OPERATING INSTRUCTION MANUAL

FOR THE

CS4-10V
MAGNET POWER SUPPLY

Rev. 3.1 – Sept. 10, 2004

CRYOMAGNETICS, INC.

INNOVATIVE SUPERCONDUCTING MAGNET SOLUTIONS

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WARNING!

DO NOT ATTEMPT TO OPERATE THIS EQUIPMENT BEFORE YOU HAVE THOROUGHLY READ THIS INSTRUCTION MANUAL.

CE

MANUFACTURER'S DECLARATION OF CONFORMITY

According to ISO / IEC Guide 22 and EN45014

Manufacturer's Name: Cryomagnetics, Inc.

Manufacturer's Address: 1006 Alvin Weinberg Drive
Oak Ridge, TN 37830

Declares. the product

Product Name: Superconducting Magnet Power Supply
Model Number: CS4-10V/100
Product Options: All Options

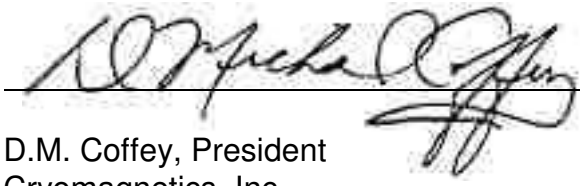
Conforms to the following Product Specifications:

Safety: EN61010-1, 1993, Amendment 2
EN61326

EMC: EN55011 Conducted Emissions,
EN55011 Radiated Emissions,
EN61000-3-2 Harmonics
EN61000-3-3 Flicker
EN61000-4-2 ESD Air Discharge, 1kv, 2kv, 4kV
EN61000-4-2 ESD Contact Discharge, 2kv, 4kV, 8kV
EN61000-4-3 Radiated Immunity 10V/m
EN61000-4-4, EFT 500V, 1kV, 2kV
IEC 1000-4-5:1995 Surge 500V, 1kV L-L
500V, 1kV, 2kV L-G
EN61000-4-6 Conducted Immunity 10V rms
EN61000-4-8 Power Frequency Magnetic Field
EN61000-4-11 Voltage Dips and Interrupts

Application of Council Directives:

The product complies with the requirements of the Low Voltage Directive 73/23/EEC as amended by 93/68/EEC and the EMC Directive 89/336/EEC as amended by 93/68/EEC.



D.M. Coffey, President
Cryomagnetics, Inc
Oak Ridge Tennessee March 31, 2003

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Model Number: CS4-10V/60
Product Options: All Options

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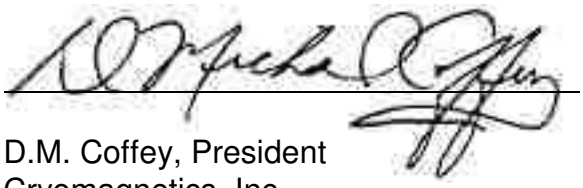

D.M. Coffey, President
Cryomagnetics, Inc
Oak Ridge Tennessee October 18, 2003

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Symbols and Abbreviations

Warning – Danger of electrical shock

A	Amperes
°C	degrees centigrade
°F	degrees Fahrenheit
Hz	Hertz
kg	kilograms
kG	kilogauss
mA	milliamperes
mV	millivolts
T	Tesla

1. Introduction

This section provides an introduction to the Cryomagnetics model CS4-10V/100 Superconducting Magnet Power Supply. Features and capabilities of the instrument are outlined and performance specifications are described.

1.1. Description

The CS-4 Superconducting Magnet Power Supply is an advanced instrument designed specifically for powering superconducting magnets. It is a true four-quadrant power supply – meaning it is capable of operating with positive current / positive voltage (sourcing power), positive current / negative voltage (sinking power), negative current / positive voltage (sinking power), and negative current / negative voltage (sourcing power). The supply allows the user to generate smooth sweeps through zero current for performing hysteresis loop experiments or other research requiring smooth magnetic field reversal.

The CS-4 is capable of delivering up to ±10 volts of output voltage and up to 100 amps of output current, depending upon which CS-4 is used. An easy-to-use menu system is provided to allow the operator to set the supply up using the parameters of his/her particular magnet. Most of the supply operating parameters are available through the standard RS-232 computer interface and/or an optional IEEE-488 interface.

Power supplies used for energizing superconducting magnets have unique requirements placed upon them. The supplies are used to source energy to magnets which can have a wide range of inductance (mH to thousands of henries). In addition, the magnet load can range from a nearly pure resistance to a nearly pure inductance – and everything in between. This places demands on the supply that are far beyond what a typical power supply used for bench top electronics would see. The supply will experience the challenges of sinking energy when a magnet is discharging every day. At the same time, the potential exists for either the magnet or power supply to be damaged in the event of a power failure or magnet quench. The CS-4's advanced circuitry enables it to take virtually any scenario encountered in superconducting magnet operation in stride.

The quiet switch-mode design of the CS-4 makes it a low noise, highly efficient supply – and one that is proven stable even on the most sensitive superconducting magnets. Versatile programmability allows the user to specify several different sweep rates for different current ranges of the magnet – making it possible to sweep a magnet slower in a particular range if it is more sensitive there without user intervention.

1.2. Features

The CS-4 has a wide range of features available:

- True Four-Quadrant Operation. The supply can provide positive or negative output current along with either polarity voltage. This gives it the ability to smoothly sweep through zero current without the need for current reversing switches or pauses.

- User – Friendly Menus. The CS-4 has intuitive menus to display and enter operating parameters. It can be set up in a matter of minutes and changes during daily operation are simple and quick.

- Easy to Read Display. The high quality vacuum fluorescent graphic display gives the operator essential information at a glance, even from across the lab.

- ± 10 Volt/± 100A High Stability Output. The CS-4 provides quiet, stable output power thanks to its low noise switch-mode design and precision current monitoring and control circuits.

- Power Fail Magnet Discharge. Should a power failure occur during operation of the magnet, the supply converts to a "Power Fail" mode wherein it draws its power from the discharging magnet rather than the AC line. When "Power Fail" mode is entered, the display is brought back on-line and the user can monitor the discharge of the magnet. If power is restored, the user can intervene to stop the discharge and re-energize the magnet if desired. "Power Fail" mode is a convenient feature of the CS-4 since it enables the user to simply turn OFF the power switch for the unit at the end of the day. The CS-4 will safely and automatically restore the display and discharge the magnet – quietly going to sleep when it's done.

- Independent Upper and Lower Current Limit Setpoints. Independent current limits allows sweeping between two setpoints without having to re-enter the menu and constantly change limit settings.

- PID-Controlled Sweeping. A PID inside the power supply's control circuits allows smooth sweeping between setpoints without the need for or dependence on voltage taps across the magnet.

- Changeable Settings During Sweep. The menu system can be entered at virtually any time during operation of the supply to change parameters. While in the menu, the top line of the display continues to update the user as to the status of the supply/magnet.

- Computer Interfacing. A versatile RS-232 interface is standard and an IEEE-488 interface is optional. Through either interface, a comprehensive set of monitor and control commands is available. The IEEE-488 interface conforms to the IEEE-488.2-1992 standard.

- LabVIEW™ drivers. Virtual Instrument drivers compatible with National Instruments LabVIEW™ are available for Cryomagnetics' instrumentation through Cryomagnetics' website.

- Analog Input Programming Interface. The user can provide analog signals to the CS-4 if desired which will be interpreted as current limit, voltage limit, and/or charge rate.

- Analog Output Monitor Interface. Analog output signals are provided to allow the user to connect the supply to a chart recorder or other monitoring instrumentation. Analog signals proportional to magnet current, magnet voltage and power supply voltage are provided.

- Built-in Persistent Switch Heater Supply. A power supply for energizing a persistent switch is built into the CS-4.

- Remote Shut-down Input. A signal can be provided by the user to the CS-4 which commands it to discharge (Zero) the magnet. This can be used to lock out operation of the magnet when helium gets too low or when some other user-defined event occurs.

- Quench Detection and Protection. The CS-4 is fully protected from damage due to quench. In addition, if a quench is detected the CS-4 will give an audible and visual indication of the quench. The current at which the quench occurred will be displayed on the unit's front panel. Since quench detection is activated on observed current transients, it must be disabled if automatic recovery is desired from abnormal conditions such as those encountered in several of the CE qualification tests. These tests include electrical fast transient and electrostatic discharge.

1.3. Specifications

Specification	Current	Voltage
DC Output:	0 to ± 100 A	0 to ± 10 V
Ripple and noise	20 uA rms	10 mV rms @ 100A
Stability (drift) at 25 ± 1C:	± 0.005% Imax	± 0.01% Vmax
Display Resolution:	1 mA	10 mV
Display Update Rate:	~ 500ms Intervals.	
Output Current Setability:	1 mA	40 mV
Sweep Rate Resolution:	0.1 mA/sec via Front Panel or 20uA/sec via Remote Interface.	
Source effect (line regulation for any line change within the rated line voltage):	0.005% Imax	0.05% Vmax
Load effect (load regulation for a load change equal to max. voltage in constant current mode or max. current in constant voltage mode):	0.01% Imax	0.01% Imax
Output Protection:	Protected from damage due to quench.	
AC Input:	220-230V a.c., 50-60 Hz, 10A	
Fuses:	10A, 250V a.c., slow blow	
Operating Temperature:	15 °C to 35 °C	
Relative Humidity	10% to 95%, noncondensing	
Overtemperature Protection:	Unit will shutdown if internal heatsink temperature exceeds 80 °C.	
Dimensions:	483 mm W X 179 mm H X 585 mm D	
Weight:	23.6 kG (52 lbs)	
RS-232 interface:	Standard	
IEEE-488 interface:	Optional, To IEEE-488.2-1992 Standard.	
Analog Programming Inputs:	0-10V Std, Option for 0-1V, ±10V, 4-20mA	
Analog Programming Outputs:	0-10V Std, Option for 0-1V, ±10V, 4-20mA	

The CS4-10V/100 is designed to operate per the specifications in this table and the instructions provided in this manual. Other use may impair the safety protections provided by the equipment.

2. Installation and Setup

The following section outlines information concerning the initial unpacking, installation and setup of the CS-4 supply. As with any equipment purchase, the user is strongly encouraged to inspect the power supply for shipping damage immediately upon receipt. Proper power and ground connections should be made using the appropriate codes and practices. Should the CS-4 require return to the factory due to shipping damage or for servicing, contact Cryomagnetics or an authorized service representative for instructions and a return authorization number.

The CS-4 is delivered to you fully tested, calibrated, and ready to operate. This includes configuring appropriate setup values if the supply is purchased with a magnet system.

2.1. Line Voltage and Fuses

The CS-4 is fused for operation using 220-230 V a.c., 50-60 Hz input power. Two 10 amp fuses are required for this input voltage configuration. The fuses are located in the power entry module. The power supply has been tested per EN61010 over the voltage range of 198-253 V a.c. Never replace the fuses with wires and never use ungrounded power cords for line power.

It is strongly recommended that AC power provided to the CS-4 be protected with a Ground Fault Interrupter (GFI) and a surge suppresser. If the unit is operating in an area subject to power failures or brownouts, the user may wish to install an Uninterruptible Power Supply (UPS) to minimize the chance of inadvertently discharging or quenching the magnet due to line effects.

2.2. Mounting

The CS-4 is compatible with all standard 19-inch wide rack cabinets. Due to the instrument's weight, it is recommended that rails be located beneath the supply to prevent bending of the supply mounting brackets. Adequate ventilation is essential to the CS-4. An unobstructed air path should be available at the ventilation slots in the rear and side panels of the instrument and at the fan outlet to avoid overheating.

2.3. Environment

The CS-4 is designed for operation in free air, non-condensing atmospheres within a temperature range of 15 to 35C (59 to 95F). It has been designed primarily for laboratory use – so harsh environments of dust or corrosive materials could result in eventual damage. A filtered enclosure is recommended for operation under these conditions.

2.4. Terminal Strip Connections

The rear panel terminal strip of the CS-4 provides service for all analog input and output signals for

the CS-4. The terminal strip is shown in Figure 2.1 and Table 2.1 outlines the definition and function of each terminal pair. A cover is provided to prevent electrostatic discharge damage to the electrical connections.

Figure 2.1

Rear Panel Terminal Strip

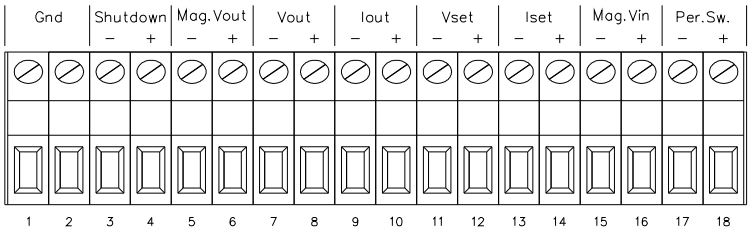


Table 2.1

Terminal Functions

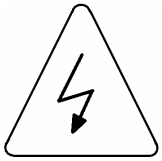
Terminal #	Name	Function
1	Ground	Ground connection for output cable shields
2	Ground	Ground connection for I/O cable shields
3	Shutdown -	Automatic Power Supply Shutdown - Input Signal from User to CS-4 (Used for magnet discharge on low helium)
4	Shutdown +	Leave open if not in use.
5	Mag.Vout -	Magnet Voltage Monitor – Output Signal Generated by CS-4
6	Mag.Vout +	
7	Vout -	Power Supply Output Voltage – Output Signal Generated by CS-4 (Isolated from true supply output)
8	Vout +	
9	Iout -	Power Supply Output Current – Output Signal Generated by CS-4 (Isolated from true supply output)
10	Iout +	
11	Vset -	Power Supply Voltage Limit / Rate Set - User Generated Analog Programming Input to CS-4
12	Vset +	
13	Iset -	Power Supply Current Limit Set - User Generated Analog Programming Input to CS-4
14	Iset +	
15	Mag.Vin -	Magnet Voltage Taps – Input Signal to CS-4 from Magnet (Not required for operation).
16	Mag.Vin +	
17	Per.Sw. -	Persistent Switch Heater Power Supply Output
18	Per.Sw. +	

Before making connections to the rear panel terminal strip, make sure the power to the CS-4 is OFF. Shield cables must be used with shields connected to terminal 2 for CE compliance. Make

all connections using the appropriate wire size. The terminal strip is designed to accept AWG 24 – 12 (0.2 – 2.5 mm^2 stranded or 0.2 – 0.4 mm^2 solid) conductor. The ends should be stripped bare 7mm. All connections should be isolated from instrument ground and from each other.

2.5. Power Output Terminals

The high current output terminals are located on the rear panel and are labeled – OUT and + OUT. Before attaching the terminals to the magnet power leads, make sure the CS-4 power is OFF. Care should be taken in attaching power leads for the magnet to insure solid contact is made using a ¼-20 bolt with nut to each terminal. Although quench protection is built into the CS-4 to prevent the occurrence of high voltages, the magnet leads should NEVER be disconnected when current is present. Potentially lethal voltage can easily occur due to the high inductance of superconducting magnets.



CAUTION – RISK OF ELECTRIC SHOCK

Note: Ferrite beads (Fair-Rite P/N 0444177081) must be installed on the output cables for compliance with CE standards for RF conducted immunity. Cables must be shielded with shields connected to terminal 1 of the terminal block.

2.6. Maintenance

The CS-4 should be inspected periodically to verify that all connections are secure, fans operate properly, and that the ventilation openings are clear.

If cleaning is required, disconnect the power cord and clean the unit with a soft cloth dampened with water.

The CS-4 does not contain user serviceable parts. If repairs should be required, contact the factory for a repair authorization number, and return to the factory for service to ensure the integrity of the unit is maintained.

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3. Magnet Setup and Operation

The CS-4 is designed specifically for operation with superconducting magnets. Before using the supply to energize a magnet; however, certain parameters specific to the superconducting magnet being used, the charge rate(s) desired during field sweep, and the operating current limit(s) should be set through the menu system. The following procedure is recommended.

3.1. Setting Magnet Parameters

The first thing the user should set up are the magnet parameters. To set these up, press the [Menu] key on the front panel. Use the arrow keys to select <Magnet> and press [Enter]. The display will indicate the Magnet Parameters. If the magnet to be energized is currently at zero field, the Persistent Mode Current should be set to 0.000A. If the magnet is already in persistent mode at some other known current, this current can be entered. Be sure the polarity of the magnet current is entered correctly.

The maximum safe operating current for the magnet should be entered in the Max Current parameter position. The supply will not allow output current to exceed this value. Should the user attempt to enter a Current Limit setting above this value (in the Limits menu), the supply will set the limit to the Max Current value observing polarity.

The field-to-current ratio of the magnet may be entered in the Magnet Parameters setup if desired. The CS-4 only uses this parameter if the user wants the display to indicate output current in terms of magnetic field units (kilogauss or Tesla) rather than amps. Consequently setting this parameter is not essential.

If the magnet to be energized is equipped with a persistent mode switch, the heater current necessary to activate it should be entered in the Switch Heater Current Field. The persistent switch heater power supply is capable of up to 100 mA of output current.

3.2. Setting Charge Rates

The charge rate(s) for energizing the magnet should be entered through the Rates menu item in the main menu. The CS-4 allows the user to set up to three different charge rates to be used in three current ranges. This allows the user to specify a slower rate for a magnet when it is near its maximum rated field.

From the main menu, use the arrow keys to select <Rates> and press [Enter]. Using the inductance of the magnet as a guide, set the desired rates keeping in mind that the best (smoothest) sweeps of the magnet are achieved when voltage limit is not exceeded. The charging voltage of the magnet is

computed by $V = L \, {}^{di}/_{dt}$, where the value of ${}^{di}/_{dt}$ is the sweep rate in amperes per second indicated in the Rates menu.

Once the rates and their respective current ranges have been set, press [Menu] and [Enter] to accept the changes (or [Esc] to abort and ignore all changes).

3.3. Setting Limits

The desired operating current for the magnet is set in the Limits menu item in the main menu. The CS-4 allows the user to enter two different limits – an upper and a lower – to enable smooth sweeps between two points. Either or both of the upper and lower current limits may be positive or negative current values as long as the upper is more positive than the lower.

From the main menu, use the arrow keys to select <Limits> and press [Enter]. Use the arrow keys to select the appropriate current limit and then enter the desired value. If changes to the voltage limit are desired, this can be entered now, too.

Once the desired current limits have been set, press [Menu] and [Enter] to accept the changes (or [Esc] to abort and ignore the changes).

3.4. Energizing the Magnet

Once the magnet parameters, charge rates, and limits have been set, the supply is ready to energize the magnet. From the main operating menu, energize the persistent switch heater supply by pressing the [PSHtr] key. The CS-4 will ask for confirmation before energizing the heater. Confirm that the heater is to be turned on by pressing [Enter] (or [Esc] to abort energizing the persistent switch heater). Wait for a few seconds or whatever time is required by the magnet's persistent switch before beginning the field sweep.

Press the up arrow key [↑] to begin energizing the magnet in the direction of the upper current limit. Alternatively, the operator can press the down arrow key [↓] to begin energizing the magnet in the direction of the lower current limit. Once the appropriate current limit is reached, the CS-4 will hold that current.

To place the magnet into persistent mode, turn off the persistent switch heater supply by pressing the [PSHtr] key. The CS-4 will ask for confirmation before turning off the heater. Press [Enter] to confirm (or [Esc] to abort). Wait a few seconds or whatever time is required by the magnet's persistent switch before zeroing the current in the leads.

Once the magnet is in persistent mode, the current in the leads may be brought back to zero by pressing the [Zero] key.

IMPORTANT

Be sure to zero the supply by pressing the [Zero] key. Pressing the down arrow key [↓] will result in the supply sweeping to the lower current limit rather than to zero.

Watch the magnet voltage while the supply begins to sweep toward zero to verify that the magnet has indeed entered persistent mode. If no voltage is detected, press [Shift-Zero] to bring the supply back to zero output current more quickly. When the supply reaches zero output current, it automatically switches to Standby mode.

3.5. Discharging the Magnet

To discharge a magnet that is in persistent mode, press the [Shift-↑↑] or [Shift-↓↓] to quickly bring the supply output current back to the current left in the magnet. Be sure to bring the current back in the proper polarity as was left in the magnet.

When current limit is reached, the supply will stabilize and hold that current. From the main operating menu, energize the persistent switch heater supply by pressing the [PSHtr] key. The CS-4 will ask for confirmation before energizing the heater. Confirm that the heater is to be turned on by pressing [Enter] (or [Esc] to abort energizing the persistent switch heater). Wait for a few seconds (or whatever time is required by the magnet's persistent switch) before beginning the field sweep.

Once the persistent switch is warm, sweep the magnet current back to zero by pressing the [Zero] key. Watch the magnet voltage to verify that the magnet is beginning to discharge. When the supply reaches zero output current, it will automatically change to Standby mode. Turn off the persistent switch heater by pressing the [PSHtr] key and [Enter] to confirm.

To sweep to the opposite current limit rather than zero, press the appropriate [↑] or [↓] key rather than the [Zero] key. The supply will smoothly sweep through zero and on to the other current limit.

3.6. Power Fail Mode

Should there be a loss of line power during energizing or discharging of the superconducting magnet, the CS-4 will automatically switch to Power Fail Mode. In Power Fail Mode, the instrument

draws the power needed to maintain itself from the superconducting magnet rather than the line.

In the event of a power failure, the CS-4 display will momentarily blank, then the normal sign-on message will appear. The instrument reinitializes itself and then restores the Operating mode display. The magnet discharges at approximately 7.5 volts – the minimum necessary to maintain CS-4 operation. Current in the leads is accurately displayed as the magnet discharges. It is not possible to abort the discharge while line power is absent because this would instantly result in the CS-4 losing the power it needs to remain active.

If line power is restored, the CS-4 will continue to discharge the magnet (Zeroing↑ or ↓) unless the user intervenes. Upon return of line power, the supply switches back to normal line powered operation and simultaneously displays a message indicating that line power has been restored. The supply will give a triple-beep every 10 seconds to alert the user that line power has been restored. Pressing any key results in clearing the line fault indication and the beeping stops. The magnet may be energized again immediately if desired – complete magnet discharge is not necessary.

3.7. Magnet Quench

The CS-4 has magnet quench detection built-in. In the event a magnet quench is detected, a message indicating the quench has occurred will be displayed and the supply will switch to Standby mode. The supply will also indicate the current at which it was operating when the quench occurred. The quench indication is cleared by pressing [Shift-Enter].

4. Displays and Menus

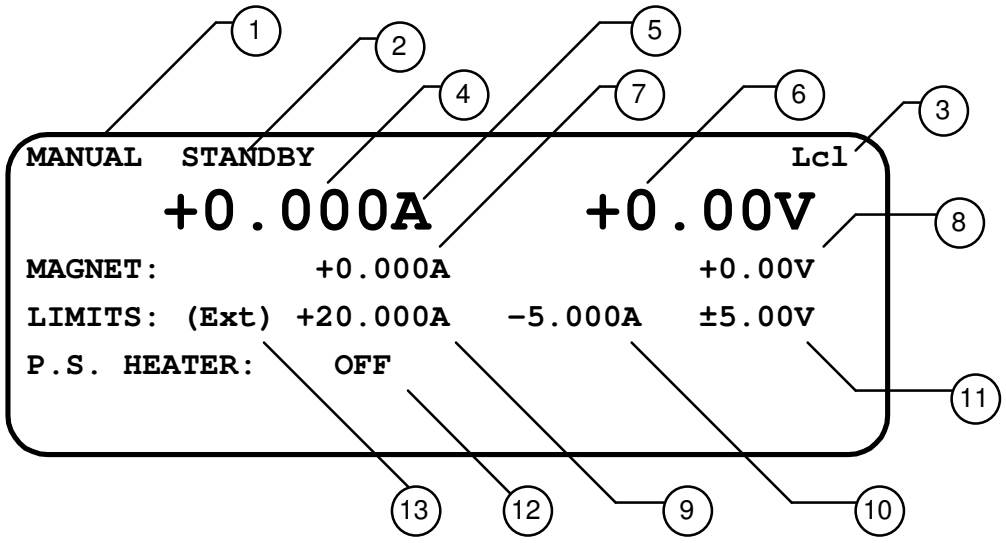
Setup and operation of the CS-4 may be performed either through the front panel keypad and simple menu instructions or through a remote computer interface (RS-232 or IEEE-488.2). Calibration and magnet-specific setup parameters are only supported through the front panel keypad. The following sections contain descriptions of how to configure and operate the CS-4 through the front panel.

Before connecting a magnet or other cabling to the CS-4, connect the power cord provided with your CS-4 to an appropriate power source. Power the instrument ON and familiarize yourself with the display and keypad.

4.1. Normal Operating Display

The normal operating display shown in Figure 4.1 provides the information necessary to quickly determine the power supply output and operating mode.

Figure 4.1 - Normal Operating Display



1	Operating Mode	6	Output Voltage	11	Output Voltage Limit
2	Sweep Mode	7	Magnet Current	12	Persistent Switch Heater
3	Local/Remote	8	Magnet Voltage	13	External Control Indicator
4	Output Current	9	Upper Sweep Limit		
5	Display Units	10	Lower Sweep Limit		

4.1.1. Operating Mode

The Operating mode field (1) will display the prior operating mode at power up. MANUAL mode is the normal operating mode. SHIM mode is available if the shim option is installed.

4.1.2 Sweep Mode

The Sweep Mode field (2) indicates the present supply activity. STANDBY indicates that the power supply output module is disabled and not developing power. SWEEP ↑ indicates that the supply output current is being swept in the direction of the upper sweep limit. SWEEP ↓ indicates that the supply output current is being swept in the direction of the lower sweep limit. PAUSED indicates that the sweep function is not active, and that the supply is maintaining a prescribed output current. Zeroing ↑ or Zeroing ↓ indicates the supply is discharging.

When the Sweep Mode is SWEEP ↑ or SWEEP ↓, the sweep will continue until the respective upper or lower current limit is reached. When Zeroing, the Sweep Mode of the supply will automatically change to STANDBY when zero current is reached.

4.1.3. Local / Remote

The Lcl indicator (3) shows that operator has pressed the **Local** button, and that the remote interfaces (RS-232 or GPIB) cannot control the supply until the operator presses the **Local** button again. The Rem indicator shows that a remote interface is controlling the supply, and that all buttons except the **Local** button are disabled.

4.1.4. Output Current

The supply output current (4) is displayed in selected units, and is updated about twice a second.

4.1.5. Display Units

The operator may select amps, kilogauss, or Tesla to display the output current (5).

4.1.6. Output Voltage

The output voltage (6) is displayed in volts and is updated about twice a second.

4.1.7. Magnet Current

The magnet current (7) is displayed in the selected units. The magnet current tracks the supply output current if the persistent switch heater is on. If the persistent switch heater is off, the magnet current will reflect the power supply output current at the time the persistent switch heater was turned off. The magnet current will show zero if a quench is detected.

4.1.8. Magnet Voltage

The magnet voltage (8) is displayed if magnet taps are connected to magnet voltage analog inputs (±Mag.Vin., terminals 15 & 16 on the rear panel terminal strip).

4.1.9. Upper Sweep Limit

The upper sweep limit (9) displays the current limit that will be used if the sweep up function is activated.

4.1.10. Lower Sweep Limit

The lower sweep limit (10) displays the current limit that will be used if the sweep down function is activated.

4.1.11. Output Voltage Limit

The output voltage limit (11) displays the maximum voltage that the supply is programmed to output.

4.1.12. Persistent Switch Heater

The persistent switch heater status field (12) will display ON or OFF.

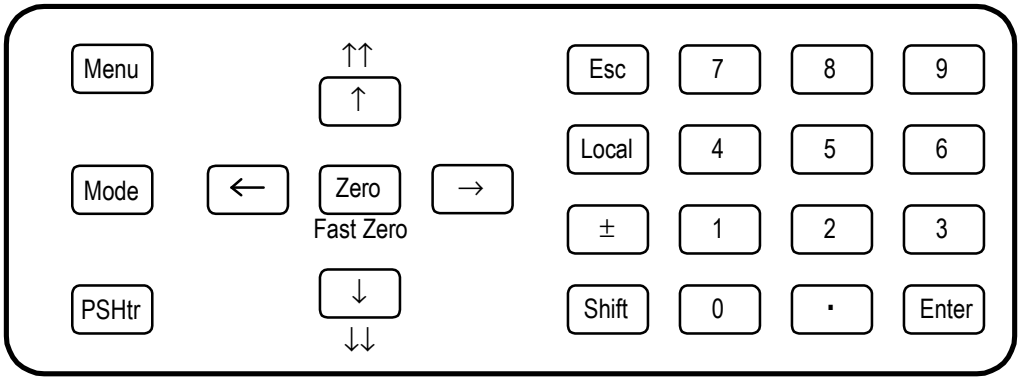
4.1.13. External Control Indicator

The external control indicator field (13) will read “Ext” if the current limit, voltage limit, or sweep rate is set to Analog Input in the Control Source Setup Menu. If all are set to Programmed the “Ext” indicator will not be displayed.

4.2. Key Pad Operation

The keypad layout is shown in Figure 4.2. The [Mode], [PSHtr], and [Local] keys may only be used when the normal operating display is visible (Menu system inactive.) The remaining keys are used in both operating and menu modes.

Figure 4.2 - Keypad Layout



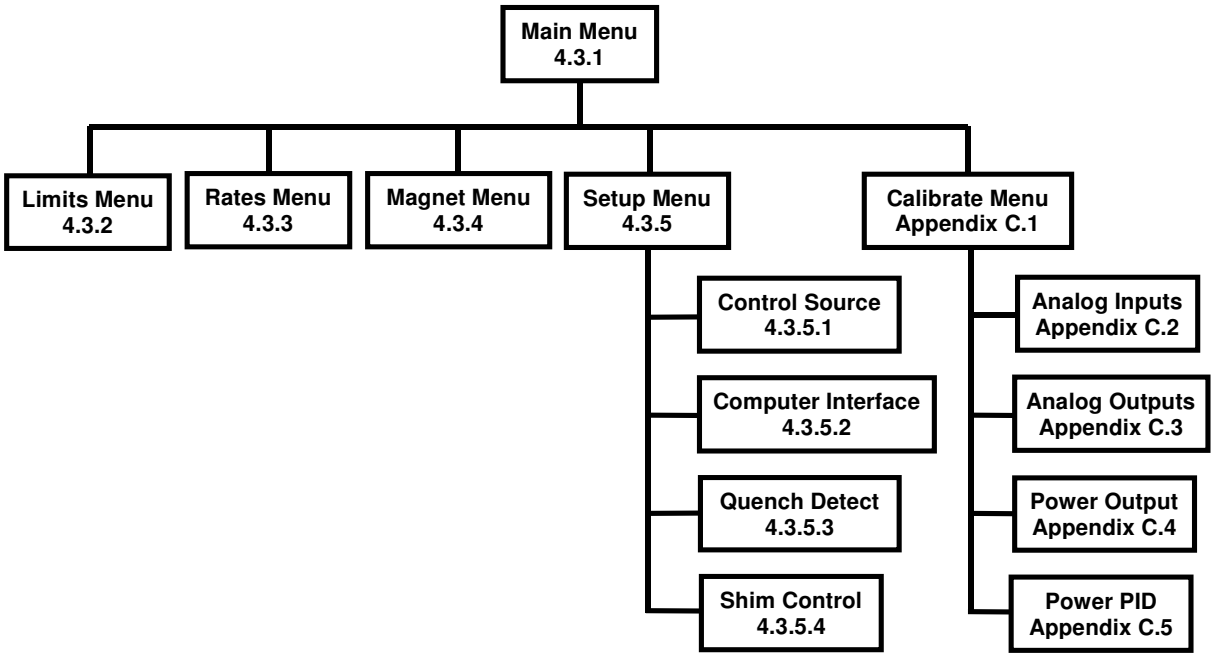
A Select/Edit indicator is displayed at the end of the second line in the Menu system (see (6) in Figure 4.4). When Select is shown, the arrow keys can be used to move the highlight to the field to be selected. When Edit is shown, the selected field or entry position is flashed to indicate the item that will be affected when a key is pressed. A field is selected by pressing the [Enter] button when the field is highlighted. Once in Edit mode, the field contents may be changed by pressing a right or left arrow key (for text fields), or entering the value directly on the numeric keypad (for numeric fields). A numeric field may be cleared by pressing the [Zero] key. When the desired changes have been made the [Enter] button is pressed to accept the changes. The [Esc] button may be pressed to avoid making a change.

4.3. Menus

The CS-4 menu system implements one or two levels of 'Undo' depending on how it is used. If a submenu is exited by pressing the [Esc] button after changes have been entered, a prompt is issued to “Press <Esc> to abort changes or <Enter> accept changes”. If [Enter] is pressed the changes are retained, but the changes are not implemented until the menu system is exited. When [Menu] is pressed in the menu system, the abort/accept prompt is displayed again, and if [Enter] is pressed, the changes are made. If [Esc] is pressed, any changes made in the menu system are forgotten. Note that [Esc] will back up one level in the menu system, but pressing [Menu] will return directly to the operating display.

The menu organization is shown in Figure 4.3.

Figure 4.3 - Menu Organization

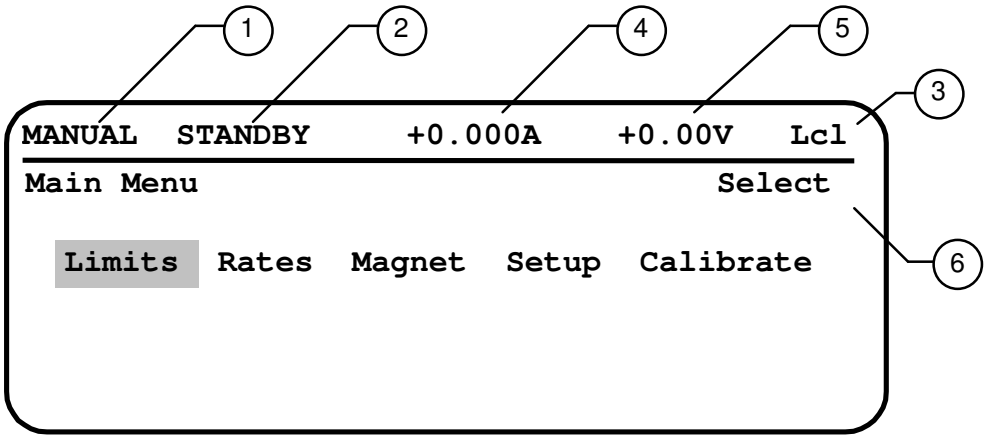


4.3.1. Main Menu

Pressing [MENU] when the operating display is active will cause the Main Menu to be displayed. Pressing [MENU] again or [Esc] returns the instrument to the operating display. Be aware that some computer interface commands are not available while the menu system is active (see Appendix B).

Figure 4.4 shows the main menu.

Figure 4.4 - Main Menu



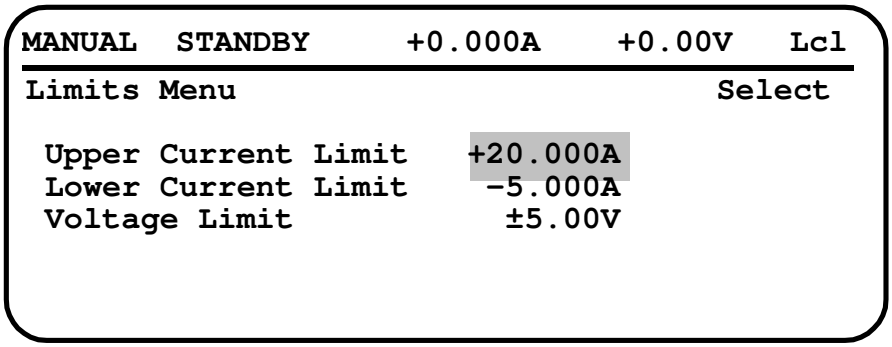
1	Operating Mode	3	Local/Remote Indicator	5	Output Voltage
2	Sweep Mode	4	Output Current	6	Select/Edit Indicator

When in the menu system the top display line continues to update the status items shown. These items are described in Section 4.1. The Select/Edit (6) indicator appears on all the menu screens and indicates whether a field has been selected for edit. The arrow keys are used to highlight the desired option when Select is shown. Press the [Enter] key to select the item.

4.3.2. Limits Menu

The Limits menu, shown in Figure 4.5, is used to set the sweep limits and voltage limit when the control source in the Setup menu is set to Programmed. The values are not used when the control source is set to Analog Input.

Figure 4.5 - Limits Menu



4.3.2.1. Upper and Lower Current Limits

In the SWEEP ↑ mode the current will sweep at the prescribed rate until the upper current limit is reached, and in the SWEEP ↓ mode the lower current limit will be used. If the menu is entered and the upper limit is set to a value lower than the present current, the current will be increased or decreased as required to reach the new upper limit when the menu is exited.

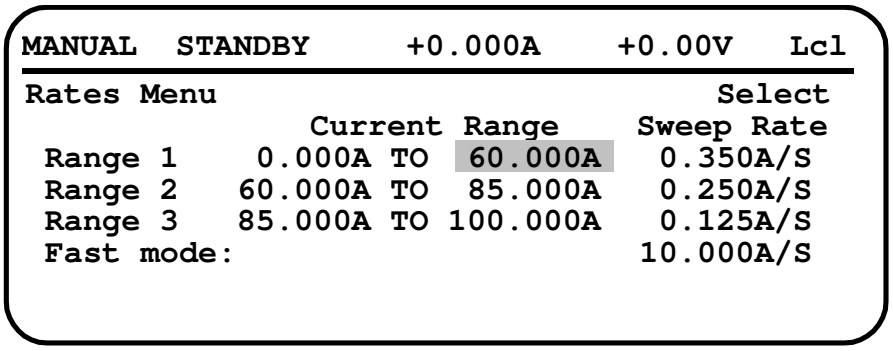
4.3.2.2. Voltage Limit

The voltage limit is used to set the maximum or minimum output voltage that will appear at the power supply output terminals during charge or discharge. Note that the voltage at the magnet will be either more or less due to the direction of current in the current leads and the lead resistance.

4.3.3. Rates Menu

The Rates menu, shown in Figure 4.6, is used to set the sweep rates when the control source in the Setup menu is set to Programmed. The values are not used when the control source is set to Analog Input.

Figure 4.6 - Rates Menu



4.3.3.1. Current Ranges

Three current ranges may be defined by setting the upper current limits for Range 1 and Range 2. Range 3 is set from the end of Range 2 to the supply output capacity.

4.3.3.2. Sweep Rates

Sweep rates may be set for each current range. This allows sweep rates to be automatically reduced at high fields and increased at low fields if desired.

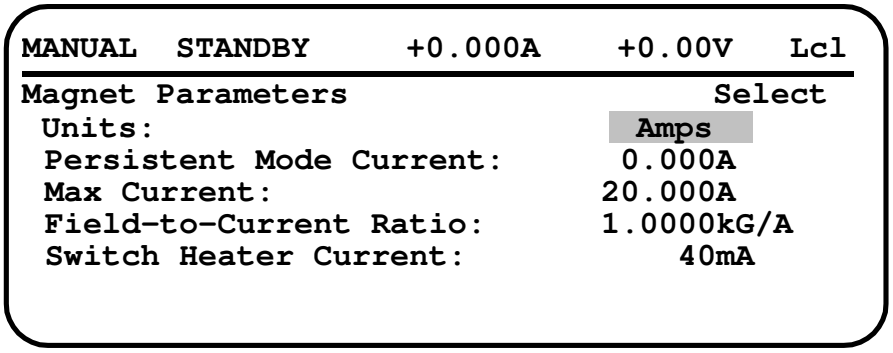
4.3.3.3. Fast Mode

Fast mode sweep rate is used when sweep up fast [Shift-↑↑], sweep down fast [Shift-↓↓], or [Shift-Fast Zero] is selected. These modes are selected by holding the shift key and pressing the up arrow, down arrow, or zero button.

4.3.4. Magnet Menu

The Magnet menu should be the first menu configured when preparing the supply for use since the Max Current parameter is used in the Limits and Rates menus.

Figure 4.7 - Magnet Parameters Menu



4.3.4.1. Units

The Units menu item allows the user to set the display units of the CS-4. Available options are Amps, kilogauss and Tesla. Once the system of units is selected, the CS-4 uses that system of units for displaying the output current, magnet current, and limits.

4.3.4.2. Persistent Mode Current

Persistent mode current displays the present magnet current if it is in persistent mode and it was last used with the supply. If the magnet was placed in persistent mode using a different power supply, or if a magnet quenches while the power supply is turned off, this field may be preset or edited.

4.3.4.3. Max Current

Max current sets the maximum current that may be set in the upper or lower current limits, and the maximum current that can be used to set the current ranges in the Rates menu. It would normally be set to the magnet's maximum safe operating limit.

4.3.4.4. Field-to-Current Ratio

The field-to-current ratio of the magnet is entered in units of kilogauss per ampere. It is used to display the magnetic field instead of output current if kilogauss or Tesla are selected in the Units menu item.

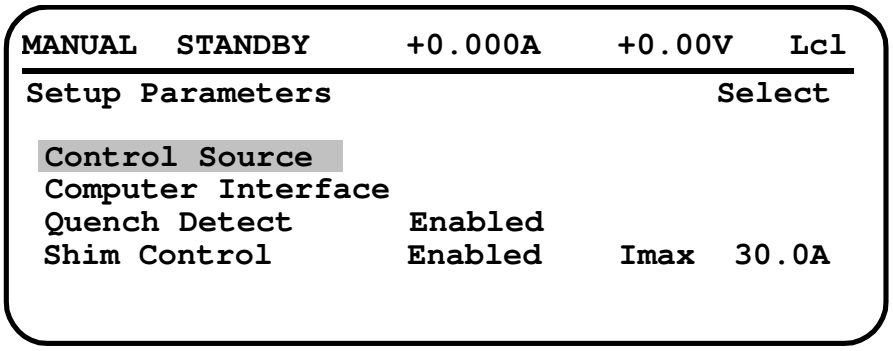
4.3.4.5. Persistent Switch Heater Current

The persistent switch heater current can be set from 0 to 100 mA. The switch heater is not turned on until it is selected in the operating display or via a remote interface command.

4.3.5. Setup Menu

The Setup menu is used to set the control source for the current and voltage limits and sweep rates, select computer interface parameters, enable or disable quench detect, and if the SHIM option is installed, it can be enabled or disabled, and the maximum shim current set. A submenu is invoked if Control Source or Computer Interface is selected.

Figure 4.8 - Setup Menu

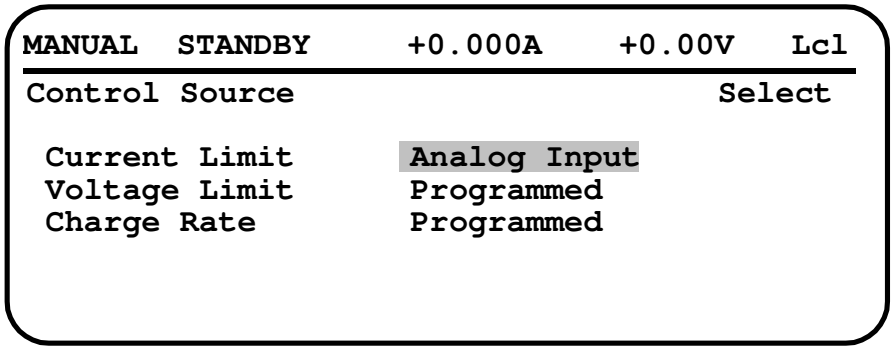


4.3.5.1. Control Source Menu

The Control Source menu, shown in Figure 4.9, is used to set the control source for the current and voltage limits and sweep rates.

Figure 4.9

Control Source Menu



4.3.5.1.1. Current Limit Source

The Current Limit is set in the Limits menu if Programmed is selected. When the control source is set to Analog Input, the output current limit follows the ± Iset analog inputs (terminals 13 & 14 on the rear panel terminal strip).

4.3.5.1.2. Voltage Limit Source

The Voltage Limit is set in the Limits menu if Programmed is selected. When the control source is set to Analog Input, the voltage limit follows the ±Vset analog input (terminals 11 & 12 on the rear panel terminal strip). Either Voltage Limit or Charge Rate source may be set to programmed through the ±Vset analog input, but not both.

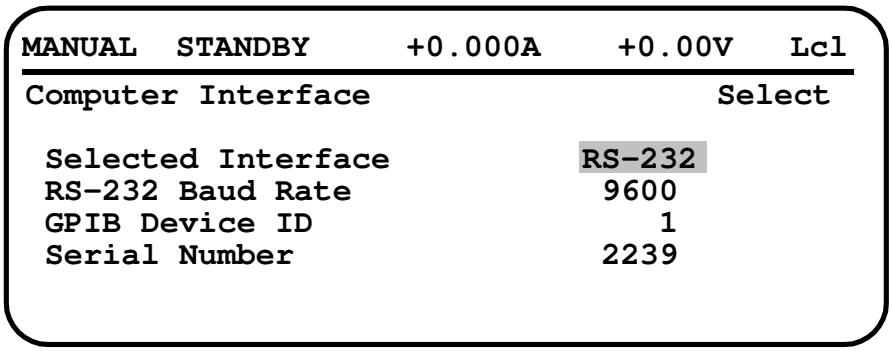
4.3.5.1.3. Charge Rate Source

When the control source for Charge Rate (sweep rate) is set to “Programmed”, the sweep rates specified in the Rates menu is used. When the control source for Charge Rate is set to “Analog Input”, the charge rate follows the ±Vset analog input. Either Voltage Limit or Charge Rate source may be set to programmed through the ±Vset analog input, but not both.

4.3.5.2. Computer Interface Menu

The Computer Interface menu, shown in Figure 4.10, is used to select the remote interface and to set the remote interface parameters. The menu also displays the unit serial number.

Figure 4.10 - Computer Interface Menu



4.3.5.2.1. Selected Interface

The selected interface field displays the computer interface to be selected the next time power is applied to the unit in accordance with the IEEE-488.2-1992 specification. The selection may be changed at any time without affecting the unit's operation.

4.3.5.2.2. RS-232 Baud Rate

The RS-232 baud rate may be set to 1200, 2400, 4800, or 9600 baud.

4.3.5.2.3. GPIB Device ID

The GPIB device ID may be set from 0 to 31.

4.3.5.2.4. Serial Number

The unit serial number is conveniently displayed for warranty purposes.

4.3.5.3. Quench Detect

The supply monitors the output current when quench detect is enabled. If a rapid decrease is detected it assumes that a quench has occurred, and the supply is immediately placed in standby. At this point the supply stops delivering any current to the magnet system, which in turn protects the magnet's quench protection system. The quench detect control allows this feature to be disabled.

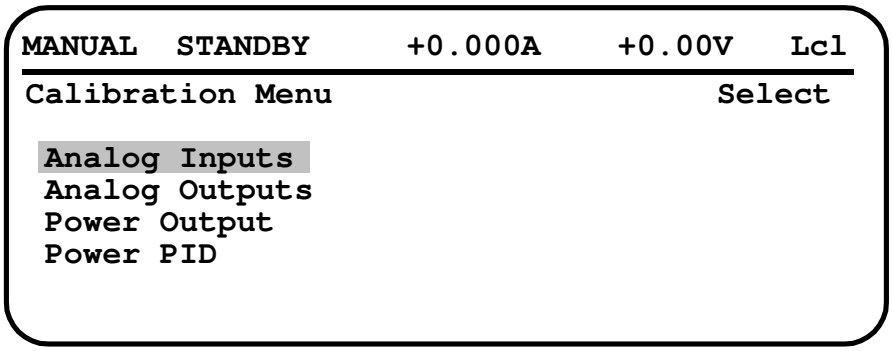
4.3.5.4 Shim Control (Shim option only)

The Shim Control allows the shim functions to be enabled or disabled by the operator, and to set the maximum output current allowed in shim mode. Imax should not normally be set above 30 A to avoid potential damage to the shim circuits in the magnet. Refer to Appendix D for shim operations.

4.3.6. Calibrate Menu

The Calibration menu, shown in Figure 4.11, provides access to submenus used to calibrate the power supply functions. The supply is fully calibrated at the factory, and further calibration should not be required. Under the Calibrate menu item, the calibration of the CS-4's analog inputs and outputs is performed, calibration of output current is made, and adjustment of the PID settings used during magnet sweep are entered. Appendix C outlines calibration procedures for the supply. Note that changing some settings could cause instabilities in your system, so care should be taken in changing calibrations. Refer to Appendix A for factory default settings for the supply.

Figure 4.11 - Calibration Menu



5. Interfacing

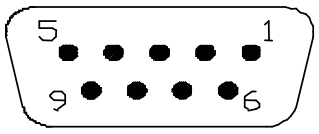
The CS-4 comes standard with an RS-232 computer interface. Front panel functions, except setup and calibration functions, may be accessed using the corresponding command string over the RS-232 port. In addition, an IEEE-488.2 port is available as an option. This port conforms to the IEEE-488.2-1992 standard.

5.1. RS-232 Computer Interface

The RS-232 port is accessed through the DB-9F connector on the rear panel of the instrument. The interface is factory configured for 9600 baud, 8 data bits, 1 stop bit, no parity. Figure 5.0 indicates the proper pin designations for the port.

Figure 5.0 - RS-232 Port Connector Wiring

Pin #	CS-4 Pin Function
1, 4, 6, 7, 8, 9	N/C
2	RS-232 Transmit
3	RS-232 Receive
5	Ground



View Facing Rear Panel Connector

Commands available to the CS-4 operator over the RS-232 computer interface are given in Appendix B. The commands available through RS-232 are identical to those available through IEEE-488.2; however, some commands may be IEEE-488.2 specific and may not provide responses consistent with the RS-232 interface. The RS-232 command set includes Local, Remote, and RWLock which are not applicable to IEEE-488.2.

Command strings are normally limited to 60 characters when the RS-232 interface is used. A <RETURN> will be generated internally when any line longer than the maximum is encountered, and any valid commands in the received line prior to the internally generated <RETURN> will be processed. An output buffer of 62 characters is used although longer responses can be successfully generated. All remote commands are case insensitive, allowing upper or lower case to be used without affecting operation of the commands.

When the RS-232 interface is selected, all commands sent to the instrument will be echoed including the terminating ASCII <RETURN> character, followed by a <NEWLINE> character when command processing is complete

5.2. IEEE-488.2 Computer Interface

The CS-4 may have an optional IEEE-488.2 computer interface. The CS-4 implements SH1, AH1, T6, L4, SR1, RL1, PP0, DC1, DT0, C0, and E1 options. The commands are compliant with the IEEE-488.2 standard. The connector is identified on the rear panel of the instrument.

Reference: IEEE Standard Codes, Formats, Protocols, and Common Commands (IEEE Std 488.2-1992) provides a detailed description of the IEEE common commands (identifiable in the command list by the asterisk as the first character.)

The command list and structure is identical to the RS-232 command set except that Local, Remote, and RWLock functions are provided through the RL1 option. Reference Appendix B for a detailed description.

6. Theory of Operation

The CS-4 is a 4 quadrant power supply with glitch free bi-directional output capability and programmable voltage limiting in both polarities.

6.1. CS-4 Circuit Description

The CS-4 Power Supply is a 68HC11 microprocessor based unit. This microprocessor has built-in EEPROM that is used to hold factory calibration and configuration data, as well as user entered calibration and setup information. Consequently, it is not possible to simply change the processor with another 68HC11. The unit will not work properly with a new processor until it has been initialized by the factory.

The processor controls virtually all aspects of the CS-4 including the display, keypad, output power module, and the high stability, 24-bit analog-to-digital converter used to monitor analog input voltages.

Output current is set by a 16 bit digital-to-analog converter controlled by a software PID algorithm updated at a 200 millisecond interval. A 20 bit sigma-delta analog-to-digital converter is used to sense the output current. The programmable current sweep rate is digitally implemented in the PID algorithm.

The microprocessor, display, I/O, and fan operate from a DC-DC converter that allows magnet discharge to be safely monitored via the display or remote interface even if wall power fails.

The CS-4's display is a bright, vacuum fluorescent unit having high contrast. It is capable of graphics and full alphanumerics and can clearly be read from a significant distance.

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7.0. Limited Warranty Policy

Cryomagnetics, Inc. warrants its products to be free from defects in materials and workmanship. This warranty shall be effective for one (1) year after the date of shipment from Cryomagnetics. Cryomagnetics reserves the right to elect to repair, replace, or give credit for the purchase price of any product subject to warranty adjustment. Return of all products for warranty adjustment shall be FOB Oak Ridge, TN, and must have prior authorization for such return from an authorized Cryomagnetics, Inc. representative.

This warranty shall not apply to any product which has been determined by Cryomagnetics, Inc. inspection to have become defective due to abuse, mishandling, accident, alteration, improper installation or other causes. Cryomagnetics, Inc. products are designed for use by knowledgeable, competent technical personnel.

In any event, the liability of Cryomagnetics, Inc. is strictly limited to the purchase price of the equipment supplied by Cryomagnetics, Inc. Cryomagnetics, Inc. shall not assume liability for any consequential damages associated with use or misuse of its equipment.

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Appendix A

Factory Calibrations, Installed Options and Certification

Model CS4-10V/100

Serial Number:

Firmware Version:

Options: GPIB

			Input Range			
Analog Input	Gain	Offset	0-1V	0-10V	+-10V	4-20mA
Set Current						
Set Voltage						
Magnet Voltage						

			Output Range			
Analog Output	Gain	Offset	0-1V	0-10V	+-10V	4-20mA
Output Current						
Output Voltage						
Magnet Voltage						

Power Output

Output Gain

Output Offset

DAC Offset

PID Settings

Proportional Gain

Integral Gain

Differential Gain

Notes: _____

_____

_____

_____

_____

_____

Certified: _____

Date: _____

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Appendix B

Computer Interface Command Reference

Commands available over the computer interface are identified by availability. Commands that are available only when the operational display is active are noted as "Operate", commands that require remote mode are noted as "Remote". All queries and IEEE-488.2 specific commands are always available, regardless of whether the state is Local, Remote, or unassigned. Commands that are IEEE 488.2 specific can be recognized by an asterisk (*) as the first character. All command mnemonics that elicit a response from the instrument (referred to as queries) end with a question (?) character. The general command format is as follows:

<subcommand1>;<subcommand2>;<subcommand3><RETURN>

where a subcommand is formatted

<Command Mnemonic><SPACE><Parameter>

Example:

*IDN?; UNITS T;UNITS?<RETURN>

Responses to each subcommand are separated by semicolons. The above example would return:

Cryomagnetics,CS4,2239,1.02;T <RETURN><LINEFEED>

where the serial number is 2239 and the firmware version number is 1.02.

Error Handling and Command Availability

The ERROR command allows error messages to be enabled or disabled when the RS-232 interface is used. The IEEE-488.2 status mechanisms may always be used to determine if an error occurred processing a command, and the category of the error. Some commands are unavailable if the instrument menu is being accessed by an operator at the instrument, or if the instrument is in LOCAL mode. If a command available only in operate mode is received while the menus are being accessed, or if a command available only in remote mode is received while not in remote mode, a device dependent error is reported in the Extended Status Register(ESR), and the message "Command blocked" will be returned if error reporting is enabled when using the RS-232 interface.

The following table lists the CS-4 commands, shows the modes where the command may be used and provides a short command description. Command details are provided in the reference that follows.

Command	Available	Description
ERROR	Remote	Set error response mode for RS-232 interface
ERROR?	Always	Query error response mode
IMAG?	Always	Query magnet current
IOUT?	Always	Query power supply output current
LLIM	Remote	Set low current sweep limit
LLIM?	Always	Query current sweep limit
LOCAL	Always	Return control to front panel (RS-232 Only)
MODE?	Always	Query selected operating mode
PSHTR	Remote	Control persistent switch heater
PSHTR?	Always	Query persistent switch heater state
RANGE	Remote	Set range limit for sweep rate boundary
RANGE?	Always	Query range limit for sweep rate boundary
RATE	Remote	Set sweep rate for selected sweep range
RATE?	Always	Query sweep rate for selected sweep range
REMOTE	Operate	Select remote operation (RS-232 Only)
RWLOCK	Operate	Select remote operation with front panel lock (RS-232 Only)
SHIM	Remote	Select shim to be queried or changed (shim option only)
SHIM?	Always	Query shim selection (shim option only)
SLIM?	Always	Query current limit for selected shim (shim option only)
SLIM	Remote	Set current limit for selected shim (shim option only)
SWEEP	Remote	Start output current sweep
SWEEP?	Always	Query sweep mode
ULIM	Remote	Set current sweep upper limit
ULIM?	Always	Query current sweep upper limit
UNITS	Remote	Select units
UNITS?	Always	Query selected units
VLIM	Remote	Set voltage limit
VLIM?	Always	Query voltage limit
VMAG?	Always	Query magnet voltage
VOUT?	Always	Query output voltage
*CLS	Always	Clear Status Command
*ESE	Always	Standard Event Status Enable Command
*ESE?	Always	Standard Event Status Enable Query
*ESR?	Always	Standard Event Status Register Query

*IDN?	Always	Identification Query
*OPC	Always	Operation Complete Command
*OPC?	Always	Operation Complete Query
*RST	Always	Reset Command
*SRE	Always	Service Request Enable Command
*SRE?	Always	Service Request Enable Query
*STB?	Always	Read Status Byte Query
*TST?	Always	Self-Test Query
*WAI	Always	Wait-to-Continue Command

Command Reference

This section describes how each CS-4 command is used and provides a cross reference to related commands. The command syntax sections show required elements enclosed in <angle brackets> and optional parameters enclosed in [square brackets]. All numbers are decimal (base 10).

ERROR Set error response mode for RS-232 interface

Availability: Remote Mode

Command Syntax: ERROR <Error Mode>

Example: ERROR 1

Parameter Range: 0 or 1 (0 - disable error reporting, 1 - enable error reporting)

Description: The **ERROR** command enables or disables error messages when the RS-232 interface is used. It is much easier to handle errors under program control when using the RS-232 interface if error messages are disabled, but it is desirable to enable error messages if a terminal program is used to interactively control and query the CS-4.

Related Commands: ERROR?

ERROR? Query error response mode

Availability: Always

Command Syntax: ERROR?

Response: <Error Mode>

Response Example: 0 **Response Range:** 0 or 1

Description: The **ERROR?** query returns the selected error reporting mode.

Related Commands: ERROR

IMAG? Query magnet current

Availability: Always

Command Syntax: IMAG? [Shim ID]

Parameter Range: Z, Z2, Z3, Z4, X, Y, ZX, ZY, C2, S2, Z2X, Z2Y

Response: <Magnet Current> <Units>

Response Example: 87.935 A

Description: The **IMAG?** query returns the magnet current (or magnetic field strength) in the present units. If the persistent switch heater is ON the magnet current returned will be the same as the power supply output current. If the persistent switch heater is off, the magnet current will be the value of the power supply output current when the persistent switch heater was last turned off. The magnet current will be set to zero if the power supply detects a quench. If in SHIM mode, the IMAG? query reports the present current of the shim selected by the SHIM command in Amps. If the optional Shim ID is provided while in shim mode, the present current of the specified shim will be reported.

Related Commands: UNITS, UNITS?

IOUT? Query power supply output current

Availability: Always

Command Syntax: IOUT?

Response: <Output Current> <Units>

Response Example: 87.935 A

Description: The **IOUT?** query returns the power supply output current (or magnetic field strength) in the present units.

Related Commands: UNITS, UNITS?

LLIM Set current sweep lower limit

Availability: Remote Mode

Command Syntax: LLIM [Limit]

Example: LLIM 20.125

Default Parameter: 0.0 **Parameter Range:** ±Maximum Magnet Current

Description: The **LLIM** command sets the current limit used when the next **SWEEP DOWN** command is issued. The value must be supplied in the selected units (Amps, KG, or Tesla).

Related Commands: LLIM?, ULIM, ULIM?, SWEEP, SWEEP?, UNITS, UNITS?

LLIM? Query current sweep lower limit

Availability: Always

Command Syntax: LLIM?

Response: <Limit> <Units>

Response Example: 20.125 A **Response Range:** ±Maximum Magnet Current

Description: The **LLIM?** query returns the current limit used when the next **SWEEP DOWN** command is issued in the selected units (Amps, KG, or Tesla).

Related Commands: LLIM, ULIM, ULIM?, SWEEP, SWEEP?, UNITS, UNITS?

LOCAL Return control to front panel

Availability: Always (RS-232 Only)

Command Syntax: LOCAL

Description: The **LOCAL** command returns control the front panel keypad after remote control has been selected by the REMOTE or RWLOCK commands.

Related Commands: REMOTE, RWLOCK

MODE? Query selected operating mode

Availability: Always

Command Syntax: MODE?

Response: <Operating Mode>

Response Example: Manual **Response Range:** Shim or Manual

Description: The **MODE?** command returns the present operating mode.

Related Commands: MODE

PSHTR Control persistent switch heater

Availability: Remote Mode

Command Syntax: PSHTR <State>

Example: PSHTR ON

Default Parameter: None **Parameter Range:** On or Off

Description: The **PSHTR** command turns the persistent switch heater on or off. Note that the switch heater current can only be set via the Magnet Menu using the front panel keypad. Also note that firmware does not prevent the persistent switch heater from being turned off or on regardless of the state of the power supply output. This command should normally be used only when the supply output is stable and matched to the magnet current.

Related Commands: PSHTR?

PSHTR? Query persistent switch heater state

Availability: Always

Command Syntax: PSHTR?

Response: 0 or 1

Description: The **PSHTR?** query returns 1 if the switch heater is ON or 0 if the switch heater is OFF.

Related Commands: PSHTR

RANGE Set range limit for sweep rate boundary

Availability: Remote

Command Syntax: RANGE <Select> <Limit>

Example: RANGE 0 25.0

Default Parameter: None **Parameter Ranges:**

Range Selection: 0 or 1

Limit: 0 to Max Magnet Current

Description: The **RANGE** command sets the upper limit for a charge rate range in amps. Range 0 starts at zero and ends at the limit provided. Range 1 starts at the Range 0 limit and ends at the Range 1 limit provided. Range 2 starts at the Range 1 limit and ends at the supply output capacity. The firmware ensures that the range 0 limit is less than or equal the range 1 limit and that the range 1 limit is less than or equal to the maximum magnet current. Note that the range parameter for the remote interface is one less than the range ID in the Rates menu accessed through the front panel.

Related Commands: RANGE?, RATE, RATE?

RANGE? Query range limit for sweep rate boundary

Availability: Always

Command Syntax: RANGE? <Select>

Example: RANGE? 1 **Parameter Range:** 0 or 1

Response: <Limit>

Response Example: 75.000 **Response Range:** 0 to Max Magnet Current

Description: The **RANGE?** query returns the upper limit for a charge rate range in amps. See RANGE for further details.

Related Commands: RANGE, RATE, RATE?

RATE Set sweep rate for selected sweep range

Availability: Remote

Command Syntax: RATE <Range> <Sweep Rate>

Example: RATE 0 0.250

Default Parameter: None **Parameter Ranges:**

Range Selection: 0 to 3

Limit: 0 to Max Magnet Current

Description: The **RATE** command sets the charge rate in amps/second for a selected range. A range parameter of 0, 1 and 2 will select Range 1, 2, or 3 sweep rates as displayed in the Rates Menu. A range parameter of 3 selects the Fast mode sweep rate.

Related Commands: RANGE, RANGE?, RATE?

RATE? Query range limit for sweep rate boundary

Availability: Always

Command Syntax: RATE? <Select>

Example: RATE? 1 **Parameter Range:** 0 to 3

Response: <Rate>

Response Example: 0.125 **Response Range:** 0 to Max Magnet Current

Description: The **RATE?** command queries the charge rate in amps/second for a selected range. A range parameter of 0, 1 and 2 will select Range 1, 2, or 3 sweep rates as displayed in the Rates Menu. A range parameter of 3 queries the Fast mode sweep rate.

Related Commands: RANGE, RANGE?, RATE

REMOTE Select remote operation

Availability: Operate (RS-232 Only)

Command Syntax: REMOTE

Description: The **REMOTE** command takes control of the CS-4 via the remote interface. All buttons on the front panel are disabled except the Local button. This command will be rejected if the menu system is being accessed via the front panel or if LCL has been selected via the Local button on the front panel. Pressing the Local button again when the menu is not selected will allow this command to be executed. This command is only necessary for RS-232 operation since the IEEE-488 RL1 option provides for bus level control of the Remote and Lock controls.

Related Commands: LOCAL, RWLOCK

RWLOCK Select remote operation

Availability: Operate (RS-232 Only)

Command Syntax: RWLOCK

Description: The **RWLOCK** command takes control of the CS-4 via the remote interface. All buttons on the front panel are disabled including the Local button. This command will be rejected if the menu system is being accessed via the front panel or if LCL has been selected via the Local button on the front panel. Pressing the Local button again when the menu is not selected will allow this command to be executed. Since safety requires remote override, the local lockout may be overridden by pressing the Local button which causes a prompt to be displayed. Pressing Shift-Local in combination will change the state to LCL, returning control to the front panel and locking out remote control. The RWLOCK command is only necessary for RS-232 operation since the IEEE-488 RL1 option provides for bus level control of the Remote and Lock controls.

Related Commands: LOCAL, RWLOCK

SHIM	Select SHIM to be controlled or queried
Availability:	Remote Mode (Shim mode only)
Command Syntax:	SHIM [Enable or Disable] <Selection>
Examples:	SHIM Z4
	SHIM Enable Z3
	SHIM Disable Z3
	SHIM Enable All
	SHIM Disable All
Default Parameter:	None
Parameter Range:	Z, Z2, Z3, Z4, X, Y, ZX, ZY, C2, S2, Z2X, Z2Y

Description: The **SHIM** command selects a shim to be controlled or queried. It also allows selected shims or all shims to be disabled or enabled. The command is only valid when operating in SHIM mode. The switch heater must be off when making a shim selection.

Related Commands: IMAG?, SHIM?, SLIM, SLIM?

SHIM?	Query SHIM selection
Availability:	Always (Shim mode only)
Command Syntax:	SHIM? [Query selection]
Response:	<Shim selection> <Enabled or Disabled>
Response Example:	ZX Enabled
Response Range:	Z, Z2, Z3, Z4, X, Y, ZX, ZY, C2, S2, Z2X, Z2Y

Description: The **SHIM?** command identifies the shim selected to be controlled or queried, and reports the enable/disable status. If the optional Shim ID is provided as a parameter, the command reports the enable/disable status of the specified shim. The command is only valid when operating in SHIM mode.

Related Commands: IMAG?, SHIM, SLIM, SLIM?

SLIM Set current limit for selected shim

Availability: Remote Mode (Shim mode only)

Command Syntax: SLIM <Limit>

Example: SLIM –5.837

Default Parameter: 0.0 **Parameter Range:** ±30.000 (See 4.3.5.4)

Description: The **SLIM** command sets the current limit for the selected shim. The command is only valid when operating in SHIM mode with the persistent switch heater off. The maximum value for the current limit is set in the setup screen of the main menu when in Manual mode. The SWEEP command is used to sweep the power supply to the target current of the selected shim.

Related Commands: IMAG?, SHIM?, SLIM, SLIM?, SWEEP

SLIM? Query current limit for selected shim

Availability: Always (Shim mode only)

Command Syntax: SLIM?

Response: <Limit> A

Response Example: 5.923 A **Response Range:** ±30A (See 4.3.5.4)

Description: The **SLIM?** Query returns the current limit used when the next SWEEP UP or SWEEP DOWN command is issued.

Related Commands: IMAG?, SHIM, SLIM, SLIM?, SWEEP

SWEEP Start output current sweep

Availability: Remote Mode

Command Syntax: SWEEP <Sweep Mode> [fast or slow]

Examples: SWEEP UP

SWEEP UP FAST

Default Parameter: None **Parameter Range (Manual):** UP, DOWN, PAUSE, or ZERO

Parameter Range (Shim): LIMIT, PAUSE, or ZERO

Description: The **SWEEP** command causes the power supply to sweep the output current from the present current to the specified limit at the applicable charge rate set by the range and rate commands. If the FAST parameter is given, the fast mode rate will be used instead of a rate selected from the output current range. SLOW is required to change from fast sweep. SWEEP UP sweeps to the Upper limit, SWEEP DOWN sweeps to the Lower limit, and SWEEP ZERO discharges the supply. If in SHIM mode, SWEEP LIMIT sweeps to the limit current.

Related Commands: LLIM, LLIM?, SLIM, SLIM?, SWEEP?, ULIM, ULIM?, UNITS, UNITS?

SWEEP? Query sweep mode

Availability: Always

Command Syntax: SWEEP?

Response: <Mode> [fast]

Response Example: sweep up fast **Response Range:** sweep up, sweep down, sweep paused, or zeroing

Description: The **SWEEP?** query returns the present sweep mode. If sweep is not active then 'sweep paused' is returned.

Related Commands: LLIM, LLIM?, SLIM, SLIM?, SWEEP, ULIM, ULIM?, UNITS, UNITS?

ULIM Set current sweep upper limit

Availability: Remote Mode

Command Syntax: ULIM [Limit]

Example: ULIM 65.327

Default Parameter: 0.0 **Parameter Range:** ±Maximum Magnet Current

Description: The **ULIM** command sets the current limit used when the next **SWEEP UP** command is issued. The value must be supplied in the selected units (Amps, KG, or Tesla).

Related Commands: LLIM, LLIM?, SWEEP, SWEEP?, ULIM?, UNITS, UNITS?

ULIM? Query current sweep upper limit

Availability: Always

Command Syntax: ULIM?

Response: <Limit> <Units>

Response Example: 65.327 A **Response Range:** ±Maximum Magnet Current

Description: The **ULIM?** query returns the current limit used when the next **SWEEP UP** command is issued in the selected units (Amps, KG, or Tesla).

Related Commands: LLIM, LLIM?, SWEEP, SWEEP?, ULIM, UNITS, UNITS?

UNITS Select units

Availability: Remote Mode

Command Syntax: UNITS <Unit Selection>

Example: UNITS T **Parameter Range:** A, T, G, or kG

Description: The **UNITS** command sets the units to be used for all input and display operations. Units may be set to Amps, Tesla or kilogauss. Note that the instrument will display kilogauss regardless of whether Gauss or kilogauss are selected.

Related Commands: IMAG?, IOUT?, LLIM, LLIM?, ULIM, ULIM?, UNITS?

UNITS? Query selected units

Availability: Always

Command Syntax: UNITS?

Response: <Selected Units>

Response Example: T **Response Range:** A, T, or kG

Description: The **UNITS?** command returns the units used for all input and display operations.

Related Commands: IMAG?, IOUT?, LLIM, LLIM?, ULIM, ULIM?, UNITS

VLIM Set voltage limit

Availability: Remote Mode

Command Syntax: VLIM <Voltage Limit>

Example: VLIM 5.0 **Parameter Range:** 0.0 to 10.0

Description: The **VLIM** command sets the power supply output voltage limit to the voltage provided.

Related Commands: VLIM?, VMAG?, VOUT?

VLIM? Query voltage limit

Availability: Always

Command Syntax: VLIM?

Response: <Voltage Limit>

Response Example: 4.75 V **Response Range:** 0 to 10.00

Description: The **VLIM?** command returns the power supply output voltage limit.

Related Commands: VLIM, VMAG?, VOUT?

VMAG? Query magnet voltage

Availability: Always

Command Syntax: VMAG?

Response: <Magnet Voltage>

Response Example: 4.75 V **Response Range:** -10.00 to +10.00

Description: The **VMAG?** command returns the present magnet voltage.

Related Commands: VLIM, VLIM?, VOUT?

VOUT? Query output voltage

Availability: Always

Command Syntax: VOUT?

Response: <Output Voltage>

Response Example: 4.75 V **Response Range:** -12.80 to +12.80

Description: The **VOUT?** command returns the present power supply output voltage.

Related Commands: VLIM, VLIM?, VMAG?

***CLS** Clear Status Command

Availability: Always

Command Syntax: *CLS

Description: The ***CLS** command operates per IEEE Std 488.2-1992 by clearing the Standard Event Status Register (ESR) and resetting the MAV bit in the Status Byte Register (STB).

Related Commands: None

***ESE** Standard Event Status Enable Command

Availability: Always

Command Syntax: *ESE <mask>

Example: *ESE 255

Default Parameter: 0 **Parameter Range:** 0 to 255

Description: The ***ESE** command operates per IEEE Std 488.2-1992 by setting the specified mask into the Standard Event Status Enable Register (ESE).

Related Commands: *ESE?

***ESE?** Standard Event Status Enable Query

Availability: Always

Command Syntax: *ESE?

Response: <ESE Mask>

Response Example: 255 **Response Range:** 0 to 255

Description: The ***ESE?** command operates per IEEE Std 488.2-1992 by returning the mask set in the Standard Event Status Enable Register (ESE) by a prior *ESE command.

Related Commands: *ESE

***ESR?** Standard Event Status Register Query

Availability: Always

Command Syntax: *ESR?

Response: <Standard Event Status Register>

Response Example: 128 **Response Range:** 0 to 255

Description: The ***ESR?** command operates per IEEE Std 488.2-1992 by returning the contents of the Standard Event Status Register and then clearing the register. The User Request bit is set any time the Local or Menu buttons on the front panel are depressed. The remaining bits are defined in the referenced standard.

Status Byte Bit Allocations:

```
X  X  X  X  X  X  0  1
|  |  |  |  |  |  |  |____ Operation Complete
|  |  |  |  |  |  |_______ Request Control
|  |  |  |  |  |__________ Query Error
|  |  |  |  |_____________ Device Dependent Error
|  |  |  |________________ Execution Error
|  |  |___________________ Command Error
|  |______________________ User Request
|_________________________ Power On
```

Related Commands: *ESE, *ESE?

***IDN?** Identification Query

Availability: Always

Command Syntax: *IDN?

Response: <Manufacturer>,<Model>,<Serial #>,<Firmware Level>

Response Example: Cryomagnetics,CS4,2239,1.02

Serial # Range: 2000 to 9999 **Firmware Level Range:** 1.00 to 9.99

Description: The ***IDN?** command operates per IEEE Std 488.2-1992 by returning the CS-4 manufacturer, model, serial number and firmware level.

Related Commands: None

***OPC** Operation Complete Command

Availability: Always

Command Syntax: *OPC

Description: The ***OPC** command operates per IEEE Std 488.2-1992 by placing the Operation Complete message in the Standard Event Status Register (ESR). The CS-4 processes each command as it is received and does not defer any commands for later processing.

Related Commands: *OPC?

***OPC?** Operation Complete Query

Availability: Always

Command Syntax: *OPC?

Description: The ***OPC** command operates per IEEE Std 488.2-1992 by placing an ASCII character "1" in the output queue since the CS-4 does not defer any commands for later processing.

Related Commands: *OPC

***RST** Reset Command

Availability: Always

Command Syntax: *RST

Description: The ***RST** command operates per IEEE Std 488.2-1992 but does not change the power supply operation due to safety concerns.

Related Commands: None

***SRE** Service Request Enable Command

Availability: Always

Command Syntax: *SRE <mask>

Example: *SRE 255

Default Parameter: 0 **Parameter Range:** 0 to 255

Description: The ***SRE** command operates per IEEE Std 488.2-1992 by setting the specified mask into the Service Request Enable Register (SRE).

Related Commands: *SRE?

***SRE?** Service Request Enable Query

Availability: Always

Command Syntax: *SRE?

Response: <SRE Mask>

Response Example: 255 **Response Range:** 0 to 255

Description: The ***SRE?** command operates per IEEE Std 488.2-1992 by returning the mask set in the Service Request Enable Register (SRE) by a prior *SRE command.

Related Commands: *SRE

***STB?** Read Status Byte Query

Availability: Always

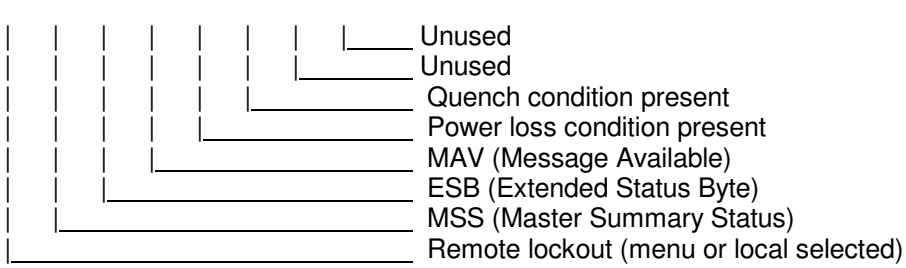
Command Syntax: *STB?

Response: <Status Byte>

Response Example: 65 **Response Range:** 0 to 255

Description: The ***STB?** command operates per IEEE Std 488.2-1992 by returning the Status Byte.

Status Byte Bit Allocations:



*** TST?** Self-Test Query

Availability: Always

Command Syntax: *TST?

Response: <Self test status>

Response Example: 1 **Response Range:** 1

Description: The ***TST?** command operates per IEEE Std 488.2-1992 by returning the self test status. Explicit tests are not performed in response to this command, but a 1 is returned for compliance with the specification.

Related Commands: None

*** WAI** Wait-to-Continue Command

Availability: Always

Command Syntax: *WAI

Description: The ***WAI?** command operates per IEEE Std 488.2-1992 by accepting the command without generating an error. Since the CS-4 only implements sequential commands the no-operation-pending flag is always TRUE.

Related Commands: OPC, *OP

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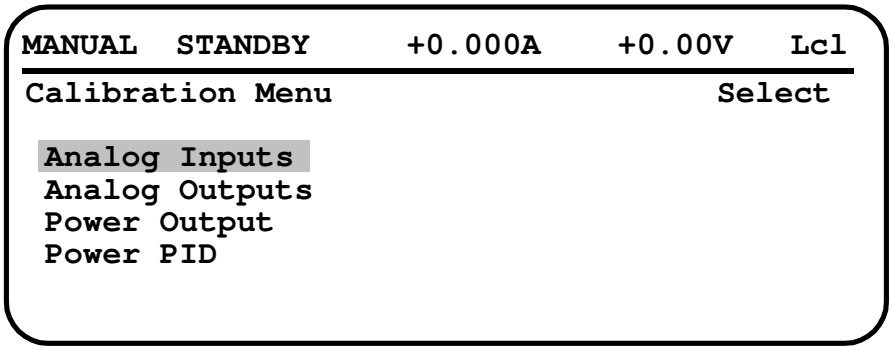
Appendix C

Calibration Procedures

C.1. Calibration Menu

The Calibration menu, shown in Figure C.1, provides access to submenus used to calibrate the power supply functions. The supply is fully calibrated at the factory, and further calibration should not be required. Failure to follow calibration procedures can seriously impair the performance of the unit. These procedures assume familiarity with this manual and operation of the supply.

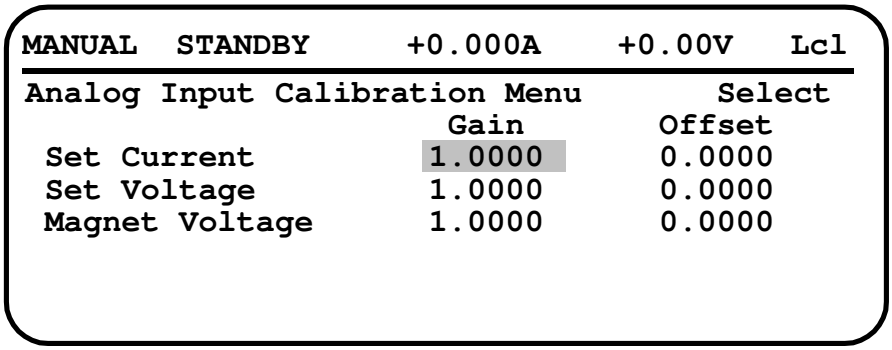
Figure C.1 - Calibration Menu



C.2. Analog Input Calibration Menu

The Analog Input Calibration menu, shown in Figure C.2, is used to calibrate the ±Iset, ±Vset, and ±Mag.Vin. inputs (reference Figure 2.1 – Rear Panel Terminal Strip). The ±Iset and ±Mag.Vin. inputs are calibrated for -10V to +10V operation. The ±Vset inputs are calibrated for 0V to +5V operation.

Figure C.2 - Analog Input Calibration Menu



C.2.1. Set Current Calibration (±Iset)

Set Current Calibration is used to calibrate the ±Iset analog input.

C.2.1.1. Current Limit Offset

Verify that the supply is in STANDBY. In the Setup Menu (ref. Figures 4.8 & 4.9 of this manual), set Current Limit source to Analog Input and return to the Operate display. Apply 0.000 volts to the ±Iset inputs and observe the Current Limit on the display. Record the displayed Current Limit. Press [Menu]. Use the arrow keys to select <Calibrate> and press [Enter]. Use the arrow keys to select <Analog Inputs> and press [Enter]. Use the arrow keys to select Set Current <Offset>. Using the recorded value of the displayed Current Limit and the present value of the offset, compute the new offset value:

New Offset = Present Offset – Displayed Current Limit

Enter the New Offset value and press [Enter]. Exit the Menu and return to Operate mode, accepting the changes that were made, and verify that the displayed Current Limit is now 0.000A.

C.2.1.2. Current Limit Gain

After setting the offset of the ±Iset analog input, the gain should be checked and adjusted if necessary. Verify that the supply is in STANDBY. Apply 5.000 volts to the ±Iset inputs and observe the Current Limit on the display. It should read “50.000A”. If it does not, record the displayed Current Limit value.

Press [Menu]. Use the arrow keys to select <Calibrate> and press [Enter]. Use the arrow keys to select <Analog Inputs> and press [Enter]. Use the arrow keys to select Set Current <Gain>. Using the recorded value of the displayed Current Limit and the present value for Set Current Gain, compute a new gain value as follows:

New Gain = (Present Gain) x (50.000) / (Displayed Current Limit)

Enter the New Gain value and press [Enter]. Exit the Menu and return to Operate mode, accepting the changes that were made, and verify that the displayed current limit is now 50.000A.

Apply -5.000 volts to the ±Iset inputs and verify that the Current Limit displays -50.000A. . In the Setup Menu, return the Current Limit source to Programmed.

C.2.2. Set Voltage Calibration (±Vset)

The ±Vset analog input can be used either to specify the voltage limit or the sweep rate (charge rate) of the CS-4 supply. Calibration of the ±Vset analog input is virtually identical to the calibration for the ±Iset analog input outlined above.

C.2.2.1. Voltage Limit (Charge Rate) Offset

Verify that the supply is in STANDBY. In the Setup Menu (ref. Figures 4.8 & 4.9 of this manual), set Voltage Limit source to Analog Input and return to the Operate display. Apply 0.050 volts to the ±Vset analog input and observe the voltage limit on the display. Record the displayed Voltage Limit. Press [Menu]. Use the arrow keys to select <Calibrate> and press [Enter]. Use the arrow keys to select <Analog Inputs> and press [Enter]. Use the arrow keys to select Set Voltage <Offset>. Using the recorded value of the Displayed Voltage Limit and the present value of the offset, compute the new offset value:

New Offset = Present Offset – Displayed Voltage Limit

Enter the New Offset value and press [Enter]. Exit the Menu and return to Operate mode, accepting the changes that were made, and verify that the displayed Voltage Limit is now 0.05V.

C.2.2.2. Voltage Limit (Charge Rate) Gain

After setting the offset of the ±Vset analog input, the gain should be checked and adjusted if necessary. Verify that the supply is in STANDBY. Apply 4.500 volts to the ±Vset inputs and observe the current limit on the display. It should read “4.50V”. If it does not, record the displayed Voltage Limit value.

Press [Menu]. Use the arrow keys to select <Calibrate> and press [Enter]. Use the arrow keys to select <Analog Inputs> and press [Enter]. Use the arrow keys to select Set Voltage <Gain>. Using the recorded value of the displayed Voltage Limit and the present value for Set Voltage Gain, compute a new gain value as follows:

New Gain = (Present Gain) x (4.50) / (Displayed Voltage Limit)

Enter the New Gain value and press [Enter]. Exit the Menu and return to Operate mode, accepting the changes that were made, and verify that the displayed Voltage Limit is now 4.50V.

In the Setup Menu, return the Voltage Limit source to Programmed.

C.2.3. Magnet Voltage Calibration (±Mag.Vin.)

Calibration of the Magnet Voltage Analog Inputs (±Mag.Vin.) is virtually identical to the calibration for the Set Voltage Calibration (±Vset) outlined above.

C.2.3.1. Magnet Voltage Offset

To calibrate the offset of the ±Mag.Vin. analog input, verify that the supply is in STANDBY. Select the Operate display. Apply 0.00 volts to the ±Mag.Vin. inputs and observe the Magnet Voltage on the display. If the displayed magnet voltage is not 0.00V, record the displayed Magnet Voltage offset value. Press [Menu]. Use the arrow keys to select <Calibrate> and press [Enter]. Use the arrow keys to select <Analog Inputs> and press [Enter]. Use the arrow keys to select Magnet Voltage <Offset>. Using the recorded value of the displayed Magnet Voltage Offset and the present value of the offset, compute the new offset value:

New Offset = – (Present Offset + Displayed Magnet Voltage Offset)

Enter the New Offset value and press [Enter]. Exit the Menu and return to Operate mode, accepting the changes that were made, and verify that the displayed Magnet Voltage is now 0.00V.

C.2.3.2. Magnet Voltage Gain

After setting the offset of the ±Mag.Vin. analog input, the gain should be checked and adjusted if necessary. Verify that the supply is in STANDBY. Apply 4.50 volts to the ±Mag.Vin. inputs and observe the Magnet Voltage on the display. It should read “4.50V”. If it does not, record the displayed Voltage Limit value.

Press [Menu]. Use the arrow keys to select <Calibrate> and press [Enter]. Use the arrow keys to select <Analog Inputs> and press [Enter]. Use the arrow keys to select Magnet Voltage <Gain>. Using the recorded value of the displayed Magnet Voltage and the present value for Magnet Voltage Gain, compute a new gain value as follows:

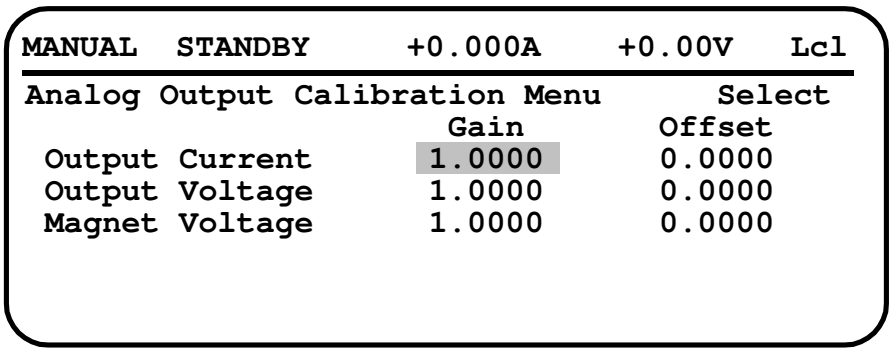
New Gain = (Present Gain) x (4.50) / (Displayed Magnet Voltage)

Enter the New Gain value and press [Enter]. Exit the Menu and return to Operate mode, accepting the changes that were made, and verify that the displayed Magnet Voltage is now 4.50V. Apply –4.50V to the ±Mag.Vin. analog input and verify that the displayed Magnet Voltage is now –4.50V.

C.3. Analog Output Calibration Menu

The Analog Output Calibration menu, shown in Figure C.3, is used to calibrate the ±Iout, ±Vout, and ±Mag.Vout analog outputs. This procedure assumes that the outputs are configured for 0 to 10V operation.

Figure C.3 - Analog Output Calibration Menu



C.3.1. Analog Output Current and Voltage Calibrations (±Iout & ±Vout)

Turn the supply off and connect a suitable load to the power output terminals. Turn the supply on and verify that the supply is in STANDBY. Set the upper current limit to zero, and press the Up arrow key on the front panel to force the supply active. Verify the display indicates that the supply is outputting zero amps at zero volts. Use a digital voltmeter (DVM) to verify that ±Iout is at 5 volts, and if not adjust the Output Current Offset in the Analog Output Calibration Menu until 5 volts is obtained. Verify that Vout is 5 volts, and if not adjust the Output Voltage Offset in the Analog Output Calibration Menu until 5 volts is obtained. Select an upper current limit of 10 amps or greater, and press the Up arrow to generate the output. When the supply has reached the current limit measure Iout.

New Gain = (Present Gain) x (Displayed Current) / ((Measured Iout - 5.0) x 20)

Enter the New Gain in the Output Current Gain field of the Analog Output Calibration Menu. Measure ±Vout and compute a new Output Voltage gain.

New Gain = (Present Gain) x (Displayed Voltage) / (Measured Vout - 5.0)

Enter the New Gain in the Output Voltage Gain field of the Analog Output Calibration Menu.

In the Limits Menu, set the upper current limit to zero to return the supply to zero output. When the output is stable verify that ±Iout and ±Vout are at 5 volts.

C.3.2. Analog Output Magnet Voltage Calibration (±Mag.Vout)

Turn the supply off and connect a suitable load to the power output terminals. Turn the supply on and verify that the supply is in STANDBY in the Operate display. Apply 0.00 volts to the ±Mag.Vin. inputs and observe the Magnet Voltage on the display. If zero is not displayed perform the Magnet Voltage Analog Input Voltage Calibration and return to this procedure. Verify that ±Mag.Vout. is at 5 volts, and if not adjust the Magnet Voltage Offset in the Analog Output Calibration Menu until 5 volts is obtained. Apply 4.50 volts to the ±Mag.Vin. inputs and observe the Magnet Voltage on the display. If 4.50 volts is not displayed perform the Magnet Voltage Analog Input Voltage Calibration and return to this procedure. Compute a gain value as follows:

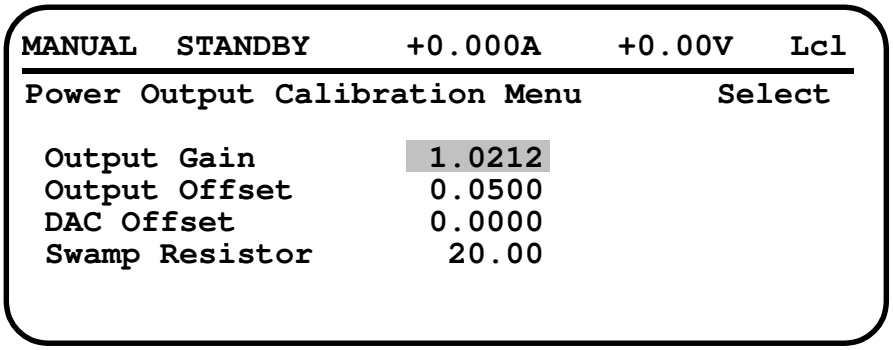
New Gain = (Present Gain) x (4.50) / ((Measured Mag.Vout. - 5.00) x 2)

Enter the New Gain in the Magnet Voltage Gain field of the Analog Output Calibration Menu.

C.4. Power Output Calibration Menu

The Power Output Calibration menu, shown in Figure C.4, is used to calibrate the power supply output current.

Figure C.4 - Power Output Calibration Menu



C.4.1. Power Output Gain and Offset

Turn the supply off and connect a suitable load to the power output terminals. Attach an accurate means of measuring the output current. The current must be measured at a low current (0.5 Amps) and at a relatively high current (50 to 80 percent of maximum). Set the upper current limit to 0.500

Amps and press the UP arrow key to activate the sweep function. When the display is stable at 0.500 Amps measure the output current. Compute a new offset:

New Offset = 0.500 - (Measured Current) - (Present Offset)

Enter the new offset value in the Output Offset field of the Power Output Calibration Menu. Set the upper current limit to 50 to 80 percent of maximum and press the UP arrow key to activate the sweep function. When the display is stable (at the current limit) press the UP arrow key again to activate the PAUSE function. Verify that PAUSE is indicated. Wait 15 to 20 minutes for temperatures to stabilize for best results. Compute a new gain:

New Gain = (Present Gain) x (Displayed Current) / (Measured Current)

Enter the new gain value in the Output Gain field of the Power Output Calibration Menu. If the sweep is paused and the output is between 50 to 80 percent of maximum an internal DAC calibration will be performed, and a notification will briefly be displayed. Return the supply to zero output current.

C.4.2. DAC Offset

Perform the Power Output Gain and Offset Calibration before starting this step. The same equipment setup should be used. DAC offset affects the supply output for a brief period when the supply first leaves the STANDBY state until the PID achieves lock on the output. Set the sweep rate to 0.001 A/Sec. Set the upper limit to 0.5 Amp. Press the Up arrow and observe the first couple of displayed current values. Press the Zero key to return the supply to STANDBY. Compute a new DAC offset.

New Offset = (Present Offset) - (Measured Current)

Enter the new gain value in the DAC Offset field of the Power Output Calibration Menu. Repeat the above procedure several times until the sweep starts within 5 mA of zero. A minimum delay of 30 seconds is required for the circuits to return quiescent between iterations.

C.4.3. Swamp Resistor

The CS-4 power supply is designed to provide stable operation on superconducting magnets with or without persistent switches. To aid in supply stability when driving purely inductive loads, the CS-4 contains an internal resistor, called a “Swamp Resistor” across its output terminals.

The factory default value of the Swamp Resistor 6 ohms. This is the value of the resistor that is internal to the CS-4 and is installed across the output terminals of the supply. Some explanation of this resistor is in order:

Magnet power supplies can sometimes run into stability problems when trying to drive large inductive loads. Since most superconducting magnets have a persistent switch across their input terminals, the load the power supply experiences appears to be a resistor (typically a 10 to 100 ohm persistent switch) in parallel with the high inductance. The resistance of the persistent switch helps the power supply cope with the parallel inductance of the magnet by effectively “swamping out” the high inductance. Some superconducting magnets; however, have no persistent switch. To the power supply, a magnet without a persistent switch appears to be a virtually pure inductance load.

The Swamp Resistor represents a load on the power supply through which some small leakage current passes. Since the displayed output current on the CS-4 must be the true output current from the supply, small leakage current through the Swamp Resistor must be subtracted out before the value is displayed. To make the correction, the CS-4 must know what value Swamp Resistor is installed. Should the user find that a different value resistor works better for his/her system, the resistance may be changed and the new value entered through the [MENU] / Calibration / Power Output Calibration / Swamp Resistor menu item. If a resistor is installed across the output terminals of the supply while leaving the factory internal resistor in place, the value entered for the Swamp Resistor should be the effective parallel resistance of the factory resistor with the additional resistor.

Lowering the value of the Swamp Resistor by parallel connection of another resistor will help stabilize the supply voltage fluctuations during magnet sweep; however, the settling time required when reaching current limit will be longer if the value is reduced. The settling time is determined by the R/L time constant of the effective Swamp Resistor and the magnet inductance. The factory default resistor is a value that represents a very good compromise between settling time and stability and in 99% of magnet systems the value will not need to be adjusted.

C.5. Power PID Calibration

The Power PID Calibration menu, shown in Figure C.4, is used to adjust the power supply output current sweep PID parameters. Factory defaults should be adequate, but the parameters may be adjusted if desired. If Restore Factory Defaults is selected, the factory default PID settings will be restored.

The PID algorithm is composed of proportional, integral, and derivative parameters. The difference between the desired current and the measured current is the error. The current is sampled at 200 millisecond intervals, and a correcting estimate is applied to the control circuits. The proportional gain determines how much correction is applied each interval. The integral gain determines how much averaging is applied, and the differential gain determines the amount of correction needed considering the rate of change of the error term.

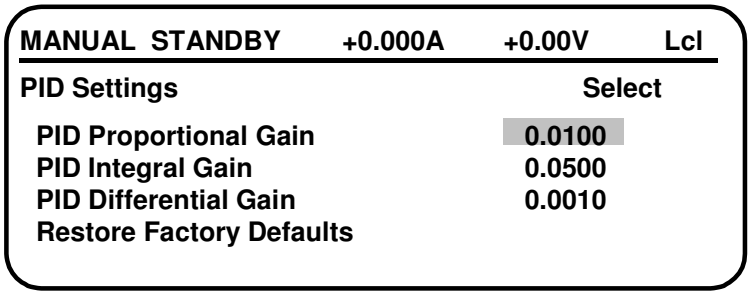
General guidance is as follows:
Tune the PID parameters with the magnet inductance and at low field since incorrect parameters will result in unstable operation. Correctly selecting a set of PID parameters will optimize the operation of the power supply with a specific inductance.

Set differential gain to a value that provides stable operation. If it is set too high, the supply will oscillate. A value of about 1.300 is the maximum that should be used. A value too low will result in the voltage coming up slow at the beginning of a sweep and overshoot when the target current is reached.

Set integral gain around 1.0. If the supply takes too long to converge to a target current, the integral may be set too high. If the integral gain is too low, the supply may overshoot by several hundred milliamps.

Set the proportional gain around 0.5. PID proportional gain determines how much error correction is applied each update. Smaller values will provide more stable operation, but slower response. Larger values will provide faster response, but will become unstable if too large.

Figure C.4 - Power Output PID Settings Men



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Appendix D

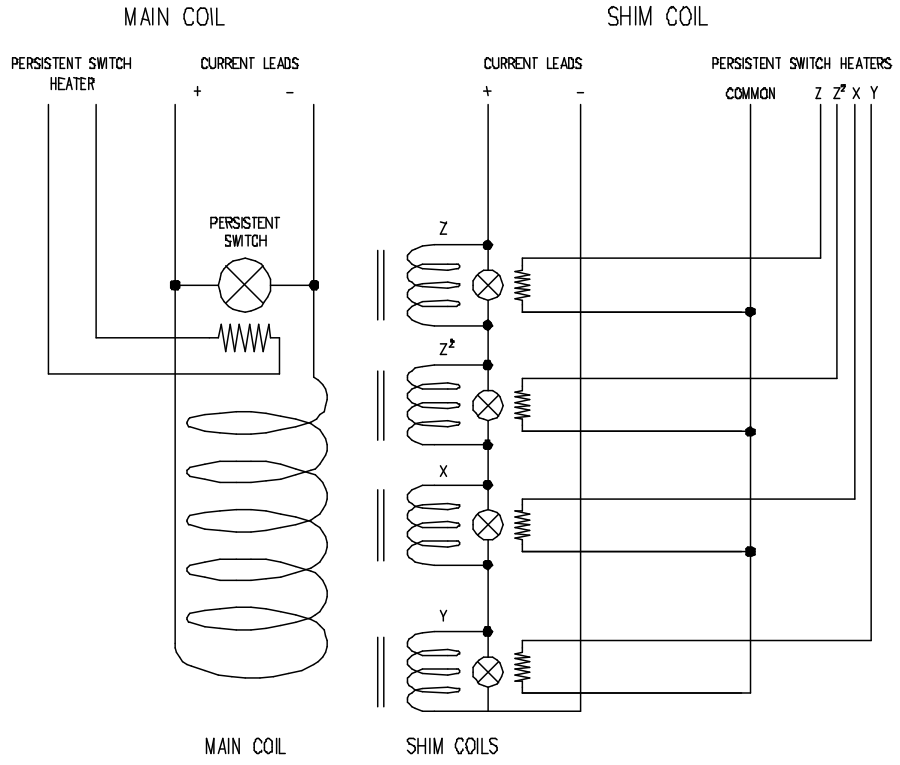
Shim Supply Option

D.1. Overview

The Shim Supply Option for the CS-4 Power Supply is a hardware and software upgrade that provides the user with the capability to control up to 12 independent superconducting shim coils in addition to the main superconducting magnet. Typical applications for this option are high homogeneity ICR or NMR magnets that incorporate superconducting shims to adjust and optimize central field shape.

Superconducting shim coils are, in effect, complete and self-contained superconducting magnets. Each consists of its own set of windings, its own persistent switch, and its own quench protection circuits. The coils are used to superimpose known magnetic field gradients over the homogeneous region of a magnet to correct for error components. Figure D.1 shows schematically a typical magnet with four superconducting shims (Z, Z2, X, and Y). These shims are typically referred to as "first order shims", although technically Z2 is generates a second order effect.

Figure D.1 - Superconducting Magnet with Shims



A comprehensive overview of superconducting shims and shimming is beyond the scope of this Appendix. Considerable documentation exists that describes in detail the various inhomogeneities

in magnetic fields and how to correct them. The purpose of this Appendix is to give a description of how the Shim Supply Option for the CS-4 Power Supply works, how to connect the Shim Supply Option to a magnet system, how to set up the supply, and how to operate the supply in shim mode.

D.2. Shim Option Description

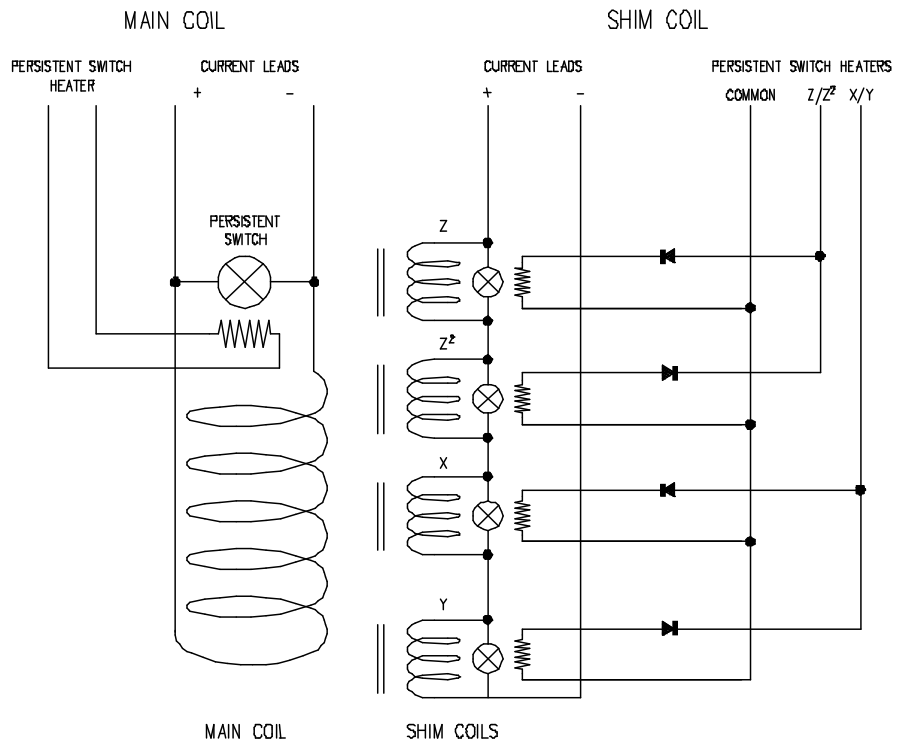
The CS-4 power supply shim supply option allows the operator to use the CS-4 for energizing and discharging multiple superconducting shim coils. The option provides the following features:

a) 12 persistent switch heater output channels.
b) Polarity selection to allow shim multiplexing.
c) 0 – 100mA heater current range.
d) +/- 30 amp output current range.
e) Automatic shim dumping during main coil energizing/discharging.
f) Independent and global shim heater enable/disable.

The shim supply option provides the operator with 12 persistent switch heater output channels that are independently controllable through the menus of the CS-4. The heater outputs may be configured in either “standard” or “multiplexed” arrangement. In the “standard” arrangement, each output channel corresponds to its own shim persistent switch heater. A common return (ground) line is used for all switches. This configuration is directly compatible with Figure D.1 above.

Some superconducting magnet systems utilize a multiplexed heater arrangement to reduce the number of heater wires necessary to operate the shims. A multiplexed heater arrangement is shown schematically in Figure D.2. Using a simple diode arrangement inside the magnet system, the number of heater wires is reduced by switching polarity of the heater signal to select the appropriate shim. For instance, positive output current on the Z/Z2 line activates the heater on the Z shim, while negative output current activates the heater on the Z2 shim. For multiplexed shim heater systems, the CS-4 Shim Supply Option offers the flexibility to be configured according to the user’s needs. Shims may be mapped to any of the outputs, and may have either positive or negative polarity.

Figure D.2 - Superconducting Magnet with Multiplexed Shim Persistent Switch Heaters



When the CS-4 Shim Supply Option is activated, the CS-4 uses its main current outputs to set the shim coil current. In shim mode the supply is software limited to a maximum current output. The current limit for each shim, the persistent switch heater current for each shim, and its overall status (enabled or disabled) is controlled through the menu system via the front panel keys.

While the CS-4 is operating in Manual Mode (the standard mode used when energizing the main superconducting magnet), the Shim Supply Option will periodically activate the persistent switch heater of each enabled shim coil for a few seconds to “dump” any current that has been induced in the coil due to coupling (mutual inductance) between the main coil and the shim coil. Without periodic dumping of current induced in superconducting shim coils, current would build to values sufficient to quench the shim coil and possibly the main coil.

Once the main coil has been energized, the user typically will change from Manual Mode to Shim Mode with the CS-4. In most systems, changing from main coil energizing to shim coil energizing requires the user to change to a different set of current leads. To insure the user does this, the CS-4 will prompt to confirm the mode change before allowing it.

D.3. Setup

The CS-4 power supply shim supply option is designed for ease of use and to allow the user to set shim coils using a minimum of keystrokes. It provides considerable flexibility in setup and operation. There are built-in confirmations that reduce the risk of accidental dumping of a shim or quenching of a coil. However, it is still necessary for the operator to be familiar and experienced with shimming to reduce the chance of errors. It is highly recommended that the operator familiarize himself with the operation of the CS-4 shim supply option PRIOR to connecting it to an operating superconducting magnet.

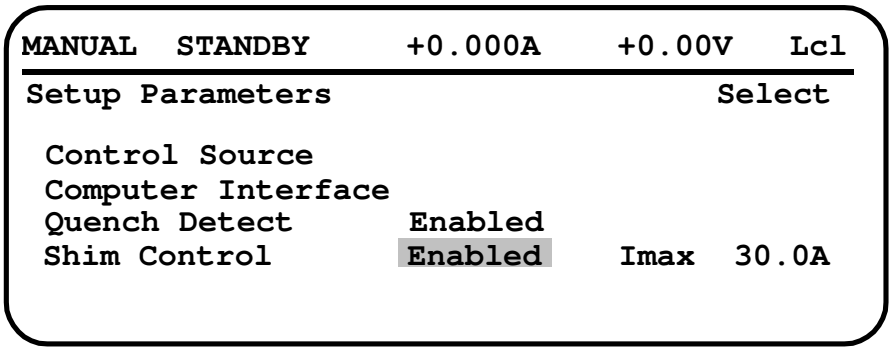
D.3.1. MANUAL Mode

Mutual inductance coupling between shim coils and the main superconducting coil is inevitable. Due to this coupling, if the main coil is energized or discharged while the shim coils are in persistent mode, significant current can be induced in the shim coils. If this current is not periodically "dumped" during the main coil charge cycle, it can build to the point where a quench of the shim coil and/or the main coil occurs.

The CS-4 shim supply option is designed to periodically scan through the shims installed in the system to dump the current induced in them during main coil charge or discharge. Dumping a shim coil involves activating the persistent switch heater on the shim coil for a period of several seconds. By effectively quenching the persistent switch, the loop is "opened" and any current induced in the coil is converted to heat and is dissipated. While dumping shim coils it is usually a good idea to connect a low resistance (~ 5 ohms) load across the main current leads on the shim coils to prevent large voltage spikes from occurring.

The CS-4 shim option will step through each of the 12 shim coil heater outputs in the system. The unit activates each heater for approximately 6 seconds – long enough for the persistent switch to change to its "normal" state. Scanning of the shim coil heaters to dump them during main coil energizing or discharge may be inhibited by activating the global inhibit command while in manual mode.

Figure D.3 – Global Enable/Disable of Shim Dumping

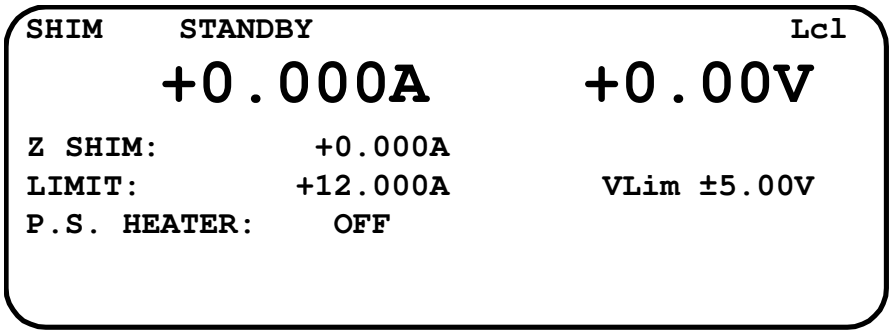


D.3.2. SHIM Mode

The [Mode] key on the front panel of the CS-4 is used to toggle the supply between MANUAL and SHIM modes. The user must have the CS-4 in an idle (STANDBY) state before a change from MANUAL to SHIM mode will be allowed. Likewise, returning from SHIM mode to MANUAL mode will be allowed only if all shims in the system are either dumped or disabled and the supply is in an idle (STANDBY) state.

The main operating display of the CS-4 while in SHIM mode is almost identical to the main operating display in MANUAL mode. The present mode is indicated in the top left corner of the display.

Figure D.4 SHIM Mode Operating Display



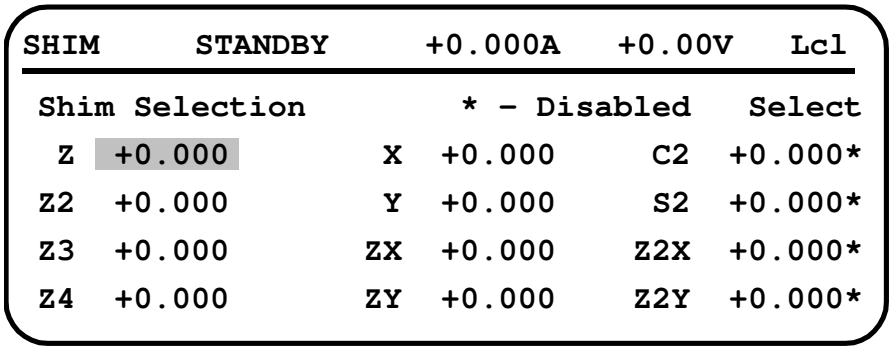
When operating in SHIM mode as indicated in Figure D.4, the left and right arrow keys may be used to select the desired shim. Shims that are disabled will not appear. Enabled shims will appear in the following order: Z, Z2, Z3, Z4, X, Y, ZX, ZY, C2 (X2-Y2), S2 (2XY), Z2X, Z2Y. If the currently selected shim is active (persistent switch heater ON), changing to another shim is inhibited

While in the Shim Mode Operating Display, the indicated shim is the only shim enabled for control and adjustment. The indicated shim's persistent switch may be activated, the shim may be swept up to the indicated current limit, the persistent switch heater may be turned off, and the supply may be swept back to zero output current leaving the shim in persistent mode at the desired current. All operations are identical to those found in the operation of the main superconducting magnet in MANUAL mode.

D.3.3. Selection Menu

Pressing the [MENU] key activates the Shim Selection Menu. This display indicates the present status of all shim coils in the system. The displayed current values are the values actually in the respective shim coil. If the [MENU] key is pressed while a shim is active (persistent switch heater current and/or output current present), only that shim may be edited in deeper menus.

Figure D.5 Shim Selection Menu

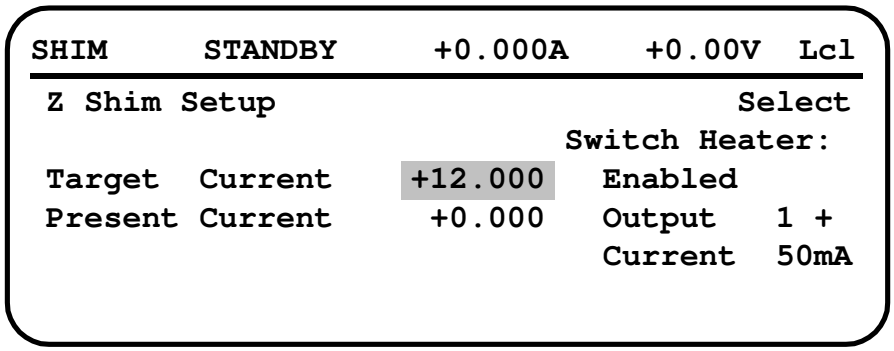


While in the shim selection menu, the arrow keys (up, down, left, right) may be used to select a particular shim coil. With the desired shim coil highlighted, press [Enter] to edit the shim settings or [Esc] to exit back to the main operating display. When in the Shim Summary Menu, pressing the [SHIFT-MENU] keys will cause the user to be asked if all shims should be disabled. If the [SHIFT-MENU] keys are pressed with all shims disabled, the user will be asked if all shims should be enabled.

D.3.4. Setup Menu

Pressing [Enter] while in the Shim Selection Menu invokes the Shim Setup Menu for the selected shim. The Shim Setup Menu is indicated in Figure D.6. Target Current, Present Current, Enable/Disable, Output Channel and Polarity, and Persistent Switch Heater Current are fields that may be edited. The left, right, up and down arrow keys may be used to select the desired field. Pressing [Enter] allows the selected field to be edited either using the up/down arrow keys, or using the numeric entry keys.

Figure D.6 Shim Setup Menu



"Target Current" is the current limit that will be used when operating the shim coil.

"Present Current" is the value of current the CS-4 believes has been left in the shim coil when it was last put into persistent mode. This is an editable field since it is possible for a quench of the shim to occur without the CS-4 detecting it. If this happens, the user may manually reset the present current value to zero.

"Enable/Disable" allows a particular shim coil to be specifically singled out and disabled. This may be used when the particular shim is not present in the system, or when the user wishes to disable it to lock it down and prevent dumping of the shim during main coil field changes.

"Output" allows the user to map the shim to a specified output channel and with a specified polarity. Valid output channels are 1 through 12 with either + or – polarity. Setting the output channel to zero (0) disables the shim. If the user attempts to set the shim to a channel already occupied by another shim, the user will be asked if the other shim should be disabled.

"Current" is the persistent switch heater current for the particular shim. This current may be anywhere from 0 to 100 milliamps. The current value, along with the channel polarity, determines the polarity and magnitude of the persistent switch heater current applied to the specified channel when the shim is selected.

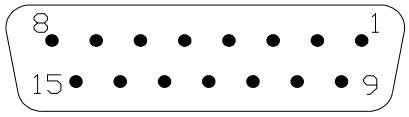
D.3.5. Hardware Connections

Connection of the CS-4 Shim Option to the shim coil persistent switch heaters is done through a DB-15 connector on the rear panel of the supply. Main output current to the shim coils is provided through the high current output terminals. Figure D.7 indicates wiring assignments.

Figure D.7 - Superconducting Shim Persistent Switch Heater Connections

View Facing Rear Panel Connector

Pin #	Function	Pin #	Function
1	Channel 1	9	Channel 7
2	Channel 2	10	Channel 8
3	Channel 3	11	Channel 9
4	Channel 4	12	Channel 10
5	Channel 5	13	Channel 11
6	Channel 6	14	Channel 12
7	Common	15	Common
8	Common		



D.4. Operation

Once the shims have been set up through the menus of the CS-4 and all connections are made to the persistent switch heaters and main current leads, the system is ready to operate. The CS-4 power supply shim supply option is intuitive and designed for ease of use.

D.4.1. Energizing Shims

When starting with fully dumped shims and with the CS-4 in SHIM mode (main operating display as indicated in Figure D.4), the user will typically perform the following sequence of events to set the selected shim.

Procedure for Initial Setting of Shim Coil Currents

a) Use the left or right arrow keys to select the first shim to be set.
b) Press the [PSHtr] key and [Enter] to confirm and turn ON the persistent switch heater.
c) Wait about 10 seconds for the persistent switch to warm.
d) Press the up arrow key [↑] or down arrow key [↓] to begin energizing the shim coil. It does not matter which key is pressed. The CS-4 will begin sweeping in the direction of the requested current limit. Once the limit is reached, the CS-4 will hold that current.
e) Press the [PSHtr] key and [Enter] to confirm and turn OFF the persistent switch heater.
f) Wait about 10 seconds for the persistent switch to cool.
g) Press the [Zero] key to bring the current in the power leads back to zero. [Shift-Zero] may be used to more quickly return to zero if desired.

After completing the sequence, the operator will use the left or right arrow key to change to the next

shim coil. The procedure will be repeated to set this shim coil current. Likewise all other shims are set. Once a first pass setting of each shim coil has been made, typically a second pass is made through the shims to minimize the effects of mutual inductance coupling from shim-to-shim. In the second and subsequent passes, the procedure is as follows:

Procedure for Resetting Shim Coil Currents

a) Use the left or right arrow keys to select the desired shim.
b) Press the up arrow key [↑] or down arrow key [↓] to bring the current in the power leads back to the current limit (the same value that was left in the shim coil). Alternatively, the [Shift-↑↑] or [Shift-↓↓] keys may be used to fast sweep back to the current limit.
c) Press the [PSHtr] key and [Enter] to confirm and turn ON the persistent switch heater.
d) Wait about 10 seconds for the persistent switch to warm and the current in the shim to stabilize at the current limit.
e) Press the [PSHtr] key and [Enter] to confirm and turn OFF the persistent switch heater.
f) Wait about 10 seconds for the persistent switch to cool.
g) At this point, the shim is in persistent mode and the operator has two options – 1) press the [Zero] key (or [Shift-Zero]) to bring the current in the power leads back to zero, or 2) use the left or right arrow keys to proceed directly to setting the next shim. It is not necessary to sweep the output current of the supply to zero prior to moving on to the next shim

This process (b through f) should be repeated for each shim.

D.4.2. Discharging Shims

The CS-4 requires that all shims be either disabled or discharged before it will allow the user to change back to Manual mode for control of the main magnet. If only a minor change in main coil current is desired (e.g., to fine tune Z0), the user may want to leave the currents in the shim coils while the change in main coil current is made. To do this, each shim coil that is not set at zero current must be disabled as described in section D.3.4.

To discharge a shim coil to zero current, the following sequence is typically followed:

a) Use the left or right arrow keys to select the desired shim.
b) Press the up arrow key [↑] or down arrow key [↓] to bring the current in the power leads back to the current limit (the same value that was left in the shim coil). Alternatively, the [Shift-↑↑] or [Shift-↓↓] keys may be used to fast sweep back to the current limit.

c) Press the [PSHtr] key and [Enter] to confirm and turn ON the persistent switch heater.
d) Wait about 10 seconds for the persistent switch to warm.
e) Press the [Zero] key to sweep the current in the shim coil back to zero.
f) After the current stabilizes at zero and the CS-4 enters STANDBY mode, press the [PSHtr] key and [Enter] to confirm and turn OFF the persistent switch heater.
g) Wait about 10 seconds for the persistent switch to cool.
h) Go to step “a” to select the next shim and repeat the process for each shim.

After zeroing or disabling each shim coil, the user may change the CS-4 back to Manual mode if desired.

CAUTION

When changing the CS-4 back to MANUAL mode, be aware that the supply’s firmware safety limit (typically +/- 30 amps) is no longer enabled. The CS-4 becomes capable of sourcing its full output current rating (e.g. 100 amps for a CS4-10V/100). Most shim coils are not designed to handle high currents and could be quenched and/or damaged by them. Be sure to change the CS-4’s power leads back to the main coil’s current terminals when changing back to MANUAL mode to avoid damaging the system.