substrate shutter. Also, if a source has more than one crucible, this is set up in the source configuration. The source parameters are programmed on the HARDWARE display.

2.5.1 Executing a Process

Once a process has been defined, it is ready to execute.

NOTE: Certain parameters cannot be changed while executing a process. The Cygnus will not allow these parameters to be changed.

- A Process is not being executed when the instrument is in the READY or STOP state.
- **STOP** freezes a process, the status information on the display is maintained and the control voltage output is set to zero.
- **START**, pressed once, will continue the process from the point at which it was stopped.
- **RESET** takes a stopped process back to the beginning of the process.

HINT: It may be desirable to execute a new process in TEST before doing an actual deposition to check correct shutter operation, sequencing and limits.

2.6 State Descriptions

Table 2-1 State Descriptions

STATE	CONDITION	RELAY CONTACT STATUS	
		Substrate Shutter	**Sensor Shutter**
NOTE: The following are Pre-Deposit states.			
READY	Cygnus will accept a START command Thickness is not incremented	Inactive	Inactive
CRUCIBLE SWITCH	Instrument advances to next state when “turret” input is low, or “turret” delay has elapsed. If IDLE PWR of the channel using this source is not equal to zero, power is set to zero before the crucible position changes.	Inactive	Inactive
RISE TIME 1[1]	Source is rising to Soak Power 1 level.	Inactive	Inactive
SOAK TIME 1[1]	Source is being maintained at Soak Power 1 level.	Inactive	Inactive
[1] Rise Time 1 and Soak Time 1 will be skipped and the channel will start with the Rise Time 2 state if Idle Power is set to a non-zero value and the channel is currently at Idle at this non-zero Idle Power.			
RISE TIME 2	Source is rising to Soak Power 2 level.	Inactive	Inactive
SOAK TIME 2	Source is being maintained at Soak Power 2 level.	Inactive	Inactive[2]
[2] If a channel is linked to another due to crosstalk correction, that channel’s Sensor Shutter will become active during Soak Time 2 if the linked channel is in Deposit.			
NOTE: The following are Deposit states.			
DEPOSIT	Thickness is zeroed on entry. Rate control, substrate shutter relay active.	Active	Active[3]
NONDEP CONTROL	Rate control, substrate relay contact inactive. Thickness is not incremented	Inactive	Active[3]
[3] RateWatcher in Delay and Sample will have the sensor shutter active. RateWatcher in Hold will have the sensor shutter inactive.			
NONDEP HOLD	Power held constant due to a crystal failure.	Inactive	Inactive
MANUAL	Source power controlled by hand-held controller.	Active	Active
TIME-POWER	Crystal failed; source maintained at average control power prior to crystal failure.	Active or Inactive	Active

Table 2-1 State Descriptions (continued)

STATE	CONDITION	RELAY CONTACT STATUS	
		Substrate Shutter	**Sensor Shutter**
NOTE: The following are Post-Deposit states.			
IDLE RAMP	Source changing to Idle Power.	Inactive	Inactive
STOP	Source output set to zero power. The display is frozen at the last rate and thickness values.	Inactive	Inactive
	NOTE: In the STOP state the instrument will accept a START provided a Crystal Failure for the sensors used in the channel being started is not present.		
NOTE: The following is a Non-Deposit state.			
MANUAL	Source power controlled by hand-held controller.	Inactive	Active

2.7 Special Features

Cygnus has several special features to enhance the performance of the instrument.

2.7.1 Crystal Switching

Cygnus offers a choice of Single, CrystalTwo, CrystalSix, Crystal12 or Rotary sensors. The CrystalTwo, CrystalSix, Crystal12, and Rotary sensors provide a backup monitor crystal in case a crystal fails during deposition. Sensor types are specified on the Channel Hardware Display.

A crystal switch will *automatically* occur when:

- The instrument is configured for a CrystalTwo sensor type, a channel is STARTed or running and there is another good crystal available when the active crystal fails.
- The instrument is configured for a CrystalSix or Crystal12, a channel is STARTed or running, and there is at least one good crystal left in the carousel when the active crystal fails.
- The instrument is configured for a Rotary sensor, the channel is running, and there is at least one good crystal in the Rotary sensor.

A crystal switch will **NOT** *automatically* occur:

- During a state of STOP or READY.
- During deposition, if the secondary crystal of a CrystalTwo sensor fails, or the last good crystal of a Rotary, CrystalSix, or Crystal12 fails. (In either case a TIME-POWER, IDLE-RAMP or STOP will occur, depending on the crystal fail option chosen.)

A crystal switch can be manually executed via the front panel, hand-held controller, remote communications, or logic statements when the system is configured for CrystalTwo, CrystalSix, Crystal12 or Rotary sensors.

NOTE: When crystal switching with the hand-held controller, Cygnus must be on a screen with a channel selected.

2.7.2 Rotary Sensor Crystal Switching

Selecting type 7, Rotary, as the sensor type enables sequential crystal switching only. Upon a crystal switch the Crystal Switch Output will first close for one second and then open (i.e., one pulse to move one position). Cygnus will not keep track of which position the Rotary Sensor is on nor will it keep track of which crystals are good and which are failed. After the one second pulse, Cygnus measurement system software will attempt to find the resonant frequency for the crystal in this position. If the Cygnus does not find a good resonant frequency for this crystal it will again pulse the Crystal Switch Output for one second and attempt to find a resonant frequency at this position. There will be a maximum of five attempts to find a good resonant frequency (i.e., a maximum of five pulses of the Crystal Switch Output). If a good resonant frequency is not found after five attempts, the Cygnus will then enter the Time Power, Idle-Ramp or STOP state depending on the Crystal Fail Option value chosen in the Channel Process Display.

There is to be a maximum of five attempts to find a good resonant frequency. However, if the Cygnus detects a crystal fail and automatically initiates a crystal switch it will recognize there has been an automatic crystal switch. The Cygnus will keep track of the number of times an automatic crystal switch has been done. Therefore if there have been five automatic crystal switches and then the sixth crystal fails, Cygnus will go directly to either Time Power, Idle-Ramp, or STOP as appropriate without any additional pulses.

After a ’Start’ command, all crystals are assumed to be good.

2.7.3 Source/Crucible Selection

Cygnus can control a source with up to 64 crucibles, through up to six binary encoded relays. This is configured by setting the Number Of Crucibles, Crucible Outputs, Turret Feedback, Turret Input, and Turret Delay parameters on the Channel Hardware display.

To define which crucible to use for the channel, set the “crucible” parameter on the CHANNEL PROCESS display. If the current crucible position is different from the one requested upon STARTing, the system’s turret controller would move into position. This will be signified on the Channel display by the state indicator CRUCIBLE SWITCH. Sequencing will continue on to RISE 1 after either the turret delay time expires or an input indicates the turret is in position, depending on which option is chosen. The specific method used is determined by the parameter Turret Feedback on the Channel Hardware display.

NOTE: If the source has been idling at a nonzero power when the START is initiated, the power will be dropped to zero before the crucible is changed.

2.7.3.1 Example: Programming Turret Source Crucible Selection

Interfacing a turret source controller to the Cygnus requires both hardware connections to the turret controller and properly defining certain instrument parameters.

Proceed to the Channel Hardware display for the source that is going to be defined as the turret source.

1. Designate the Number of Crucibles; for example, 4.
2. Select the Crucible Output. This defines the number of the first relay that encodes the crucible number selected by the active channel. Relays are defined sequentially with the first relay containing the least significant bit (LSB). The greater the number of crucibles selected, the greater the number of relays required. The number required is based on binary encoding (actual coding is binary -1, with 00 representing position 1 and 11 representing position 4). Any unused sequence of relays may be used if it is long enough to provide sufficient selections.
3. Select the Crucible Output Type as normally open (NO), or normally closed (NC).

   Example:

   Number of crucibles = 4
   Crucible output = 6
   Crucible output type = NO

   For this example, wiring to the controller is based on Table 2-2. Only relays 6 and 7 are needed to encode the four possible positions

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Table 2-2 Wiring To The Controller

Crucible Position	Contact Status	
	Relay #6	Relay #7
1	Open	Open
2	Closed	Open
3	Open	Closed
4	Closed	Closed

NOTE: If the crucible output type were normally closed (NC), Table 2-2 would need to be modified by exchanging open and closed.

4 Determine whether Turret Feedback is desired. This allows the turret position controller to stop further instrument processing until the requested turret position is satisfied. If chosen, a turret input must be connected to the turret position controller's feedback signal within one minute, else a STOP Crucible ERR occurs.

If Turret Feedback is not chosen, program a Turret Delay Time, which allows an adequate time for positioning to take place. Once the delay time has expired, instrument state processing continues.

5 The selection of a particular crucible for a channel is defined in the CHANNEL PROCESS display.

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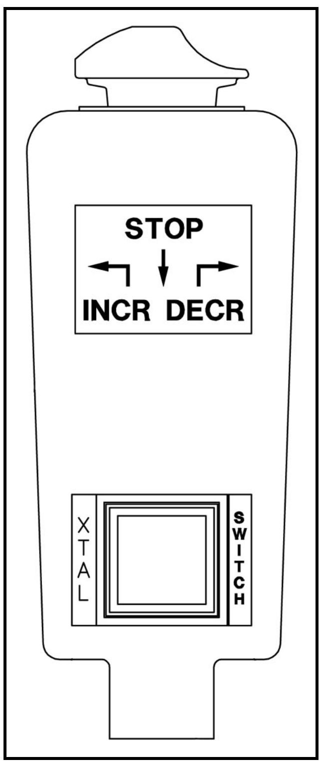
2.7.4 Hand-Held Controller

A Hand-Held Controller, see Figure 2-13, is provided as an accessory with the Cygnus. The Controller serves as a wired remote to manually control power, switch crystals and produce a STOP.

The Controller is attached to the instrument with a modular plug to the front panel. Power is affected (only when in Manual mode) by moving the POWER/STOP switch laterally. A STOP is produced by moving the POWER/STOP switch down (only when in Manual mode). An All STOP is performed when the STOP function is pressed twice within one second, or is continuously pressed. When in a READY or STOP state and the instrument is on the SENSOR Maintenance display, a crystal switch is activated by pressing the red button on the body of the controller. The ship kit includes a convenience hook for the Controller that can be attached to the instrument's mounting ears or some other accessible location.

Figure 2-13 Hand-Held Controller



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2.7.5 Test Mode

This instrument contains a software-controlled test mode which simulates actual operation. Optionally, time can be compressed so that a long process can be simulated in one tenth of the time. The purpose of the test mode is to verify basic operation and to demonstrate typical operation. The rate display during test mode operation is:

$$\text{Rate Display} = \frac{40}{\text{Density (gm/cc)}} \times \frac{\text{Tooling \%}}{100}\ \text{Å/sec} \qquad [1]$$

Crystal fails are ignored in test mode. Crystal switching is disabled. All other relays and inputs operate normally.

2.7.6 Floppy Disk (Optional)

The floppy disk drive is an optional accessory for the Cygnus. This option allows storage of all parameter information to the 3.5 inch 1.44 MByte floppy diskette. The maximum number of files that may be stored onto the floppy disk is 224 for a 1.44 MByte diskette and 112 files when using a 720 KByte diskette

The parameter set may be stored under a new or existing filename and retrieved from an existing file. A file containing the Cygnus parameter set is referred to as a configuration file.

Multiple files may be contained on one diskette. Filenames may be eight characters long. All files must be contained on the root directory. Storage/retrieval from sub-directories is not allowed.

The instrument supports the writing of filenames using alphanumeric characters selected using the cursor keys. Characters A through Z and numbers 0 through 9 inclusive are available. The instrument has the ability to display the files contained on the diskette. A scrolling feature is enabled to view those filenames that cannot fit on the screen. Error messages include: Disk Full; File Not Found; Disk Write Protected; Media Error; Disk not Found; File is Read Only.

CAUTION

Do not bend the diskette.

Keep the diskette dry and do not expose the diskette to temperature extremes.

Do not remove the diskette from the instrument while a save or retrieve operation is taking place.

2.7.7 Lock Codes

A Program Lock Code can be entered to prevent unauthorized changing of parameters. This Lock Code can be entered through the front panel using the PROGRAM LOCK display. An additional Lock Code can be entered through remote communications to prevent parameter entry from the front panel while communicating to Cygnus using remote communications. The word “LOCK” in inverse video will be displayed in the upper right corner of the display.

HINT: To clear the lock, hold down the clear key on power up. ***HOWEVER***, if no lock code is present, all parameters will be cleared by doing this.

2.7.8 Datalog

Datalog automatically saves to diskette every time a source shutter closure occurs. When the Datalog data is saved to a diskette, the information will be saved under a filename.

Datalog files saved to diskette will be automatically named using the date and Channel number. The format of the filename is YYMMDDC#.IDL where YY is 00 to 89 for the last two digits of the year 20YY, MM is 01 to 12 for the month, DD is 1 to 31 for the day and # is the Channel number 1 to 6. If the diskette already contains a file with the same filename as the new datalog information, the new datalog information will be appended to the old file.

At each source shutter close, the datalog information will be appended to the file (when saved to diskette) until the end of the Process.

The Datalog data set is defined as follows:

```
               DATE:    MM-DD-YYYY
               TIME:    XX:XX
          CHANNEL #:    #
           RUN TIME:    XX:XX
    DEPOSITION TIME:    XX:XX
          THICKNESS:    ###.###       kÅ
     AVE. AGG. RATE:    ###.###       Å/s
      AVE. RATE DEV:    ##.###        Å/s
       ENDING POWER:    ##.##         %
         AVE. POWER:    ##.##         %
         COMPLETION:    POST-DEPOSIT NORMAL
                        (time-power, ave. value,
                        crystal fail, remote, keyboard,
                        max. power, hand-held controller)
```

Crystal Use History (example)

SENSOR 1

XTAL	BEG. FREQ.	END FREQ.	BEG. LIFE	END LIFE	BEG. ACT.	END ACT.	STAB.	QUAL.
1	5975323	5876991	0%	2%	245	240	30	22
2	5978368	5879012	0%	2%	225	189	1200	99
3	5768733	5677987	3%	5%	176	168	0	0
4	5346278	5129870	48%	51%	150	105	0	0
5	4876789	4567899	78%	81%	101	101	25	1
6	4678843	4500000	98%	100%	100	92	0	0

SENSOR 2

XTAL	BEG. FREQ.	END FREQ.	BEG. LIFE	END LIFE	BEG. ACT.	END ACT.	STAB.	QUAL.
2	5978368	5879012	0%	2%	225	189	1200	99
3	5768733	5677987	3%	5%	176	168	0	0
5	4876789	4567899	78%	81%	101	101	25	1

SENSOR 8

XTAL	BEG. FREQ.	END FREQ.	BEG. LIFE	END LIFE	BEG. ACT.	END ACT.	STAB.	QUAL.
1	5975323	5876991	0%	2%	245	240	30	22

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If two Channels are co-deposited, the first Channel to have a source shutter close will be data-logged first.

The ability to turn ON/OFF datalogging and where to output the datalog data set is determined by a programmable parameter located in the General Parameters display. The CRYSTAL USE HISTORY data is an optional subset of the datalog string. A second parameter located in the General Parameters display is used to determine if the CRYSTAL USE HISTORY is to be output. Additionally, the datalog string format is selectable between a page format and a comma delimited format. The comma delimited format is actually comma-and-quote delimited intended for file importation into a spreadsheet program. When a spreadsheet program imports a file having the comma delimited format data groups that are strictly numbers become value entries, data groups surrounded by quotes are stored as labels. For the page format, only those sensors which are used in a particular Material for a particular Layer will be datalogged. For the comma delimited format, all the data fields are returned for all the sensors and crystals. If a sensor is not used during the deposition, the data field will contain a zero.

Outputting the Datalog Data Set to multiple outputs at the same time (for example, Save to diskette and Output to Remote Comm at the same time) is not allowed.

2.7.9 Auto Soak 2

When Auto Soak 2 is enabled, the Soak 2 power parameter will automatically be updated at the end of deposit or nondeposit control. The value will be the power at the end of control. This allows the next Soak 2 on the channel to be done at the last power used to maintain control.

To enable Auto Soak 2, the parameter Dep After PreDep is set to 2.

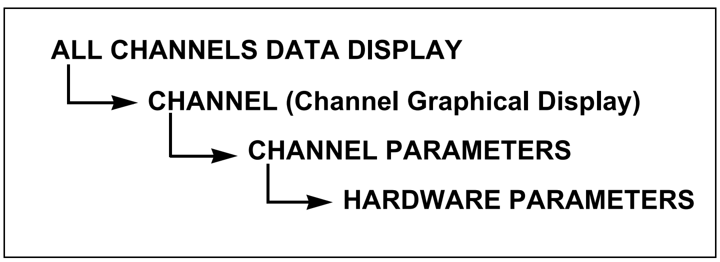
NOTE: The Soak 2 power parameter retains the new value even if Auto Soak 2 is subsequently disabled.

Chapter 3
Channel Parameters

3.1 Introduction

Cygnus can store the definition parameters for 6 Channels (or sources). There are three primary displays associated with each Channel. These are the Channel Parameters display, the Channel Hardware parameters display, and a graphical data display. Each Channel is completely defined by programming Channel Parameters and Channel Hardware parameters. Channel Parameters define the material to be deposited and the deposition profile, for example: Density, Z-Ratio, Rise Times and Soak Times. Channel Hardware parameters define the digital-to-analog (DAC) functions, sensor type, as well as the shutter and crucible outputs.

Figure 3-1 Display Tree for Channel Set Up



Channel set up is initiated by selecting the Channel (F6) key in the All Channels data display. Selecting F6 brings up the Channel Graphical Display for the Channel number indicated by the cursor.

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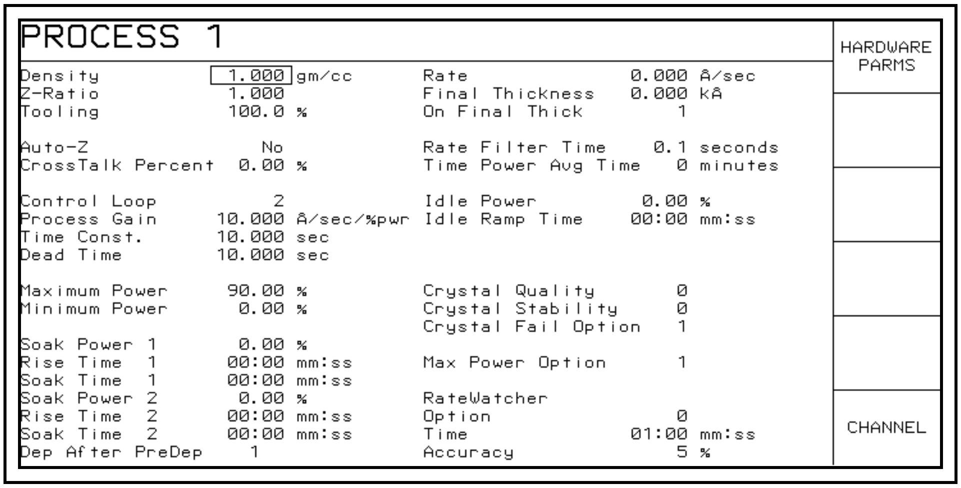
3.2 Channel Parameters

Channel definition is done by pressing the F1 function key on the CHANNEL display. Selecting F1 brings up the Channel Parameters display as shown in Figure 3-2.

Figure 3-2 Channel Parameters Display



<u>**Channel Parameters Display Function Keys**</u>

F1 HARDWARE PARMS

To access the Channel Hardware Parameters Display, select function key F1

F6 CHANNEL

To return to the Channel Graphical display, select function key F6.

3.2.1 Channel Parameter Definitions

DENSITY . . . . 0.100 to 99.99 gm/cc (default = 1.000)

This parameter is specific to the material being deposited onto the Crystal. It is one of two parameters that relate the mass loading on the crystal to a thickness.

Z-Ratio. . . . . 0.100 to 15.000 (default = 1.000)

This parameter is specific to the material being deposited. It is one of two parameters that relate the mass loading on the crystal to a thickness. This parameter is superseded if Auto Z-Ratio is selected.

TOOLING. . . . . 1.0 to 999.9% (default = 100.0)

This is a correction factor used for correlating the thickness accumulation on the crystal with the thickness accumulation on the substrate. This thickness difference is due to the geometric distribution of material flux from the source.

The tooling factor is calculated using the equation:

$$\text{TOOLING} = \text{TF}_i \times (\text{T}_m / \text{T}_x) \quad [1]$$

where TF_i = Initial Tooling Factor, T_m = Actual Thickness at the Substrate, and T_x = Thickness on the Crystal.

If the TOOLING parameter is changed, the new TOOLING value is used for subsequent calculation of the rate and thickness. Also, the thickness accumulated thus far will be re-scaled based on the change to the TOOLING.

SECONDARY TOOLING . . . . 1.0 to 999.9% (default = 100.0)

This is a second tooling factor for use with the CrystalTwo Switch. It allows a second tooling factor for the second crystal of the CrystalTwo Switch to accommodate the thickness difference between the two different crystal positions. The function is the same as the Tooling factor and is calculated in the same manner.

CONTROL LOOP . . . . 0, 1, 2 (default = 2)

This parameter establishes the control loop algorithms pertaining to either a slow responding source or a fast responding source. Permissible values are 0, 1, or 2. Select a 0 to choose the non-PID control loop, good for fast- and medium-speed responding systems with high noise levels (e.g., an electron beam gun with or without a liner, having a large sweep amplitude of low frequency, 10 Hz or less). Select a 1 for the PI control loop, good for fast, medium, or slow systems with medium noise levels (e.g., an electron beam gun with medium sweep amplitude frequency, 20 to 100 Hz; also, sputtering and resistive sources). Select a 2 for the PID Control Loop, good for medium or slow systems with low noise levels (e.g., an electron beam gun with sweep off or at a high frequency, 100+ Hz; also, sputtering and resistive sources).

PROCESS GAIN . . . . 0.01 to 999.99 Å/sec/% pwr (default = 10.00)

This parameter determines the change in % Power for a given rate deviation (dRate/dPower). The larger the process gain value, the smaller the change in power for a given rate error.

PRIMARY TIME CONSTANT. . . . . . 0.010 to 9999.99 sec (default = 1.00)

This is the evaporation source's time constant. This value is defined as the time difference between the actual start of a change in rate and the time at which 63% of the rate step is achieved. This value may be measured according to the above criterion or it may be determined empirically. This parameter is disabled if the CONTROL LOOP option parameter is set to 0.

SYSTEM DEAD TIME . . . . 0.010 to 9999.99 sec (default = 1.00)

This value is defined as the time difference between a change in % power and the start of an actual change in rate. This parameter is disabled if the CONTROL LOOP option parameter is set to 0.

MAXIMUM POWER . . . . 0.0 to 99.99% (default = 90.00)

This parameter is used to set the maximum permissible % power level. The control voltage output will not exceed this limit.

MINIMUM POWER . . . . 0.0 to 99.98% (default = 0.00)

This parameter is used to set the minimum permissible % power level. The control voltage output will not go below this limit during either the Deposit or Non-Deposit Rate control states.

Power Ramps (Pre deposit states)

The next six parameters — Soak Power 1, Rise Time 1, Soak Time 1, and Soak Power 2, Rise Time 2 and Soak Time 2 — are used to define two power ramps provided to precondition materials.

SOAK POWER 1 . . . . 0.0 to 99.99% (default = 0.00)

This parameter is usually set to the power level at which the source material just begins to melt. The instrument ramps the power level from zero to Soak Power 1 linearly over the time period Rise Time 1.

RISE TIME 1 . . . . 00:00 to 99:59 min:sec (default = 00:00)

This parameter provides the time period over which the source power is ramped from 0 to Soak Power 1. See note.

SOAK TIME 1 . . . . 00:00 to 99:59 min:sec (default = 00:00)

This parameter provides the time period for which the instrument holds at Soak Power 1. See note.

NOTE: Rise Time 1 and Soak Time 1 will be skipped and the channel will start with the Rise Time 2 state if Idle Power is set to a non-zero value and the channel is currently at Idle at this non-zero Idle Power.

SOAK POWER 2 . . . . 0.00 to 99.99% (default = 0.00)

This parameter sets the power level at which the rate from the source very nearly matches the desired deposition Rate. If Auto Soak 2 is enabled, this parameter will automatically be updated when leaving deposit or nondeposit control.

RISE TIME 2 . . . . 00:00 to 99:59 min:sec (default = 00:00)

This parameter sets the time period in which the instrument linearly ramps the power level from Soak Power 1 to Soak Power 2.

SOAK TIME 2 . . . . 00:00 to 99:59 min:sec (default = 00:00)

This parameter sets the time period for which the instrument holds the power level at Soak Power 2.

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DEP AFTER PREDEP . . . . 0, 1, 2 (default = 1)

This parameter is used to determine which rate control state to enter after Soak Time 2. It will also determine whether Auto Soak 2 is enabled.

0 = NonDeposit Control after Soak 2. No Auto Soak 2.

1 = Enter Deposit Control after Soak 2. No Auto Soak 2.

2 = Enter Deposit Control after Soak 2. Enable Auto Soak 2.

RATE . . . . 0.000 to 999.9 Å/sec (default = 0.000)

NOTE: Rate = 0.000 will take a channel in control to post deposit.

This specifies the rate at which the deposition is to be controlled during the DEPOSIT and NON-DEPOSIT CONTROL states. The Rate is calculated based on:

- The rate information acquired by the sensor in use, based on the density and tooling values entered for this Channel.
- The tooling factor that corrects for any relative difference in flux distribution reaching the sensor.

FINAL THICKNESS . . . . 0.000 to 999.9 kÅ (default = 0.000)

This is the thickness setting that triggers the end of the DEPOSIT state. The Substrate Shutter output returns to its normal state. The deposition profile then proceeds to the State indicated by the ON FINAL THICK parameter value, or by a user supplied input via the I/O or one of the Remote Communications ports.

ON FINAL THICKNESS. . . . . 0, 1, 2 (default = 1)

The On Final Thickness parameter value determines the next step of the deposition profile.

0 = NonDeposit Control. Entering a value of 0 directs the deposition profile to enter the NonDeposit Control state, returning the substrate shutter output to its normal state, when the final thickness value is reached during the Deposit state.

1 = Idle Ramp. Entering a value of 1 directs the deposition profile to enter the Idle Ramp state when the final thickness value is reached during the Deposit state.

2 = Continue. Entering a value of 2 directs the deposition profile to continue in the Deposit state. Thickness continues to be accumulated.

AVERAGING TIME . . . . 0 to 30 min (default = 0)

This parameter value determines the amount of time used in calculating the average rate and average power for use in Time Power.

The Averaging Time parameter is the time interval used to calculate both the average rate and average power applied, if a crystal fails, for Time-Power and Non-Deposit Hold states. When the Averaging TIme parameter value is 0, then a 2.5 second average, ignoring the most recent 0.5 second, is the averaging interval.

A channel warning ABBREVIATED AVERAGE is generated if the averaging interval has not been reached, but there was at least a "complete whole minute" of data to average.

A channel error NO TIME POWER AVG is generated if a crystal fail occurred within the first minute of control with Averaging TIme set >0. This error also occurs if there is a crystal fail during the first 2.5 seconds of control with the Averaging TIme =0. (There are also SC and RC commands to get and set the average rate and average power values.)

Idle Ramp State

The next two parameters define an idle ramp provided to maintain the control voltage power level after the Deposit or NonDeposit Control state. Control voltage is ramped from the power level at the end of the Deposit (or NonDeposit Control) state to the Idle Power level. The control voltage is maintained at the Idle Power level until the instrument enters the STOP state or until the Channel is started again. If the Idle Power is non-zero, the started channel will skip Rise 1 and Soak 1, and will begin at Rise 2.

IDLE POWER . . . . 0.0 to 99.99% (default = 0.00%)

This is one of two parameters used to affect an Idle Power Ramp. This value is the power level at which the source is maintained after the DEPOSIT (or NonDeposit Control) state. Idle Power is usually the same as Soak Power 1.

IDLE RAMP TIME . . . . 00:00 to 99:59 min:sec (default = 00:00)

This is the time interval over which the source power is ramped linearly from the power level at the end of Deposit (or NonDeposit Control) to Idle Power.

CRUCIBLE. 1 to the maximum number of crucibles programmed. (default = 1)

This parameter identifies which crucible of a multiple pocket source to use when the channel is started.

CRYSTAL QUALITY . . . . 0 to 9 (default = 0)

This parameter is used to ensure tight rate control by monitoring the information obtained from the crystal. It can be used to effect a crystal fail when operating in the single frequency mode. The “single frequency” mode is when the Z-Ratio type is set for Material Z, “dual frequency” mode is when the Z-Ratio type is set for Auto Z. See Table 3-1.

Table 3-1 Crystal Quality Number and Threshold of Rate Deviation

Crystal Quality Number	Threshold of Rate Deviation
9	2.5%
8	5.0%
7	7.5%
6	10.0%
5	12.5%
4	15.0%
3	20.0%
2	25.0%
1	30.0%
0	Disabled

For each rate reading, the percent relative deviation from the sensor’s rolling average rate is calculated. Each time this deviation is greater than the allowed percent relative deviation, as determined by the Crystal Quality value, a counter is incremented by one count. If the deviation is within tolerance, the counter will count down. (The counter will not count below zero.) When the count reaches 100, a crystal fail will be initiated. In this manner only sustained erratic rate readings will trigger a crystal fail and instantaneous noise will be ignored.

If Auto Z is in use, the crystal quality will trigger an Auto Z failure instead of a crystal fail. This will change the instrument from dual frequency measurement mode to single frequency measurement mode. For some materials, it is possible to regain rate stability by this change. Once the switch to single frequency has occurred and a waiting period has elapsed (four times the Primary Time Constant plus the System Dead Time plus ten seconds), the counter will again track the rate deviation. If the counter reaches 100 a second time, a crystal fail will be triggered.

CRYSTAL STABILITY . . . . 0 to 9 (default = 0)

The Crystal Stability parameter can also be used to effect a crystal fail. In normal operation, when mass is added to a crystal its frequency of oscillation will decrease. There are, however, a number of reasons, such as thermal shock, high stresses in the film, electrical arcing from an electron beam gun, or frequency instabilities, that may cause a positive frequency shift between successive measurements. The Crystal Stability function is used to monitor these positive frequency excursions while the Channel is active. Values range from 0 to 9. The default value of 0 disables the function. Values 1 through 9 correspond to the maximum positive frequency accumulation permitted. See Table 3-2.

Table 3-2 Crystal Stability Number and Positive Frequency Accumulation

Crystal Stability Number	Positive Frequency Accumulation (Hz)
9	25
8	100 (max single shift of 50)
7	100
6	200 (max single shift of 100)
5	200
4	400
3	500
2	1000
1	5000 (max single shift of 1250)
0	Disabled

Each time there is a positive shift in frequency, the magnitude of the positive frequency excursion is accumulated. If the cumulative total, or the maximum single shift, exceeds the limit set by the Crystal Stability value a crystal fail function is triggered.

CRYSTAL FAIL OPTION . . . . 0, 1, 2 (default = 1)

This parameter value determines what action will be taken if there is a crystal failure for this Channel during control.

0 = Time Power. Entering a value of 0 will cause the Channel to enter the Time Power state upon a crystal failure.

1 = Idle Ramp. A value of 1 will cause the Channel to enter the Idle Ramp state upon a crystal failure.

2 = Stop. A value of 2 will cause the Channel to Stop upon a crystal failure.

MAX POWER OPTION . . . . 0, 1, 2 (default = 1)

This parameter value determines what action will be taken if the Channel reaches maximum power and is held at maximum power for 5 seconds.

0 = Continue. Selecting a value of 0 will allow the Channel to continue in its current state.

1 = Idle Ramp. A value of 1 will cause the Channel to enter the Idle Ramp state.

2 = Stop. A value of 2 will cause the Channel to Stop.

RateWatcher™ Sample and Hold Feature

Four parameters — RateWatcher Option, RateWatcher Averaging Time, RateWatch Time and RateWatch Accuracy — enable the Sample and Hold feature. When enabled, this feature periodically samples the deposition rate by automatically opening the sensor shutter and exposing the sensor to the deposition source. The power is adjusted so the actual rate is set to the desired rate. The sensor shutter is then automatically closed and power is held constant at the adjusted level. A five second time delay for thermal stabilization occurs between opening the shutter and taking measurements.

The RateWatcher Sample phase uses the measured deposition rate to control the source power. When the deposition rate meets the requirements of the RateWatcher Accuracy parameter, the RateWatcher Acceptance Window Time is started. If the rate falls out of the RateWatcher Accuracy requirement, the RateWatcher Acceptance Time Interval is reset to zero.

If the deposition rate meets the RateWatcher Accuracy requirement for the duration of the Acceptance Window Time, the sensor shutter is closed and RateWatcher enters Hold phase for the Hold Time duration.

Finally, after the Hold Time has elapsed, RateWatcher will enter a 5 second Delay phase. During the Delay phase, the crystal is exposed to the deposition, but the accumulated rate and sustained power are that from the previous Hold phase. This Delay phase allows the crystal to thermally stabilize to the deposition before re-entering the RateWatcher Sample phase.

The RateWatcher Sample Acceptance Window Time (that is, the length of time that the rate must be within the accuracy range before going into hold) will be calculated as follows:

Parameters		RateWatcher "Sample" Acceptance Window Time	Rate and Power are simultaneously averaged using the following stored data
Averaging Time	Rate Filter Time		
0 min	< 10 sec	5 seconds	2 second interval before most recent 0.5 seconds
0 min	≥ 10 sec	10 seconds	2 second interval before most recent 0.5 seconds
1 min	any	60 seconds	2 second interval before most recent 0.5 seconds
> 1 min	any	Averaging Time * 60 seconds	Averaging Time excluding the most recently calculated 1 minute average

RATEWATCHER OPTION . . . . 0, 1, 2 (default = 0)

This parameter controls the use of the RateWatcher.

0 = None, disabled

1 = Non-deposit state only

2 = Non-deposit and deposit states

RATEWATCH HOLD TIME . . . . 00:01 to 99:59 min:sec (default = 00:05)

RateWatch Time determines the time interval over which the sensor shutter will be closed between samples.

RATEWATCH ACCURACY . . . . 1 to 99 % (default = 5)

During the rate sampling period, the deposition rate is measured by the crystal; source power control is active. When the rate is within the desired accuracy for a period of time, the shutter is closed and the deposition state returns to HOLD.

RATE FILTER TIME. . . . . 0.1, 0.4, 1.0, 4.0, 10.0, 20.0, 30.0 sec. (default = 0.1)

This parameter is used to apply a boxcar filter to the measured “raw” rate which is used to produce the Rate DAC output voltage.

The Rate Filter Time may be used for enhanced resolution. If a source has a long time constant, rate may be taken as constant over longer intervals Averaging provides an opportunity to reduce rate noise. Depending on the source of the noise, averaging can improve rate resolution:

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- If the noise is crystal frequency resolution limited — the thickness change over one second provides ten times the thickness change vs. the thickness change measured over a tenth of a second. A one second averaging interval will improve rate resolution by 10 times.
- If the sensor noise is random, then RMS reduction of rate noise is provided by the square root of the number of point's averaged (example a 10 point average provides a factor of 3.1 noise reduction).

The selection of the appropriate Rate Filter Time value will be dependent on the characteristics of the source.

CROSS TALK PERCENT . . . . 0.00 to 99.99% (default = 0.00)

This parameter is used for co-deposition of two sources. The selection of two co-deposition sources is always a Channel N= (odd value) and Channel (N+1).

This parameter provides a value used in an algorithm that compensates for cross interference during co-deposition. Mass accumulation onto the sensor for source Channel N due to evaporant from source Channel (N+1) can be subtracted from the mass accumulation onto sensor Channel N due to source Channels N and (N+1). The correction is expressed as a percentage of the rate at sensor Channel N over the rate at sensor Channel (N+1) due to only source Channel (N+1). When calculating cross sensitivity, the density and Z-Ratio parameter values should be the same for each source. See section 7.5 on page 7-4 for a procedure on how to determine Cross Talk Percent values.

The Cross Talk Percent value is calculated according to the equation (while depositing from source Channel (N+1) only).

$$\left(\frac{\text{Thickness at sensor Channel N}}{\text{Thickness at sensor Channel (N+1)}}\right) \times 100\% = \text{VALUE} \qquad [1]$$

This is the value entered into the Cross Talk Percent parameter for Channel N.

AUTO-Z . . . . YES / NO (default = NO)

This parameter designates the method in which the Z-Ratio value will be obtained for use in computing thickness with this sensor.

YES indicates that the Auto Z calculation feature of the system is used. If Auto-Z cannot be enabled on a crystal, the “Unable To Auto Z” message will be displayed.

NO indicates that the Z-Ratio established in Z-Ratio parameter is used.

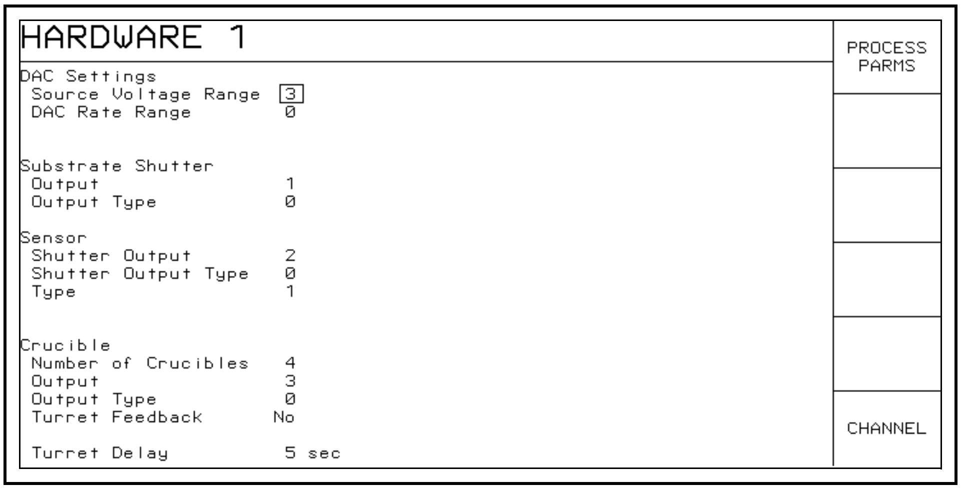
The default value is NO and the Z-Ratio value will be used.

3.3 Channel Hardware Parameters

Channel Hardware parameters define the digital-to-analog (DAC) functions, sensor type, as well as the shutter and crucible outputs for the specified Channel.

Channel Hardware definition is done by pressing the F1 function key on the Channel Parameters display. Selecting F1 brings up the Channel Hardware parameters display as shown in Figure 3-3.

Figure 3-3 Channel Hardware Parameters Display



Channel Hardware Display Function Keys

F1 PROCESS PARMS

To return to the Channel Parameters display, select F1.

F6 CHANNEL

To return to the Channel display, select F6.

3.3.1 Channel Hardware Parameters Definition

NOTE: All Hardware parameters can be changed only when a channel is in the STOP or READY state and is not crystal switching on the channel.

SOURCE VOLTAGE RANGE . . . . . 0, 1, 2, 3, 4, 5 (default = 3)

This parameter selects the control voltage range for the Channel being edited. Permissible values are 0, 1, 2, 3, 4 and 5 for maximum output voltages of 10, 5, 2.5, -10, -5, and -2.5 Volts respectively. The default value is 3, for a control voltage output of 0 to -10 Volts.

NOTE: This parameter is not available if DAC Option 3 (Rate & Thickness) has been selected under General Parameters, DAC Output Option.

DAC RATE RANGE. . . . . 0 - 999 (default = 0)

This parameter determines the function of the Digital-To-Analog (DAC) recorder output. Values range from 0 to 4. Refer to the General Parameters display DAC Output Option for information pertaining to the DAC Rate and DAC Thickness outputs.

0 . . . . . . indicates the function is Channel Rate in the range of 0 to 10 Å/s.
1 . . . . . . is for Channel Rate in the range of 0 to 50 Å/s.
2 . . . . . . is for Channel Rate in the range of 0 to 100 Å/s.
3 . . . . . . is for Channel Rate in the range of 0 to 1000 Å/s.
4 . . . . . . is for Channel Rate in the range of 0 to 1 Å/s.
5 - 999 . . . . . is for Channel Rate in the range of 0 to the value entered.

DAC THICKNESS RANGE . . . . 0 - 99999 (default = 0)

This parameter determines the function of the Digital-To-Analog (DAC) recorder output. Values range from 0 to 4. Refer to the General Parameters display DAC Output Option for information pertaining to the DAC Rate and DAC Thickness outputs.

0 . . . . . . indicates the function is Channel thickness in the range of 0 to 100 Å.
1 . . . . . . is for Channel thickness in the range of 0 to 1000 Å.
2 . . . . . . is for Channel thickness in the range of 0 to 2000 Å.
3 . . . . . . is for Channel thickness in the range of 0 to 3000 Å.
4 . . . . . . is for Channel thickness in the range of 0 to 5000 Å.
5 - 99999 . . . is for channel thickness in the range of 0 to the value entered.

NOTE: The recorder output for the specified DAC Thickness Range is modulo of the channel's thickness value and the DAC Thickness Range's upper limit value. The recorder output will roll over to zero volts when the channel's thickness reaches the DAC Thickness Range upper limit value, and for every N times the DAC Thickness Range upper limit value.

SUBSTRATE SHUTTER OUTPUT . . . . 0 to 38 (default = 0)

This parameter designates which of the 38 outputs is to be used as the Substrate Shutter output. Values range from 0 through 38. 0 indicates that a Shutter is not used and the values 1 through 38 correspond to the appropriate relay or open collector type output. If a value other than 0 is entered the output chosen as the Substrate Shutter output is designated as such in the I/O Map Display. The Substrate Shutter output is activated upon the Channel entering the Deposit or Manual states and stays active until the Channel exits the Deposit and Manual states.

SUBSTRATE SHUTTER OUTPUT TYPE . . . . . 0, 1 (default = 0)

This parameter designates the normal state of the relay contacts for the Substrate Shutter Output output. Permissible values are 0 and 1. 0 indicates a Normally Open output, 1 indicates a Normally Closed output.

SENSOR SHUTTER OUTPUT . . . . 0 to 38 (default = 0)

This parameter designates which of the 38 outputs is to be used to activate the Crystal Shutter for this Channel. Values range from 0 to 38. Values 1 through 38 correspond to the appropriate output. Value 0 indicates that a shutter is not used. If a value other than 0 is entered, the output chosen as the Crystal Shutter output is designated as such on the I/O Map Display. The sensor shutter output is activated when this Channel enters either the Deposit, Manual, Non-Deposit Control states and during the Sample portion of the RateWatcher function.

SENSOR SHUTTER OUTPUT TYPE . . . . 0, 1 (default = 0)

This parameter designates the normal state of the contact closure for the Sensor Shutter output. Permissible values are 0 and 1. 0 indicates a Normally Open output, 1 indicates a Normally Closed output.

SENSOR TYPE . . . . 1, 2, 6, 7, 12 (default = 1)

This parameter provides selection among the Single sensor (1), CrystalTwo sensor (2), CrystalSix sensor (6), and Rotary sensor (7), Crystal12 (12). It enables the Crystal Switch feature for the CrystalTwo, CrystalSix, Crystal12 and Rotary sensor heads and enables the crystal indexing feature on the hand held power controller. If a value of 1 is entered, the Sensor Switch Output parameter is removed from the display.

SENSOR SWITCH OUTPUT . . . . . . 0 to 38, (default = 0)

This parameter designates which of the 38 outputs is to be used as the Sensor Switch output for the Channel. Values range from 0 to 38. Values 1 through 38 correspond to the appropriate output. Value 0 indicates that the Sensor Switch Output is not used. *A nonzero value must be entered if a Sensor Type value of 2, 6, 7, or 12 is chosen.* This non-zero value's output is displayed on the I/O Map screen. The contact closure on this relay is always Normally Open.

If CrystalTwo is chosen, the output will close upon initiating a Crystal Switch and then open upon initiating a second Crystal Switch. If CrystalSix is chosen, then upon initiating a Crystal Switch, the output will first close for one second, then open for one second, then close for one second and then open (i.e., two pulses to move one position). If a Rotary or Crystal12 sensor is chosen, upon initiating a Crystal Switch the output will first close for one second and then open (that is, one pulse to move one position).

NUMBER OF CRUCIBLES . . . . 1, 4, 8, 16, 32, 64 (default = 1)

This parameter can be used to automatically index the turret position when using a multiple pocket turret source. The value selected denotes the number of pockets in the turret source. The value 1 indicates a single pocket source, and the parameters — Crucible Output, Crucible Output Type, Turret Feedback and Turret Delay or Turret Input — are removed from the Display. The number of crucibles determines the number of outputs needed for crucible indexing. As

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the outputs are binary encoded (actual coding is binary - 1, with 000 representing position 1 and 111 representing position 8), 2 outputs are needed for 4 crucibles, 3 for 8, 4 for 16, 5 for 32 and 6 for 64.

CRUCIBLE OUTPUT . . . . 0 to 37 (default = 0)

This parameter designates which of the outputs are to be used as crucible outputs. The value 0 indicates the crucible output is inactive. The value entered into this parameter indicates which of the outputs begins the sequence used as crucible control outputs. For example, a 4 entered into the Number of Crucibles parameter and a 1 entered into the Crucible Output parameter will designate outputs 1 and 2 as crucible control outputs with the least significant bit of the binary coding in output 1. An 8 entered into the Number of Crucibles parameter and a 1 entered into the Crucible Output parameter will designate outputs 1, 2, and 3 as crucible control outputs with the least significant bit of the binary coding in output 1.

CRUCIBLE OUTPUT TYPE. . . . . . . 0, 1 (default = 0)

This parameter designates the normal state of the output contacts for the Crucible outputs. 0 indicates an Normally Open output, 1 indicates a Normally Closed output.

TURRET FEEDBACK . . . . YES / NO (default = NO)

Some turret source indexers provide feedback to signify when the turret is in the proper position. This parameter allows Cygnus to accept this input and respond accordingly. A YES indicates that Turret Feedback is expected and the Turret Input parameter is displayed on the screen. A NO indicates there is no Turret Feedback forthcoming and the Turret Delay parameter is displayed. The default value is NO. See the Turret Input and Turret Delay descriptions below.

NOTE: If the Turret Feedback is set to YES and the Channel is STARTed, the Channel will proceed to the Crucible Switch state. If the turret input is not received within 60 seconds the Channel will enter the STOP state.

TURRET INPUT . . . . 0 to 28 (default = 0)

This parameter designates which of the 28 inputs is to be the Turret Feedback input. Values 1 through 28 correspond to the appropriate input. Value 0 indicates that an input for turret feedback is not used. However, an input must be assigned, or the channel will never proceed past the crucible switching state. If a value other than 0 is entered, then the input chosen as the Turret Input is designated as such on the I/O Map display. Input lines are activated with a contact closure to ground.

TURRET DELAY . . . . 1 to 60 sec (default = 5)

If Turret Feedback is not used a timer will be set to allow the source crucible time to rotate into position. This parameter sets the amount of time the Process will remain in the Crucible Switch state waiting for the crucible to rotate before proceeding to the Rise 1 state.

CAUTION

The Channel will proceed to the Rise 1 state after the Turret Delay time expires. This could result in damage to your equipment if the crucible is not in position after expiration of the Turret Delay time.

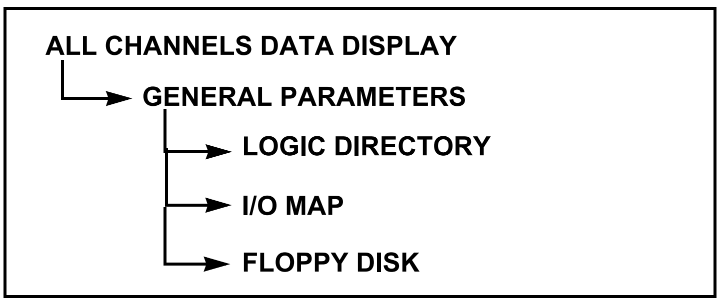
Chapter 4
General Parameters

4.1 Introduction

Cygnus system level configuration is accomplished through the General Parameters display. Further configuration of the Logic Statements and I/O is accomplished through displays accessed from the General Parameters display.

General parameters set up is initiated by selecting the GENERAL PARMS (F1) key in the All Channels data display.

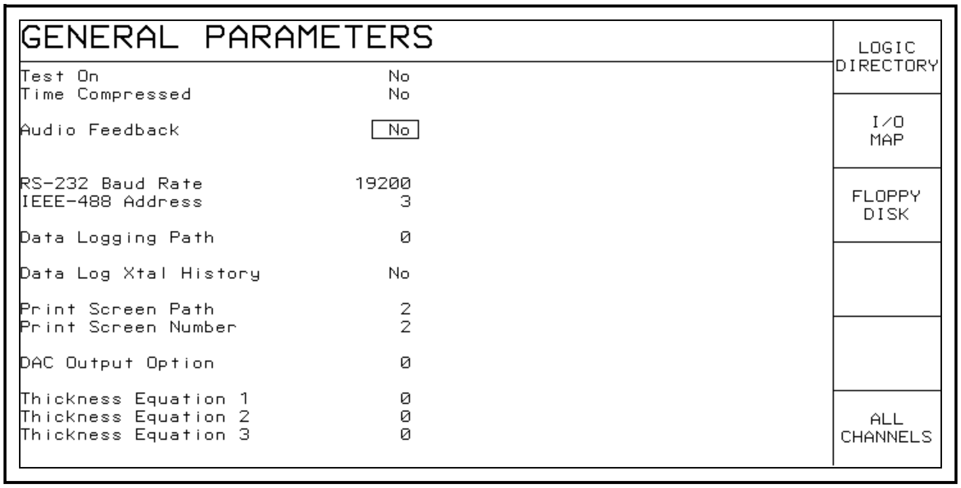
Figure 4-1 Display Tree for General Parameters, Logic Statement, and I/O Set Up



4.2 General Parameter Display

The GENERAL PARAMETERS display is shown in Figure 4-2.

Figure 4-2 GENERAL PARAMETERS Display



<u>**GENERAL PARAMETERS Display Function Keys**</u>

F1 LOGIC DIRECTORY

To access the Logic Directory display, press function key F1.

F2 I/O MAP

To access the I/O Map display, press function key F2

F3 FLOPPY DISK

To save or load files from the floppy disk, press the F3 function key to access the Floppy Disk display.

F6 ALL CHANNELS

To move to the All Channels Data display, press function key F6.

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4.3 General Parameters Definition

NOTE: All general parameters can be changed only when all channels are in STOP or READY states and are not crystal switching on any channel.

TEST ON . . . . YES / NO (default = NO)

This feature provides a constant rate signal which can be varied by altering the density and tooling parameters. It is designed to allow testing of a Channel without actually running a deposition. YES turns the test signal on.

TIME COMPRESSED . . . . YES / NO (default = NO)

When in TEST mode, this feature allows a faster than real time (10x) execution of the Channel. This is useful when testing a long Process. A value of YES increases the speed of execution 10 to 1.

AUDIO FEEDBACK. . . . . YES / NO (default = YES)

Activates Audio Feedback; signifying data entry. The value Yes activates the audio signal.

RS-232C BAUD RATE. . . . . 2400, 4800, 9600, 19200 (default = 19200)

For RS-232C serial interfaces, this parameter sets the rate for data transfer.

IEEE488 ADDRESS. . . . . 1 to 30 (default = 3)

Applies only if the IEEE-GPIB interface option board is installed. The GPIB address is a number which identifies Cygnus to the Host Computer. This address must be unique from other devices on the GPIB interface.

DATALOGGING PATH . . . . 0, 2, 3 (default = 0)

This parameter determines the path for the Datalog output. A value of 0 turns datalogging off. A value of 2 outputs the Datalog string to the floppy disk in a page format. A value of 3 outputs the Datalog string to the floppy disk in a comma delimited format.

NOTE: If a configuration file from a unit with version 1.70 or earlier firmware is to be loaded into a unit with version 1.80 or later, verify that the path is **not** set to 1 as this will prevent the file from loading due to a "File Range Error".

DATA LOG XTAL HISTORY . . . . . . YES / NO (default = NO)

This parameter selects whether to output the crystal use history. The crystal history includes the beginning and ending crystal frequency, the activity, and the S&Q counts.

PRINT SCREEN PATH . . . . 2 (default = 2)

This parameter determines which path to output the print screen function.
2 = File (floppy disk)

NOTE: If a configuration file from a unit with version 1.70 or earlier firmware is to be loaded into a unit with version 1.80 or later, verify that the path is **not** set to 1 as this will prevent the file from loading due to a "File Range Error".

PRINT SCREEN NUMBER . . . . 0 to 999 (default = 0)

This parameter is used to distinguish between files printed to the floppy disk. After each print execution the number is incremented.

DAC OUTPUT OPTION. . . . . 0, 1, 2, 3 (default = 0)

The standard Cygnus has a single DAC board with six outputs, DAC 1 to DAC 6. These DAC outputs are dedicated to source control voltage outputs (Power output). Optionally a second DAC board can be added to provide DAC outputs 7 through 12 which can be used to output Rate and/or Thickness.

When option 0 is selected, the DAC outputs have the following function:
DAC 1. . . . . Channel 1 Power
DAC 2. . . . . Channel 2 Power
DAC 3. . . . . Channel 3 Power
DAC 4. . . . . Channel 4 Power
DAC 5. . . . . Channel 5 Power
DAC 6. . . . . Channel 6 Power
DAC 7. . . . . Channel 1 Rate
DAC 8. . . . . Channel 2 Rate
DAC 9. . . . . Channel 3 Rate
DAC 10. . . . . Channel 4 Rate
DAC 11. . . . . Channel 5 Rate
DAC 12. . . . . Channel 6 Rate

When option 1 is selected, the DAC outputs are:
DAC 1. . . . . Channel 1 Power
DAC 2. . . . . Channel 2 Power
DAC 3. . . . . Channel 3 Power
DAC 4. . . . . Channel 4 Power
DAC 5. . . . . Channel 5 Power
DAC 6. . . . . Channel 6 Power
DAC 7. . . . . Channel 1 Thickness
DAC 8. . . . . Channel 2 Thickness
DAC 9. . . . . Channel 3 Thickness
DAC 10. . . . . Channel 4 Thickness
DAC 11. . . . . Channel 5 Thickness
DAC 12. . . . . Channel 6 Thickness

When Option 2 is selected, the DAC outputs are:
DAC 1. . . . . Channel 1 Power
DAC 2. . . . . Channel 2 Power
DAC 3. . . . . Channel 3 Power

DAC 4 . . . . Channel 4 Power
DAC 5 . . . . Channel 1 Thickness
DAC 6 . . . . Channel 2 Thickness
DAC 7 . . . . Channel 3 Rate
DAC 8 . . . . Channel 4 Rate
DAC 9 . . . . Channel 1 Rate
DAC 10 . . . . Channel 2 Rate
DAC 11 . . . . Channel 3 Thickness
DAC 12 . . . . Channel 4 Thickness

When Option 3 is selected, the DAC outputs are:
DAC 1 . . . . Channel 1 Rate
DAC 2 . . . . Channel 2 Rate
DAC 3 . . . . Channel 3 Rate
DAC 4 . . . . Channel 4 Rate
DAC 5 . . . . Channel 5 Rate
DAC 6 . . . . Channel 6 Rate
DAC 7 . . . . Channel 1 Thickness
DAC 8 . . . . Channel 2 Thickness
DAC 9 . . . . Channel 3 Thickness
DAC 10 . . . . Channel 4 Thickness
DAC 11 . . . . Channel 5 Thickness
DAC 12 . . . . Channel 6 Thickness

THICKNESS EQUATION 1,2,3 . . . . 0 to 654321 (default = 0)

Each of the three thickness equations can be set up to sum the thickness of the specified Channels. Each Channel can only be used once in an equation but can be used in all three. For example, 12 means sum the thickness of Channels 1 and 2, 1234 sums the first four Channels. Thickness equations are designed to be used in logic statements.

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4.4 Logic Directory Set Up

Cygnus has programmable logic capabilities that allow it to specifically respond to certain process states as well as External Inputs and to send control signals (Outputs) to external devices based on Inputs or specific instrument conditions. The logic capabilities can also be used to control the execution of a Channel without operator intervention. These capabilities can be specifically tailored by programming the Logic Statements.

4.4.1 Logic Statement Overview

The Logic Directory is accessed by pressing the LOGIC DIRECTORY key (F1) on the General Parameters display, refer to Figure 4-1 on page 4-1. From the Logic Directory display, press the SELECT LOGIC STATEMENT (F5) function key to edit a logic statement.

- Single or multiple actions may be triggered by Inputs or the fulfillment of a user specified logical condition.
- Single or multiple complex defined conditions are used to define an event.
- The logical operators; AND, OR, and NOT (negate) as well as grouping operators (parentheses) are available to define very precise conditionality.
- It is possible to execute an action immediately or delay it for a defined period of time through the use of a timer or counter.
- Each Logic Statement is evaluated every measurement cycle of 100 ms.
- The components of the Logic statements may be the transition between or entry of a specific state, specific programmable time limits, programmable thickness limits or various error conditions
- Inputs and outputs may be named on the I/O MAP display. Additionally on this display, the outputs may be defined as normally open (NO) or normally closed (NC).
- Logic statements may be chained together using the Statement ### Event.

These features allow moderately complex vacuum processing plants to be controlled without the addition of any other intelligent machines. Fourteen TTL inputs and eight relay outputs are standard. An additional fourteen inputs and eight relay outputs are available with an optional I/O card. With a second optional I/O card, eight more relays and fourteen open collector outputs are available.

Cygnus has the capacity for 100 logic statements.

4.4.2 Editing Logic Statements

A series of conditional events and a related series of actions may be defined through the Logic Statements. When a logic statement has an event or action defined, the Logic Directory screen will display ">" character after the statement number. When the event string is determined to be true the associated actions are executed in left to right order. The state of the Logic statement is indicated on the Logic Directory display. *Three small asterisks under the Logic Statement number indicate the statement is true (active).* The expressions are evaluated in numerical sequence starting with logic statement 1.

To initiate Logic Statement Set-Up, select function key F1 (GENERAL PARAMETERS) on the All Channels display. Then, select function key F1 (LOGIC DIRECTORY). On the Logic Directory display, select F5, SELECT LOGIC STATEMENT, to define and edit the logic statement. This will invoke the Logic Statements display (see Figure 4-5). Upon entry, the cursor will be placed at the last referenced Logic statement. Entries for four statements are shown on each display page.

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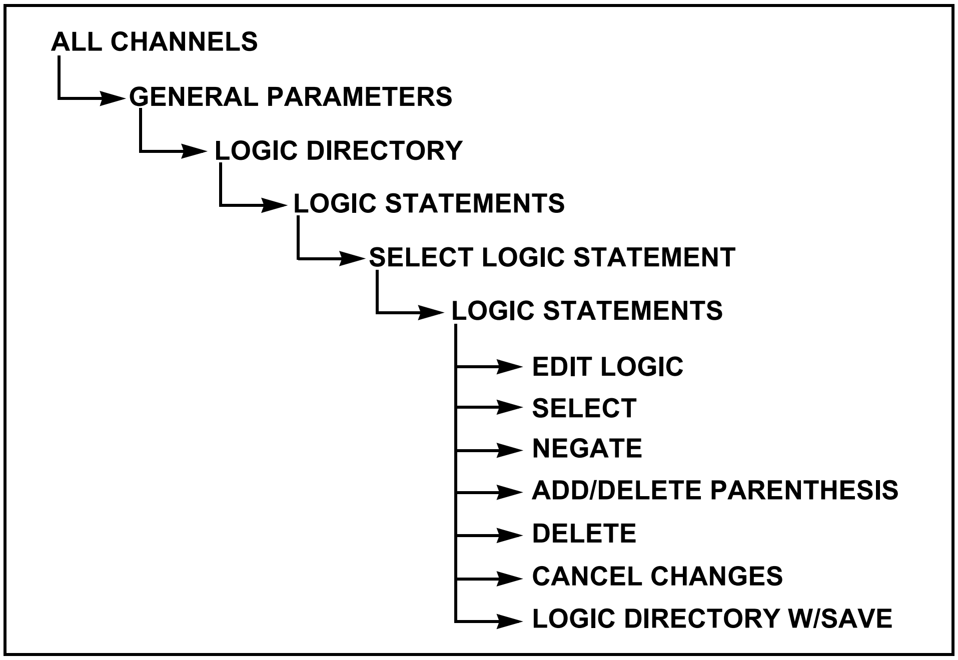
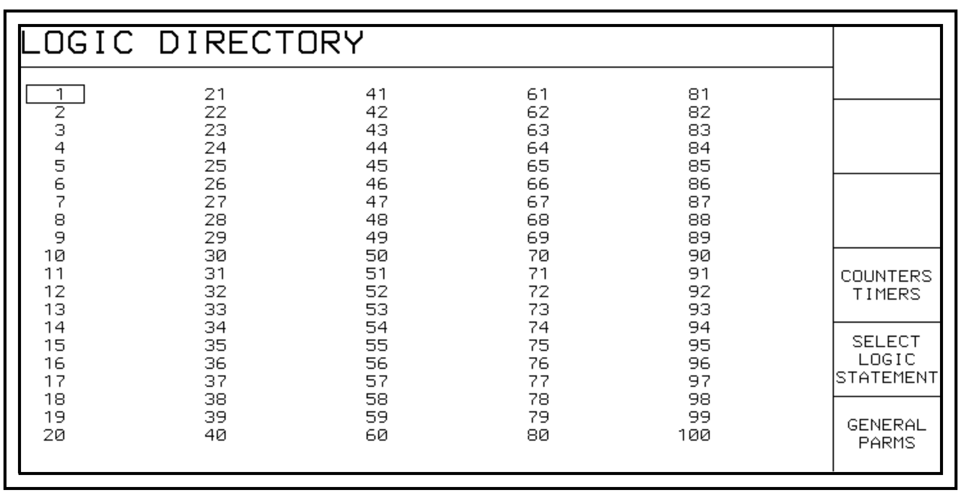
Figure 4-3 Display Tree for Logic Statement Editing



4.4.2.1 Logic Statement Directory

Figure 4-4 Cygnus Logic Directory



4.4.2.2 Logic Statements

A Logic Statement is selected for editing by positioning the box cursor at the desired statement number and pressing the key F5. Then by selecting the SELECT function (F1), the edit mode is entered where Events and Actions can be inserted.

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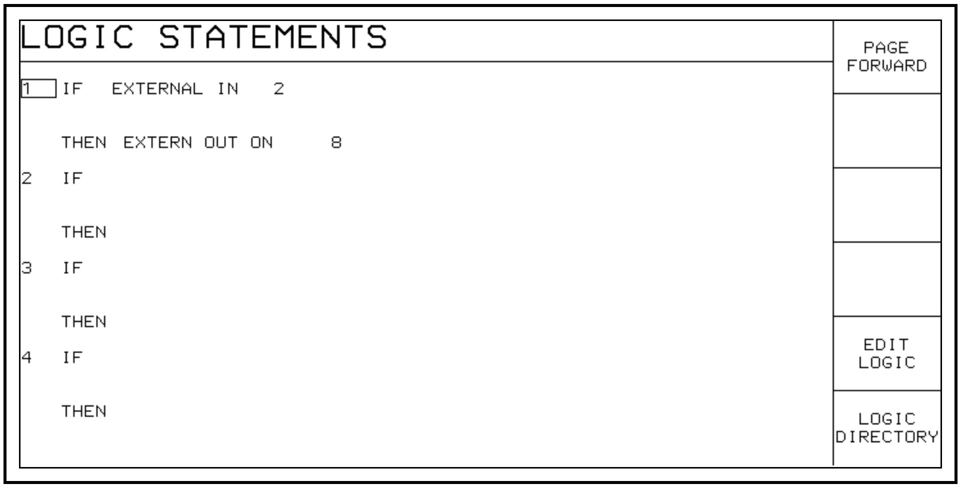
Figure 4-5 Logic Directory Display



LOGIC STATEMENTS Display Function Keys

F1 PAGE FORWARD

To access the next page of Logic Statements, select function key F1.

F2 PAGE BACK

To access the previous page of Logic Statements, select function key F2.

F5 EDIT LOGIC

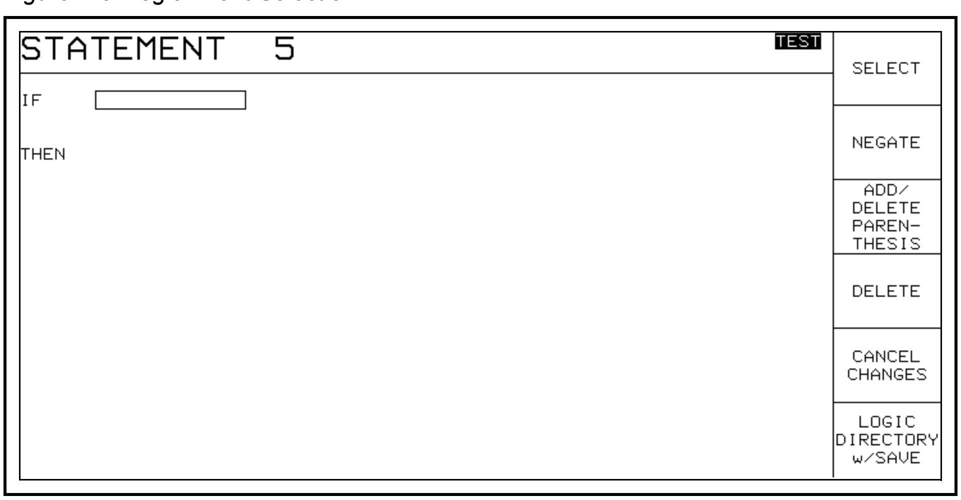
To select or change Event or Action definitions, select function key F3.

F6 LOGIC DIRECTORY

To move to the LOGIC DIRECTORY display, select function key F6.

4.4.2.3 Logic Statement Event Editing

Figure 4-6 Logic Event Selection



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Logic Statement Display Function Keys

F1 SELECT

If the cursor is on IF (Event), or THEN (Action), pressing this key will bring up the respective Event or Action List.

F2 NEGATE

If the cursor is on an Event pressing this key will negate the Event.

F3 ADD/DELETE PARENTHESIS

If on an Event pressing this key will insert a parenthesis: a left parenthesis will be added if no previous parenthesis is defined; a right parenthesis is added if the cursor is on an Event which does not have a right parenthesis and a left parenthesis is already defined. If the cursor is on an Event which has a parenthesis defined, pressing this panel will delete the parenthesis.

F4 DELETE

If on an Event or Action, pressing this key will delete the Event or Action as well as associated connector and parenthesis.

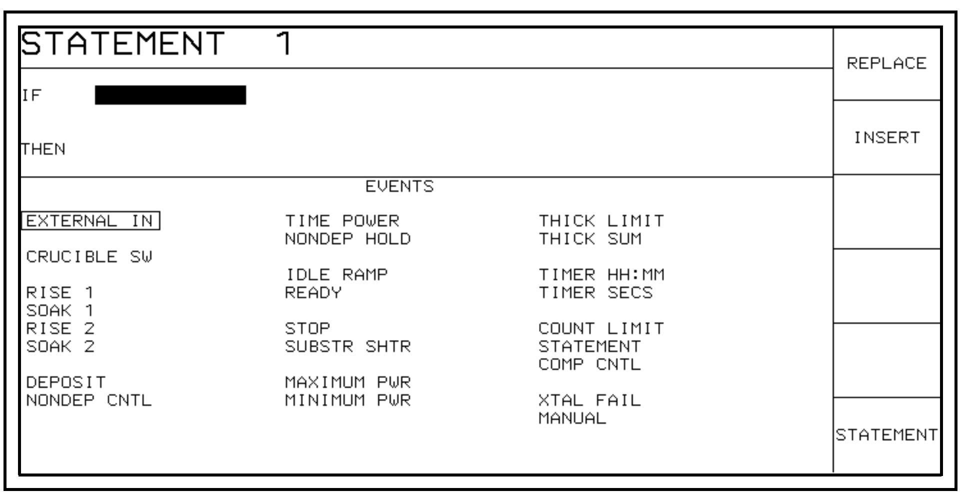
F5 CANCEL CHANGES

Pressing this key will cancel any changes and return the Logic Statement to be the same as when the display was entered.

F6 LOGIC DIRECTORY w/SAVE

Pressing this key returns to the Logic Directory and saves the Logic Statement.

Figure 4-7 Event Selection



Event Selection Display Function Keys

F1 REPLACE

Changes the Event or Action in reverse video to what is contained in the box cursor.

F2 INSERT

Inserts the Event or Action in the box cursor into the Logic Statement at the position indicated by reverse video. Previously entered Events or Actions are moved to the right.

F6 STATEMENT

Exits the Event or Action List display and returns to the Logic Statement Editing display.

Logic Connectors

If the cursor is on a connector designated by ccc, pressing F1 (SELECT) will toggle the ccc between a logical AND and a logical OR.

4.4.2.3.1 Event Definitions (IF)

NOTE: The presence (or absence) of an input is leading edge detected on the transition from high to low (or low to high). Inputs are not "re-evaluated" if held level at either the high or low state.

COMP CNTL

Sets the logic condition to be true when a Set Logic Statement vvv command is received from the remote communications port. The logic condition remains true until a Clear Logic Statement vvv command is received from the remote communications port. See Remote Commands RG5 and RG6

COUNT LIMIT ### ###

Sets the logic condition to be true when the designated Counter ### (1 to 20) reaches the desired count value ### (1 to 999)

CRUCIBLE SW ###

Sets the logic condition to be true at the beginning of the Crucible Switch state for the designated Channel. If 0 is selected it will apply to any Channel. The condition remains true until the end of the Crucible Switch state.

DEPOSIT ###

Sets the logic condition to be true at the beginning of the Deposit state of the designated Channel, or any Channel if 0 is entered for the Channel ###. The condition remains true until the end of the DEPOSIT state.

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EXTERNAL IN ###

Designates a hardware input which, when it changes state, can be used to trigger an Action. Inputs can be given names up to 10 characters long. Inputs are activated by pulling the specific input's terminal to ground (<0.8 V) through a contact closure to common (GND) or with TTL/CMOS logic having current sink capability of 2 mA (1 low power TTL load).

IDLE RAMP ###

Sets the logic condition to be true at the start of Idle Ramp for the designated Channel, or for any Channel if 0 is entered for the Channel ###. The condition remains true until the end of Idle Ramp.

MANUAL ###

Sets the logic condition to be true when the Manual state is entered for the designated Channel, or for any Channel if 0 is entered for the Channel ###. The condition remains true until leaving the Manual state.

MAXIMUM PWR ###

Sets the logic condition to be true as long as the designated source is at Maximum Power. If 0 is entered it will apply to any channel. The condition remains true until the designated source is less than Maximum Power.

MINIMUM PWR ###

Sets the logic condition to be true as long as the designated source is at Minimum Power while the source is in either the Deposit state or the Non-Deposit Control state. If 0 is entered it will apply to any channel. The condition remains true until the designated source is greater than Minimum Power.

NONDEP CNTL ###

This Event is evaluated true if the designated Channel is in the Non-Deposit Control state, i.e. there is rate control with the substrate shutter closed. If 0 is selected it will apply to any Channel. The condition remains true until the end of the Non-Deposit Control state.

NONDEP HOLD ###

This function is similar to Time Power except the substrate shutter for the designated source is closed and there is no determinant end point. If 0 is selected it will apply to any Channel. The condition remains true until the state is exited, for example when a Stop command is given.

READY ###

Sets the logic condition to be true as long as the designated Channel is in the READY state. If 0 is selected it will apply to any Channel.

RISE 1 ###

Sets the logic condition to be true at the start of Rise Time 1 for the designated Channel. If 0 is selected it will apply to any Channel. The condition remains true until the end of the Rise Time 1.

RISE 2 ###

Sets the logic condition to be true at the start of Rise Time 2 for the designated Channel. If 0 is selected it will apply to any Channel. The condition remains true until the end of Rise Time 2.

SOAK 1 ###

Sets the logic condition to be true at the start of Soak Time 1 for the designated Channel. If 0 is selected it will apply to any Channel. The condition remains true until the end of Soak Time 1.

SOAK 2 ###

Sets the logic condition to be true at the start of Soak Time 2 for the designated Channel. If 0 is selected it will apply to any Channel. The condition remains true until the end of Soak Time 2.

STATEMENT ###

This Event can be used to test when a logic statement becomes “true.” This allows for linking statements together. A “true” statement is indicated by three small asterisks below the statement number.

STOP ###

Sets the logic condition to be true as long as the designated Channel is in STOP. If 0 is selected it will apply to any Channel.The condition remains true until a RESET or a START command is received.

SUBSTR SHTR ###

Sets the logic condition to be true whenever the substrate shutter output for the designated source is active. If 0 is selected it will apply to any Channel.

THICK LIMIT # ###

Sets the logic condition to be true once the designated Channel # reaches Thickness ### value. The condition remains true while the thickness for the designated Channel is above the Thickness Limit Value.

THICK SUM # ###

Sets the logic condition to be true when the sum of thickness indicated by the designated Thickness Equation # reaches the thickness value ###.

TIME POWER ###

Sets the logic condition to be true upon entering a Time Power state for the designated Channel. If 0 is selected it will apply to any Channel.

TIMER HH:MM ### HH:MM

Sets the logic condition to be true when the designated timer ### reaches the specified time HH:MM.

TIMER SECS ### sss.s

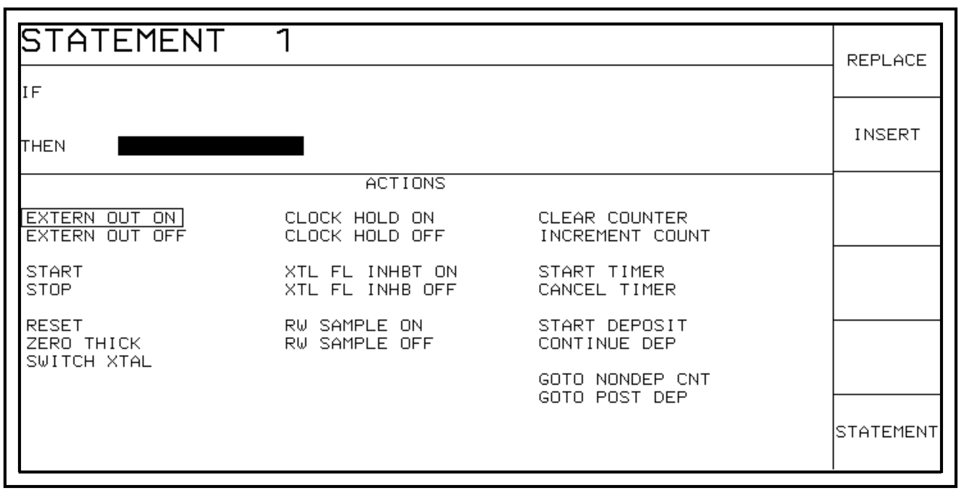
Sets the logic condition to be true when the designated Timer ### reaches the specified time expressed in seconds, sss.s

XTAL FAIL ###

Sets the logic condition to be true as long as there is a Crystal Fail without having a Crystal Switch for the designated channel ###. If 0 is selected it will apply to any channel. The logic condition remains false if the XTAL FAIL INHIBIT Action is active. The condition remains true until a working crystal is input to the appropriate sensor.

4.4.2.4 Logic Statement Action Editing

Figure 4-8 Action Selection



<u>**Action Selection Display Function Keys**</u>

F1 REPLACE

Changes the Event or Action in reverse video to what is contained in the box cursor.

F2 INSERT

Inserts the Event or Action in the box cursor into the Logic Statement at the position indicated by reverse video. Previously entered Events or Actions are moved to the right.

F6 STATEMENT

Exits the Event or Action List display and returns to the Logic Statement Editing display.

4.4.2.4.1 Action Definitions (THEN)

NOTE: The following are level outputs and once turned on will remain active until turned off. This is true even if the Logic string is cleared.
XTL FL INHBT(ON/OFF) ###
CLOCK HOLD (ON/OFF) ##
EXTERN OUT (ON/OFF) ##
RW SAMPLE ON ##

CANCEL TIMER ###

Sets the value of timer ### to zero.

CLEAR COUNTER ###

Clears the designated counter ###

CLOCK HOLD (ON/OFF) ###

This feature "holds" the state timer for the designated Channel ### during any non-rate control state. These states include the pre-deposit states: Ready, Crucible Switch, Rise 1, Soak 1, Rise 2, Soak 2; and the post-deposit state: Idle Ramp. For the feature to be activated the state's timer must be non-zero. If the instrument is in the Ready state and a Start command is executed while CLOCK HOLD is active, the instrument will progress to the first pre-deposit state with a non-zero state time. If the instrument is in the Crucible Switch state, waiting for Turret Feedback Input, and CLOCK HOLD is activated, when the turret positioned input is activated the instrument will progress to the next pre-deposit state having a non-zero state time. The instrument is prevented from continuing state processing until the CLOCK HOLD action is turned OFF.

CONTINUE DEP ###

Puts the designated Channel ### into the Deposit state but does not zero the thickness. This action can not be done from a Ready, Stop, or Crucible Switch state. If the crystal is failed, this action will put the source into the Time Power state if the previous state was Non-Deposit Hold, otherwise it is not allowed.

EXTERN OUT (ON/OFF) ###

Designates a hardware output ### and places it into its ON or OFF state. Outputs can be given names up to 10 characters long. Outputs are named in the I/O Map display.

GOTO NONDEP CNT ###

Places the designated Channel ### into the Non-Deposit Control state. This cannot be done from the Ready, Stop, or Crucible Switch states. If the crystal is failed this action will place the Channel into the Non-Deposit Hold state if the previous state was Time Power, otherwise it is not allowed.

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GOTO POST DEP

This action places the designated Channel ### into the Idle Ramp state. This action cannot be done if in Crucible Switch.

INCREMENT COUNT

Increases the count by one in the designated counter ###.

RESET

This action is identical to pressing the RESET button on the front panel for the designated Channel ###. When 0 is entered all the Channels will be RESET.

RW SAMPLE ON

Leave RateWatch HOLD on Channel ### and do not return to RateWatch HOLD until turned off.

RW SAMPLE OFF

Allows return to RateWatch HOLD on Channel ### when sampling accuracy has been met.

START

This action is identical to pressing the START button on the front panel for the designated Channel ###.

START DEPOSIT

This function is used to place the designated Channel ### into Deposit from the NONDEP CNTL state. If the crystal is failed this command will make the source go into Time Power if the previous state was Non-Deposit Hold, otherwise the action is not allowed. Can not be done from Ready, Stop, or Crucible Switch. When in Ready or Stop use the Start action.

START TIMER

Starts the designated timer ###.

STOP

This action is identical to pressing the Stop button on the front panel for the designated Channel ###. A value of 0 stops all channels.

SWITCH XTAL

This Action activates the Crystal Switch output for the sensor number indicated. It sets the alternate crystal active when using CrystalTwo Switch. It indexes to the next crystal position when using the CrystalSix, Crystal12, or Rotary sensor. This function is available only if a CrystalTwo, a CrystalSix, Crystal12, or a Rotary sensor type is chosen.

XTL FL INHBT (ON/OFF)

The ON action prohibits the Crystal Fail output relay from activating. This is useful when changing crystals for the designated Channel ### (0 indicates all Channels). The OFF action cancels the corresponding ON action.

ZERO THICK

This Action is identical to selecting the ZERO THICKNESS key in the Channel display. The Action will zero the thickness accumulated on the display for the designated Channel ###. A value of 0 will zero the thickness on all channels.

4.5 Counters Timers

Figure 4-9 Display Tree for Counters Timers

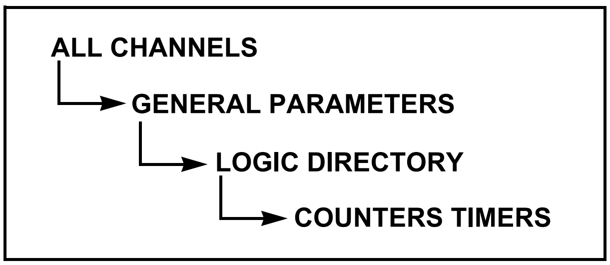
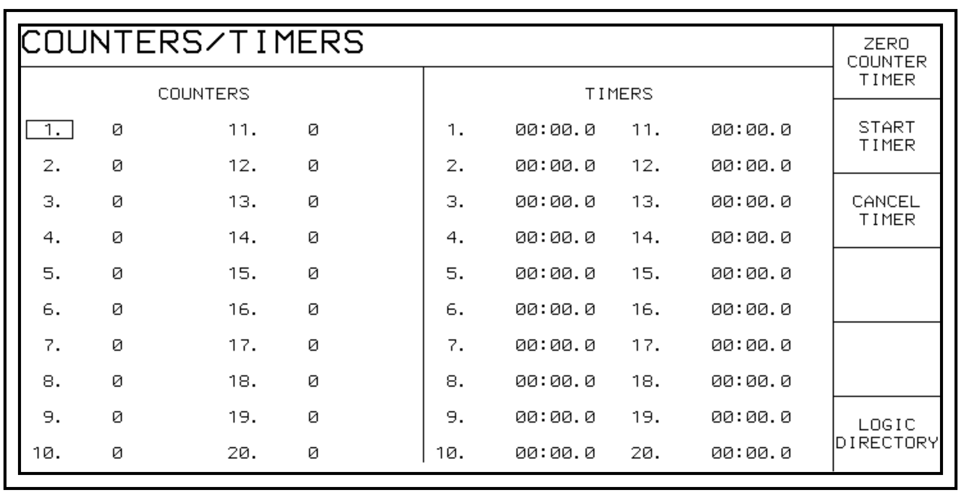


Figure 4-10 Timers Counters



COUNTERS/TIMERS

COUNTERS				TIMERS				Function Keys
1.	0	11.	0	1.	00:00.0	11.	00:00.0	ZERO COUNTER TIMER
2.	0	12.	0	2.	00:00.0	12.	00:00.0	
3.	0	13.	0	3.	00:00.0	13.	00:00.0	START TIMER
4.	0	14.	0	4.	00:00.0	14.	00:00.0	
5.	0	15.	0	5.	00:00.0	15.	00:00.0	CANCEL TIMER
6.	0	16.	0	6.	00:00.0	16.	00:00.0	
7.	0	17.	0	7.	00:00.0	17.	00:00.0	
8.	0	18.	0	8.	00:00.0	18.	00:00.0	
9.	0	19.	0	9.	00:00.0	19.	00:00.0	LOGIC DIRECTORY
10.	0	20.	0	10.	00:00.0	20.	00:00.0	

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<u>**COUNTERS / TIMERS Display Function Keys**</u>

F1 ZERO COUNTER TIMER

To set the value of the selected timer to 00:00, select function key F1.

F2 START TIMER

To start the selected timer, select function key F2.

F3 CANCEL TIMER

To stop the selected timer, select function key F3

F6 LOGIC DIRECTORY

To move to the LOGIC DIRECTORY display, select function key F6.

4.6 I/O Map

The I/O Map is selected by pressing the F2 key (I/O MAP) in the General Parameters display. On the I/O MAP display, the desired I/O Board is chosen with the box cursor. The I/O Map display is shown in Figure 4-12. Upon entry the cursor will be placed at the last referenced output or input number.

Figure 4-11 Display Tree for I/O Map Editing

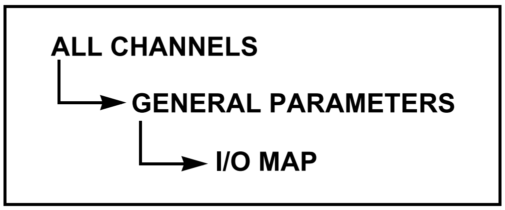
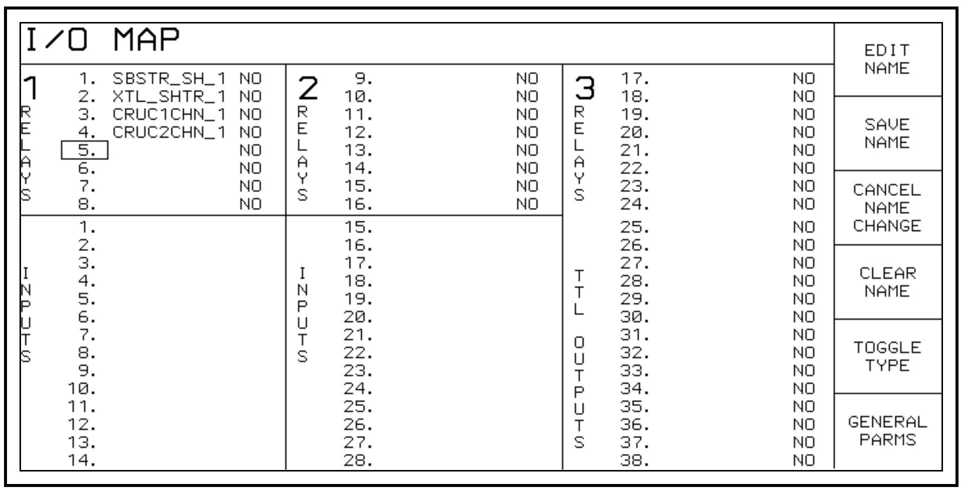


Figure 4-12 I/O Map Board Display



<u>I/O MAP Display Function Keys</u>

F1 EDIT NAME

Pressing this key will display a series of 10 underscores representing ten positions. The left and right arrow keys are used to move back and forth among the 10 positions. The up and down arrow keys are used to scroll through an alphanumeric listing, A through Z, 0 through 9, and the following characters: !, #, _, ~, %, & and -. Once the desired character is displayed, pressing the E key enters the character and advances the reverse video cursor box to the next position.

The following names are used by Cygnus to identify the relays selected for the corresponding functions:

SBSTR_SH#
XTL_SHTR_#
CRUC1CHN_#
CRUC2CHN_#
CRUC3CHN_#
CRUC4CHN_#
CRUC5CHN_#
CRUC6CHN_#

The following name is used by Cygnus to identify the INPUT selected for the turret switch feedback function.

TURRET_#

The value for '#' may range from 1 to 6 corresponding to the number of available channels.

To avoid confusion, it is recommended that you do not use these names.

The value for number may range from 1 to 6 corresponding to the number of available channels.

F2 SAVE NAME

Pressing this key saves the Name of the Input or Output. Once saved, this Name will be displayed whenever this Output (or Input) is chosen in the Edit Logic Display.

F3 CANCEL NAME CHANGE

Pressing this key cancels any changes to the Name made after pressing the F1 KEY (EDIT NAME).

F4 CLEAR NAME

Pressing this key clears the Name associated with the designated output (or input).

F5 TOGGLE TYPE

Pressing this key toggles the output type from Normally Open (NO) to Normally Closed (NC).

F6 GENERAL PARMS

Pressing this key returns the display to the General Parameters display.

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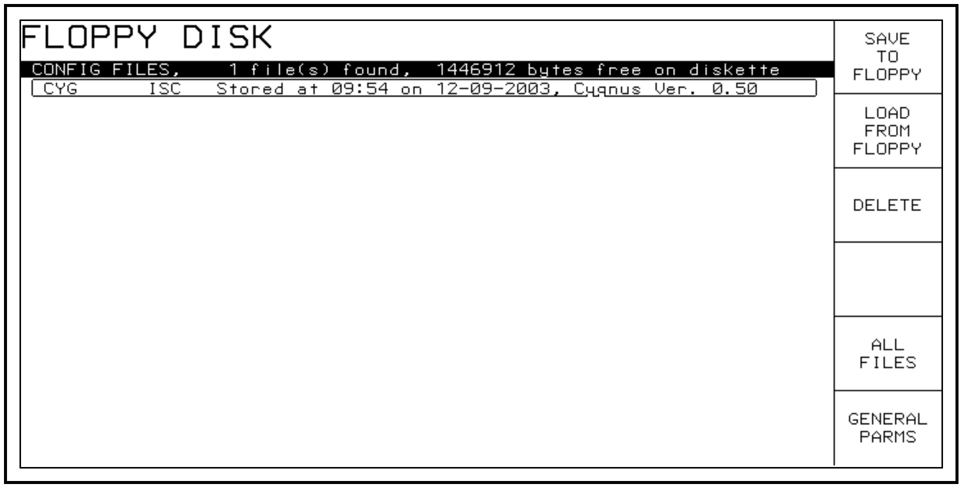
4.7 Floppy Disk

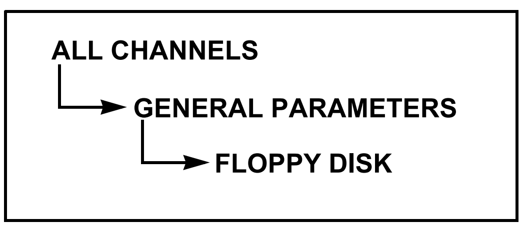
Figure 4-13 Floppy Disk Display



Parameters can be saved to and loaded from the diskette by going to the FLOPPY DISK display. This screen is reached by going from the General Parameters display to the Floppy Disk display (F3).

Upon entering this display a directory of all the Cygnus configuration files contained on the diskette is displayed and the following key selections are available. The box cursor can be positioned around any of the Configuration Files by moving the cursor arrows. Left and Right correspond to Page Up and Page Down. The Up and Down arrows will move the box cursor one position.

Figure 4-14 Display Tree for the Floppy Disk Display



<u>**FLOPPY DISK Display Function Keys**</u>

F1 SAVE TO FLOPPY

Pressing this key will select the Configuration File contained within the box cursor and prompt the user to "Save the file FILENAME.ISC?". At this time the filename may be changed. The filename is changed using the Up and Down arrow keys to scroll through the Alphanumeric listing A through Z, 0 through 9, and the characters: _, !, #, +, -, %, & and . at the reverse video box cursor position or using the Right and Left arrow keys to position the reverse video box cursor.

The key choices are changed to CONTINUE and CANCEL. Selecting CONTINUE saves the file to the diskette. Selecting CANCEL returns the display to the Configuration Files display.

F2 LOAD FROM FLOPPY

Pressing this key will select the Configuration File contained within the box cursor and prompt the user to “Load the file FILENAME.ISC?”. The key choices are changed to CONTINUE and CANCEL. Selecting CONTINUE loads the contents of the file into Cygnus. Selecting CANCEL returns the display to the Configuration Files display.

F3 DELETE

Pressing this key will select the Configuration File contained within the box cursor and prompt the user to “Delete the file FILENAME.ISC?”.

F5 ALL FILES

Pressing this key provides a directory of all the files contained on the diskette. From the ALL FILES display, function keys for DELETE, CONFIG FILES, and GENERAL PARMS are available.

F6 GENERAL PARMS

Pressing this key returns to the General Parameters display.

CAUTION

Do not remove the diskette during SAVE or LOAD operations.

It is recommended that when doing a LOAD operation, the instrument have the same hardware configuration, including optional Sensor Measurement Boards, as when the parameters were saved to diskette.

If the file retrieved from the floppy diskette contains parameters which are valid only with optional equipment installed, these parameter values will not be altered.

Chapter 5
Remote Communications

5.1 Remote Communications Overview

This instrument may be remotely controlled, programmed or interrogated. This is accomplished through remote communications and the use of a remote command set. The instrument will respond to messages that contain these commands. It will accept and operate on messages one at a time. It will respond to each command by carrying out valid operations and/or returning a message to the sender. A host/server relationship is established in remote communications. The instrument, as server, responds to the remote host’s commands.

5.2 Physical Connections

Two types of data communications hardware ports are available. Standard equipment includes a bit serial RS-232C port. Optionally, an IEEE488 parallel port may be added. Generally speaking, both the host and server must have the same form of communications equipment and complementary set-up. For serial communications, baud rates must match and so must the data word format.

The word format for bit serial lines (RS-232C) is comprised of ten signal bits- eight data bits, one start bit, one stop bit and no parity. The eight data bits comprise a byte of information or character whose ASCII value ranges from 0 to 255.

Both RS-232C and IEEE488 ports can be used simultaneously.

5.2.1 RS232C Serial Port

RS-232C serial communications are accomplished through an industry standard 9-pin female connector found on the rear panel of the instrument. A mating male connector is required for attachment of a host interface. The host and instrument can be separated by up to fifty feet using multiconductor shielded data cable.

The instrument is configured as DCE or Data CommunicationsEquipment.

The following pin assignments should be used when constructing a cable:

Table 5-1 RS-232C Cable Pin Assignments

Cygnus (9-Pin D-sub)			**Host**	
Pin 1	(Not used)			The 760-406-P1 RS232 Loop-back connector provided in the ship kit connects the following pins: 2 to 3, 4 to 6 and 7 to 8.
Pin 2	TXD		RXD	
Pin 3	RXD	———→	TXD	
Pin 4	DSR	←———	DTR	
Pin 5	GND	←———	GND	
Pin 6	DTR	————	DSR	
Pin 7	CTS	———→	RTS	
Pin 8	RTS	←———	CTS	
Pin 9	GND (Shield)	———→		

The port incorporates hardware flow control via Request to Send / Clear to Send (RTS/CTS) and Data Terminal Ready / Data Set Ready (DTR/DSR) signaling.

Request To Send (RTS) . . . . The instrument informs the host it is ready to receive a character by asserting the RTS signal. It lowers the signal when the receive buffer is full.

Clear to Send (CTS). . . . . The host informs the instrument it is ready to receive a character by asserting the CTS signal. The host should lower the signal if its receive buffer becomes full and raise the signal when it can receive data again. This signal has an internal pull up in the instrument. Therefore, if left disconnected the instrument will assume the host is always capable of receiving data (no flow control).

Data Terminal Ready (DTR) . . . . The instrument informs the host that it is powered up and able to communicate by asserting this signal.

Data Set Ready (DSR). . . . . The host informs the instrument that it is able to communicate. The instrument will ignore all incoming data if this signal is de-asserted. This signal has an internal pull up in the instrument. Therefore, if left disconnected the instrument will assume the host is always able to communicate.

5.2.2 IEEE488 Port

An IEEE488 circuit card may be purchased and installed into Cygnus, IPN 760-142-G1. The instrument appears on the IEEE488 bus as a device. A unique device address must be assigned. A standard IEEE488 24-pin connector is provided on the circuit card.

The instrument makes use of the IEEE488 status byte.

Whenever there is message available (MAV) in the instrument, bit-4 of the status byte will be set. By enabling the automatic serial polling and checking the status byte, very reliable data transfer between the instrument and the host computer can be achieved. The timeouts for the device and the host should be set sufficiently long (at least 0.5 s).

Additionally, service requests are supported. A service request is a request by the instrument to transmit information to the host. The instrument does this by triggering the RQS bit of the status byte. A host-initiated serial poll then identifies the requesting device by the presence of a 1 in the RQS (2^6) bit of the status byte. The following conditions of the instrument can be detected by examining the low 4 bits of the status byte in combination with the bit-4.

Table 5-2 Instrument Conditions

bit position	7	6	5	4	3	2	1	0
MAV/Data ready	-	-	-	1	-	-	-	-
Final thickness	-	1	-	1	0	0	0	1
Stop	-	1	-	1	0	0	1	0
Power up	-	1	-	1	0	1	0	0

5.3 Message Protocols

The message protocol serves as a structure for the contained command or response information. It also can provide a level of acknowledgment between the host and server and a mechanism for verifying the information content.

5.3.1 INFICON Cygnus Message Formats

The same message format is used for the serial port and for the IEEE-488 port. All messages are comprised of byte serial information. The byte values represent command or response characters, control characters, or numeric values. Mnemonics will be used to describe portions of each message format.

NOTE: These mnemonics are not part of the message stream; they are used to represent specific ASCII codes, characters or numeric values that comprise the message stream.

5.3.2 Basic Protocol

Key:

<> . . . . Enclosed element further defined below (or above, if repeated use)

() . . . . Optional Element

I . . . . Or

x...x . . . . One or more of x included

5.3.2.1 Command Packet (Host to Instrument Message)

<length><message><checksum>

Length . . . . 2 bytes Low / High (not including checksum or length bytes) Numeric value from 0 to 16,383 (two bytes) representing the number of characters in the command. In order of transmission, the low byte will precede the high byte. For most commands, the number for characters will be less than 256. In this situation the low byte will contain the character count while the high byte will have zero value.

Message . . . . <Command>(<Command>...<Command>)

Command = <Command Group> (<Command Sub-group>) (<Command ID>) (<Parameter>...<Parameter>)

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Details of the following are given later in the document.

Command Group = 1 ASCII byte, specifying category of command:

E = Echo
H = Hello
Q = Query
R = Remote Action
S = Status
U = Update

Command Sub-group = 1 ASCII byte, used with some command groups to further specify commands:

For commands Q and U:
C = Channel
G = General
I = Input Name
L = Logic Statement
O= Output Name
T = Type of Output

For commands R and S:
C= Channel
G = General

No sub-groups are allowed for E and H commands.

Command ID = 1 binary byte. Defines specific command within Group/Sub-group. See definitions under relevant commands.

Parameter = <Byte>|<Integer>|<Float>|<String>|

Byte = 1 byte
Integer = 4 byte, low to high
Float = 4 byte, ANSII standard, single precision, low to high
String = Null terminated series of ASCII characters

Checksum. . . . . 1 byte, sum, modulo 256, of all bytes, not including length. Modulo 256 is the numeric value from 0 to 255 representing the modulo 256 remainder of the sum of the values of the ASCII codes that comprise the response.

5.3.2.2 Response Packet (Instrument to Host Message)

<Length><CCB><Timer><Response Message><Checksum>

Length . . . . Number of bytes including CCB, Timer, and Response Message. Length bytes and Checksum are not included in Length Count. Numeric value from 0 to 16,383 (two bytes) representing the number of characters in the response. Two byte values, high and low order, are required to represent this number. In order of transmission, the low byte will precede the high byte.

CCB . . . . (Condition Code Byte) = 1 byte binary. MSB set indicates command packet error.

Timer . . . . 1 byte binary, number between 0 and 255, increments every tenth second.

Response Message . . . . <Command Response>...<Command Response>|<Packet Error Code>

NOTE: If CCB MSB is set, indicating a command packet error, the response message will be a single packet response error.

Packet Error Code = 1 byte ASCII
C = Invalid Checksum
F = Illegal format (too many bytes for the commands requested)
I = Invalid message
M = Too many commands (only 100 allowed)

NOTE: If the CCB MSB is clear, the command packet was parsed and a valid command packet format was detected. The number of command responses equals the number of commands sent.

Command Response = <ACK><response>|<response error code>

NOTE: "ACK" is the ASCII code with decimal value 6 or hex value 6 indicating Positive Acknowledgement of a command. It is not sent when a Response Error Code is returned.

Response =

(<integer>|<float>|<string>|<other>.<integer>|<float>|<string>|<other>)

Response Error Code = 1 byte ASCII
A= Illegal Command
B = Illegal parameter value
C = Illegal ID
E = Data not available

F = Cannot do now (e.g. some commands require the channel or console to be in Ready / Stop.
L = Length Error, response could overflow the return buffer.
P = Prior command failed (if one command of a multiple command packet fails, none of the following commands will be done, and this error code will be returned.

Checksum. . . . . 1 byte, sum, modulo 256, of all bytes, including CCB, Timer, and Response Message but not including length. Modulo 256 is the numeric value from 0 to 255 representing the modulo 256 remainder of the sum of the values of the ASCII codes that comprise the response.

5.4 Cygnus Communication Commands

The standard command set is structured into six categories- **ECHO**, **HELLO**, **QUERY**, **UPDATE**, **STATUS** and **REMOTE**. Most commands require arguments. A space is used between commands and arguments and between multiple arguments.

The instrument uses a set of negative response codes (nrc) for commands resulting in an error.

5.4.1 ECHO Command

The format is:

E <string>

The **E**cho command returns the ASCII string argument back to the sender. This command is useful for set-up or troubleshooting.

5.4.2 HELLO Command

The format is:

H<Command ID>

Response:

ACK<<Byte>|<Integer>|<String>(<Byte>|<Integer>|<String>...<Byte>|<Integer>|<String>)>|<Response Error Code>

Command ID	Meaning	Response
1	ASCII Name and Version	<String> = "Cygnus Version x.xx"
2	Structure Version, Compatibility Version, and Range Version	<Integer><Integer><Integer>
3	Firmware version number	<Float>

Structure Version . . . . The structure version is increased when new parameters are added.

Compatibility Version . . . . A compatibility version change means that the internal parameter structure has changed so dramatically that parameter sets with different compatibility versions cannot be used.

Range Version . . . . A range version change means one or more parameters have different ranges from previous versions.

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5.4.3 Parameter Commands

Query commands are used to request established parameter values. There is a specific query command for each parameter group. Depending on the actual hardware configuration, the response to some Query commands may be an "E" error code indicating there is no data to retrieve. Each command has one to three arguments.

Update commands are used to change a specified parameter to a new value or condition. Some parameters are order dependent in that they cannot be updated prior to certain other parameters. There is a specific update command for each parameter group.

The command variations include:

Table 5-3 Parameter Commands

QUERY command	parameter	UPDATE Command
QA	All Parameters	**UA**
QC	Channel Parameters	**UC**
QG	General Parameters	**UG**
QI	Input Name	**UI**
QL	Logic Statements	**UL**
QO	Output Name	**UO**
QT	Output Type	**UT**

5.4.3.1 All Parameters

5.4.3.1.1 Query All Parameters

Query: The message format is:

QA

Command Response:

ACK<Returns values for the entire instrument configuration in the following order:
Length = 2 bytes (low byte / high byte)
All Channel 1 parameters, All Channel 2 parameters,...All Channel 6 parameters.
All General Parameters
All Logic Statements
All Output Types
All Output Names
All Input Names>|<Response Error Code>

NOTE: This length is NOT the same as the length of the packet. It tells how many bytes follow in the data.

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5.4.3.1.2 Update All Parameters

Update: The message format is:

UA <All configuration parameters>
Length = 2 bytes (low byte / high byte)
All Channel 1 parameters, all Channel 2 parameters,...all Channel 6 parameters.
All General parameters
All Logic Statements
All Output Types
All Output Names
All Input Names

Command Response:

ACK|<Response Error Code>

NOTE: All channels in the instrument need to be in Ready or Stop for this command to be accepted.

5.4.3.2 Channel Parameters

5.4.3.2.1 Query Channel Parameters

Query: This command returns a specific parameter or all parameters for a specified channel.

The message format is:

QC<Command ID><Channel Number>

Command ID = <Byte> See Table 5-4.

Channel Number = <Byte> 1 to 6

Command Response:

ACK<<Integer>|<Float>>|<Response Error Code>

Description: Type of response depends on Command ID, see "Data Type" column of the table below.

Special Case: QC0<Channel Number> will return all Channel parameters for the given channel, in numerical order.

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5.4.3.2.2 Update Channel Parameters

Update: The message format is:

UC <Command ID><Channel Number><Parameter Value>

Command ID = <byte>.

Channel Number = <byte> 1 to 6

Parameter Value = <integer>|<float>

Description: Type of value depends on Command ID, see the "Data Type" column in Table 5-4.

Command Response:

ACK|<Response Error Code>

Special Case: UC0<Channel Number>. Will send all Channel parameters for the given channel, in numeric order.

NOTE: UC0 and hardware related channel parameters may only be updated if specified channel is in Ready or Stop and are not crystal switching.

Table 5-4 Channel Parameters

Channel Command ID	Name	Units / Allowed Values / Notes	Data Type	Low Limit	High Limit
1 (0x01)	Density	g/cm^3	float	0.100	99.999
2 (0x02)	Z Ratio		float	0.100	15.000
3 (0x03)	Tooling	%	float	1.0	999.9
4 (0x04)	Control Loop	0 = non-PID 1 = PI 2 = PID	Int	0	2
5 (0x05)	Process Gain	A/s/%pwr.	float	0.010	999.99
6 (0x06)	Time Const	sec	float	0.010	9999.99
7 (0x07)	Dead Time	sec	float	0.010	9999.99
8 (0x08)	Crystal Quality		Int	0	9

Table 5-4 Channel Parameters (continued)

Channel Command ID	Name	Units / Allowed Values / Notes	Data Type	Low Limit	High Limit
9 (0x09)	Crystal Stability		Int	0	9
10 (0x0a)	Maximum Power	%	float	0.01	99.99
11 (0x0b)	Minimum Power	%	float	0.00	99.98
12 (0x0c)	Soak Power 1	%	float	0.00	99.99
13 (0x0d)	Rise Time 1	sec See Note 4	Int	0	5999 (99:59)
14 (0x0e)	Soak Time 1	sec See Note 4	Int	0	5999 (99:59)
15 (0x0f)	Soak Power 2	%	float	0.00	99.99
16 (0x10)	Rise Time 2	sec See Note 4	Int	0	5999 (99:59)
17 (0x11)	Soak Time 2	sec See Note 4	Int	0	5999 (99:59)
18 (0x12)	Idle Power	%	float	0.00	99.99
19 (0x13)	Idle Ramp Time	sec See Note 4	Int	0	5999 (99:59)
20 (0x14)	Rate	A/sec	float	0.000	999.9
21 (0x15)	Final Thickness	kA	float	0.000	999.9
22 (0x16)	On Final Thickness	0 = NonDep Control 1 = Idle Ramp 2 = Continue	Int	0	2
23 (0x17)	Crystal Fail Option	0 = Time Power 1 = Idle Ramp 2 = Stop	Int	0	2

Table 5-4 Channel Parameters (continued)

Channel Command ID	Name	Units / Allowed Values / Notes	Data Type	Low Limit	High Limit
24 (0x18)	Max Power Option	0 = Continue 1 = Idle Ramp 2 = Stop	Int	0	2
25 (0x19)	Scale	0 = Power 1 = +/- 10 Å/s 2 = +/- 20 Å/s	Int	0	2
26 (0x1a)	Scan Rate	0 = Auto 1 = Slow 2 = Med. 3 = Fast	Int	0	3
27 (0x1b)	Source Voltage Range	0 = +10V 1 = +5V 2 = +2.5V 3 = -10V 4 = -5V 5 = -2.5V	Int	0	5
28 (0x1c)	DAC Rate Range	0 = 0 to 10 Å/s 1 = 0 to 50 Å/s 2 = 0 to 100 Å/s 3 = 0 to 1000 Å/s 4 = 0 to 1 Å/s	Int	0	4
29 (0x1d)	DAC Thick Range	0 = 0 to 100 Å 1 = 0 to 1000 Å 2 = 0 to 2000 Å 3 = 0 to 3000 Å 4 = 0 to 5000 Å	Int	0	4
30 (0x1e)	Substrate Shutter Output	0, 1-38 See Note 1	Int	0	38
31 (0x1f)	Substrate Shutter Output Type	0 = NO, 1 = NC	Int	0	1
32 (0x20)	Sensor Shutter Output	0, 1-38 See Note 1	Int	0	38
33 (0x21)	Sensor Shutter Output Type	0 = NO, 1 = NC	Int	0	1

Table 5-4 Channel Parameters (continued)

Channel Command ID	Name	Units / Allowed Values / Notes	Data Type	Low Limit	High Limit
34 (0x22)	Sensor Type	1 = Single 2 = CrystalTwo 6 = CrystalSix 7 = Rotary 12 = Crystal12	Int	1	12
35 (0x23)	Sensor Switch Output	0, 1-38	Int	0	38
36 (0x24)	Secondary Tooling	%	float	1.0	999.9
37 (0x25)	Number of Crucibles	1,4,8,16,32,64	Int	1	64
38 (0x26)	Crucible	1-64	Int	1	64
39 (0x27)	Crucible Output	0, 1-37 See Note 1 See Note 3	Int	0	37
40 (0x28)	Crucible Output Type	0 = NO, 1 = NC	Int	0	1
41 (0x29)	Turret Feedback	1 = Yes, 0 = No	Int	0	1
42 (0x2a)	Turret Input	0, 1-28 See Note 2	Int	0	28
43 (0x2b)	Turret Delay	sec	Int	1	60
44 (0x2c)	RateWatch Time	sec See Note 4	Int	60	5999 (99:59)
45 (0x2d)	RateWatch Accuracy	%	Int	0	99
46 (0x2e)	Averaging Time	minutes	Int	0	30

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Table 5-4 Channel Parameters (continued)

Channel Command ID	Name	Units / Allowed Values / Notes	Data Type	Low Limit	High Limit
47 (0x2f)	Dep after PreDep	0 = Non Deposit Control 1 = Deposit, No Auto Soak 2 = Deposit, Auto Soak	Int	0	2
48 (0x30)	Rate Filter Time	sec. 0.1, 0.4, 1.0, 4.0, 10.0, 20.0, 30.0	Float	0.1	30
49 0x31	Cross Talk Percent	%	float	0.00	99.99
50 0x32	Auto-Z	1 = YES 0 = NO	Int	0	1
51	RateWatch Option	0 = None 1 = Non Deposit 2 = Non Deposit and Deposit	Int	0	2

NOTE 1: Outputs are numbered 1 through 38. Each can be used only once.

NOTE 2: Inputs are numbered 1 through 28. Each can be used only once.

NOTE 3: The number of Crucible Outputs required is dependent on the total number of crucibles. See the following table. These outputs must be in consecutive order. The Crucible Output parameter indicates the first output to be used. Therefore, the maximum value of this parameter is dependent on the number of crucibles. For example, if the number of crucibles is 16, and number of outputs is 4, and so the largest value acceptable for the crucible output is 35, as outputs 35, 36, 37, and 38 will be used.

Number of Crucibles	Number of Outputs
4	2
8	3
16	4
32	5
64	6

NOTE 4: The front panel display will show the time in Minutes:Seconds format, i.e., 5999 sec will be shown as 99:59 mm:ss, etc.

5.4.3.3 General Parameters

5.4.3.3.1 Query General Parameters

The message format is:

QG<Command ID>

Command ID = <Byte> (See Table 5-5.)

Command Response:

ACK<Integer> (All the QG responses are integers.)|<Response Error Code>

Special Case: QG0 will return all General Parameters, in numeric order.

5.4.3.3.2 Update General Parameters

Update: The message format is:

UG<Command ID><Parameter Value>

Command ID = <byte> See "Command ID" column in table below.

Parameter Value = <integer>
Description: type of parameter value depends on Command ID, see "units" column of Table 5-5.

Command Response:

ACK|<Response Error Code>

NOTE: General parameters may only be updated if all channels are in Ready or Stop and are not crystal switching on any channel.

Special Case: UG0 will send all General parameters in numeric order.

Table 5-5 General Parameters

QG Command ID	Name	Units / Allowed Values / Notes	Low Limit	High Limit
1 (0x01)	Test On	1 = Yes, 0 = No	0	1
2 (0x02)	Time Compressed	1 = Yes, 0 = No	0	1
3 (0x03)	Audio Feedback	1 = Yes, 0 = No	0	1
4 (0x04)	(Not Used)	Int	0	0

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Table 5-5 General Parameters (continued)

QG Command ID	Name	Units / Allowed Values / Notes	Low Limit	High Limit
5 (0x05)	Data Logging Path	0 = Off, 2 = File, Page Format 3 = File, Comma Delimited	0	3
6 (0x06)	Print Screen Path	2 = Floppy Disk	1	2
7 (0x07)	Print Screen Number		0	999
8 (0x08)	RS232 Baud Rate	2400, 4800, 9600, 19200	2400	19200
9 (0x09)	IEEE-488 Address	(0-30)	0	30
10 (0X0a)	(Not Used)	Int	0	0
11 (0x0b)	Data Log Crystal History	1 = Yes, 0 = No	0	1
12 (0x0c)	DAC Output Option	0 = Power / Rate 1 = Power / Thickness 2 = Pwr / Rate / Thick (4 Channel) 3 = Rate / Thickness	0	3
13 (0x0d)	Thickness Equation 1	See Note	0	654321
14 (0x0e)	Thickness Equation 2	See Note	0	654321
15 (x0f)	Thickness Equation 3	See Note	0	654321

NOTE: This parameter represents which channels are to be summed together. A digit represents each channel. 0 is no channel selected. 1 is channel one, 2 is channel two and so on. The value 654321 means sum all six channels. Only the digits 0 to 6 are allowed. Each channel can only be used once in an equation.

5.4.3.4 Input Name Parameters

5.4.3.4.1 Query Input Name

Query: The message format is:

QI<Input Number>

Input Number = <byte> 0 to 28 (0 = all inputs)

Command Response:

If Input Number was 1 to 28:

ACK<Input Name>|<Response Error Code>

If Input Number was 0:

ACK<Input 1 Name><Input 2 Name>...<Input 28 Name>|<Response Error Code>

Input Name = <string> Up to 10 characters, null terminated.

5.4.3.4.2 Update Input Names

Update: The message format is:

UI<Input Number><Input Name>|<Input Number = 0><Input 1 Name><Input 2 Name>...<Input 28 Name>

Input Number = <byte> 0 to 28 (0 = all inputs)

Input Name = <string> Up to 10 Characters, null terminated.

Command Response:

ACK|<Response Error Code>

NOTE: Input Names may only be updated if all channels are in Ready or Stop and are not crystal switching on any channel.

5.4.3.5 Logic Statements Parameters

Format of Logic Statement:

If Event 1 (###) AND/OR Event 2 (###) AND/OR Event 3 (###) AND/OR Event 4 (###) AND/OR Event 5 (###)

Then Action 1 (###) AND Action 2 (###) AND Action 3 (###) AND Action 4 (###) AND Action 5 (###)

The "AND" between the Actions in the "Then" portion of the logic statement is implicit, it is not received as part of the response.

There can be between 0 and 5 Events, and 0 and 5 Actions.

5.4.3.5.1 Query Logic Statements

Query: The command message format is:

QL<Statement Number>

Statement Number = <byte> 0 to 100 (0 = All 100 Statements)

Command Response:

ACK<Length of Logic Elements><Set of Logic Elements>|<Response Error Code>

Response to QL:

ACK<100 of the individual responses shown above>|<Response Error Code>

Length of Logic Elements

This length is NOT the same as the length of the packet. It tells how many bytes follow in the "event/action" set.

5.4.3.5.2 Update Logic Statements

UPDATE: The command message format is;

UL<Statement Number><Length of Logic Elements><Logic Elements>

Statement Number = <byte> 0 to 100 (0 = All Statements)

Length of Logic Elements = This length is not the same as the length of the packet. It tells how many bytes follow in the "Logic Elements" set.

Command Response

ACK|<Response Error Code>

Set of Logic Elements

The Logic Elements can be made up of the following elements. All elements except Numeric 2 are one byte, Numeric 2 is a 4 byte integer.

Left parenthesis . . . . "(" 0x28

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Right parenthesis . . . . ")" 0x29

Ampersand (and) . . . . "&" 0x26

Or sign . . . . "I" 0x7c

Event Code . . . . See Event codes table, "normal" column

Negated Event Code . . . . See Event codes table, "negated" column

Numeric 1 . . . . byte, Numeric 1 is present if the event code requires a numeric. The range is dependent on the specific code.

Numeric 2 . . . . Integer, Numeric 2 is present if the event code requires a second numeric. It is a 4 byte integer. The range is dependent on the specific code.

Space . . . . " " 0x20, separates "If" and "Then"

Action code. . . . . See Action codes table

Numeric 3 . . . . byte, Numeric 3 is present if the action code requires a numeric. The range is dependent on the specific code.

Terminator . . . . (ETX) 0x03, Indicates end of "Then"

The ordering of the Logic Elements is as follows: (The term "Event Code" includes "Negated Event Code")

Event Terms:

First element of term can be "(", a space, or an Event code
If a space there are no Events, but there may be Actions. (see below)
If "(", the next element must be an Event code.
If an Event code, if numerics are required for a specific code, they will be next.
After an Event code, with its numerics, there may or may not be a ")".
Next will be either a connector or a space.
If a space, an Action code will follow.
If a connector, an Event code will follow.

Action Terms:

Up to 5 Action codes make up the action terms. Each code will be followed by a numeric if it is required. Note there are no connectors passed with the Actions, as all Actions are ANDed together.

The logic statement response ends with an 0x03.

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Table 5-6 shows Event Codes in HEX notation.

- "s" indicates Channel Number: 0 to 6
- "n" indicates Channel Number: 1 to 6

Table 5-6 Event Codes

Name	Description	Normal	Negated
External In x	External Input x (x = 1 to 28)	0x41	0xBF
Crucible SW s	Crucible Switch s	0x42	0xBE
Rise 1 s	Rise 1 s	0x43	0xBD
Soak 1 s	Soak 1 s	0x44	0xBC
Rise 2 s	Rise 2 s	0x45	0xBB
Soak 2 s	Soak 2 s	0x46	0xBA
Deposit s	Deposit s	0x47	0xB9
NonDep Cntl s	Non Deposit Control s	0x48	0xB8
Time Power s	Time Power s	0x49	0xB7
NonDep Hold s	Non Deposit Hold s	0x4A	0xB6
Idle Ramp s	Idle Ramp s	0x4B	0xB5
Ready s	Ready s	0x4C	0xB4
Stop s	Stop s	0x4D	0xB3
Substr Shtr s	Substrate Shutter s	0x4E	0xB2
Manual s	Manual s	0x4F	0xB1
Thick Limit n xxx.xxx	Thickness Limit n xxx.xxx kÅ (see note 1)	0x50	0xB0
Timer HH:MM x xx:xx	Timer Limit HH:MM x xx:xx (x = 1 to 20, xx:xx is valid time) (see note 2)	0x51	0xAF
Timer SECS x xxx.x	Timer Limit Sec x xxx.x (x = 1 to 20, xxx.x is valid time) (see note 3)	0x52	0xAE
Counter Limit x xxx	Counter x xxx (x = 1 to 20, xxx = 0 to 999)	0x53	0xAD
Statement x	Logic Statement x (x = 1 to 100)	0x54	0xAC
Comp Cntl	Computer Control	0x55	0xAB
Xtal Fail s	Crystal Fail s	0x56	0xAA

Table 5-6 Event Codes (continued)

Name	Description	Normal	Negated
Maximum Pwr s	Maximum Power s	0x57	0xA9
Minimum Pwr s	Minimum Power s	0x58	0xA8
Thick Sum x xxx.xxx	Thickness Sum x xxx.xxx (x = 1 to 3, equation number from general parameters; xxx.xxx = 0 to 999.9 kÅ) see note 1	0x59	0xA7
NOTE 1: Thickness Limit and Thickness Sum will be sent as an integer Angstroms (the number here *1000) **NOTE 2:** Timer Limit HH:MM second numeric will be sent as an integer number of minutes. **NOTE 3:** Timer Limit Sec value will be sent as an integer tenth of seconds.			

Table 5-7 shows Action Codes in HEX notation.

- "s" indicates Channel number: 0 to 6
- "n" indicates Channel number: 1 to 6

Table 5-7 Action Codes

Name	Description	Code
External Out On x	Set External Output x (x = 1 to 38)	0x41
External Out Off x	Clear External Output x (x = 1 to 38)	0x42
Start n	Start (Go to Pre-Dep) n	0x43
Stop s	Stop (Idle at Power = 0) s	0x44
Reset s	Reset s	0x45
Zero Thick s	Zero Thickness s	0x46
Switch Xtal n	Switch Crystal n	0x47
Clock Hold On n	Non-Rate Control Clock Hold On n	0x48
Clock Hold Off n	Non-Rate Control Clock Hold Off n	0x49
Xtl Fl Inhibit On s	Crystal Fail Inhibit On s	0x4A
Xtl Fl Inhibit Off s	Crystal Fail Inhibit Off s	0x4B
Start Timer x	(Re)Start Timer x (set timer to zero and start incrementing) (x = 1 to 20)	0x4C
Cancel Timer x	Cancel Timer x (set timer to zero and don't increment) (x = 1 to 20)	0x4D
Clear Counter x	Clear Counter x (x = 1 to 20)	0x4E

Table 5-7 Action Codes (continued)

Name	Description	Code
Increment Counter x	Increment Counter x (x = 1 to 20)	0x4F
Start Deposit n	Start Deposit n	0x50
Goto NonDep Cnt n	Go to Non-Deposit Control n	0x51
Goto Post Dep n	Go to Post Deposit n	0x52
Continue Dep n	Continue Deposit n	0x53
RW Sample ON s	Leave RateWatch hold. (Can't return to hold until turned off.)	0x54
RW Sample OFF s	Allows return to RateWatch hold.	0x55

5.4.3.6 Output Name Parameters
5.4.3.6.1 Query Output Names

Query: The message format is:

QO<Output Number>

Output Number = <byte> 0 to 38 (0 = All Outputs)

Command Response:

If Output Number was 1 to 38:

ACK<Output Name>|<Response Error Code>

If Output Number was 0:

ACK<Output 1 Name><Output 2 Name>...<Output 38 Name>|<Response Error Code>

Output Name = <string> Up to 10 characters, null terminated.

5.4.3.6.2 Update Output Names

Update: The message format is:

UO<Output Number><Output Name>|<Output Number = 0><Output 1 Name><Output 2 Name>...<Output 38 Name>

Output Number = <byte> 0 to 38 (0 = All Outputs)

Output Name = <string> Up to 10 characters, null terminated

Command Response:

ACK|<Response Error Code>

NOTE: Output Names may only be updated if all channels are in Ready or Stop and are not crystal switching on any channel.

5.4.3.7 Type of Output Parameters

5.4.3.7.1 Query Output Type

Query: The message format is:

QT<Output Number>

Output Number = <byte> 0 to 38 (0 = All Outputs)

Command Response:

If Output Number was 1 to 38:

ACK<Output Type>|<Response Error Code>

If Output Number was 0:

ACK<Output 1 Type><Output 2 Type>...<Output 38 Type>|<Response Error Code>

Output Type = <byte> 0 or 1 (0 = NO, 1 = NC)

5.4.3.7.2 Update Output Type

Update: This command changes the type code for a specified output. Type code values are 0 or 1, where 0 is Normally Open and 1 is Normally Closed.

The message format is:

UT<Output Number><Output Type>|<Output Number = 0><Output 1 Type><Output 2 Type>...<Output 38 Type>

Output Number = <byte> 0 to 38 (0 = All Outputs)

Output Type = <byte> 0 or 1 (0=NO, 1 = NC)

Response:

ACK|<Response Error Code>

NOTE: Output Types may only be updated if all channels are in Ready or Stop and are not crystal switching on any channel.

5.4.4 STATUS Commands

Status commands return pertinent information based on a specific request made. Commands are provided to determine global information which is system level or channel information. A status code is required for each command. The command variations include:

SC . . . . Status of a Channel

SG . . . . Status of system or instrument level condition.

5.4.4.1 Status Channel Command

The message format is:

SC<Command ID><Channel Number>

Command ID = <byte> See Table 5-8.

Channel Number = <byte> 0 to 6, 0 means all channels.

Command Response:

If Channel Number = 1 to 6:

ACK<<byte>|<Integer>|<float>|<Special>>|<Response Error Code>
See the "Response" column in Table 5-8.

If Channel Number = 0:

ACK<<byte><byte><byte><byte><byte><byte>|<integer><integer><integer><integer><integer><integer>|<float><float><float><float><float><float>|<Special><Special><Special><Special><Special><Special>>|<Response Error Code>

Description: If Channel Number = 0, the response for each of the six channels are given, channel 1 is given first.

Table 5-8 Status Channel Commands

SC Command ID (HEX)	Meaning	Response
0 (0x00)	Data	Byte Sensor Status, Byte State, Float Rate Filtered, Float Thickness, Float Power, Float Rate Deviation
1 (0x01)	Filtered Rate	Float, A/s
2 (0x02)	Displayed Rate	Float, A/s, averaged over one second.
3 (0x03)	Source Power Output	Float, %
4 (0x04)	Thickness	Float, kÅ

Table 5-8 Status Channel Commands (continued)

SC Command ID (HEX)	Meaning	Response
5 (0x05)	State	byte, encoding as follows: 0 = Ready 1 = Crucible Switch 2 = Rise 1 3 = Soak 1 4 = Rise 2 5 = Soak 2 6 = Deposit 7 = Time Power 8 = Non Deposit Control 9 = Non Deposit Hold 10 = Idle Ramp 11 = Manual 12 = Stop
6 (0x06)	State Time	Integer, seconds, time in the current state
7 (0x07)	Accumulated Time	Integer, seconds, time since Ready
8 (0x08)	Crystal Life	Integer, range will be 0 to 100
9 (0X09)	Crystals Remaining	Integer, range between 0 and 12, number of good crystals on CrystalTwo, CrystalSix, Crystal12, or Rotary.
10 (0X0A)	Crystal Position	byte, range between 1 and 12. The current crystal position on a CrystalTwo, CrystalSix, or Crystal12
11 (0X0B)	Sensor State	byte, range between 0 and 2. 0 = Good crystal, 1 = Failed crystal, 2 = Invalid measurement on crystal
12 (0x0C)	Fundamental Frequency	Integer, unconverted. See Note 2.
13 (0x0D)	Fundamental Activity	Integer, range 0 to 650

Table 5-8 Status Channel Commands (continued)

SC Command ID (HEX)	Meaning	Response
14 (0x0E)	Data Log	Multple pieces of information, as follows: Year (Integer) Month (Integer Day (Integer) Hour (Integer) Minute (Integer) Run TIme (Integer)(seconds) Deposit Time (Integer)(seconds) Ending Thickness (Float)(kÅ) Average Rate (Float)(Å/s) Average Rate Deviation (Float)(Å/s) Ending Power (Float)(%) Average Power (Float)(%) Where is goes next (Byte)(0=Non Deposit Control or Non Deposit Manual, 1 = Post Deposit, 2 = Stop) Termination Reason (Byte)(0-8 match the "cause of Stop" coding in command 18 below; 9 = Normal termination; 10 = Manual substrate shutter closing) Time Power Flag (Byte) (0=No, 1 = Yes) Power Fail Flag (Byte)(0=No, 1=Yes) Power Fail Thickness (float)(kÅ, 0 if not a power fail, otherwise the thickness when the power was lost.) See Note 1.
15 (0x0F)	Data log with Crystal History.	All of the data from command 14 plus the following for each of 12 (potential) crystals on the sensor: Crystal Number (Byte) Begin Frequency (Float)(Hz) End Frequency (Float)(Hz) Begin Life (Integer) End Life (Integer) Begin Activity (Integer) End Activity (Integer) Stability (Float) (Hz) Quality Count (Integer) (repeat for remaining crystals) See Note 1.
16 (0x10)	Deposit Average Rate	Float, based on Averaging Time parameter. Only available when in a control state. See Note 1.

Table 5-8 Status Channel Commands (continued)

SC Command ID (HEX)	Meaning	Response
17 (0x11)	State before Stop	Byte. See state encodings listed with SC5. If not currently in Stop, will return "No Data" error. See Note 1.
18 (0x12)	Cause of Stop	Byte. If not currently in Stop, will return "No Data" error. Code Cause 0 Front Panel 1 Max Power 2 Crystal Fail 3 Power Loss 4 Crucible Switch Error 5 Crystal Switcher Fail 6 Remote Command 7 Internal Logic 8 Hand Held Controller See Note 1.
19 (0x13)	Channel Errors	2 bytes 0x8000 Xtal Fail 0x4000 Xtal Switch Error 0x2000 Cruc Switch Error 0x1000 No Time Power Ave.
20 (0x14)	Channel Status	2 bytes 0x8000 Max Power 0x4000 Min Power (during control only) 0x2000 Xtal Switching 0x1000 Cruc Switching 0x0800 Abbreviated Average 0x0400 Unable to Auto-Z 0x0200 RateWatcher Sample 0x0100 RateWatcher Hold 0x0080 RateWatcher Delay
21	Deposit Average Power	Float, based on Averaging Time Parameter. Only available when in a control state. See Note 1.
22	Raw Rate	Float, Å/s

Table 5-8 Status Channel Commands (continued)

SC Command ID (HEX)	Meaning	Response
23	Enhanced Sensor Status	Byte, same as 11 with bits 7 and 6 set per Z-Ratio type. Bit 1 Bit 0 0 0 Good Crystal 0 1 Failed Crystal 1 0 Invalid Measurement on Crystal 1 1 Undefined Bit 7 Bit 6 0 0 Auto Z-Ratio 0 1 Sensor Z-Ratio 1 0 Material Z-Ratio 1 1 Undefined
24	Current Z-Ratio	Float, Z-Ratio currently in use
25	Anharmonic Reading	Integer, unconverted. See Note 2.
26	Anharmonic Activity	Integer, Range 0 - 650
27	One Minute Rate Average & One Minute Power Average	Float, Float: Returns a "No Data Error" if not enough data to do a one minute average of the rate or the power. See Note 1.
28	Crystal Inventory	Returns "No Data Error" for single sensor and rotary sensors. For multi-crystal sensors, returns the crystal inventory as follows: Number of crystals - 1 byte Current Position - 1 byte For each crystal returns the following: Crystal Status - 1 byte Fundamental Frequency - 4 byte integer. See Note 2. Activity - 4 byte integer
29	New crystal frequency	Returns the Fundamental and Anharmonic "NEW" crystal frequencies, returned as two 4 byte integers. See Note 2.
30	LCQ value	Returns the LCQ running value, returned as one 4 byte float.
Note 1: If all channels are selected for this command and any one of the six channels does not have data, then the "No Data Error" is returned alone. Note 2: Frequencies are returned as an integer. To convert to Hz, multiply by 0.004656612823		

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5.4.4.2 Status General Commands

The message format is:

SG<Command ID>|<Command ID><Action Value>

Command ID = <byte>

Action Value = <byte> See Table 5-9.

Table 5-9 Status General Commands

SG Command ID	Meaning	Action Value	Response
0	Data at Timer Value	<Byte> = Requested Timer Value	108 Bytes. Six sets of channel data at the requested timer tick: Sensor Status (Byte) State (Byte) Rate (filtered) Float Thickness (Float) Power (Float) Rate Deviation (Float) If data is not available for the timer tick requested, then the return will be "No Data" error. (1 byte)
1 (0x01)	Which channels running		1 Byte, Each bit represents a channel, a bit set means channel running (i.e. not in Ready or Stop). MSB is channel 1. Two LSB unused.
2 (0x02)	Output Status		5 Bytes. Each bit represents an output, bit set means output active. MSB of first byte is output 1. Two LSB of last byte unused.
3 (0x03)	Input Status		4 Bytes. Each bit represents an input. bit set means input active. MSB of first byte is input 1. Four LSB of last byte unused.
4 (0x04)	Logic statement status		13 Bytes. Each bit represents a logic statement, bit set means logic statement is true. MSB of first byte is logic statement 1. Four LSB of last byte unused.

Table 5-9 Status General Commands (continued)

SG Command ID	Meaning	Action Value	Response
5 (0x05)	General Errors		2 Bytes 0x8000 Power Loss 0x4000 No Disk in Drive 0x2000 Disk is Full 0x1000 Disk Write Protected 0x0800 Disk Error 0x0400 File Checksum Error 0x0200 File Format Error 0x0100 File Read Error 0x0080 File Range Error 0x0040 Parameters Defaulted 0x0020 Data Log Failure 0x0008 Memory Allocation Fail 0x0004 Loaded Different Version
6 (0x06)	Get Date		3 Integers, Month, Day, and Year.
7 (0x07)	Get Time		3 Integers, Hour, Minute, Second
8 (0x08)	Channels with Errors and Status		2 Bytes. The first is Channel Error with the MSB representing Channel 1. The second is Status with the MSB representing Channel 1.
9 (0x09)	Thickness Sum x, x = 0 to 3; 0 = All equations, 1 to 3 refer to specific thickness equation per general parameters	<byte> 0 to 3	3 Floats for Action Value = 0 1 Float for Action Value = 1 to 3 representing Thickness in kiloAngstroms.
10 (0x0A)	General Status Messages		2 bytes 0x8000 Test = Test Mode On 0x4000 Remote Lock 0x2000 Program Lock

Table 5-9 Status General Commands (continued)

SG Command ID	Meaning	Action Value	Response
11 (0x0B)	System Configuration		2 bytes Configuration Status 0 0x0001 Measurement Board 1 Detected 1 0x0002 Measurement Board 2 Detected 2 0x0004 Measurement Board 3 Detected 3 0x0008 Not Used 4 0x0010 I/O Board 1 Installed 5 0x0020 I/O Board 2 Installed 6 0x0040 I/O Board 3 Installed 7 0x0080 Reserved 8 0x0100 IEEE-488 Board Installed 9 0x0200 Reserved 10 0x0400 Reserved 11 0x0800 Reserved 12 0x1000 Reserved 13 0x2000 Reserved 14 0x4000 Reserved 15 0x8000 Reserved
12 (0x0C)	Timer Status	<Byte> Timer Number	0 = Timer Inactive 1 = Timer Active
13 (0x0D)	Timer Value	<Byte> Timer Number	4 Bytes, Integer number in tenths of a second
14 (0x0e)	Counter Value	<Byte> Counter Number	2 Bytes, Integer number of count

5.4.5 REMOTE Commands

Remote commands perform an action based on the specific command given. Commands are provided to affect global features which are system level oriented (RG commands) or channel oriented (RC commands). Every command requires a remote code and may require a value. Command variations include:

RC . . . . Affects conditions for a specified Channel.

RG . . . . Affects system or instrument level conditions.

5.4.5.1 Remote Channel Action Commands

These commands are used to affect actions associated with Channels. Single or multiple values may be required for some commands. If the Channel designated is not currently active, an "F" (cannot change value now) error code will be returned.

The message format is:

RC<Command ID><Channel Number><(Action Value)>

Command ID = <byte>. See Remote Channel Command table below

Channel Number = <byte> 1 to 6

Action Value = <byte>|<Integer>|<Float>. A few commands have a value with them. See the Table 5-10 below.

Command Response:

ACK|<Response Error Code>

Table 5-10 Remote Channel Commands

RC Command ID	Meaning	Action Value
1 (0x01)	Stop	
2 (0x02)	Reset	
3 (0x03)	Start	
4 (0x04)	Zero Thickness	
5 (0x05)	Start New Deposit -Will always zero thickness on entry. This cannot be done from Ready, Stop, or Crucible Switch, or while crystal switching (use Start, RC3, from Ready or Stop). When there is no good crystal, this command will go to "Time Power" if the previous state was Non-Deposit Hold, otherwise, it is not allowed.	
6 (0x06)	Go to Non-Deposit Control. This cannot be done from Ready, Stop, Crucible Switch, or while crystal switching (use Start, RC3, from Ready or Stop). When there is no good crystal, this command will go to "Non-Deposit Hold" if the previous state was Time Power, otherwise, it is not allowed.	

Table 5-10 Remote Channel Commands (continued)

RC Command ID	Meaning	Action Value
7 (0x07)	Go to Post Deposit (Idle Ramp). Cannot be done if in Ready, Stop, Crucible Switch, or while crystal switching.	
8 (0x08)	Go to Manual (Substrate Shutter does not change position). Cannot be done if in Crucible Switch or there is not a good crystal.	
9 (0x09)	Set Power Level. Only allowed in Manual, Time Power, or Non-Deposit Hold State	<Float> 0 to 99.99
10 (0x0A)	Open Substrate Shutter. Only allowed if in Manual	
11 (0x0B)	Close Substrate Shutter. Only allowed if in Manual	
12 (0x0C)	Clock Hold On, Stops timer in Pre-Deposit or Post Deposit	
13 (0x0D)	Clock Hold Off, Restarts timer in Pre-Deposit or Post Deposit after Clock Hold On.	
14 (0x0E)	Continue Deposit. Go to Deposit, but don’t zero the thickness. Cannot be done from Ready, Stop, Crucible Switch, or while crystal switching.	
15 (0x0F)	Set Averaged Rate. Only in Time Power or Non-Deposit Hold, the estimated rate is used	<Float> 0 to 999.9
16 (0x10)	Switch Crystal	
17 0x11	Crystal Fail Inhibit On. Crystal Fail output always set to FALSE, even during crystal fail.	
18 0x12	Crystal Fail Inhibit Off. Crystal Fail output has normal meaning	
19 0x13	Clear Q and S counts	
20 0x14	RateWatcher sampling on. Will immediately cause the Deposit state to leave HOLD and not return until turned off.	
21 0x15	RateWatcher Sampling Off. Allows the Deposit state to go into the RateWatcher HOLD.	

Table 5-10 Remote Channel Commands (continued)

RC Command ID	Meaning	Action Value
22 0x16	Clears all failed crystals except the current crystal.	
23 0x17	Reinitialize the crystal information	
24 0x18	Rotate Sensor Head	

5.4.5.2 Remote General Action Commands

The message format is:

RG<Command ID>(<Action Value>)

Command ID = <byte> See Remote General Action commands below.

Action Value = <byte>...<byte>|<Integer>...<Integer>|<Float>...<Float>

Command Response:

ACK|<Response Error Code>

Table 5-11 Remote General Action Commands

RG Command ID	Meaning	Action Value
1 (0x01)	Stop All	
2 (0x02)	Reset All	
3 (0x03)	Remote Lock On, i.e. No parameters can be updated from the front panel.	
4 (0x04)	Remote Lock Off	
5 (0x05)	Set Logic Statement <Action Value> to True. Only takes action if the Logic Statement Event is set to "Computer Control", otherwise it is ignored.	<Byte> 1 to 100

Table 5-11 Remote General Action Commands

RG Command ID	Meaning	Action Value
6 (0x06)	Clear Logic Statement<Action Value> to False. Only takes action if the Logic Statement Event is set to "Computer Control", otherwise it is ignored.	<Byte> 1 to 100
7 (0x07)	Unused	
8 (0x08)	Unused	
9 (0x09)	Set date (Month, Day, Year) Month = 1-12, Day = 1-31, Year = 2000-2089	<int><int><int>
10 (0x0A)	Set Time (Hour, Minute, Second) Hour = 0-23, Minute = 0-59, Second = 0-59	<int><int><int>
11 (0x0B)	Zero Counter x, x = 0 to 20	<byte> 0 to 20
12 (0x0C)	Zero Timer x, x = 0 to 20	<byte> 0 to 20
13 (0x0D)	Start Timer x, x = 1 to 20	<byte> 1 to 20
14 (0x0E)	Cancel Timer x, x = 0 to 20	<byte> 0 to 20

5.4.6 Negative Response Error Codes

An error code in the form of a single ASCII character is returned when a command results in an error. There are two types of Error codes: a Packet Error Code or a Response Error Code. Both are described under section section 5.3.2.2, Response Packet (Instrument to Host Message), on page 5-6.

5.5 Sample Cygnus Commands

The following illustrate examples of typical message streams.

5.5.1 Remote Communications Example — Updating a Channel's Rate Parameter

An example of setting the Rate parameter to 10.00 A/s in Channel 3 by Remote Communication is shown below.

The Rate parameter is changed by a UC command, since it will Update the parameter value of a Channel.

The Rate parameter is a "Float" data type, and is a 32 bit number.

The Character "U" = 0x55 (hexadecimal 8 bit value)

The Character "C" = 0x43 (hexadecimal 8 bit value)

Rate Command ID is 20 = 0x14 (hexadecimal 8 bit value)

Channel 3 = 0x03 (hexadecimal 8 bit value)

10 (decimal) = 00002041 (hexadecimal floating point 32 bit value in LSB to MSB order)

Putting them all together builds the 8 byte message shown as a byte message in hexadecimal:

5543140300002041

Calculate the message checksum = {(sum of all bytes in the message) modulus 0x0100}

Checksum = {0x55 + 0x43 + 0x14 + 0x03 + 0x00+ 0x00 + 0x20 + 0x41) modulus 0x0100}

Checksum = {(0x0110) modulus 0x100}

Checksum = 0x10

Now to send the message, put a two byte length (LSB, MSB) ahead of the message and a one byte checksum after the message.

08005543140300002041 10

The successful response byte should be (refer to section 5.3.2.2 on page 5-6 for details for CCB and Timer).

Example: CCB = 0x00 and we have Timer = 0xA1

030000A106A7 where 0300 = two byte length (LSB, MSB), 00 = CCB, A1 = Timer value, 06 = ACK (command acknowledged) and A7 = Checksum.

Chapter 6
Installation and Interfaces

6.1 Location Guidelines

Before you permanently install this controller, we recommend that you read this entire section on Installation and Interfaces and follow its recommendations as closely as possible. INFICON has taken numerous steps to ensure its equipment will operate in a variety of harsh situations. Failure to adhere to these simple practices may adversely affect the performance and longevity of this controller, or controllers made by any manufacturer.

6.1.1 Sensor Types

The choice of sensor type is dictated by the Process, the deposition material and the physical characteristics of the process chamber. General guidelines for each sensor type produced by INFICON are outlined in the Sensor Selection table, Table 6-1. For specific recommendations, consult your INFICON representative.

Table 6-1 Sensor Selection Table

	Max. Bakeout Temperature*	Water Tube & Size (Max. Envelope)	Coax Length	Body & Holder	IPN
CrystalSix Sensor	130 °C	3.5” dia. x 2.0” high (8.9 cm x 5.1 cm)	30” (76 cm)	304 SS (plate, holders & material shield)**	750-446-G1
Crystal12 Sensor	130 °C	4.0” dia. x 3.3” high (10.16 cm x 8.382 cm)	30” (76 cm)	304 SS	750-667-G1
Standard Sensor	130 °C	1.063” x 1.33” x .69” high (2.7 cm x 3.4 cm x 1.75 cm)	30” (76 cm)	304 SS	750-211-G1
Standard Sensor w/Shutter	130 °C	1.06” x 2.24” x .69” (2.7 cm x 5.7 cm x 1.75 cm)	30” (76 cm)	304 SS	750-211-G2
Sputtering Sensor	105 °C	1.36 x .47” (3.45 cm x 1.18 cm)	30” (76 cm)	Au-plated BeCu	007-031
Compact Sensor	130 °C	1.11” x 1.06” x 1.06” (2.8 cm x 2.7 cm x2.7 cm)	30” (76 cm)	304 SS	750-213-G1
Compact Sensor w/Shutter	130 °C	2.08” x 1.62” x 1.83” (5.3 cm x 4.1 cm x 4.6 cm)	30” (76 cm)	304 SS	750-213-G2
UHV Bakeable Sensor	450 °C	1.35” x 1.38” x .94” (5.3 cm x 4.1 cm x 4.6 cm)	12” (30.5 cm) 20” (50.8 cm) 30” (76.2 cm)	304 SS	007-219 007-220 007-221
UHV Bakeable Sensor w/Shutter	400 °C	1.46” x 1.37” x 1.21” (3.7 cm x 3.5 cm x 3.1 cm)	12” (30.5 cm) 20” (50.8 cm) 30” (76.2 cm)	304 SS	750-012-G1 750-012-G2 750-012-G3
Shutter Assembly	400 °C	two models available	N/A	300-series SS	750-210-G1 750-005-G1 (Sputtering)

* For bake only; water flow is required for actual deposition monitoring. These temperatures are conservative maximum device temperatures, limited by the properties of Teflon (PTFE) at higher temperatures. In usage, the water cooling allows operation in environments that are significantly elevated, without deleterious affects.
** Aluminum body for heat transfer.

NOTE: Do not allow water tubes to freeze. This may happen if the tubes pass through a cryogenic shroud and the water flow is interrupted.
For best operation, maintain the input water temperature at less than 30°C. In high temperature environments more heat may transfer to the water through the water tubes than through the actual transducer. In extreme cases it may be advantageous to use a radiation shield over the water tubes.

CAUTION

The performance of this instrument depends on the careful installation of the chosen transducer. Improper installation will cause problems with deposition repeatability, crystal life and rate stability.

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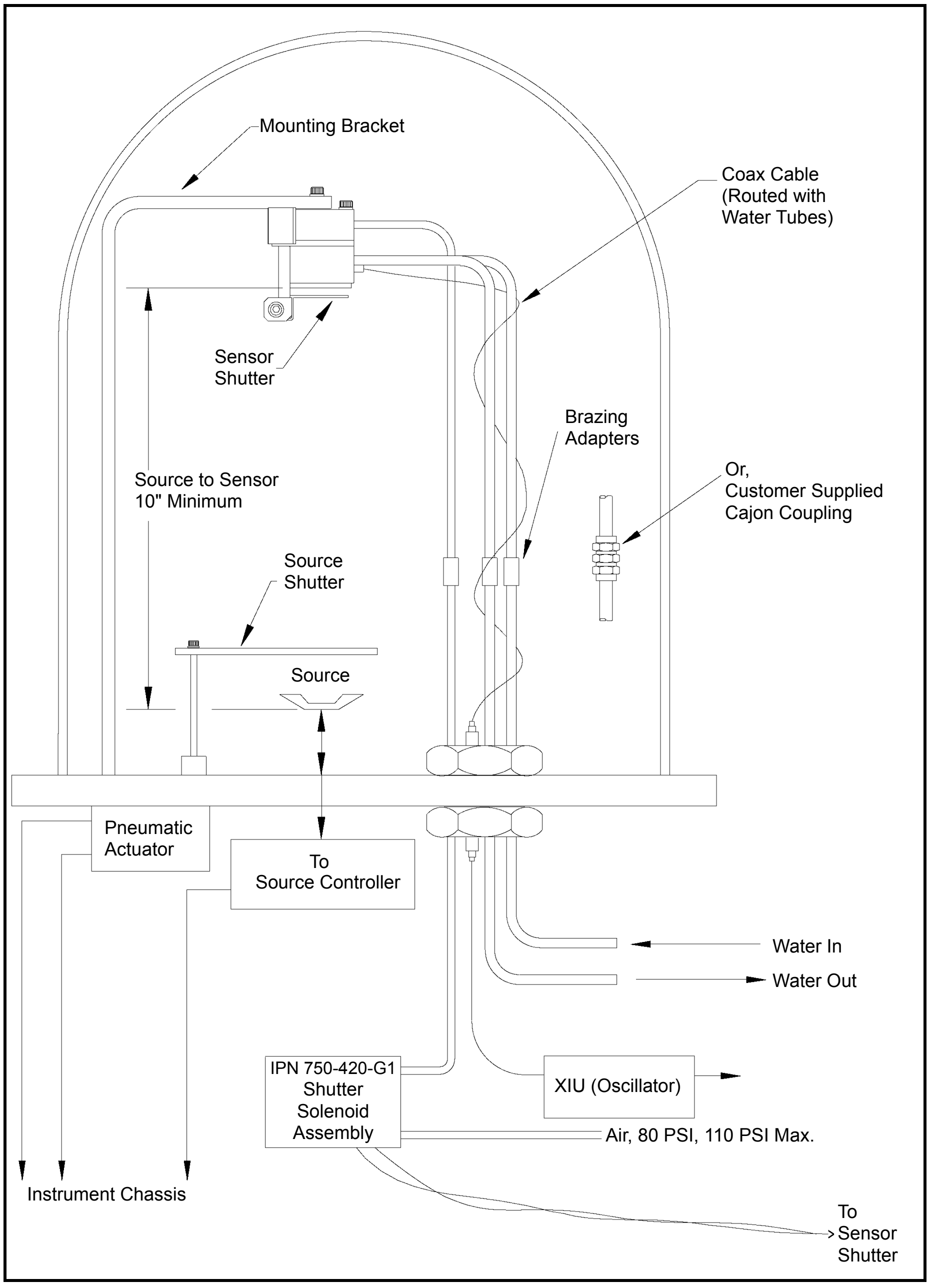
6.1.2 Sensor Installation

Figure 6-1 shows a typical installation of an INFICON water cooled crystal sensor in the vacuum process chamber. Use the illustration and the following guidelines to install your sensors for optimum performance and convenience.

Figure 6-1 Typical Installation



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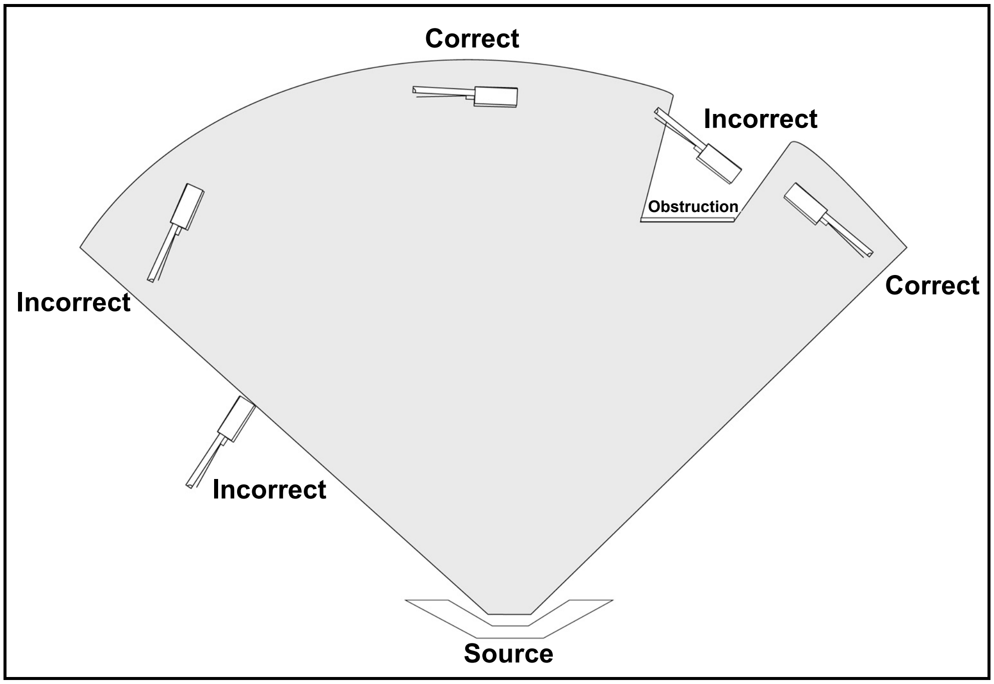
Generally, install the sensor as far as possible from the evaporation source (a minimum of 10" [25.4 cm] is recommended) while still being in a position to accumulate thickness at a rate proportional to accumulation on the substrate. Figure 6-2 shows proper and improper methods of installing sensors.

Figure 6-2 Sensor Installation Guidelines



To guard against spattering, use a source shutter or crystal shutter to shield the sensor during the initial soak periods. If the crystal is hit with even a minute particle of molten material, it may be damaged and stop oscillating. Even in cases when it does not completely stop oscillating, it may become unstable. Follow these precautions:

- Mount the sensor to something rigid and fixed in the chamber. Do not rely on the water tubes to provide support.
- Plan the installation to insure there are no obstructions blocking the path between the Sensor and the Source. Be certain to consider rotating or moving fixtures.
- Install sensors so their central axis (an imaginary line drawn normal to the center of the crystal's face) is aimed directly at the virtual source being monitored.
- Be sure there is easy access for the exchange of crystals.
- For systems employing simultaneous source evaporation (co-deposition), try to locate the sensors so the evaporant from each source is flowing to only one sensor. It is not generally possible to do this without special shielding or optional "material directors".

6.1.3 Control Unit Installation

The control unit is designed to be rack mounted. It may be also used on a table. The controller is forced-air cooled, with the air flow exiting the rear of the unit for clean room convenience.

It is generally advisable to centrally locate the controller, minimizing the length of external cabling. Sensor board to XIU cables are available in lengths of 15’ (4.6 m), 30’ (9.2 m), 50’ (15.3 m), and 100’ (30.5 m).

6.2 Avoiding Electrical Interference

Careful consideration of simple electrical guidelines during installation will avoid many problems caused by electrical noise.

To maintain the required shielding and internal grounding and ensure safe and proper operation, the instrument must be operated with all enclosure covers, sub-panels and braces in place and fully secured with the screws and fasteners provided.

NOTE: When using Cygnus with an RF sputtering system, the cable between Cygnus and oscillator should be kept as far away from the RF transmission cable as possible. Interference from the RF transmission cable may cause an erroneous crystal fail.

6.2.1 Verifying/Establishing Earth Ground

If a ground must be established, the following procedure is recommended:

- Where soil conditions allow, drive two ten foot copper clad steel rods into the ground six feet apart. Pour a copper sulfate or a salt solution around to improve the ground’s conduction. A near zero resistance measurement between the two rods indicates earth ground is achieved.
- Keep connections to this grounding network as short as possible.

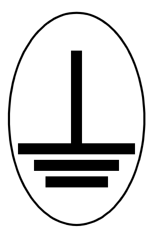
6.2.2 Connections to Earth Ground

There are two earth connectors:

- The ground connection on the controller is a threaded stud with a hex nut. One suggestion is to connect a ring terminal to the ground strap, thus allowing a good connection, and easy removal and installation. See Figure 6-3 for the suggested method of grounding.
- This instrument is also connected to earth via a sealed three-core power cable, which must be plugged into a socket outlet with a protective earth terminal. Extension cables must always have three conductors including a protective earth conductor.

WARNING - Risk Of Electric Shock

Never interrupt the protective earthing intentionally. Any interruption of the protective earth connection inside or outside the instrument, or disconnection of the protective earth terminal is likely to make the instrument dangerous.



This symbol indicates where the protective earth ground is connected inside the instrument. Never unscrew or loosen this connection.

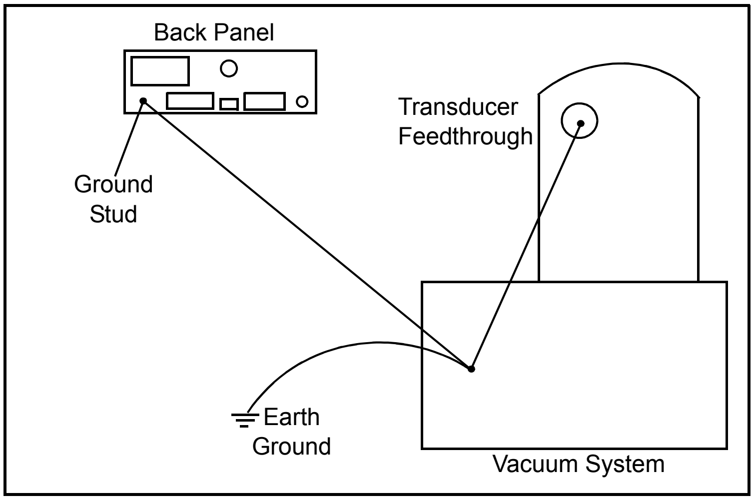
CAUTION

An external ground connection is required to ensure proper operation, especially in electrically noisy environments.

When used with RF powered sputtering systems, the grounding method may have to be modified to the specific situation. An informative article on the subject of Grounding and RFI Prevention was published by H.D. Alcaide, in “Solid State Technology”, p.117, April, 1982.

In many cases, a braided ground strap is sufficient. However, there are cases when a solid copper strap (0.030" thick x 1" wide) is required because of its lower RF impedance.

Figure 6-3 System Grounding Diagram



6.2.3 Minimizing Noise Pickup From External Cabling

When a controller is fully integrated into a deposition system, there are many wire connections, each a potential path for noise to reach the inside of the control unit. The likelihood of these wires causing a problem can be greatly diminished by adhering to the following guidelines.

- Use shielded coax cable or twisted pairs for all connections.
- Minimize cable lengths.
- Avoid routing cables near areas that have the potential to generate high levels of interference. For example, large power supplies such as those used for electron beam guns or sputtering sources can be a source of large, rapidly changing electromagnetic fields. Placing cables as little as one foot away from these problem areas can significantly reduce noise pickup.
- Be sure that a good ground system and straps are in place per the recommendations in section 6.2.2 on page 6-6.
- Ensure that all instrument covers and option panels are in place and tightly secured with the provided fasteners.

NOTE: Always use shielded cables when making connections to the Cygnus rear panel to minimize electrical noise pickup.

6.3 Connecting the Controller

The operation of the controller depends on the proper connection of power and signal interfaces to owner equipment and sources.

6.3.1 Verifying the Correct Input Voltage

WARNING - Risk Of Electric Shock

This instrument has line voltage present on the primary circuits whenever it is plugged into a main power source.

Never remove the covers from the instrument during normal operation.

There are no operator serviceable items within this instrument.

Removal of the top or bottom covers must be done only by a technically qualified person.

In order to comply with accepted safety standards, this instrument must be installed into a rack or system which contains a mains switch. This switch must break both sides of the line when it is open and it must not interfere with the safety ground.

The controller is initially powered by AC line current. The four supported nominal voltage settings and their acceptable voltage input ranges are shown in Table 6-2.

Table 6-2 Supported Nominal Voltage Settings

Nominal Setting	Acceptable Input Range
100 V(ac)	85 to 110 V(ac)
120 V(ac)	108 to 132 V(ac)
230 V(ac)	207 to 253 V(ac)
240 V(ac)	204 to 264 V(ac)

One of these nominal voltages has been factory set and that number shows through the window in the power input module. The line voltage provided in your facility must be within the voltage range indicated in Table 6-2 for the nominal setting.

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If the nominal line voltage is 230 V(ac), use the 240 V(ac) nominal setting whose input range includes 230 V(ac) ±10%.

WARNING

Verify that the correct fuse is in place by first unplugging the unit, then pull the fuse extractor and visually inspect the fuse for the proper rating. Use of an improper fuse may create a safety hazard.

For 100 or 120 V(ac) operation, use a 4 amp Type T fuse. For 230 or 240 V(ac) operation, use a 2 amp Type T fuse.

Also, visually verify that the voltage selector drum has been oriented to the proper position.

6.3.2 Voltage Selection

If necessary, the power supply voltage range can be checked or changed on site by a knowledgeable technician using extreme caution.

CAUTION

Damage to the unit and/or its interfaces will result by operating the unit in the incorrect voltage range.

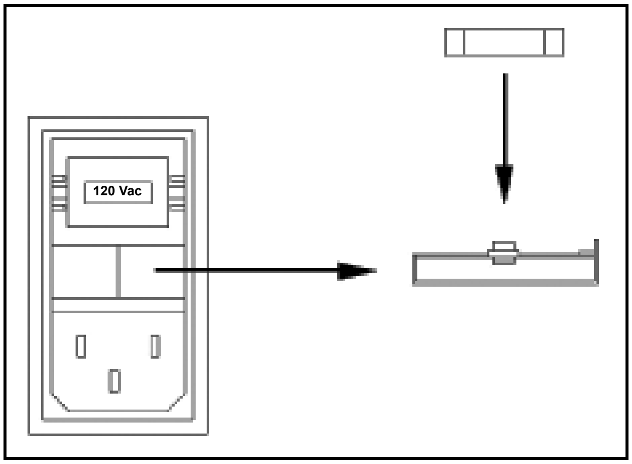
WARNING - Risk Of Electric Shock

This instrument has line voltage present on the primary circuits whenever it is plugged into a main power source.

If the voltage selector drum needs to be changed to match your nominal line voltage, it is required that the power cord be removed. Pry open the hinged door that covers the voltage select drum and fuse. Pull out the drum. Reorient the selector to the desired nominal line voltage. Reinsert the drum.

Pull out the fuse holder and check the fuse type and rating. The fuse must be a 4 amp Type T for either the 100 V(ac) or 120 V(ac) settings, or a 2 amp Type T for either the 230 V(ac) or 240 V(ac) settings. Install the proper fuse, push the holder firmly into place, and close the hinged door over the fuse and selector drum. The selected nominal voltage will show through the window. See Figure 6-4

Figure 6-4 Voltage Selector Drum and Fuse



6.3.3 Routing XIU Cables

XUI to controller cables can be 15’ (4.6 m), 30’ (9.2 m), 50’ (15.3 m), and 100’ (30.5 m) in length. The signals traveling on this cable are both analog and digital. It is suggested that it not be routed near areas with high levels of electromagnetic interference, even if its length must be somewhat increased.

6.3.4 Interface Cable Fabrication and Pin-Out

It is necessary to fabricate several cables in order to interface the controller to the deposition system. Refer to section 6.2.3, Minimizing Noise Pickup From External Cabling, on page 6-7.

6.3.4.1 Source Control Connection

A Digital to Analog Converter (DAC) card, IPN 760-1112-G1, is included as standard equipment with the controller. It provides 6 conversion channels. These 6 channels may be programmed for source control or chart recorder functions as desired. The 6 connectors are BNC.

6.3.4.2 Input/Relay Module Connections

The Input/Relay module, IPN 760-162-G1, is included as standard equipment with the controller and is used to interface with other machinery of the vacuum system. It can control components such as heaters, rotators or shutters through its 8 relays. It can respond to external instructions through its 14 isolated input lines. Standard equipment provides 8 relays and 14 input lines. Optionally, this can be expanded to 24 relays, 28 TTL inputs, and 14 open collector type outputs with the addition of 2 optional I/O cards.

The module provides separate connectors for relay outputs and input lines. A 25-pin D-sub, male connector is used for the eight relays. A 15-pin D-sub, male connector is used for the input lines. Mating connectors are provided in ship kits IPN 779-610 and 760-024. Refer to Figure 2-2 on page 2-3 for connector locations. Relay connections are rated at 30 V(dc) or 30 V(ac) RMS or 42 V(peak) maximum; 2.5 A maximum.

Inputs are activated by pulling the specific Input terminal to ground (<0.8 V) through a contact closure to common (GND) or with TTL/CMOS Logic having current sink capability of 2 mA (1 low power TTL load).

WARNING - Risk Of Electric Shock

The relay, relay circuit, and associated pins in the I/O connector(s) have a maximum voltage rating of 30 V(dc) or 30 V(ac) RMS or 42 V(peak). The maximum current rating per connector pin or relay contact is 2.5 Amps.

Table 6-3 Input/Relay Pin Connections

I/O Board #1			
Relay #	**Pins**	**TTL Input #**	**Pin**
1	7, 6	1	15
2	9, 8	2	14
3	11, 10	3	13
4	13, 12	4	12
5	5, 4	5	11
6	3, 2	6	10
7	1, 14	7	9
8	15, 16	8	8
		9	7
		10	6
		11	5
		12	4
		13	3
		14	2
		GND	1

I/O Board #3			
Relay #	**Pins**	**TTL Output #**	**Pin**
17	7, 6	25	9
18	9, 8	26	10
19	11, 10	27	11
20	13, 12	28	12
21	5, 4	29	13
22	3, 2	30	14
23	1, 14	31	15
24	15, 16	32	1
		33	2
		34	3
		35	4
		36	5
		37	6
		38	7
		GND	8

I/O Board #2			
Relay #	**Pins**	**TTL Input #**	**Pin**
9	7, 6	15	15
10	9, 8	16	14
11	11, 10	17	13
12	13, 12	18	12
13	5, 4	19	11
14	3, 2	20	10
15	1, 14	21	9
16	15, 16	22	8
		23	7
		24	6
		25	5
		26	4
		27	3
		28	2
		GND	1

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6.3.4.3 RS-232C Communications

RS-232C serial communications is included in the controller as standard equipment. It is used to remotely control or monitor the Cygnus. An industry standard 9-pin D-Sub connector is required for the host computer side connection. Depending on the computer source, all connections may not be necessary. The length of the cable is limited to fifty feet according to published standards. The controller interface operates as DTE (Data Terminal Equipment). Pin assignments are for the Cygnus connector.

Table 6-4 RS-232C Pin Connections

Signal Name		Pin	EIA Name
TX	Transmit Data	2	BA
RX	Receive Data	3	BB
RTS	Request To Send	8	CA
CTS	Clear To Send	7	CB
DSR	Data Set ready	4	CC
SG	Signal Ground	5	AB
	(Not Used)	1	
DTR	Data Terminal Ready	6	CD
GND	Shield Ground	9	

6.3.4.4 Isolated +24 V(dc) Supply

An isolated +24 V(dc) power supply is available on a 9-pin D-Sub connector on the Cygnus back panel. This supply is rated for 1.75 Amps maximum.

The pin assignments for this connector are:

Table 6-5 +24 V(dc) Pin Connections

Pin	Function
1	Return
2	Return
3	Return
4	Not Connected
5	Not Connected
6	+24 Volts
7	+24 Volts
8	+24 Volts
9	Not Connected

CAUTION

Both the isolated 24 V(dc) supply and the RS-232C remote communications port use a 9-pin D-sub connector. Care must be taken not to inadvertently connect the RS-232C remote communications cable to the 24-volt supply connector. Also, care must be taken not to inadvertently connect the 24 V(dc) supply cable to the RS-232C remote communications connector.

6.3.4.5 Optional DAC Card

An optional Digital to Analog Converter (DAC) card can be installed into the Cygnus. This card provides additional DAC outputs, numbered 7 through 12, for Thickness and/or Rate as determined by the DAC Output Option parameters (refer to section 4.3 on page 4-3). The pin assignments for DAC outputs 7 through 12 are shown in Table 6-6.

Table 6-6 Optional DAC Pin Assignments

Output Number	Pin
7	1, 6 (GND)
8	2, 7 (GND)
9	3, 8 (GND)
10	4, 9 (GND)
11	5, 10 (GND)
12	11, 12 (GND)

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Chapter 7
Calibration Procedures

7.1 Importance of Density, Tooling and Z-Ratio

The quartz crystal microbalance is capable of precisely measuring the mass added to the face of the oscillating quartz crystal sensor. The instrument's knowledge of the density of this added material (specified in the density parameter in the Channel Parameters set up) allows conversion of the mass information into thickness. In some instances, where highest accuracy is required, it is necessary to make a density calibration as outlined in section 7.2.

Because the flow of material from a deposition is not uniform, it is necessary to account for the different amount of material flow onto the sensor compared to the substrates. This factor is accounted for in the tooling parameter in Channel Parameters set up. The tooling factor can be experimentally established by following the guidelines in section 7.3.

In the Cygnus if the Z-ratio is not known, it could be estimated from the procedures outlined in section 7.4, or, typically, the Auto Z function can be used to determine the Z-ratio.

7.2 Determining Density

NOTE: The bulk density values retrieved from the Material Library are sufficiently accurate for most applications.

Follow the steps below to determine density value:

1. Place a substrate (with proper masking for film thickness measurement) adjacent to the sensor, so that the same thickness will be accumulated on the crystal and this substrate.
2. Set density to the bulk value of the film material or to an approximate value.
3. Set Z-ratio to 1.000 and tooling to 100%.
4. Place a new crystal in the sensor and make a short deposition (1000-5000 Å), using manual control.
5. After deposition, remove the test substrate and measure the film thickness with either a multiple beam interferometer or a stylus-type profilometer.
6. Determine the new density value with the following equation:

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$$\text{Density}(g/cm^3) = D_1\left(\frac{T_x}{T_m}\right) \quad [1]$$

where:

D_1 = Initial density setting

T_x = Thickness reading on Cygnus

T_m = Measured thickness

7 A quick check of the calculated density may be made by programming the instrument with the new density value and observing that the displayed thickness is equal to the measured thickness, provided that the instrument's thickness has not been zeroed between the test deposition and entering the calculated density.

NOTE: Slight adjustment of density may be necessary in order to achieve $T_x = T_m$.

7.3 Determining Tooling

1 Place a test substrate in the system's substrate holder.

2 Make a short deposition and determine actual thickness.

3 Calculate tooling from the relationship:

$$\text{Tooling}(\%) = TF_i\left(\frac{T_m}{T_x}\right) \quad [2]$$

where

T_m = Actual thickness at substrate holder

T_x = Thickness reading on Cygnus

TF_i = Initial tooling factor

4 Round off percent tooling to the nearest 0.1%.

5 When entering this new value for tooling into the program, T_m will equal T_x if calculations are done properly.

NOTE: It is recommended that a minimum of three separate evaporations be made when calibrating tooling. Variations in source distribution and other system factors will contribute to slight thickness variations. An average value tooling factor should be used for final calibration.

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7.4 Laboratory Determination of Z-Ratio

NOTE: On Cygnus, the Auto Z function is available to automatically calculate the Z-Ratio. Especially when precise Z-Ratio values are significant, Auto Z is recommended. Refer to section 9.1.6 on page 9-9 for a description of Auto Z theory.

A list of Z-values for materials commonly used is available in the Material Library. For other materials, Z can be calculated from the following formula:

$$Z = \left(\frac{d_q \mu_q}{d_f \mu_f}\right)^{\frac{1}{2}} \quad [3]$$

$$Z = 9.378 \times 10^5 (d_f \mu_f)^{-\frac{1}{2}} \quad [4]$$

where:

d_f = density (g/cm3) of deposited film

μ_f = shear modulus (dynes/cm2) of deposited film

d_q = density of quartz (crystal) (2.649 gm/cm3)

μ_q = shear modulus of quartz (crystal) (3.32 x 1011 dynes/cm2)

The densities and shear moduli of many materials can be found in a number of handbooks.

Laboratory results indicate that Z-values of materials in thin-film form are very close to the bulk values. However, for high stress producing materials, Z-values of thin films are slightly smaller than those of the bulk materials. For applications that require more precise calibration, the following direct method is suggested:

1 Establish the correct density value as described in section 7.2 on page 7-1.

2 Install a new crystal and record its starting frequency Fco. It will be necessary to send the SC 12 n command to get this information (see section 5.4.4, STATUS Commands, on page 5-24).

3 Make a deposition on a test substrate such that the percent crystal life display will read approximately 50%, or near the end of crystal life for the particular material, whichever is smaller.

4 Stop the deposition and record the ending crystal frequency Fc using the SC 12 n command.

5 Remove the test substrate and measure the film thickness with either a multiple beam interferometer or a stylus-type profilometer.

6 Using the density value from step 1 and the recorded values for F_{co} and F_c, adjust the Z-Ratio value in thickness equation [5] to bring the calculated thickness value into agreement with the actual thickness. If the calculated value of thickness is greater than the actual thickness, increase the Z-Ratio value. If the calculated value of thickness is less than the actual thickness, decrease the Z-Ratio value.

$$T_f = \frac{Z_q \times 10^4}{2\pi z p}\left\{\left(\frac{1}{F_{co}}\right)ATan\left(zTan\left(\frac{\pi F_{co}}{F_q}\right)\right) - \left(\frac{1}{F_c}\right)ATan\left(zTan\left(\frac{\pi F_c}{F_q}\right)\right)\right\} \qquad [5]$$

where:

T_f = thickness of deposited film (kÅ)

F_{co} = starting frequency of the sensor crystal (Hz)

F_c = Final frequency of the sensor crystal (Hz)

F_q = Nominal blank frequency = 6045000 (Hz)

z = Z-Ratio of deposited film material

Z_q = Specific acoustic impedance of quartz = 8765000 (MKS units)

p = density of deposited film (g/cc)

For multiple layer deposition (for example, two layers), the Z-value used for the second layer is determined by the relative thickness of the two layers. For most applications the following three rules will provide reasonable accuracies:

- If the thickness of layer 1 is large compared to layer 2, use material 1 Z-value for both layers.
- If the thickness of layer 1 is thin compared to layer 2, use material 2 Z-value for both layers.
- If the thickness of both layers is similar, use a value for Z-Ratio which is the weighted average of the two Z values for deposition of layer 2 and subsequent layers.

7.5 Determining Cross Sensitivity Correction For Co-Deposition

The Cross Talk Percent correction feature of the Cygnus is beneficial to applications involving the simultaneous deposition of two materials. When depositing two materials it is not always possible to isolate each crystal so that it samples material from a single source. The Cross Sensitivity feature is used to eliminate this "cross talk" of material from the second source being deposited onto the crystal intended to control the deposition rate from the first source.

7.5.1 Procedure Overview

The procedure consists of steps to deposit on both crystals having only one source turned on and then to calculate the interference at sensor Channel “N+1” as a percentage of the rate at sensor Channel "N". The first source is then turned off and a deposit is made on both crystals having only the second source turned on. The interference at sensor Channel "N" is then calculated as a percentage of the rate at sensor Channel "N+1".

Having calculated and entered the cross talk percent values, a co-deposition can then be run with the cross talk corrected for each crystal. A detailed procedure on how to accomplish this is outlined below. The amount of cross talk at each sensor must be less than 100%.

NOTE: Due to the way the cross sensitivity parameter is implemented in the Cygnus, the selection of Co-Deposition channels are based on the Channel number N=Odd value and N+1=Even value adjacent source channels. Also, the density and Z-Ratio values for both channels are required to be the same when calculating the Cross Talk Percent values. After calculating the proper Cross Talk Percent values, the density and Z-Ratio parameters are returned to their proper values.

7.5.2 Procedure Assumptions and Requirements

- It is assumed the operator is familiar with the operation and programming of the instrument.
- Use Channel N and (N+1) as the adjacent channels to have Cross Talk Percent calculated for each channel.
- The Tooling Factors for each sensor must be determined prior to calculating the Cross Sensitivity values. If this has not been done, refer to section 7.3 on page 7-2.
- Set the Max Power Option parameter for each channel to 0 (Continue).
- Program the Final Thickness value for each channel to be 999.9 kÅ.
- Program the pre-deposition and post-deposition states for the Sources and the desired deposition Rates you wish to co-deposit.
- Program all source and sensor shutters to their appropriate values.
- Use the detailed procedure below to calculate the Cross Talk Percent values to be entered into the respective Channel Definitions.

7.5.3 Detailed Procedure

Proceed as follows to calculate the amount of cross talk at Sensor Channel N due to material from Source Channel (N+1):

1. Enter 0.1 into the Rate parameter for Channel N. Enter zero into the Maximum Power parameter for Channel N.
2. Enter zero into the Cross Talk Percent parameter for Channel (N+1). The value in the Cross Talk Percent parameter for Channel N should also be zero.
3. Enter the Density and Z-Ratio for the Material in Channel (N+1) into the Density and Z-Ratio parameters for both materials. Enter a value of Auto-Z parameter = No for both Channel N and Channel (N+1).
4. Start the co-deposition, allowing Channels N and (N+1) to sequence through the pre-deposition phases. The power for source Channel (N+1) should be ramped to the appropriate levels while the power for source Channel N should be held at 0 %.
5. After Channels N and (N+1) enter DEPOSIT and the rate from source Channel (N+1) is stable at the desired deposition rate, manually zero the thickness accumulation for both Channels. This may be done from the All Channel display by placing the cursor on Channel N and pressing the panel key Zero Thickness (F2), moving cursor to Channel (N+1) and again pressing the panel key Zero Thickness (F2) in rapid succession or by using the Zero Thickness commands via the remote communications or internal logic.
6. Allow a thickness to accumulate for Channels N and (N+1) (on both sensors) for at least 1 minute. Longer thickness accumulations may be necessary for low rates and/or to reduce the error introduced by not being able to zero the thickness for both Channels concurrently. Larger thickness accumulations will result in a more accurate calculated value.
7. Calculate the Cross Talk Percent value for Channel N using the following equation: CTP(N) = (Thickness at sensor Channel N / Thickness at sensor Channel (N+1)) X 100%
8. Enter the calculated value, CTP(N), as the Cross Talk Percent parameter's value for Channel N. Zero the thickness accumulation for both Channels concurrently and monitor the thickness accumulation for both Channels.
9. The thickness for Channel N should remain at 0.000 kÅ. Small adjustments of the value for the Cross Talk Percent may be necessary in order to obtain a zero thickness accumulation for Channel N.
10. Stop the deposition, allowing the material in source Channel (N+1) to cool sufficiently so that no material is being deposited. Place the instrument into the Ready state by pressing Reset.

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Proceed as follows to calculate the amount of cross talk at Sensor Channel (N+1) due to material from Source Channel N:

1. Enter the desired Rate parameter's value for Channel N. Enter the appropriate Maximum Power value into Channel N.
2. Enter a Rate of 0.1 into the rate parameter for Channel (N+1). Enter zero as the value of the Maximum Power parameter for Channel (N+1).
3. Enter the density and Z-Ratio for Channel N into the Density and Z-Ratio parameters for both Channels. Enter a value of Auto-Z parameter = No for both Channel N and Channel (N+1).
4. Enter a value of zero into the Cross Talk Percent parameter for Channel N. The value in the Cross Talk Percent parameter for Channel (N+1) should also be zero.
5. Start the co-deposition, allowing Channels N and (N+1) to sequence through the pre-deposition phases. The power for source Channel N should be ramped to the appropriate levels while the power to source Channel (N+1) should be held at 0 %.
6. After Channels N and (N+1) enter the DEPOSIT state and the rate from source Channel N is stable at the desired deposition rate, zero the thickness accumulation for both Channels. This may be done from the All Channel display by placing the cursor on Channel N and pressing the panel key Zero Thickness (F2), moving cursor to Channel (N+1) and again pressing the panel key Zero Thickness (F2) in rapid succession or by using the Zero Thickness commands via the remote communications or internal logic.
7. Allow the thickness to accumulate for Channels N and (N+1) (on both sensors) for at least 1 minute. Longer thickness accumulations may be necessary for low rates and/or to reduce the error introduced by not being able to zero the thickness for both Channels concurrently. Larger thickness accumulations will result in a more accurate calculated value.
8. Calculate the Cross Sensitivity value for Channel (N+1) using the following equation: CTP(N+1) = (Thickness at Sensor Channel (N+1)/Thickness at Sensor Channel N)X100%
9. Enter the calculated value, CTP(N+1), as the Cross Talk Percent parameter's value for Channel (N+1). Zero the thickness accumulation for both Channels concurrently and monitor the thickness accumulation for both Channels.
10. The thickness for Channel (N+1) should remain at 0.000 kÅ. Small adjustments of the value for the Cross Talk Percent may be necessary in order to obtain a zero thickness accumulation for Channel (N+1).
11. Stop the deposition and place the instrument into the READY state by pressing Reset. Enter the desired deposition rate into the Rate parameter for Channel (N+1). Enter the appropriate Maximum Power value into Channel (N+1). Also

enter the appropriate Final Thickness values into Channels N and (N+1) and set the Max Power Option for each channel to the desired value. Enter the correct values for Density and Z-Ratio parameters for Channel N and (N+1). Enter the desired value into the Auto-Z parameter for Sensor Channel N and (N+1).

12 Enter the appropriate Cross Talk Percent values into the definitions for Channels N and (N+1).

This completes the calculation of Cross Talk Percent values. The instrument is now ready for co-depositions.

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Chapter 8
Troubleshooting, Status and Error Messages

8.1 Status and Error Messages

ABBREVIATED AVERAGE

During a rate control state, a crystal failure occurred after more than 1 minute but before the number of minutes specified in the "Averaging Time" channel parameter. Indicates the time over which the Rate and Power are averaged is less than the requested time interval specified by the "Averaging Time" channel parameter.

ALREADY RUNNING

This message appears if a START command is given to the Channel and the Channel is already executing its process.

ALREADY SWITCHING

An attempt is being made to switch a crystal or switch a crucible while a crystal switch or crucible switch is already in progress.

CANNOT TOGGLE INPUT

Output types can be toggled between Normally Open and Normally Closed. An Input does not have a type function and cannot be toggled.

CANT DO: XTAL SWITCH

An XIU test can not be done while a crystal switch is in progress.

CAROUSEL CHANGE-OUT

The crystal carousel assembly has been removed from a Crystal12 sensor.

CHANNEL TOO BIG

A Channel value greater than 6 can not be entered into a Thickness Equation.

CRUC SWITCH ERROR

This error occurs when a Channel has been in the Crucible Switch state for greater than 1 minute without receiving a valid Turret Feedback input signal.

CRUC SWITCHING

Indicates a crucible switch is in progress.

DATA LOG FAILURE

The instrument is attempting to output the datalog string faster than the external device (e.g., computer, or floppy disk) can accept the data. This means the datalog information for this Channel is lost.

DISK ERROR

The instrument is unable to save or retrieve information on the floppy disk.

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DISK IS FULL

There is not enough capacity on the floppy disk to save the requested configuration file or datalog string.

DISK WRITE PROTECTED

The Save requested cannot be performed when the floppy disk is physically write protected.

DUPLICATE CHANNEL

Channel values entered into a Thickness Equation can not be duplicated, for example a value of 123 is allowed, a value of 223 is not allowed.

EDIT IN PROGRESS

The I/O Map display cannot be exited while an edit name operation is occurring.

FILE CHECKSUM ERROR

Indicates the instrument configuration file being loaded from the floppy disk is corrupt and does not pass the checksum verification. The instrument parameters remain unchanged from prior to the load operation.

FILE FORMAT ERROR

Indicates the file being loaded from the floppy disk is not in the proper instrument configuration file format. The instrument parameters remain unchanged from prior to the load operation.

FILE RANGE ERROR

This error message indicates the configuration file contains a value which exceeds the allowed range for a particular parameter. This may occur if transferring files between two different versions of instrument software and one of the software versions has a different acceptable range of values for a given parameter.

FILE READ ERROR

The load operation could not be completed due to an error reading the floppy disk. The instrument parameters remain unchanged from prior to the retrieve operation.

HARDWARE DEFINED

An attempt is being made to use an Input or Output that has been previously defined.

ILLEGAL BAUD RATE

Baud rate selections are 2400, 4800, 9600, or 19200.

ILLEGAL DATE

The month or day entry is invalid. Month numbers must be in the 01 to 12 range; day numbers must be in the correct range for the month specified.

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ILLEGAL INPUT

An attempt was made to enter an invalid parameter or a function key was pressed and the function can not be completed at the time the key was pressed.

ILLEGAL LOCK CODE

The correct lock code is necessary to unlock parameters.

ILLEGAL SENSOR TYPE

Sensor type may be only 1, 2, 6, 7, or 12.

ILLEGAL TIME

Time is invalid. Numbers designating hours must be in the 00 to 23 range; numbers designating minutes must be in the 00 to 59 range.

IN CRUCIBLE SWITCH

The requested function can not be performed while the Channel is in the Crucible Switch state.

INVALID EQUATION

Strings must have connectors and required numerics before exiting the Logic Statement.

I/O EQUATIONS LOCKED

The strings comprising the I/O equations cannot be accessed while the program lock code is set.

LOADED DIFFERENT VER

Successful loading of an older Cygnus configuration file. New parameters may have been added at their default values and/or parameter ranges may have been increased.

LOCK

Indicates the remote communications or program lock code is on.

LOCK CODE ACCEPTED

The correct lock code has been entered.

LOCK CODE CLEARED

The lock code has been deleted.

LOCKED -NOT CHANGED

An attempt is being made to change a logic statement while the remote lock code is on.

MAX POWER

Indicates the specified maximum power has been reached on an active Channel. The power value will be displayed in inverse video.

MAXIMUM TERMS

No more than 5 terms are allowed in any one Event or Action string.

MEM ALLOC FAIL

This message appears if a Data Log or Print Screen operation fails because of an overuse of system memory. If this message appears contact the INFICON Service Department.

MIN POWER

Indicates the specified minimum power has been reached on an active Channel. The Min Power message will only be displayed when the Channel is at the minimum power level and the Channel is in one of the rate control states. The power value will be displayed in inverse video.

MUST BE IN MANUAL

When in the Source Maintenance display the Toggle Sensor Shutter, Toggle Source Shutter, and Crucible Switch functions can not be done unless the Channel is in the Manual state.

MUST EDIT NAME FIRST

The user requested a save name or save message operation without first having edited the name or message.

NO DISK IN DRIVE

Save or Load requires a floppy disk to be inserted: the disk is not detected by the instrument.

NO GOOD CRYSTAL

An attempt is being made to Start a Channel when there is a crystal failure for the Channel's sensor.

NO ROTATE: CRYSTAL 2

A rotate crystal head function can not be done on a Crystal 2.

NO ROTATE: RUNNING

A rotate crystal head function can not be performed while the Channel process is being executed.

NO SWITCH: BAD XTAL

An attempt is being made to switch the crystal and there are no good crystals remaining in the sensor head. This message will only appear when the Channel process is being executed. When in Ready a crystal switch to a failed crystal is permitted.

NO SWITCH: NO BOARD

A crystal switch cannot be done because no measurement board is installed for this channel.

NO SWITCH: NO OUTPUT

A crystal switch cannot be done because no output is set for crystal switching in the Channel hardware parameters set up display.

NO SWITCH: SINGLE

A crystal switch cannot be requested while using a single head sensor.

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NO SWITCH THIS DISP

The crystal switch function using the Hand Held controller is not allowed when the instrument in on the current display.

NO TEST: NO BOARD

No XIU Test is performed if there is no measurement card for that channel.

NO TIME POWER AVG

Indicates a crystal failure occurred within the first minute of control when the Averaging Time parameter value is >0, or a crystal failure occurred within the first 2.5 seconds of control when the Averaging Time parameter value is =0.

NOT IN READY

Indicates the Channel cannot perform the requested function unless it is in the READY state.

NOT ON CHANNEL

An attempt is made to do a START, STOP, RESET, or Crystal Switch from the front panel when not on a display that selects a channel.

ONLY ONE CRUCIBLE

This message appears when a Crucible Switch function is attempted and the Number of Crucibles value is 1.

OUTPUT USED EQU #

The output value being entered into the parameter is already in use by Logic equation #.

PARAMETERS DEFAULTED

Indicates the instrument parameters have been set to their default values. Any previously programmed values will have been changed to the default values.

POWER LOSS

Indicates the instrument lost line power immediately prior to the current power on cycle.

POWER MUST BE ZERO

When in the Source Maintenance display the power must be zero before a Crucible Switch function is performed.

PROGRAM LOCKED

Indicates the instrument is in Program Lock. This prohibits any parameter from being entered from the front panel until the Program Lock Code is entered on the Program display.

RATEWATCHER DELAY

The RateWatcher feature is active. The sensor is stabilizing for 5 seconds before SAMPLE. The previous sample period's Average Rate is being integrated for thickness. The previous sample period's Average Power is being held constant.

RATEWATCHER HOLD

The RateWatcher feature is active. The sensor shutter is closed. The previous sample period's Average Rate is being integrated for thickness. The previous sample period's Average Power is being held constant.

RATEWATCHER SAMPLE

The RateWatcher feature is active. The sensor shutter is open. The source rate is being measured and it's power controlled.

STOP - CRUCIBLE ERR

The Channel is in the STOP state because the Crucible Input was not present after being in the Crucible Switch state for more than 1 minute.

STOP - FRONT PANEL

Indicates the front panel STOP key has been pressed.

STOP - Hand Held

STOP executed from the Hand-Held Controller.

STOP - LOGIC n

STOP executed from Logic Statement n.

STOP - MAX POWER

Indicates the Channel is stopped because Max Power has been exceeded for over 5 seconds.

STOP - POWER LOSS

Indicates the instrument is in the STOP state due to a prior power loss.

STOP -REMOTE

A remote communications command has placed the Channel into the STOP state.

STOP - SWITCHER

Indicates the Channel is in the STOP state due to a sensor switcher failure.

STOP - XTAL FAIL

Indicates the Channel is in the STOP state due to a crystal fail while in pre- or post-deposit, or while in deposit.

SWITCH IN PROGRESS

The manual state can not be exited while a crystal switch is in progress.

TEST

Indicates the instrument is in TEST mode as determined in the General Parameters set-up.

TIME / DATE SET OK

The Time and / or Date change has been accepted.

UNABLE TO AUTO Z #

Indicates the requested Auto Z measurement cannot be completed due to the crystal condition. This is caused by a weak or unstable first anharmonic measurement. This also may be caused by the instrument not recognizing the crystal as a new crystal, or inserting a used crystal.

VALUE TOO LARGE

Parameter entry is out of range. Allowable values will vary according to your unit configuration or the parameter being defined. Press CLEAR to delete the value and enter again.

VALUE TOO SMALL

Parameter entry is out of range. Allowable values will vary according to your unit configuration or the parameter being defined. Press CLEAR to delete the value and enter again.

XIU TEST PASSED

The XIU has passed the XIU test.

XIU TEST FAILED

The XIU has failed the XIU test.

XTAL FAIL

Indicates the crystal for the Channel is failed.

XTAL SWITCH ERROR

This message indicates a CrystalSix or Crystal12 sensor switcher failure. The instrument did not detect the proper position after having attempted to rotate the sensor head.

XTAL SWITCHING

Indicates a crystal switch is in progress.

8.2 Troubleshooting Guide

If the instrument fails to work, or appears to have diminished performance, the following Symptom/Cause/Remedy chart may be helpful.

CAUTION

There are no user serviceable components within the instrument case.

Potentially lethal voltages are present when the line cord, Inputs or Outputs are connected.

Refer all maintenance to qualified personnel.

This instrument contains delicate circuitry which is susceptible to transients. Disconnect the line cord whenever making any interface connections. Refer all maintenance to qualified personnel.

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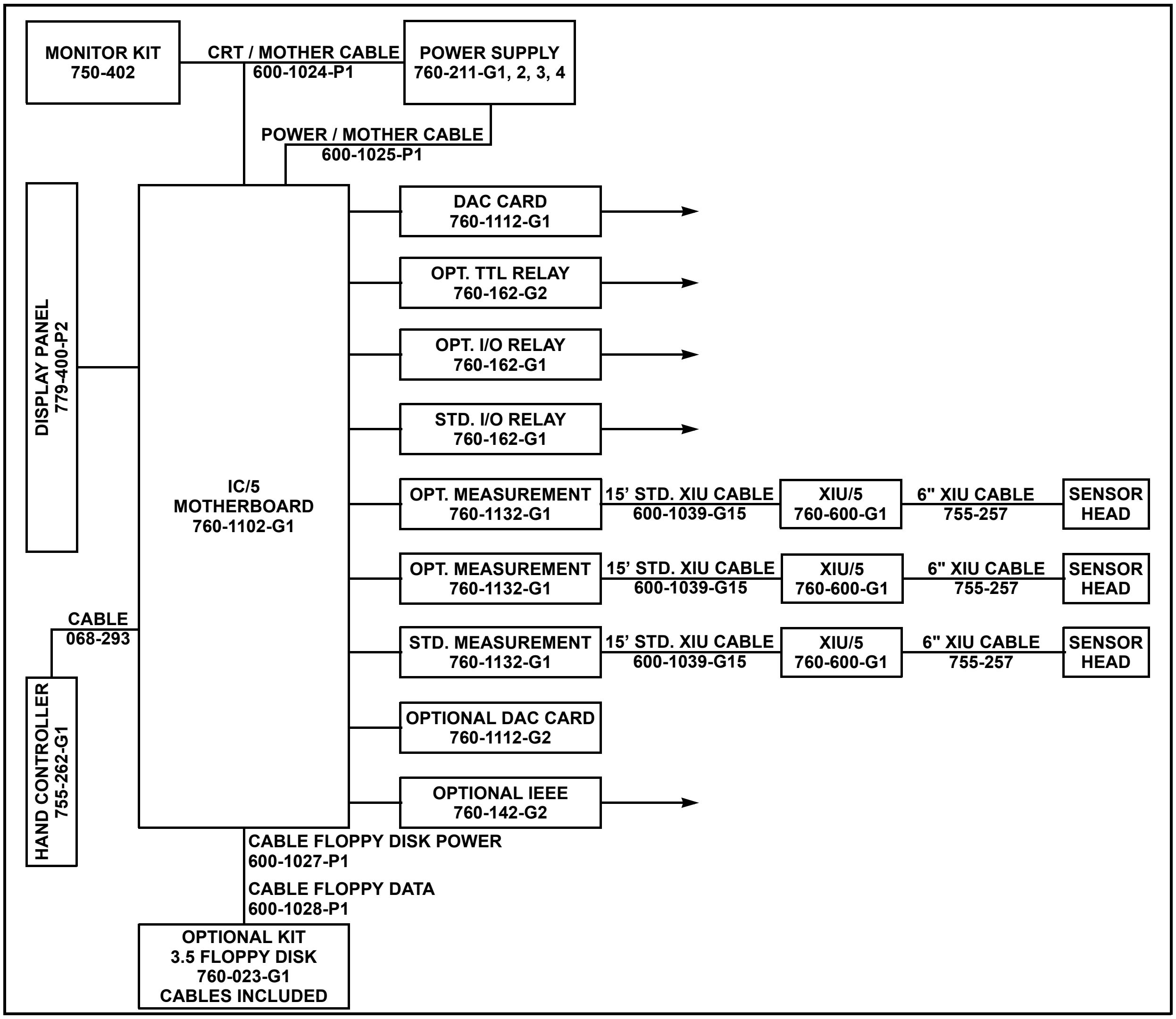
8.2.1 Major Instrument Components and Assemblies



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8.2.2 Troubleshooting the Instrument

Table 8-1 Troubleshooting the Instrument

SYMPTOM	CAUSE	REMEDY
1. power on LED not illuminated	a. blown fuse/circuit breaker tripped	a.have qualified personnel replace fuse/reset circuit breaker
	b. electrical cord unplugged from wall or back of instrument	b. reconnect power cord
	c. incorrect line voltage	c. have qualified personnel verify line voltage, verify the instrument is configured for the correct voltage
2. unit "locks" up	a. cover or back panels not attached to the instrument	a. ensure all covers and panels are in place and securely fastened
	b. high electrical noise environment	b. reroute cables to reduce noise pickup (1 ft away from high power conducting lines makes a sizable reduction in the amount of noise entering the instrument), keep all ground wires short with large surface area to minimize ground impedance
	c. poor grounds or poor grounding practice	c. verify proper earth ground, use appropriate ground strap, eliminate ground loops by establishing the correct system grounding, verify proper instrument grounding
3. instrument does not retain parameters on power down (loss of parameters on power up)	a. faulty static RAM	a. SRAM battery has a normal life expectancy of ten years. If your instrument has an SRAM problem contact the INFICON service department
	b. power supply problem	b. contact INFICON service department

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Table 8-1 Troubleshooting the Instrument (continued)

SYMPTOM	CAUSE	REMEDY
4. some keys on front panel function while others do not	a. faulty keypad or faulty keypad ribbon cable	a. contact INFICON service department
5. all keys on the front panel fail to function	a. instrument is "locked" up	a. turn power to OFF or to STBY, then to ON, see item 2 above
6. control voltage output does not function properly	a. DAC board damaged from applying voltage to the control voltage output	a. ensure cable connection to the DAC board does not have a potential across the contacts, contact INFICON service department
	b. reversed polarity of control voltage relative to that accepted by the source power supply	b. verify source output polarity of the DAC and the required input polarity of the source power supply, refer to the instruction manual to reconfigure the instrument if necessary
	c. improper control cable fabrication	c.check for correct cable wiring in the appropriate section of the manual
7. CRT or LCD display dull or blank	a. brightness/contrast adjustment required	a. refer to manual for location of adjustment potentiometer, adjust as desired
	b. LCD or CRT/power supply problem	b. contact INFICON service department
8. poor rate control	a. control loop parameters improperly selected	a. refer to the instruction manual section on tuning control loop parameters
	b. electron beam sweep frequency "beating" with the instrument's measurement frequency	b. adjust the sweep frequency so it is not a multiple of the instrument's measurement frequency

Table 8-1 Troubleshooting the Instrument (continued)

SYMPTOM	CAUSE	REMEDY
9 crystal fail message is always on	a. XIU/oscillator not connected	a. verify proper sensor/oscillator connections
	b. XIU oscillator malfunctioning	b. if available, insert a known working XIU/oscillator in place of suspect one; if XIU/oscillator is confirmed bad, contact INFICON service department
	c. defective cable from feedthrough to XIU/oscillator or from instrument to XIU/oscillator	c. use an ohm meter or DVM to check electrical continuity or isolation as appropriate
	d. poor electrical contact in the transducer, feedthroughs, or in-vacuum cable	d. use an ohm meter or DVM to check electrical continuity or isolation as appropriate
	e. failed crystal/no crystal	e. replace crystal/insert crystal
	f. two crystals placed into the crystal holder	f. remove one of the crystals
	g. frequency of crystal out of range	g. verify that the crystal frequency is within the required range, use INFICON crystals.

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8.2.3 Troubleshooting Transducers/Sensors

NOTE: Many sensor head problems may be diagnosed with a DVM (Digital Volt Meter). Disconnect the short oscillator cable from the feedthrough and measure the resistance from the feedthrough's center pin to ground. If the reading is less than 1-2 megohms, the source of the leakage should be found and corrected. Likewise, with the vacuum system open check for center conductor continuity, a reading of more than 1 ohm from the feedthrough to the transducer contact indicates a problem. Cleaning contacts or replacing the in-vacuum cable may be required.

A somewhat more thorough diagnosis may be performed with the optional Crystal Sensor Emulator, 760-601-G2. See section 8.4 on page 8-25 for a discussion of its use and diagnostic capabilities.

NOTE: A more detailed troubleshooting guide is shipped with the sensor. Refer to that manual for more detailed information in some cases.

Table 8-2 Troubleshooting Transducers/Sensors

SYMPTOM	CAUSE	REMEDY
1. large jumps of thickness reading during deposition	a. mode hopping due to defective crystal	a. replace crystal, use ModeLock™ measurement system
	b. stress causes film to peel from crystal surface	b. replace crystal
	c. particulate or "spatter" from molten source striking crystal	c. thermally condition the source thoroughly before deposition, use a shutter to protect the crystal during source conditioning
	d. scratches or foreign particles on the crystal holder seating surface (improper crystal seating)	d. clean and polish the crystal seating surface on the crystal holder
	e. small pieces of material fell on crystal (for crystal facing up sputtering situation)	e. check the crystal surface and blow it off with clean air
	f. small pieces of magnetic material being attracted by the sensor magnet and contacting the crystal (sputtering sensor head)	f. check the sensor cover's aperture and remove any foreign material that may be restricting full crystal coverage

Table 8-2 Troubleshooting Transducers/Sensors (continued)

SYMPTOM	CAUSE	REMEDY
2. crystal ceases to oscillate during deposition before it reaches its "normal" life	a. crystal struck by particulate or "spatter" from molten source	a. thermally condition the source thoroughly before deposition, use a shutter to protect the crystal during source conditioning
	b. material on crystal holder partially masking crystal cover aperture	b. clean crystal holder
	c. existence of electrical short or open condition	c.using an ohm meter or DVM, check for electrical continuity in the sensor cable, connector, contact springs, connecting wire inside sensor, and feedthroughs
	d. check for thermally induced electrical short or open condition	d. see C above
NOTE: Crystal life is highly dependent on process conditions of rate, power radiated from source, location, material, and residual gas composition.		
3. crystal does not oscillate or oscillates intermittently (both in vacuum and in air)	a. intermittent or poor electrical contact (contacts oxidized)	a. use an ohm meter or DVM to check electrical continuity, clean contacts
	b. leaf springs have lost retentivity (ceramic retainer, center insulator)	b. bend leaves to approximately 45°
	c. RF interference from sputtering power supply	c. verify earth ground, use ground strap adequate for RF ground, change location of instrument and oscillator cabling away from RF power lines, connect instrument to a different power line
	d. cables/oscillator not connected, or connected to wrong sensor input	d. verify proper connections, and inputs relative to programmed sensor parameter

Table 8-2 Troubleshooting Transducers/Sensors (continued)

SYMPTOM	CAUSE	REMEDY
4. crystal oscillates in vacuum but stops oscillation after open to air	a. crystal was near the end of its life; opening to air causes film oxidation which increases film stress	a. replace crystal
	b. excessive moisture accumulates on the crystal	b. turn off cooling water to sensor prior to venting, flow warm water through sensor while chamber is open
5. thermal instability: large changes in thickness reading during source warm-up (usually causes thickness reading to decrease) and after the termination of deposition (usually causes thickness reading to increase)	a. inadequate cooling water/cooling water temperature too high	a. check cooling water flow rate, be certain that cooling water temperature is less than 30 °C; refer to appropriate sensor manual
	b. excessive heat input to the crystal	b. if heat is due to radiation from the evaporation source, move sensor further away from source and use sputtering crystals for better thermal stability; install radiation shield
	c. crystal not seated properly in holder	c. clean or polish the crystal seating surface on the crystal holder
	d. crystal heating caused by high energy electron flux (often found in RF sputtering)	d. use a sputtering sensor head
	e. poor thermal transfer from water tube to body (CrystalSix sensor)	e. use a new water tube whenever the clamping assembly has been removed from the body; if a new water tube is not available, use a single layer of aluminum foil between the cooling tube and sensor body, if your process allows
	f. poor thermal transfer (Bakeable)	f. use Al or Au foil washer between crystal holder and sensor body

Table 8-2 Troubleshooting Transducers/Sensors (continued)

SYMPTOM	CAUSE	REMEDY
6. poor thickness reproducibility	a. variable source flux distribution	a. move sensor to a more central location to reliably sample evaporant, ensure constant relative pool height of melt, avoid tunneling into the melt
	b. sweep, dither, or position where the electron beam strikes the melt has been changed since the last deposition	b. maintain consistent source distribution by maintaining consistent sweep frequencies, sweep amplitude and electron beam position settings
	c. material does not adhere to the crystal	c. make certain the crystal surface is clean; avoid touching crystal with fingers, make use of an intermediate adhesion layer
	d. cyclic change in rate	d. make certain source's sweep frequency is not "beating" with the instrument's measurement frequency
7. large drift in thickness (greater than 200 A for a density of 5.00 g/cc) after termination of sputtering	a. crystal heating due to poor thermal contact	a. clean or polish the crystal seating surface on the crystal holder
	b. external magnetic field interfering with the sensor's magnetic field (sputtering sensor)	b. rotate sensor magnet to proper orientation with external magnetic field, refer to the sputtering sensor manual IPN 074-157
	c. sensor magnet cracked or demagnetized (sputtering sensor)	c. check sensor magnetic field strength, the maximum field at the center of the aperture should be 700 gauss or greater

Table 8-2 Troubleshooting Transducers/Sensors (continued)

SYMPTOM	CAUSE	REMEDY
8. CrystalSix and Crystal12: crystal switch problem (does not advance or not centered in aperture)	a. loss of pneumatic supply, or pressure is insufficient for proper operation	a. ensure air supply is regulated at 80-90 PSIG
	b. operation has been impaired as a result of material accumulation on cover	b. clean material accumulation as needed, refer to either the CrystalSix manual IPN 074-155 or Crystal12 manual IPN 074-398 for maintenance
	c. improper alignment	c. realign as per instructions in either the CrystalSix manual IPN 074-155 or Crystal12 manual IPN 074-398
	d. 0.0225" diameter orifice not installed on the supply side of solenoid valve assembly.	d. install orifice as shown in either the CrystalSix manual IPN 074-155 or Crystal12 manual IPN 074-398
9. Crystal12: Carousel Change Out and Xtal Fail messages remain after installing carousel.	a. open circuit	a. initiate a Crystal Switch or Rotate Head function
10. Crystal12: Unit indexes twelve times and displays Xtal Switch Error, Xtal Fail, and Carousel Change Out message.	a. loss of electrical signal	a. check for electrical continuity and isolation
	b. resistor #1 is open	b. check for electrical continuity and isolation
	c. no carousel installed	c. install carousel
	d. torsion spring of electrical connection assembly broken	d. replace electrical connection assembly — refer to Crystal12 manual IPN 074-398

8.2.4 Troubleshooting Computer Communications

Table 8-3 Troubleshooting Computer Communications

SYMPTOM	CAUSE	REMEDY
1. communications cannot be established between the host computer and the instrument	a. improper cable connection	a. verify for correct cable wiring as described in the manual
	b. BAUD rate in host computer not the same as the instrument	b. verify BAUD rate in the host's applications program, verify BAUD rate in the instrument
	c. incompatible protocols being used	c. verify that the instrument protocol: RS232, GPIB, matches host
	d. incorrect device address (GPIB)	d. verify device address in host's applications program, (or in IBCONF file for National Instrs. GPIB) and verify instrument address
2. error code returned and CCB has MSB clear	a. A = illegal command	a. the command sent was not valid; verify command syntax

Table 8-3 Troubleshooting Computer Communications (continued)

SYMPTOM	CAUSE	REMEDY
	b. B = illegal value	b. the parameter's value sent is outside the range for the given parameter, verify parameter's range
	c. C = illegal ID	c. the command sent was for a parameter which doesn't exist; verify the correct parameter number
	d. E = no data to retrieve	d. some parameters may not be in use, depending on the value of other parameters
	e. F = cannot change value now	e. the command sent is for a parameter that cannot be changed while the channel or instrument is not in STOP or READY; place the instrument in the STOP or READY state in order to change the value
	f. L = length error	f. The response could overflow the return buffer.
	g. P = prior command failed	g. If one command of a multi-command packet fails, none of the following commands will be performed and this error code will be returned for these commands.
3. Error code returned and CCB has MSB set.	a. C = invalid checksum	a. Received packet checksum was different from checksum byte value.
	b. F = illegal format	b. Too many bytes for the commands requested.
	c. L = illegal length	c. Not zero nor bigger than max allowed (Add).
	d. M = too many commands	d. maximum of 100 commands allowed.
	e. T = Time-out	

8.3 Replacing the Crystal

The procedure for replacing the crystal is basically the same with all transducers, except the CrystalSix and Crystal12.

CAUTION

Always use clean nylon lab gloves and plastic tweezers for handling the crystal (to avoid contamination which may lead to poor adhesion of the film to the electrode).

Do not rotate the ceramic retainer assembly after it is seated (as this will scratch the crystal electrode and cause poor contact).

Do not use excessive force when handling the ceramic retainer assembly since breakage may occur.

NOTE: Certain materials, especially dielectrics, may not adhere strongly to the crystal surface and may cause erratic readings.

NOTE: Thick deposits of some materials, such as SiO, Si, and Ni will normally peel off the crystal when it is exposed to air, as a result of changes in film stress caused by gas absorption. When you observe peeling, replace the crystals.

8.3.1 Standard and Compact

Follow the procedure below to replace the crystal in the Standard and Compact sensor: (see Figure 8-1)

1. Gripping the crystal holder with your fingers, pull it straight out of the sensor body.
2. Gently pry the crystal retainer from the holder (or use the Crystal Snatcher; see Figure 8-4 on page 8-24).
3. Turn the retainer over and the crystal will drop out.
4. Install a new crystal, with the patterned electrode face up.
5. Push the retainer back into the holder and replace the holder in the sensor body.

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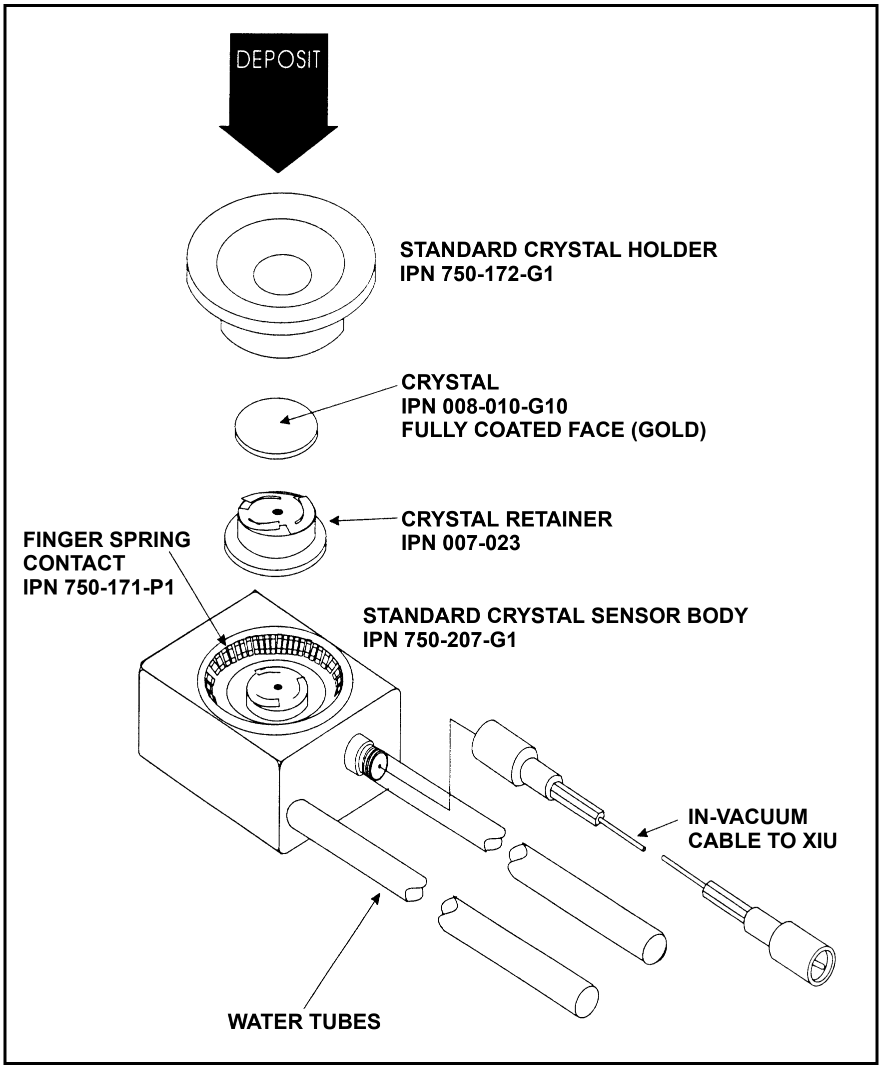
Figure 8-1 Standard Crystal Sensor (Exploded)



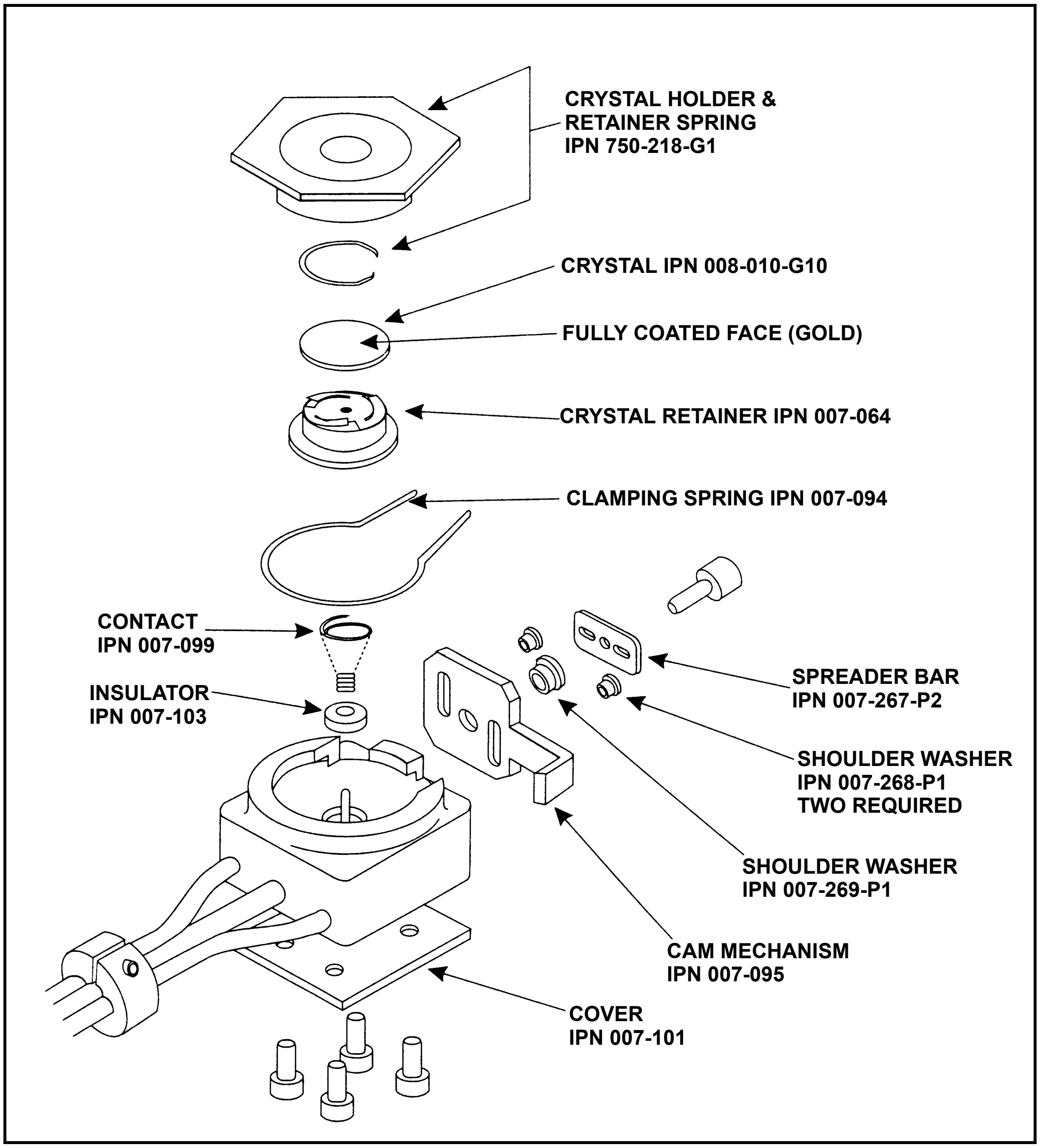
8.3.2 Shuttered and Dual Sensors

There is no difference in the crystal replacement procedure between shuttered and non-shuttered Standard and Compact sensors, since the shutter pivots away from the crystal opening when the shutter is in the relaxed state.

8.3.3 Bakeable Sensor

For the Bakeable sensor, the procedure is the same as the regular crystal except that you must first unlock the cam assembly by flipping it up. Once the crystal has been replaced, place a flat edge of the holder flush with the cam mechanism and lock it in place with the cam. See Figure 8-2.

Figure 8-2 Bakeable Crystal Sensor



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8.3.4 Sputtering Sensor

Observe the general precautions for replacing crystals and follow the instructions below to replace the crystal in a sputtering sensor.

1 Grip the body assembly with your fingers and pull it straight out to separate it from the water-cooled front part. (You may have to disconnect the sensor cable in order to separate the parts.) See Figure 8-3.

2 Pull the crystal holder straight out from the front of the sensor.

3 Remove the ceramic retainer from the crystal holder by pulling it straight out with the crystal snatcher (see section 8.3.5 on page 8-24).

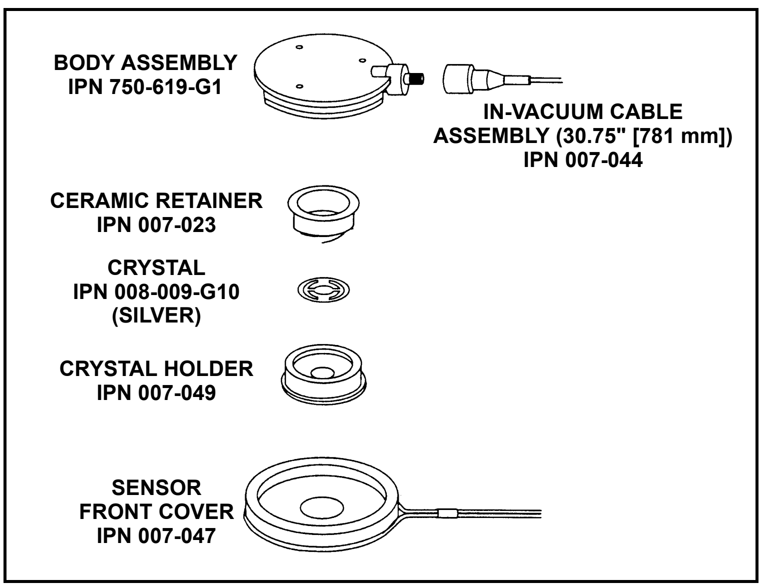
4 Turn the crystal holder over so that the crystal drops out.

5 Install a new crystal into the crystal holder with the patterned electrode facing the back and contacting the leaf springs on the ceramic retainer. (Use only special crystals for sputtering, IPN 008-009-G10.)

6 Put the ceramic retainer back into the crystal holder and put the holder into the front cover of the sensor.

7 Align the position of the back part so that the connector matches with the notch on the front of the sensor. Snap the two parts together. Reconnect the sensor cable if it has been disconnected.

Figure 8-3 Sputtering Crystal Sensor



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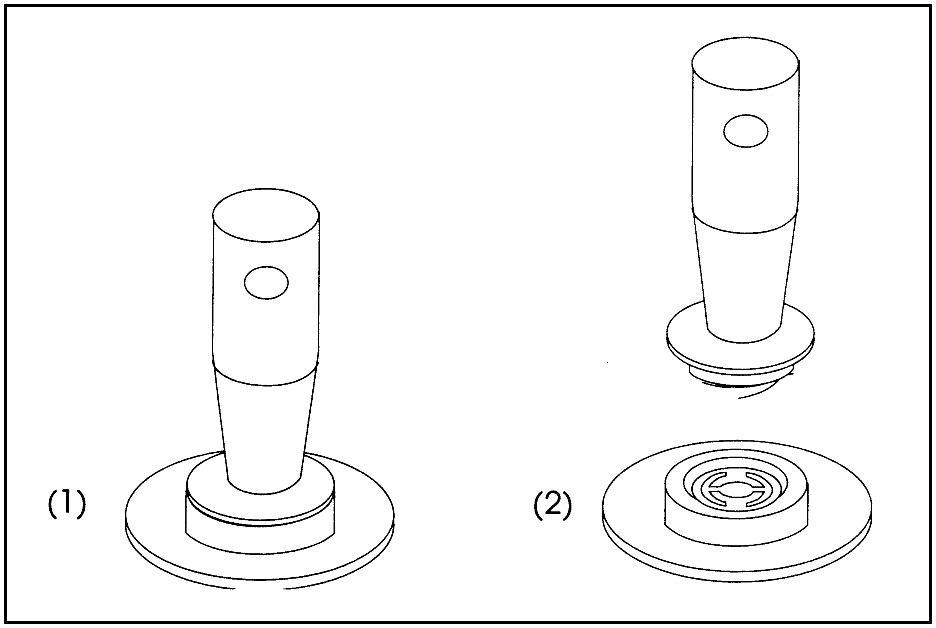
8.3.5 Crystal Snatcher

Use the crystal snatcher, supplied with the sensor, as follows:

1. Insert crystal snatcher into ceramic retainer (1) and apply a small amount of pressure. This locks the retainer to the snatcher and allows the retainer to be pulled straight out (2).
2. Reinsert the retainer into the holder after the crystal has been replaced.
3. Release the crystal snatcher with a slight side-to-side motion.

Figure 8-4 Use of the Crystal Snatcher



8.3.6 CrystalSix

Refer to the CrystalSix Operating Manual (IPN 074-155) for specific instructions for this device.

8.3.7 Crystal12

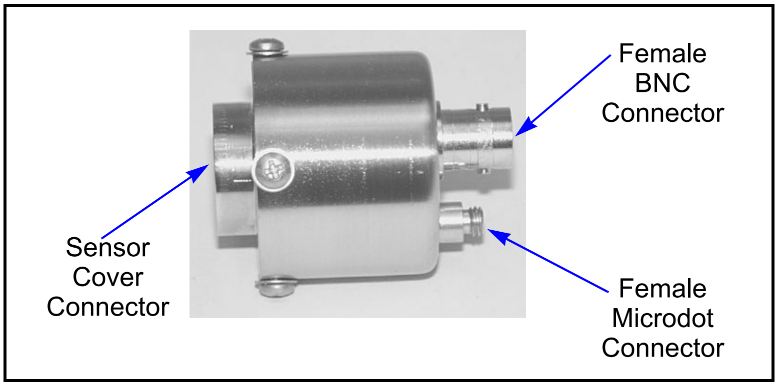
Refer to the Crystal12 Operating Manual (IPN 074-398) for specific instructions for this device.

8.4 Crystal Sensor Emulator IPN 760-601-G1 or 760-601-G2

NOTE: 760-601-G2 is fully compatible with all Thin Film Deposition Controllers. Crystal Sensor Emulator 760-601-G1 (obsolete) is not compatible for use with an IC/5, IC/4 or Cygnus.

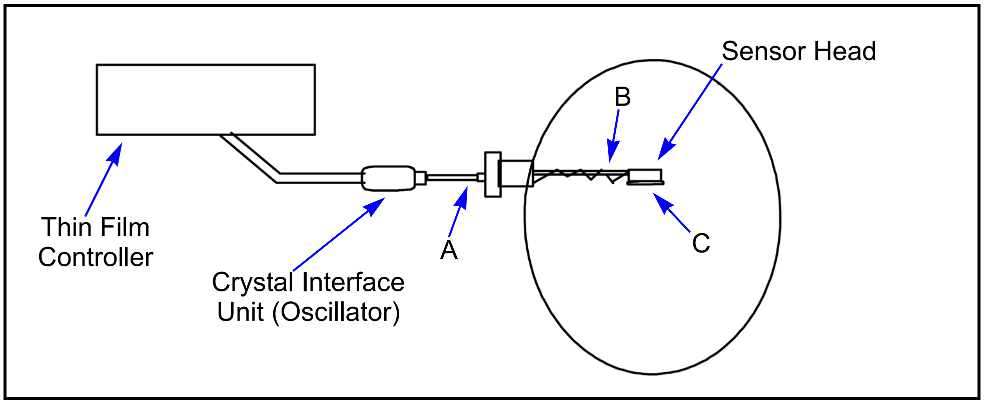
The Crystal Sensor Emulator option is used in conjunction with the Thin Film Deposition Controller to rapidly diagnose problems with the Deposition Controller's measurement system. See Figure 8-5.

Figure 8-5 Crystal Sensor Emulator



The Crystal Sensor Emulator may be attached at various points in the measurement system, from the oscillator to the sensor head. It provides a known "good" monitor crystal with known "good" electrical connections. Using the emulator and the controller in a systematic manner provides a fast means of isolating measurement system, cable, or sensor problems. See Figure 8-6.

Figure 8-6 Crystal Sensor Emulator Attachment Points



CAUTION

This product is designed as a diagnostic tool, and is not intended for use in vacuum. Do not leave the Crystal Sensor Emulator installed in the vacuum system during processing.

8.4.1 Diagnostic Procedures

The following diagnostic procedures employ the Crystal Sensor Emulator to analyze a constant Crystal Fail message. The symptom is a Crystal Fail message that is displayed by the Deposition Controller even after the monitor crystal has been replaced with a new “good” monitor crystal.

NOTE: The "Unable To Auto Z" message will be displayed if the Crystal Sensor Emulator is attached to a deposition controller and you are attempting to use the Auto Z feature. This is to be expected and is normal.

8.4.1.1 Measurement System Diagnostic Procedure

1. Refer to Figure 8-6 on page 8-25. Remove the six-inch BNC cable from the Feed-Through at point A.
2. Connect the Crystal Sensor Emulator to the 6 inch BNC cable at Point A.
   - If the XTAL Fail message disappears after approximately five seconds, the measurement system is working properly. Re-install the six-inch BNC cable to the Feed-Through. Go to section 8.4.1.2.
   - If the XTAL Fail message remains, continue at step 3.
3. Disconnect the six-inch BNC cable from the Oscillator and from the Emulator.
4. Visually inspect the six-inch BNC cable to verify that the center pins are seated properly.
5. Use an Ohm meter to verify the electrical connections on the six-inch BNC cable.
   - There must be continuity (<0.2 ohms) between the center pins.
   - There must be isolation (>10 megohms) between the center pins and the connector shield.
   - There must be continuity between the connector shields.

   Replace the six-inch BNC cable if it is found to be defective and repeat Step 2 of this procedure.
6. If the six-inch BNC cable is not defective, re-connect the six-inch cable to the oscillator and to the Crystal Sensor Emulator. If the XTAL Fail message remains, contact INFICON's Service Department. Refer to section 1.3 on page 1-6.

8.4.1.2 Feed-Through Or In-Vacuum Cable Diagnostic Procedure

1 Refer to Figure 8-6 on page 8-25. Remove the In-Vacuum cable from the Sensor Head at point B.

2 Connect the Crystal Sensor Emulator to the In-Vacuum cable.

- If the XTAL Fail message disappears after approximately five seconds, the Feed-Through and In-Vacuum Cable are working properly. Re-install the In-Vacuum cable to the Sensor Head. Go to section 8.4.1.3 on page 8-28.
- If the XTAL Fail message remains, continue at step 3.

3 Disconnect the In-Vacuum cable from the Feed-Through and the Emulator. Disconnect the six-inch BNC cable from the Feed-Through.

4 Using an Ohm Meter, verify electrical continuity from the BNC center pin on the Feed-Through to the Microdot center pin on the Feed-Through. A typical value would be less than 0.2 ohms.

5 Verify electrical isolation of the center pin on the Feed-Through from the electrical ground (Feed-Through body). A typical value would be in excess of 10 megohms.

If the Feed-Through is found to be defective, replace the Feed-Through, re-attach the BNC and In-Vacuum cables, and repeat this procedure starting at Step 2, otherwise continue at step 6.

6 Verify electrical continuity from center pin to center pin on the In-Vacuum cable.

7 Verify that the center pin of the In-Vacuum cable is electrically isolated from the In-Vacuum cable shield.

If the In-Vacuum cable is found to be defective, replace the In-Vacuum cable. Re-attach the BNC and In-Vacuum cables, and repeat this procedure starting at Step 2, otherwise continue at step 8.

8 Connect the In-Vacuum Cable to the Feed-Through.

9 Verify electrical continuity from the center pin on the BNC connector of the Feed-Through to the center pin on the un-terminated end of the In-Vacuum cable.

10 Verify electrical isolation from the center pin to electrical ground (Feed-Through body).

If the Feed-Through/In-Vacuum cable system is found to be defective, look for defective electrical contacts at the Feed-Through to In-Vacuum cable connection. Repair or replace the Feed-Through as necessary. Re-attach the BNC and In-Vacuum cables and repeat this procedure starting at step 2. Otherwise, continue at step 11.

11 Connect the six-inch BNC cable to the Feed-Through and disconnect it from the Crystal Interface Unit (or Oscillator)

12 Verify electrical continuity from the center pin of the Microdot connector on the Feed-Through to the un-terminated end of the six-inch BNC cable.

13 Verify electrical isolation from the center pin to electrical ground (Feed-Through body).

If the Feed-Through/six-inch BNC cable system is found to be defective, look for defective contacts at the Feed-Through to BNC cable connection. Repair or replace the Feed-Through as necessary, re-attach the BNC cable to the XIU and In-Vacuum cable to the Crystal head and repeat this procedure starting at step 2.

8.4.1.3 Sensor Head Or Monitor Crystal Diagnostic Procedure

1 Remove the Crystal Cover from the Sensor Head.

2 Refer to Figure 8-6 on page 8-25. Connect the Crystal Sensor Emulator to the Sensor Head at Point C.

- If the XTAL Fail message disappears after approximately 5 sec. then the Sensor Head is operating properly. Re-insert the Crystal Cover into the Sensor Head and go to section 8.4.1.4 on page 8-29.
- If the XTAL Fail message remains, continue at step 3.

3 Disconnect the In-Vacuum cable from the Sensor Head and the Feed-Through. Remove the Crystal Sensor Emulator from the Sensor Head.

4 Using an Ohm meter, verify the electrical connections on the Sensor Head.

- Verify there is electrical continuity from the center pin contact on the Microdot connector on the Sensor Head to the finger spring contact in the Sensor Head.
- There must be electrical isolation between the center pin of the Microdot connector and the Sensor Head body.

If the Sensor Head is found to be defective, contact INFICON's Service Department to have the Sensor Head repaired. Refer to section 1.3 on page 1-6.

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5 Connect the In-Vacuum Cable to the Sensor Head.

- Verify there is continuity (<0.2 ohm) from the finger spring contact in the Sensor Head to the center pin on the un-terminated end of the In-Vacuum cable.
- Verify there is isolation (>10 megohm) between the finger spring contact and the In-Vacuum cable shield.

If the Sensor Head or the In-Vacuum cable system is found to be defective, look for defective contacts at the In-Vacuum cable to Sensor Head connection, repair or replace the Sensor Head as necessary. Re-attach the In-Vacuum cable to the Feed-Through and repeat this procedure starting at step 2.

6 Ensure that the leaf springs in the Sensor Head and those in the ceramic retainer are bent to an angle of approximately 60 degrees from flat.

8.4.1.4 System Diagnostics Pass But Crystal Fail Message Remains

If the system is operating properly, yet the Crystal Fail message is still displayed, perform the following tasks.

1 On the ceramic retainer verify that the center rivet is secure. Repair or replace the ceramic retainer as necessary.

2 Inspect the inside of the Crystal Cover for build-up of material. Clean or replace the Crystal Cover as necessary.

After verifying the Sensor Head contacts, the Sensor Head/In-Vacuum cable connection, and the ceramic retainer contacts, re-assemble the system. If the Crystal Fail message remains, replace the monitor crystal with a good monitor crystal. Verify that the monitor crystal works properly by inserting it into a known good measurement system. If you continue to experience problems, contact an INFICON Applications Engineer for Technical Support.

8.4.2 % XTAL Life

The Crystal Sensor Emulator contains a quartz crystal having a fundamental frequency at 5.5 MHz. With the Crystal Sensor Emulator connected, the % XTAL Life display should read approximately 30% for Cygnus deposition controllers which allow a 1.5 MHz frequency shift.

8.4.3 Sensor Cover Connection

The Crystal Sensor Emulator can be used to verify the measurement system for INFICON's Thin Film Deposition Controllers and Monitors.

NOTE: The Crystal Sensor Emulator 760-601-G1 is not compatible for use with a Cygnus. Use 760-601-G2 for all thin film deposition controllers.

However, the Crystal Sensor Emulator's Sensor Cover Connector is compatible with some sensor heads, and is incompatible with others. This is discussed in the following sections.

8.4.3.1 Compatible Sensor Heads

The Sensor Cover Connection will fit the sensor heads shown in Table 8-4.

Table 8-4 Compatible Sensor Heads

Sensor Head	Part Number
Standard Sensor Head	750-211-G1
Standard Sensor Head with Shutter	750-211-G2
Compact Sensor Head	750-213-G1
Compact Sensor Head with Shutter	750-213-G2
Dual Sensor Head	750-212-G2

8.4.3.2 Incompatible Sensor Heads

The Sensor Heads for which the Crystal Sensor Emulator's Sensor Cover Connector will not fit are shown in Table 8-5.

Table 8-5 Incompatible Sensor Heads

Sensor Head	Part Number
UHV Bakeable Sensor Head (12 inch)	007-219
UHV Bakeable Sensor Head (20 inch)	007-220
UHV Bakeable Sensor Head (30 inch)	007-221
UHV Bakeable Sensor Head w/ Shutter (12 inch)	750-012-G1
UHV Bakeable Sensor Head w/ Shutter (20 inch)	750-012-G2
UHV Bakeable Sensor Head w/ Shutter (30 inch)	750-012-G3
Sputtering Sensor Head	750-618-G1
CrystalSix Sensor Head with position select	750-446-G1
CrystalSix Sensor Head	750-260-G1
Crystal12 Sensor Head	750-667-G1

NOTE: The Crystal Sensor Emulator’s Sensor Cover will not fit the crystal holder opening of the older style INFICON transducers that have the "soldered" finger springs.

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8.4.4 Specifications

Dimensions

1.58 in. diameter x 1.79 in.
(40.13 mm diameter x 45.47 mm)

Temperature Range

0 to 50 ^{o}C

Frequency

760-601-G1: 5.5 MHz ± 30 ppm at room temperature
760-601-G2: 5.5 MHz ± 1 ppm at room temperature

Materials

304 Stainless Steel, Nylon, Teflon, brass. Some internal components contain zinc, tin, and lead.

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Chapter 9
Measurement and Control Theory

9.1 Basics

The Quartz Crystal deposition monitor, or QCM, utilizes the piezoelectric sensitivity of a quartz monitor crystal to added mass. The QCM uses this mass sensitivity to control the deposition rate and final thickness of a vacuum deposition. When a voltage is applied across the faces of a properly shaped piezoelectric crystal, the crystal is distorted and changes shape in proportion to the applied voltage. At certain discrete frequencies of applied voltage, a condition of very sharp electro-mechanical resonance is encountered. When mass is added to the face of a resonating quartz crystal, the frequency of these resonances are reduced. This change in frequency is very repeatable and is precisely understood for specific oscillating modes of quartz. This heuristically easy to understand phenomenon is the basis of an indispensable measurement and process control tool that can easily detect the addition of less than an atomic layer of an adhered foreign material.

In the late 1950's it was noted by Sauerbrey[1,2] and Lostis[3] that the change in frequency, $\Delta F = F_q - F_c$, of a quartz crystal with coated (or composite) and uncoated frequencies, F_c and F_q respectively, is related to the change in mass from the added material, M_f , as follows:

$$\frac{M_f}{M_q} = \frac{(\Delta F)}{F_q} \qquad [1]$$

where M_q is the mass of the uncoated quartz crystal. Simple substitutions lead to the equation that was used with the first "frequency measurement" instruments:

$$T_f = \frac{K(\Delta F)}{d_f} \qquad [2]$$

where the film thickness, T_f, is proportional (through K) to the frequency change, ΔF, and inversely proportional to the density of the film, d_f. The constant, $K = N_{at} d_q / F_q^2$; where d_q (= 2.649 gm/cm^3) is the density of single crystal quartz and N_{at} (=166100 Hz cm) is the frequency constant of AT cut quartz. A crystal with a starting frequency of 6.0 MHz will display a reduction of its frequency by 2.27 Hz when 1 angstrom of Aluminum (density of 2.77 gm/cm^3) is added to its surface. In this manner the thickness of a rigid adlayer is inferred from the precise

1.G. Z. Sauerbrey, Phys. Verhand .8, 193 (1957)
2.G. Z. Sauerbrey, Z. Phys. 155,206 (1959)
3.P. Lostis, Rev. Opt. 38,1 (1959)

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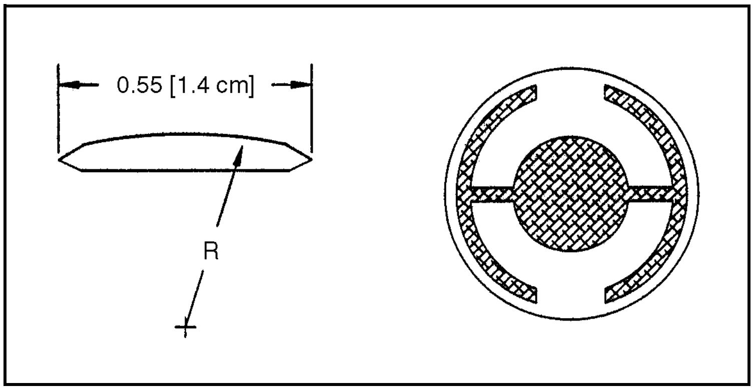
measurement of the crystal's frequency shift. The quantitative knowledge of this effect provides a means of determining how much material is being deposited on a substrate in a vacuum system, a measurement that was not convenient or practical prior to this understanding.

9.1.1 Monitor Crystals

No matter how sophisticated the electronics surrounding it, the essential device of the deposition monitor is the quartz crystal. The quartz resonator shown in Figure 9-1 has a frequency response spectrum that is schematically shown in Figure 9-2. The ordinate represents the magnitude of response, or current flow of the crystal, at the specified frequency.

Figure 9-1 Quartz Resonator



The lowest frequency response is primarily a "thickness shear" mode that is called the fundamental. The characteristic movement of the thickness shear mode is for displacement to take place parallel to the major monitor crystal faces. In other words, the faces are displacement antinodes as shown in Figure 9-3. The responses located slightly higher in frequency are called anharmonics; they are a combination of the thickness shear and thickness twist modes. The response at about three times the frequency of the fundamental is called the third quasiharmonic. There are also a series of anharmonics slightly higher in frequency associated with the quasiharmonic.

The monitor crystal design depicted in Figure 9-1 is the result of several significant improvements from the square crystals with fully electroded plane parallel faces that were first used. The first improvement was to use circular crystals. This increased symmetry greatly reduced the number of allowed vibrational modes. The second set of improvements was to contour one face of the crystal and to reduce the size of the exciting electrode. These improvements have the effect of trapping the acoustic energy. Reducing the electrode diameter limits the excitation to the central area. Contouring dissipates the energy of the traveling acoustic wave before it reaches the edge of the crystal. Energy is not reflected back to the center where it can interfere with other newly launched waves, essentially making a small crystal appear to behave as though it is infinite in extent. With the crystal's vibrations restricted to the center, it is practical to clamp the outer edges of the

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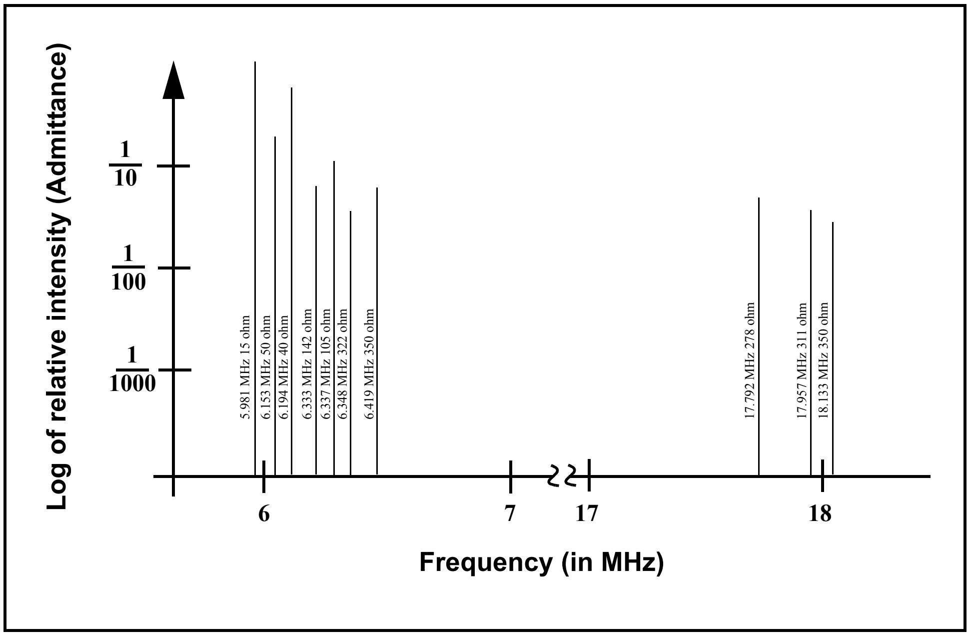
crystal to a holder and not produce any undesirable effects. Contouring also reduces the intensity of response of the generally unwanted anharmonic modes; hence, the potential for an oscillator to sustain an unwanted oscillation is substantially reduced.

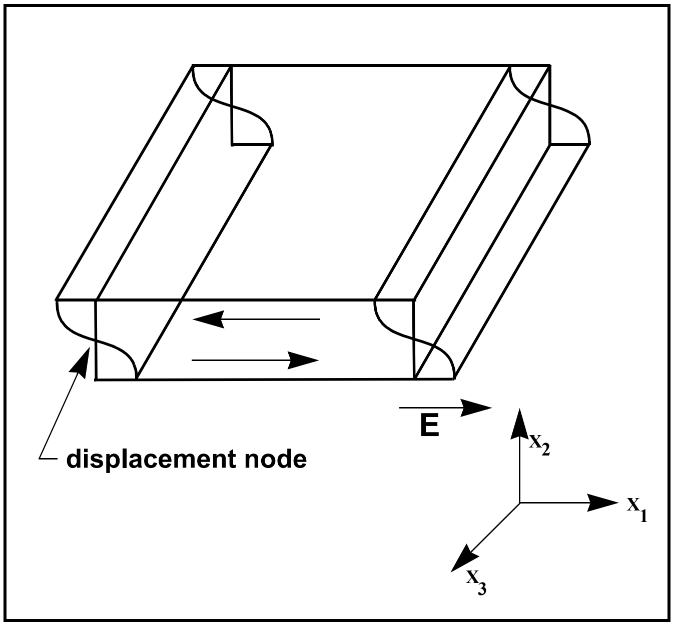
Figure 9-2 Frequency Response Spectrum



The use of an adhesion layer has improved the electrode-to-quartz bonding, reducing “rate spikes” caused by micro-tears between the electrode and the quartz as film stress rises. These micro-tears leave portions of the deposited film unattached and therefore unable to participate in the oscillation. These free portions are no longer detected and the wrong thickness consequently inferred.

The “AT” resonator is usually chosen for deposition monitoring because at room temperature it can be made to exhibit a very small frequency change due to temperature changes. Since there is presently no way to separate the frequency change caused by added mass (which is negative) or even the frequency changes caused by temperature gradients across the crystal or film induced stresses, it is essential to minimize these temperature-induced changes. It is only in this way that small changes in mass can be measured accurately.

Figure 9-3 Thickness Shear Displacement



9.1.2 Period Measurement Technique

Although instruments using equation [2] were very useful, it was soon noted they had a very limited range of accuracy, typically holding accuracy for DF less than 0.02 F_q. In 1961 it was recognized by Behrndt[4] that:

$$\frac{M_f}{M_q} = \frac{(T_c - T_q)}{T_q} = \frac{(\Delta F)}{F_c} \qquad [3]$$

where T_c and Tq are the periods of oscillation of the crystal with film (composite) and the bare crystal respectively. The period measurement technique was the outgrowth of two factors; first, the digital implementation of time measurement, and second, the recognition of the mathematically rigorous formulation of the proportionality between the crystal's thickness, l_q, and the period of oscillation, $T_q = 1/F_q$. Electronically the period measurement technique uses a second crystal oscillator, or reference oscillator, not affected by the deposition and usually much higher in frequency than the monitor crystal. This reference oscillator is used to generate small precision time intervals which are used to determine the oscillation period of the monitor crystal. This is done by using two pulse accumulators. The first is used to accumulate a fixed number of cycles, m, of the monitor crystal. The second is turned on at the same time and accumulates cycles from the reference oscillator until m counts are accumulated in the first. Since the frequency of the reference is stable and known, the time to accumulate the m counts is known to an accuracy equal to ± $2/F_r$ where F_r is the reference oscillator's frequency. The

4.K. H. Behrndt, J. Vac. Sci. Technol. 8, 622 (1961)

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monitor crystal's period is $(n/F_r)/m$ where n is the number of counts in the second accumulator. The precision of the measurement is determined by the speed of the reference clock and the length of the gate time (which is set by the size of m). Increasing one or both of these leads to improved measurement precision.

Having a high frequency reference oscillator is important for rapid measurements (which require short gating times), low deposition rates and low density materials. All of these require high time precision to resolve the small, mass induced frequency shifts between measurements. When the change of a monitor crystal's frequency between measurements is small, that is, on the same order of size as the measurement precision, it is not possible to establish quality rate control. The uncertainty of the measurement injects more noise into the control loop, which can be counteracted only by longer time constants. Long time constants cause the correction of rate errors to be very slow, resulting in relatively long term deviations from the desired rate. These deviations may not be important for some simple films, but can cause unacceptable errors in the production of critical films such as optical filters or very thin layered superlattices grown at low rates. In many cases the desired properties of these films can be lost if the layer to layer reproducibility exceeds one, or two, percent. Ultimately, the practical stability and frequency of the reference oscillator limits the precision of measurement for conventional instrumentation.

9.1.3 Z-Match Technique

After learning of fundamental work by Miller and Bolef [5], which rigorously treated the resonating quartz and deposited film system as a one-dimensional continuous acoustic resonator, Lu and Lewis[6] developed the simplifying Z-Match™ equation in 1972. Advances in electronics taking place at the same time, namely the micro-processor, made it practical to solve the Z-Match equation in "real-time". Most deposition process controllers sold today use this sophisticated equation that takes into account the acoustic properties of the resonating quartz and film system as shown in equation [4].

$$T_f = \left(\frac{N_{at}d_q}{\pi d_f F_c Z}\right)\arctan\left(Z\tan\left[\frac{\pi(F_q - F_c)}{F_q}\right]\right) \quad [4]$$

where $Z=(d_q u_q/d_f u_f)^{1/2}$ is the acoustic impedance ratio and u_q and u_f are the shear moduli of the quartz and film, respectively. Finally, there was a fundamental understanding of the frequency-to-thickness conversion that could yield theoretically correct results in a time frame that was practical for process control. To achieve this new level of accuracy requires only that the user enter an additional material parameter, Z, for the film being deposited. This equation has been tested

5.J. G. Miller and D. I. Bolef, J. Appl. Phys. 39, 5815, 4589 (1968)
6.C. Lu and O. Lewis, J Appl. Phys. 43, 4385 (1972)

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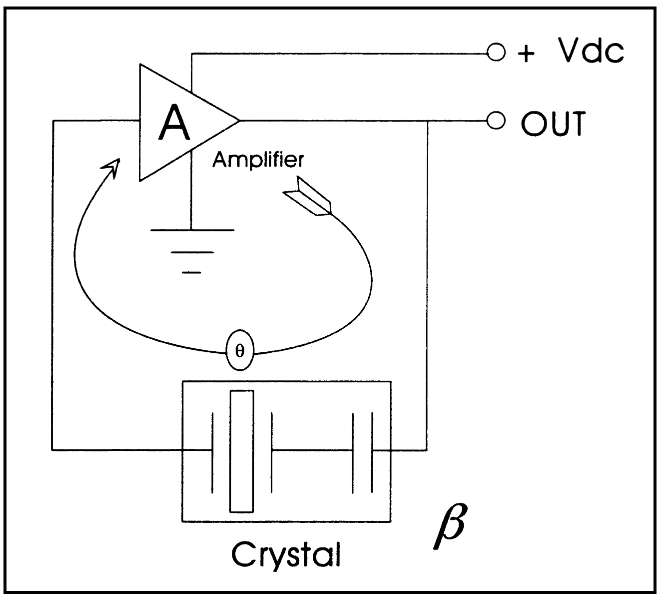
for a number of materials, and has been found to be valid for frequency shifts equivalent to $F_f = 0.4F_q$. Keep in mind that equation [2] was valid to only $0.02F_q$ and equation [3] was valid only to $\sim0.05F_q$.

9.1.4 Active Oscillator

All of the instrumentation developed to date has relied on the use of an active oscillator circuit, generally the type schematically shown in Figure 9-4. This circuit actively keeps the crystal in resonance, so that any type of period or frequency measurement may be made. In this type of circuit, oscillation is sustained as long as the gain provided by the amplifiers is sufficient to offset losses in the crystal and circuit and the crystal can provide the required phase shift. The basic crystal oscillator's stability is derived from the rapid change of phase for a small change in the crystal's frequency near the series resonance point, as shown in Figure 9-5.

Figure 9-4 Active Oscillator Circuit



The active oscillator circuit is designed so the crystal is required to produce a phase shift of 0 degrees, which allows it to operate at the series resonance point. Long- and short-term frequency stabilities are a property of crystal oscillators because very small frequency changes are needed to sustain the phase shift required for oscillation. Frequency stability is provided by the quartz crystal even though there are long term changes in electrical component values caused by temperature or aging or short-term noise-induced phase jitter.

As mass is added to a crystal, its electrical characteristics change. Figure 9-6 on page 9-8 is the same plot as Figure 9-5 overlaid with the response of a heavily loaded crystal. The crystal has lost the steep slope displayed in Figure 9-5. Because the phase slope is less steep, any noise in the oscillator circuit translates

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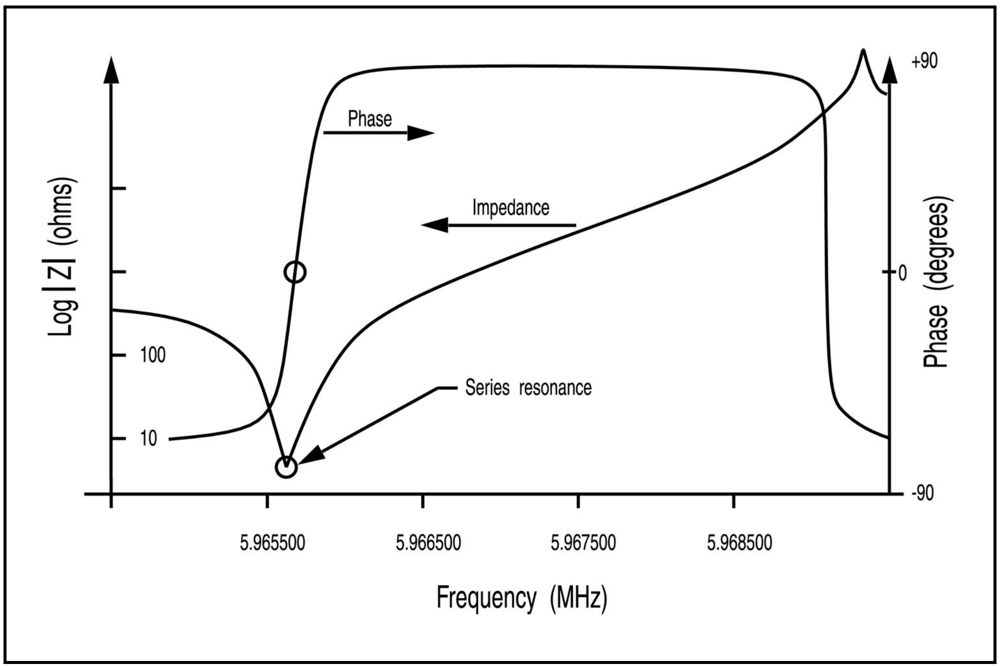
into a greater frequency shift than that which would be produced with a new crystal. In the extreme, the basic phase/frequency shape is not preserved and the crystal is not able to provide a full 90 degrees of phase shift.

The impedance, |Z|, is also noted to rise to an extremely high value. When this happens it is often more favorable for the oscillator to resonate at one of the anharmonic frequencies. This condition is sometimes short lived, with the oscillator switching between the fundamental and anharmonic modes, or it may continue to oscillate at the anharmonic. This condition is known as mode hopping and in addition to annoying rate noise can also lead to false termination of the film because of the apparent frequency change. It is important to note that the controller will frequently continue to operate under these conditions; in fact there is no way to tell this has happened except that the film's thickness is suddenly apparently thinner by an amount equivalent to the frequency difference between the fundamental and the anharmonic that is sustaining the oscillation.

Figure 9-5 Crystal Frequency Near Series Resonance Point



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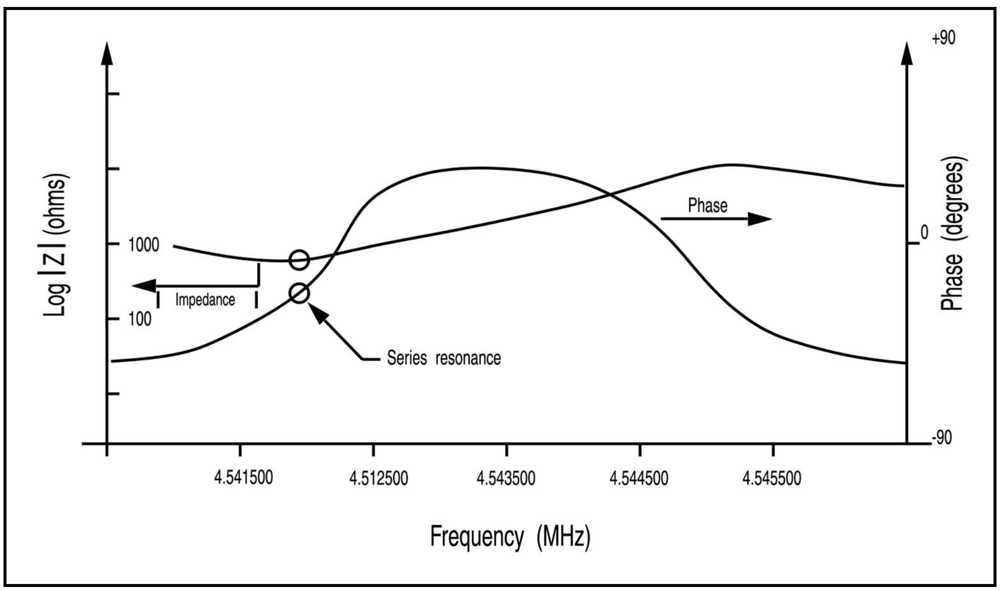
9.1.5 ModeLock Oscillator

INFICON has created a new technology that eliminates the active oscillator and its limitations. This new system constantly tests the crystal's response to an applied frequency in order to not only determine the resonant frequency, but also to verify that the crystal is oscillating in the desired mode. This new system is essentially immune to mode hopping and the resulting inaccuracies. It is fast and accurate, determining the crystal's frequency to less than .005 Hz at a rate of 10 times per second. Because of the system's ability to identify and then measure particular crystal modes, it is now possible to offer new features that take advantage of the additional informational content of these modes. This new "intelligent" measurement system uses the phase/frequency properties of the quartz crystal to determine the resonant frequency. It operates by applying a synthesized sine wave of specific frequency to the crystal and measuring the phase difference between the applied signal's voltage and the current passing through the crystal. At series resonance, this phase difference is exactly 0 degrees; that is, the crystal behaves like a pure resistance. By separating the applied voltage and the current returned from the crystal and monitoring the output of a phase comparator it is possible to establish whether the applied frequency is higher or lower than the crystal's resonance point. At frequencies well below the fundamental, the crystal's impedance is capacitive and at frequencies slightly higher than resonance it is inductive in nature. This information is useful if the resonance frequency of a crystal is unknown. A quick sweep of frequencies can be undertaken until the output of the phase comparator changes, marking the resonance event. For AT crystals we know that the lowest frequency event encountered is the fundamental. The events slightly higher in frequency are anharmonics. This information is useful not only for initialization, but also for the rare case when the instrument loses track of the fundamental. Once the frequency spectrum of the crystal is determined the instrument's task is to follow the changing resonance frequency and to periodically provide a measurement of the frequency for subsequent conversion to thickness.

Figure 9-6 Heavily Loaded Crystal



The use of the "intelligent" measurement system has a series of very apparent advantages when compared to the previous generation of active oscillators, namely immunity from mode hopping, speed of measurement and precision of measurement. The technique also allows the implementation of a sophisticated feature that cannot even be contemplated using the active oscillator approach. The same capability that allows the new technology to sweep and identify the fundamental can be used to identify other oscillation modes, such as the anharmonics and the quasiharmonic. Not only can the instrument track the

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fundamental mode continuously, but also it can be implemented to alternate between one or more other modes. This interrogation of multiple modes can be performed as fast as 10 Hz for two modes of the same crystal.

9.1.6 Auto Z-Match Theory

The one drawback in using equation [4] on page 9-5 is that the acoustic impedance must be known. There are several cases where accuracy has to be compromised because of incomplete or limited knowledge of the material constants of the deposited materials.

- Often the Z-Ratio for the bulk material is different from that of the deposited thin film. Thin films are especially sensitive to process parameters, particularly in a sputtering environment. Consequently, the values available for bulk materials may not be pertinent.
- For many exotic materials, including alloys, the Z-Ratio is not known nor easily available.
- There has always been a need to accurately measure layer thickness of multiple material films using the same crystal sensor. This is particularly true for multi-layer optical coatings and high-temperature superconductor fabrication. The effective Z-Ratio of the composite of multi-material layers is not known.

In such cases, the only recourse is to assume the Z-Ratio to be unity (that is, ignoring the reality of wave propagation in composite media). This false premise introduces error in the thickness and rate predictions. The magnitude of this error depends upon the film thickness and the amount of departure of the true Z-Ratio from unity.

In 1989, A. Wajid became aware of the ModeLock oscillator[7]. He speculated there might be a relationship between the fundamental and one of the anharmonics similar to the relationship noted by Benes[8] between the fundamental and the third quasiharmonic. The frequencies of the fundamental and the anharmonics are very similar, solving the problem of capacitance of long cables. He found the ideas needed for establishing the required connections in papers published by Wilson[9] in 1974 and Tiersten and Smythe[10] in 1979.

Contouring a crystal, that is, giving one face a spherical shape, has the effect of separating the various modes further apart and preventing the transfer of energy from one mode to another. For the sake of identification it is common to assign mode [100] to the fundamental, [102] to the lowest frequency anharmonic and [120] to the next lowest frequency anharmonic. The three indices of the mode

7.U.S. Patent No. 5,117,192 (May 26, 1992) International Patents Pending.
8.E. Benes, J. Appl. Phys. 56(3), 608-626 (1984)
9.C. J. Wilson, J. Phys. d7,2449 (1974)
10.H. F. Tiersten and R.C. Smythe, J. Acoust. Soc. Am., 65(6), 1455 (1979).

assignment refer to the number of phase reversals in the wave motion along the three axes of the crystal. The above-referenced papers by Wilson and Tiersten & Smythe are examinations of modal properties, relating the various properties of the radius of curvature to the placement of the anharmonics relative to the fundamental.

As material is deposited upon one face of a crystal, the entire spectrum of resonances shifts to lower frequencies. The three above mentioned modes are observed to have slightly different mass sensitivity and hence undergo slightly different frequency shifts. It is this difference that is used to estimate the Z-Ratio of the material. Using the modal equations and the observed frequencies of the modes [100] and [102], one can calculate the ratio of two elastic constants C_{66} and C_{55}. Both of these elastic constants relate to shear motion. The essential element of Wajid's theory is the following equation:

$$\frac{(C_{55}/C_{66})_{coated}}{(C_{55}/C_{66})_{uncoated}} \sim \frac{1}{(1+MZ)} \qquad [5]$$

where M is the aerial mass density (film mass to quartz mass ratio per unit area) and Z is the Z-Ratio. It is a fortunate coincidence that the combination MZ also appears in the Lu-Lewis equation [4], which can be used to extract an estimate of the effective Z-Ratio from the equations below:

$$\tan\left(MZ\pi\frac{F_c}{F_q}\right) + Z\tan\left(\pi\frac{F_c}{F_q}\right) = 0 \qquad [6]$$

or

$$Z = -\frac{\tan\left(MZ\pi\frac{F_c}{F_q}\right)}{\tan\left(\pi\frac{F_c}{F_q}\right)} \qquad [7]$$

Where, F_q and F_c denote uncoated and coated crystal frequencies in the fundamental mode (mode [100]). Due to the multi-valued nature of the mathematical functions involved, the value of Z-Ratio extracted in this manner is not always a positive definite quantity. This is hardly of any consequence however, because M is uniquely determined with the estimated Z and the measured frequency shift. Thus, thickness and rate of deposition are subsequently calculated from the knowledge of M.[11]

One must be aware of the limitations of this technique. Since the estimate for Z-Ratio is dependent on the frequency shifts of the two modes, any spurious shift due to excessive mechanical or thermal stress on the crystal will lead to errors.

11.U.S. Patent No. 5,112,642 (May 12, 1992) International Patents Pending.

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Needless to say, similar errors occur with the Z-Match™ technique under similar circumstances. However, the automatic Z-Ratio estimate is somewhat more prone to error, because the amplitude distribution of the mode [102] is asymmetric, whereas that of the mode [100] is symmetric over the active area of the crystal.

In our experience, film-induced stress on the crystal has the most deleterious effect. This effect is most pronounced whenever there is a presence of gas in the environment, for example, in reactive evaporation or sputtering processes. In such cases, if the bulk Z-Ratio is already well known, it is better to use the bulk value instead of the automatically determined Auto Z-Ratio. In cases of co-deposition and sequential layers, automatic Z-Ratio estimation is significantly superior.

9.1.7 Control Loop Theory

The instrumental advances in measurement speed, precision and reliability would not be complete without a means of translating this improved information into improved process control. For a deposition process, this means keeping the deposition rate as close as possible to the desired rate. The purpose of a control loop is to take the information flow from the measurement system and to make power corrections that are appropriate to the characteristics of the particular evaporation source. When properly operating, the control system translates small errors in the controlled parameter, or rate, into the appropriate corrections in the manipulated parameter, power. The controller's ability to quickly and accurately measure and then react appropriately to the small changes keeps the process from deviating very far from the set point.

The controller model most commonly chosen, for converting error into action is called PID. In the PID, P stands for proportional, I stands for integral and D stands for derivative action. Certain aspects of this model will be examined in detail a little further on. The responsiveness of an evaporation source can be found by repetitively observing the system response to a disturbance under a particular set of controller settings. After observing the response, improved controller parameters are estimated and then tried again until satisfactory control is obtained. Control, when it is finally optimized, essentially matches the parameters of the controller model to the characteristics of the evaporation source.

Techniques for calculating optimum source control parameters can be classified by the type of data used for tuning. They fall into basically three categories:

- Closed Loop Methods
- Open Loop Methods
- Frequency Response Methods

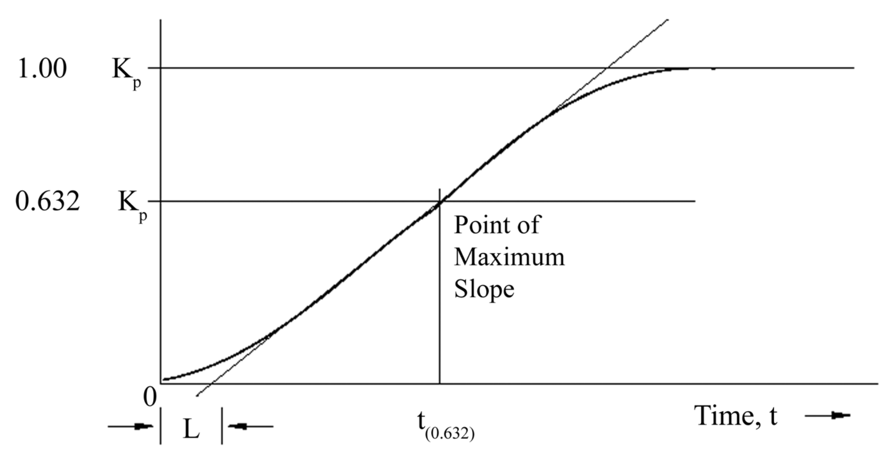
Of these categories, the open loop methods are considered superior. They are considered superior because of the ease with which the necessary experimental data can be obtained and because of the elimination (to a large extent) of trial and error when the technique is applied. The important response characteristics are determined as shown in Figure 9-7.

In general, it is not possible to characterize all processes exactly; some approximation must be applied. The most common is to assume that the dynamic characteristics of the process can be represented by a first-order lag plus a dead time. The Laplace transform for this model (conversion to the s domain) is approximated as:

$$\frac{\text{Output}}{\text{Input}} = \frac{K_p \exp(-Ls)}{T_1 s + 1} \qquad [8]$$

Three parameters are determined from the process reaction curve. They are the steady state gain, K_p, the dead time, L, and the time constant, T_1. Several methods have been proposed to extract the required parameters from the system response as graphed in Figure 9-7. These are: a one point fit at 63.2% of the transition (one time constant); a two point exponential fit; and a weighted least-square-exponential fit. From the above information a process is sufficiently characterized so that a controller algorithm may be customized.

Figure 9-7 Response of Process To An Open Loop Step Change (At t=0 Control Signal is Increased)



$T_1 = t_{(0.632)} - L$

K_p = (Change in Output) / (Change in Control Signal)

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A controller model used extensively is the PID type, shown in Laplace form in equation [9].

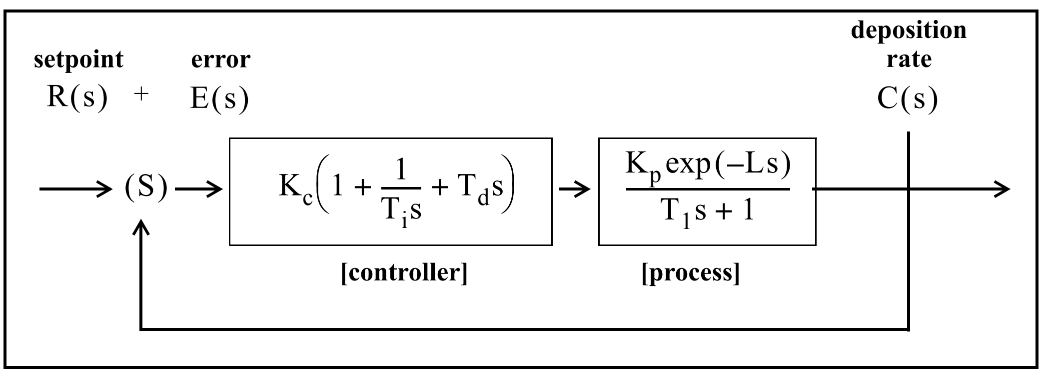
$$M(s) = K_c\left(1 + \frac{1}{T_i s} + T_d s\right)Es \qquad [9]$$

Where

- M(s) = manipulated variable or power
- K_c = controller gain (the proportional term)
- T_i = integral time
- T_d = derivative time
- E(s) = process error

Figure 9-8 represents the controller algorithm and a process with first order lag plus a dead time. The process block implicitly includes the dynamics of the measuring devices and the final control elements, in our case the evaporator power supply. R(s) represents the rate setpoint. The feedback mechanism is the error generated by the difference between the measured deposition rate, C(s), and the rate set point, R(s).

Figure 9-8 PID Controller Block Diagram



The key to using any control system is to choose the proper values of K_c, T_d and T_i. Optimum control is a somewhat subjective quantity as noted by the presence of several mathematical definitions as shown below.

The integral of the squared error (ISE) is a commonly proposed criterion of performance for control systems.

It can be described as:

$$ISE = \int e^2(t)dt \qquad [10]$$

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where error = e = setpoint minus the measured rate. The ISE measure is relatively insensitive to small errors, but large errors contribute heavily to the value of the integral. Consequently, using ISE as a criterion of performance will result in responses with small overshoots but long settling times, since small errors occurring late in time contribute little to the integral.

The integral of the absolute value of the error (IAE) has been frequently proposed as a criterion of performance:

$$IAE = \int |e(t)| dt \quad [11]$$

This criterion is more sensitive to small errors, but less sensitive to large errors, than ISE.

Graham and Lathrop[12] introduced the integral of time multiplied by the absolute error (ITAE) as an alternate criterion of performance:

$$ITAE = \int t|e(t)| dt \quad [12]$$

ITAE is insensitive to the initial and somewhat unavoidable errors, but it will weight heavily any errors occurring late in time. Optimum responses defined by ITAE will consequently show short total response times and larger overshoots than with either of the other criteria. It has been found that this criteria is generally most useful for deposition process control.

The most satisfactory performance criterion for deposition controllers is the ITAE. There will be overshoot, but the response time is quick, and the settling time is short. For all of the above integral performance criteria, controller tuning relations have been developed to minimize the associated errors. Using manually entered or experimentally determined process response coefficients, ideal PID controller coefficients can be readily calculated for the ITAE criteria as shown below.

$$K_c = (1.36/K_p)(L/T_1)^{-0.947} \quad [13]$$

$$T_i = (1.19T_1)(L/T_1)^{0.738} \quad [14]$$

$$T_d = (0.381T_1)(L/T_1)^{0.995} \quad [15]$$

For slow systems, in order to help avoid controller windup (windup is the rapid increase in control signal before the system has the chance to respond to the changed signal), the time period between manipulated variable (control voltage) changes is lengthened. This allows the system to respond to the previous controller setting change, and aggressive controller settings can be used. A secondary advantage is that immunity to process noise is increased since the data used for

12.Graham, D., and Lanthrop, R.C., “The Synthesis of Optimum Transient Response: Criteria and Standard Forms, Transactions IEEE, vol. 72 pt. II, November 1953.

control is now comprised of multiple readings instead of a single rate measurement, taking advantage of the mass integrating nature of the quartz crystal.

With process systems that respond quickly (short time constant) and with little to no measurable dead time, the PID controller often has difficulty with the deposition process noise (beam sweep, fast thermal shorts of melt to crucible, etc.). In these situations a control algorithm used successfully is an integral/reset type of controller. This type of controller will always integrate the error, driving the system towards zero error. This technique works well when there is little or no dead time. If this technique is used on a process with measurable lag or dead time, then the control loop will tend to be oscillatory due to the control loop over-compensating the control signal before the system has a chance to respond.

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Appendix A
Material Table

CAUTION

Some of these materials are toxic. Please consult the material safety data sheet and safety instructions before use.

An * is used to indicate that a Z-Ratio has not been established for a certain material. A value of 1.000 is defaulted in these situations.

Table A-1 Material Table

Formula	Density	Z-Ratio	Material Name
Ag	10.500	0.529	Silver
AgBr	6.470	1.180	Silver Bromide
AgCl	5.560	1.320	Silver Chloride
Al	2.700	1.080	Aluminum
Al_2O_3	3.970	0.336	Aluminum Oxide
Al_4C_3	2.360	*1.000	Aluminum Carbide
AlF_3	3.070	*1.000	Aluminum Fluoride
AlN	3.260	*1.000	Aluminum Nitride
AlSb	4.360	0.743	Aluminum Antimonide
As	5.730	0.966	Arsenic
As_2Se_3	4.750	*1.000	Arsenic Selenide
Au	19.300	0.381	Gold
B	2.370	0.389	Boron
B_20_3	1.820	*1.000	Boron Oxide
B_4C	2.370	*1.000	Boron Carbide
BN	1.860	*1.000	Boron Nitride
Ba	3.500	2.100	Barium
BaF_2	4.886	0.793	Barium Fluoride
BaN_2O_6	3.244	1.261	Barium Nitrate
BaO	5.720	*1.000	Barium Oxide
$BaTiO_3$	5.999	0.464	Barium Titanate (Tetr)
$BaTiO_3$	6.035	0.412	Barium Titanate (Cubic)

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
Be	1.850	0.543	Beryllium
BeF_2	1.990	*1.000	Beryllium Fluoride
BeO	3.010	*1.000	Beryllium Oxide
Bi	9.800	0.790	Bismuth
Bi_2O_3	8.900	*1.000	Bismuth Oxide
Bi_2S_3	7.390	*1.000	Bismuth Trisulphide
Bi_2Se_3	6.820	*1.000	Bismuth Selenide
Bi_2Te_3	7.700	*1.000	Bismuth Telluride
BiF_3	5.320	*1.000	Bismuth Fluoride
C	2.250	3.260	Carbon (Graphite)
C	3.520	0.220	Carbon (Diamond)
C_8H_8	1.100	*1.000	Parlyene (Union Carbide)
Ca	1.550	2.620	Calcium
CaF_2	3.180	0.775	Calcium Fluoride
CaO	3.350	*1.000	Calcium Oxide
$CaO\text{-}SiO_2$	2.900	*1.000	Calcium Silicate (3)
$CaSO_4$	2.962	0.955	Calcium Sulfate
$CaTiO_3$	4.100	*1.000	Calcium Titanate
$CaWO_4$	6.060	*1.000	Calcium Tungstate
Cd	8.640	0.682	Cadmium
CdF_2	6.640	*1.000	Cadmium Fluoride
CdO	8.150	*1.000	Cadmium Oxide
CdS	4.830	1.020	Cadmium Sulfide
CdSe	5.810	*1.000	Cadmium Selenide,
CdTe	6.200	0.980	Cadmium Telluride
Ce	6.780	*1.000	Cerium
CeF_3	6.160	*1.000	Cerium (III) Fluoride
CeO_2	7.130	*1.000	Cerium (IV) Dioxide
Co	8.900	0.343	Cobalt
CoO	6.440	0.412	Cobalt Oxide
Cr	7.200	0.305	Chromium
Cr_2O_3	5.210	*1.000	Chromium (III) Oxide
Cr_3C_2	6.680	*1.000	Chromium Carbide

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
CrB	6.170	*1.000	Chromium Boride
Cs	1.870	*1.000	Cesium
Cs_2SO_4	4.243	1.212	Cesium Sulfate
CsBr	4.456	1.410	Cesium Bromide
CsCl	3.988	1.399	Cesium Chloride
CsI	4.516	1.542	Cesium Iodide
Cu	8.930	0.437	Copper
Cu_2O	6.000	*1.000	Copper Oxide
Cu_2S	5.600	0.690	Copper (I) Sulfide (Alpha)
Cu_2S	5.800	0.670	Copper (I) Sulfide (Beta)
CuS	4.600	0.820	Copper (II) Sulfide
Dy	8.550	0.600	Dysprosium
DY_2O_3	7.810	*1.000	Dysprosium Oxide
Er	9.050	0.740	Erbium
Er_2O_3	8.640	*1.000	Erbium Oxide
Eu	5.260	*1.000	Europium
EuF_2	6.500	*1.000	Europium Fluoride
Fe	7.860	0.349	Iron
Fe_2O_3	5.240	*1.000	Iron Oxide
FeO	5.700	*1.000	Iron Oxide
FeS	4.840	*1.000	Iron Sulphide
Ga	5.930	0.593	Gallium
Ga_2O_3	5.880	*1.000	Gallium Oxide (B)
GaAs	5.310	1.590	Gallium Arsenide
GaN	6.100	*1.000	Gallium Nitride
GaP	4.100	*1.000	Gallium Phosphide
GaSb	5.600	*1.000	Gallium Antimonide
Gd	7.890	0.670	Gadolinium
Gd_2O_3	7.410	*1.000	Gadolinium Oxide
Ge	5.350	0.516	Germanium
Ge_3N_2	5.200	*1.000	Germanium Nitride
GeO_2	6.240	*1.000	Germanium Oxide
GeTe	6.200	*1.000	Germanium Telluride

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
Hf	13.090	0.360	Hafnium
HfB_2	10.500	*1.000	Hafnium Boride,
HfC	12.200	*1.000	Hafnium Carbide
HfN	13.800	*1.000	Hafnium Nitride
HfO_2	9.680	*1.000	Hafnium Oxide
$HfSi_2$	7.200	*1.000	Hafnium Silicide
Hg	13.460	0.740	Mercury
Ho	8.800	0.580	Holminum
Ho_2O_3	8.410	*1.000	Holminum Oxide
In	7.300	0.841	Indium
In_2O_3	7.180	*1.000	Indiurn Sesquioxide,
In_2Se_3	5.700	*1.000	Indium Selenide
In_2Te_3	5.800	*1.000	Indium Telluride
InAs	5.700	*1.000	Indium Arsenide
InP	4.800	*1.000	Indium Phosphide
InSb	5.760	0.769	Indium Antimonide
Ir	22.400	0.129	Iridium
K	0.860	10.189	Potassium
KBr	2.750	1.893	Potassium Bromide
KCl	1.980	2.050	Potassium Chloride
KF	2.480	*1.000	Potassium Fluoride
KI	3.128	2.077	Potassium Iodide
La	6.170	0.920	Lanthanum
La_2O_3	6.510	*1.000	Lanthanum Oxide
LaB_6	2.610	*1.000	Lanthanurn Boride
LaF_3	5.940	*1.000	Lanthanum Fluoride
Li	0.530	5.900	Lithium
LiBr	3.470	1.230	Lithium Bromide
LiF	2.638	0.778	Lithium Fluoride
$LiNbO_3$	4.700	0.463	Lithium Niobate
Lu	9.840	*1.000	Lutetium
Mg	1.740	1.610	Magnesium
$MgAl_2O_4$	3.600	*1.000	Magnesium Aluminate

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Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
$MgAl_2O_6$	8.000	*1.000	Spinel
MgF_2	3.180	0.637	Magnesium Fluoride
MgO	3.580	0.411	Magnesium Oxide
Mn	7.200	0.377	Manganese
MnO	5.390	0.467	Manganese Oxide
MnS	3.990	0.940	Manganese (II) Sulfide
Mo	10.200	0.257	Molybdenum
Mo_2C	9.180	*1.000	Molybdenum Carbide
MoB_2	7.120	*1.000	Molybdenum Boride
MoO_3	4.700	*1.000	Molybdenum Trioxdide
MoS_2	4.800	*1.000	Molybdenum Disulfide
Na	0.970	4.800	Sodium
Na_3AlF_6	2.900	*1.000	Cryolite
$Na_5Al_3F_{14}$	2.900	*1.000	Chiolite
NaBr	3.200	*1.000	Sodium Bromide
NaCl	2.170	1.570	Sodium Chloride
$NaClO_3$	2.164	1.565	Sodium Chlorate
NaF	2.558	0.949	Sodium Fluoride
$NaNO_3$	2.270	1.194	Sodium Nitrate
Nb	8.578	0.492	Niobium (Columbium)
Nb_2O_3	7.500	*1.000	Niobium Trioxide
Nb_2O_5	4.470	*1.000	Niobium (V) Oxide
NbB_2	6.970	*1.000	Niobium Boride
NbC	7.820	*1.000	Niobium Carbide
NbN	8.400	*1.000	Niobium Nitride
Nd	7.000	*1.000	Neodynium
Nd_2O_3	7.240	*1.000	Neodynium Oxide
NdF_3	6.506	*1.000	Neodynium Fluoride
Ni	8.910	0.331	Nickel
NiCr	8.500	*1.000	Nichrome
NiCrFe	8.500	*1.000	Inconel
NiFe	8.700	*1.000	Permalloy
NiFeMo	8.900	*1.000	Supermalloy

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
NiO	7.450	*1.000	Nickel Oxide
P_3N_5	2.510	*1.000	Phosphorus Nitride
Pb	11.300	1.130	Lead
$PbCl_2$	5.850	*1.000	Lead Chloride
PbF_2	8.240	0.661	Lead Fluoride
PbO	9.530	*1.000	Lead Oxide
PbS	7.500	0.566	Lead Sulfide
PbSe	8.100	*1.000	Lead Selenide
$PbSnO_3$	8.100	*1.000	Lead Stannate
PbTe	8.160	0.651	Lead Telluride
Pd	12.038	0.357	Palladium
PdO	8.310	*1.000	Palladium Oxide
Po	9.400	*1.000	Polonium
Pr	6.780	*1.000	Praseodymium
Pr_2O_3	6.880	*1.000	Praseodymium Oxide
Pt	21.400	0.245	Platinum
PtO_2	10.200	*1.000	Platinum Oxide
Ra	5.000	*1.000	Radium
Rb	1.530	2.540	Rubidium
RbI	3.550	*1.000	Rubidiurn Iodide
Re	21.040	0.150	Rhenium
Rh	12.410	0.210	Rhodium
Ru	12.362	0.182	Ruthenium
S_8	2.070	2.290	Sulphur
Sb	6.620	0.768	Antimony
Sb_2O_3	5.200	*1.000	Antimony Trioxide
Sb_2S_3	4.640	*1.000	Antimony Trisulfide
Sc	3.000	0.910	Scandium
Sc_2O_3	3.860	*1.000	Scandium Oxide
Se	4.810	0.864	Selenium
Si	2.320	0.712	Silicon
Si_3N_4	3.440	*1.000	Silicon Nitride
SiC	3.220	*1.000	Silicon Carbide

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Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
SiO	2.130	0.870	Silicon (II) Oxide
SiO_2	2.648	1.000	Silicon Dioxide
Sm	7.540	0.890	Samarium
Sm_2O_3	7.430	*1.000	Samarium Oxide
Sn	7.300	0.724	Tin
SnO_2	6.950	*1.000	Tin Oxide
SnS	5.080	*1.000	Tin Sulfide
SnSe	6.180	*1.000	Tin Selenide
SnTe	6.440	*1.000	Tin Telluride
Sr	2.600	*1.000	Strontium
SrF_2	4.277	0.727	Strontium Fluroide
SrO	4.990	0.517	Strontium Oxide
Ta	16.600	0.262	Tantalum
Ta_2O_5	8.200	0.300	Tantalum (V) Oxide
TaB_2	11.150	*1.000	Tantalum Boride
TaC	13.900	*1.000	Tantalum Carbide
TaN	16.300	*1.000	Tantalum Nitride
Tb	8.270	0.660	Terbium
Tc	11.500	*1.000	Technetium
Te	6.250	0.900	Tellurium
TeO_2	5.990	0.862	Tellurium Oxide
Th	11.694	0.484	Thorium
ThF_4	6.320	*1.000	Thorium.(IV) Fluoride
ThO_2	9.860	0.284	Thorium Dioxide
$ThOF_2$	9.100	*1.000	Thorium Oxyfluoride
Ti	4.500	0.628	Titanium
Ti_20_3	4.600	*1.000	Titanium Sesquioxide
TiB_2	4.500	*1.000	Titanium Boride
TiC	4.930	*1.000	Titanium Carbide
TiN	5.430	*1.000	Titanium Nitride
TiO	4.900	*1.000	Titanium Oxide
TiO_2	4.260	0.400	Titanium (IV) Oxide
Tl	11.850	1.550	Thallium

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Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
TIBr	7.560	*1.000	Thallium Bromide
TICI	7.000	*1.000	Thallium Chloride
TII	7.090	*1.000	Thalliurn Iodide (B)
U	19.050	0.238	Uranium
U_3O_8	8.300	*1.000	Tri Uranium Octoxide
U_4O_9	10.969	0.348	Uranium Oxide
UO_2	10.970	0.286	Uranium Dioxide
V	5.960	0.530	Vanadium
V_2O_5	3.360	*1.000	Vanadium Pentoxide
VB_2	5.100	*1.000	Vanadium Boride
VC	5.770	*1.000	Vanadium Carbide
VN	6.130	*1.000	Vanadium Nitride
VO_2	4.340	*1.000	Vanadium Dioxide
W	19.300	0.163	Tungsten
WB_2	10.770	*1.000	Tungsten Boride
WC	15.600	0.151	Tungsten Carbide
WO_3	7.160	*1.000	Tungsten Trioxide
WS_2	7.500	*1.000	Tungsten Disulphide
WSi_2	9.400	*1.000	Tungsten Silicide
Y	4.340	0.835	Yttrium
Y_20_3	5.010	*1.000	Yttrium Oxide
Yb	6.980	1.130	Ytterbium
Yb_2O_3	9.170	*1.000	Ytterbium Oxide
Zn	7.040	0.514	Zinc
Zn_3Sb_2	6.300	*1.000	Zinc Antimonide
ZnF_2	4.950	*1.000	Zinc Fluoride
ZnO	5.610	0.556	Zinc Oxide
ZnS	4.090	0.775	Zinc Sulfide
ZnSe	5.260	0.722	Zinc Selenide
ZnTe	6.340	0.770	Zinc Telluride
Zr	6.490	0.600	Zirconium
ZrB_2	6.080	*1.000	Zirconium Boride
ZrC	6.730	0.264	Zirconium Carbide

Table A-1 Material Table (continued)

Formula	Density	Z-Ratio	Material Name
ZrN	7.090	*1.000	Zirconium Nitride
ZrO_2	5.600	*1.000	Zirconium Oxide
	10.000	*1.000	USER

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