



HCS01CL WITH GRADIENT COILS
OPERATION AND MAINTENANCE
MANUAL

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INTRODUCTION

This manual provides information and instructions for installing, operating, and maintaining the HCS01CL Triaxial Helmholtz Coil System (HCS01CL) with gradient coils.

SYSTEM DESCRIPTION

The HCS01CL is a three-axis Helmholtz coil system that may be used to apply precise and accurate magnetic fields in three orthogonal axes. The HCS01CL consists of three six-foot square sets of Helmholtz coils (see Fig. 2) arranged to form three orthogonal axes; a rack assembly (see Fig. 3) which contains bipolar power supplies (BOP) and a coil control magnetometer; and a Digital-to-Analog card that plugs into a PCI slot in a PC.

The system also includes a concentric three-axis Helmholtz coil system that can be used to generate precision gradients in all three axes. The gradient three-axis Helmholtz coils are wound directly on top of the main three-axis Helmholtz coils so the centers of the two systems coincide.

A three-axis fluxgate sensor that is part of the CCM-3 coil control magnetometer is mounted on a podium that is located in the central region of the coil assembly. The sensor, field control unit electronics, and BOPs form a negative feedback system which forces the field in the center of the coil system to approach zero, thereby automatically compensating for uniform ambient fields (e.g. Earth's field).

The PC is connected to the CCM-3. The plug-in Digital-to-Analog board inside the PC controls the polarity and magnitude of the magnetic fields and gradients under the direction of the operator. A video display terminal (VDT) displays the current field and gradient values being applied in rectangular coordinates. The operator uses a standard PC keyboard to enter field values, control field polarity, turn the field on or off, and adjust the zero fields at the center of the coil.

The BOPs, CCM-3 and the PC power cords are plugged into a single power distribution unit (PDU). One switch on the PDU is used to turn the HCS01CL power on or off.

The following figures provide a general arrangement diagram for the system plus views of the coil and rack assemblies.

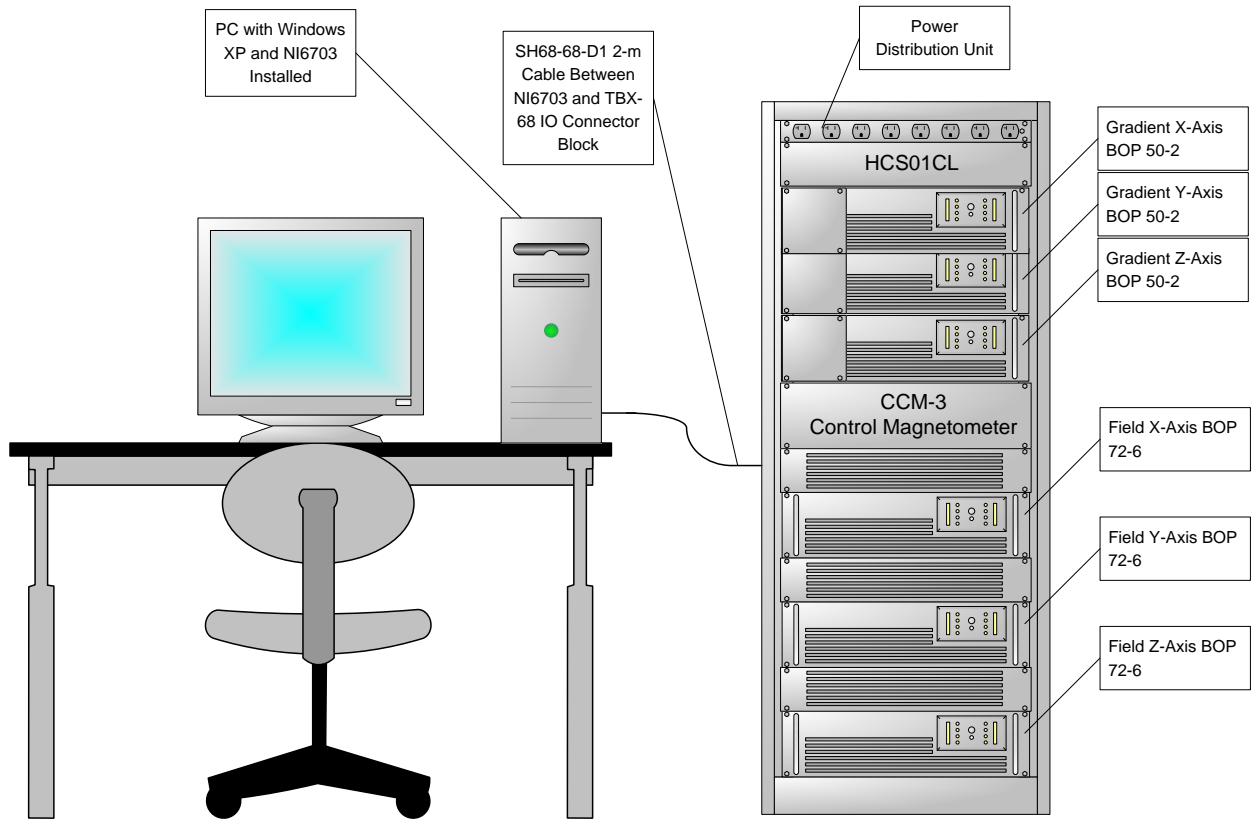


Figure 1 HCS01CL with gradient general arrangement diagram.

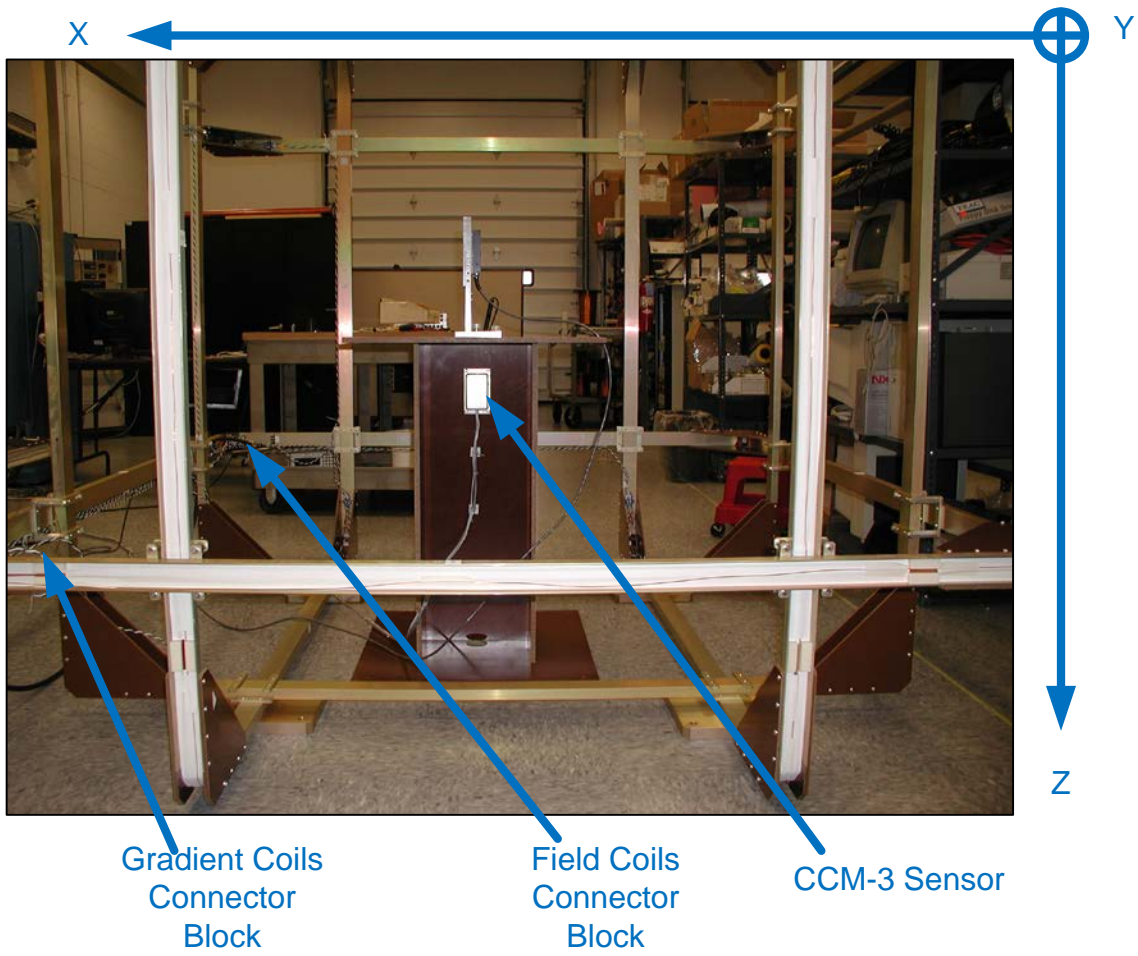


Figure 2 HCS01CL Coil Assembly.

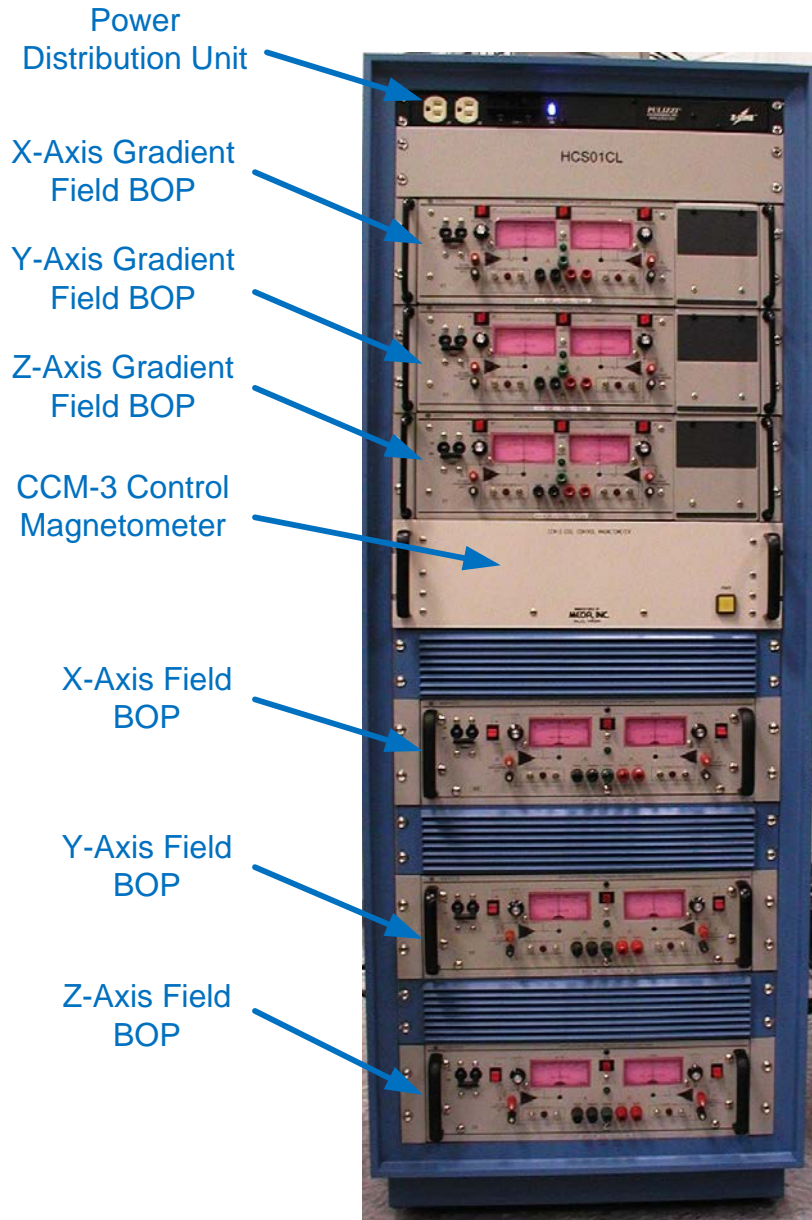


Figure 3 HCS01CL with Gradient Rack Assembly Front View.

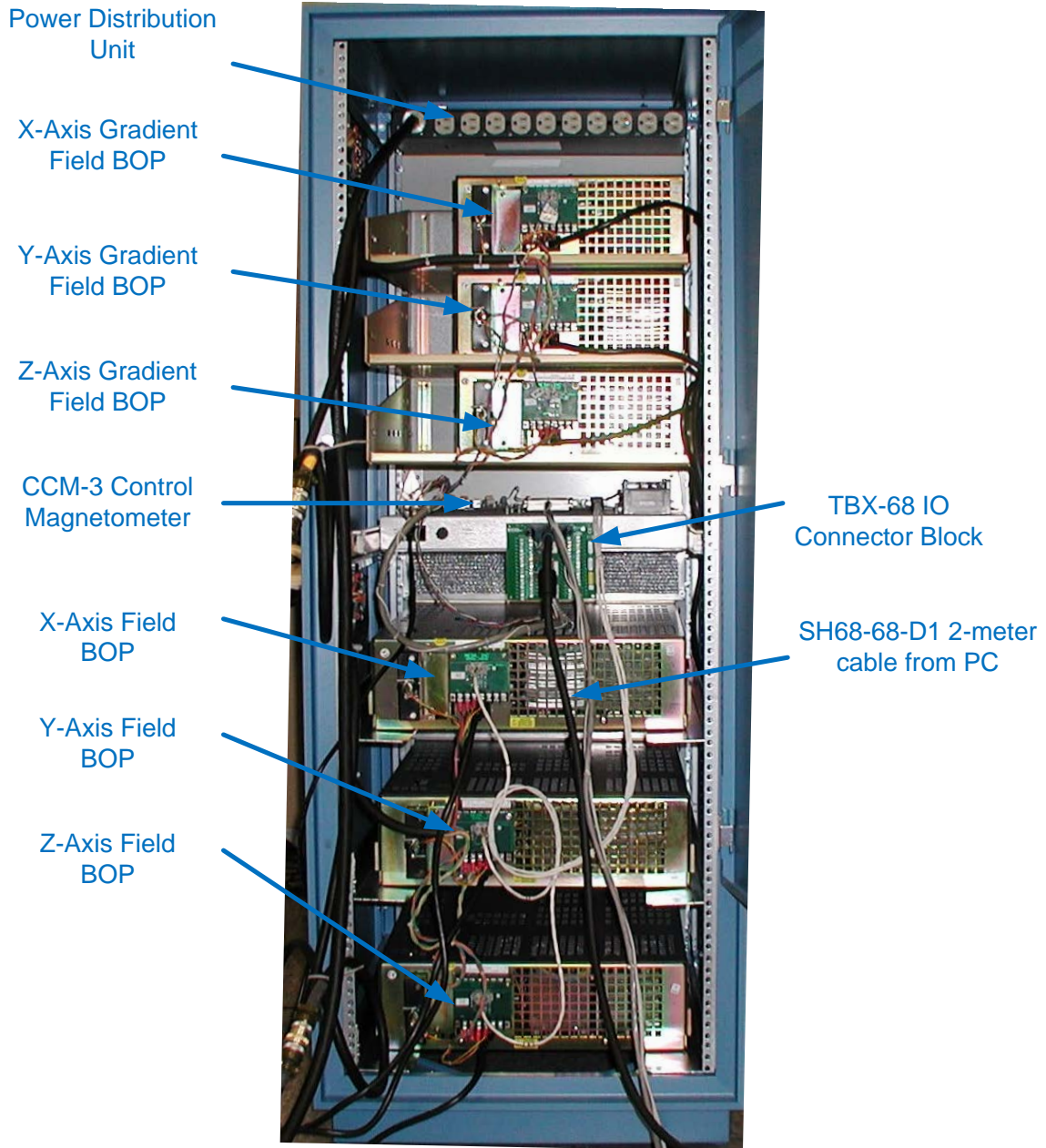


Figure 4 HCS01CL with Gradient Rack Assembly Rear View

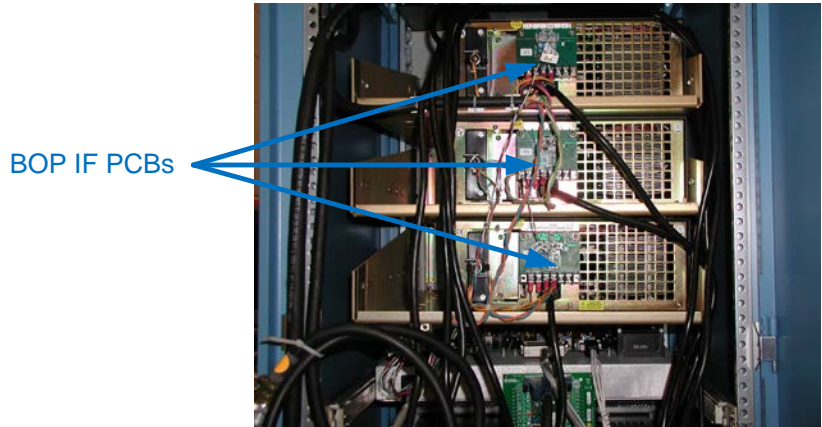


Figure 5 Rack rear view details

SYSTEM SPECIFICATIONS

GENERATED FIELD	
Range:	$\pm 100,000$ nT
Resolution:	1.5 nT
Accuracy (Zero field corrected):	
Initial @ 23°C	$\pm(2$ nT + 0.05% of setting)
Temperature Coefficient	± 10 ppm/°C nominal
ZERO FIELD	
Trim Range	± 4000 nT nominal
Resolution	<1 nT
Stability	
Temperature	± 0.1 nT/°C nominal
Drift	± 4 nT per month at constant temperature
PHYSICAL CHARACTERISTICS	
Overall coil size	80" x 80" x 82"
Coil weight	Approximately 150 lbs.
Control unit size	22"W x 34"H x 26"D
Control unit weight	Approximately 350 lbs.
ENVIRONMENT	
Operating temperature	0°C to 50°C
Storage temperature	-10°C to 70°C
Relative humidity	10% to 90%
POWER REQUIREMENTS	
Voltage	115 VAC @ 60 Hz
Current	30 Amperes maximum
FIELD UNIFORMITY	
	<0.03% of applied field within 20 cm diameter sphere at coil system center
AXIS ORTHOGONALITY	
Without Compensation	≤ 1.0 degrees
With Compensation	≤ 0.1 degrees

GRADIENT FIELD	
Range	± 100 nT/inch
Accuracy	$\pm(1\%$ of setting +0.4 nT/inch)
Resolution	0.006 nT/inch

INSTALLATION

UNPACKING AND INSPECTION

The HCS01CL will arrive at the site in several packages. The coil assembly, rack assembly and PC were disassembled and placed into different packages. Reassembly of the system is discussed in future sections.

A list of the packages and their contents accompanies the shipment. Verify that each of the listed packages has been received. Carefully unpack each item. Use the packing slip which is attached to each package to verify that the contents are complete. Inspect each item for shipping damage before attempting to reassemble the system.

If any items are damaged, please contact MEDA to determine a remedy and file a claim with the responsible transport service.

SITE REQUIREMENTS

The HCS01CL can generate very uniform, stable, and accurate magnetic fields in the central region of the coil assembly. External environmental conditions can cause suboptimal performance of the HCS01CL.

The floor upon which the coil assembly is mounted should be constructed of non-magnetic materials. If the floor is concrete and contains reinforcing rods then the coil assembly base should be raised at least ten (10) inches above the floor.

Field uniformity in the central region of the coil system will be affected by ambient magnetic field gradients. These gradients can be caused by ferromagnetic material in the vicinity of the coil assembly. The magnetic field gradient should be less than 20 nT per foot within a one-foot diameter sphere centered about the geometric center of the coil assembly.

The HCS01CL can compensate for uniform changes in the ambient field but not for gradient changes. The coil assembly should be located in a region where there is minimal movement of ferromagnetic objects such as automobiles, forklifts, steel doors, etc. No ferromagnetic objects should be located within 15 feet of the edge of the coil assembly. The coil assembly should be located at least fifty (50) feet from a parking lot, railroad right-of-way, or roadway.

It is highly recommended that the temperature of the facility, where the HCS01CL is located, be maintained between 22 and 24°C.

COIL ASSEMBLY

Overview of Assembly Procedure

Prior to beginning the assembly, the Z coils are placed on the floor, because it is much easier to lift them up into position from there than to bring them down from above the erected X and Y coil nest.

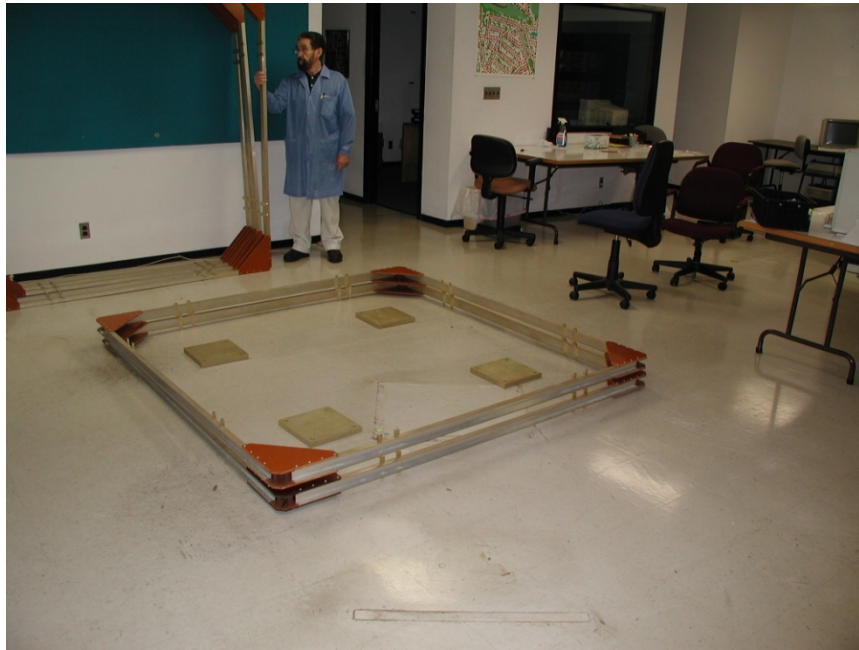


Figure 6 Starting configuration with Z-axis coils on the floor

The first step is to place the two X coils, which are the middle-sized coils, directly on the mounting pads. This results in two freestanding vertical coils as shown in Fig. 8 and Fig. 9.

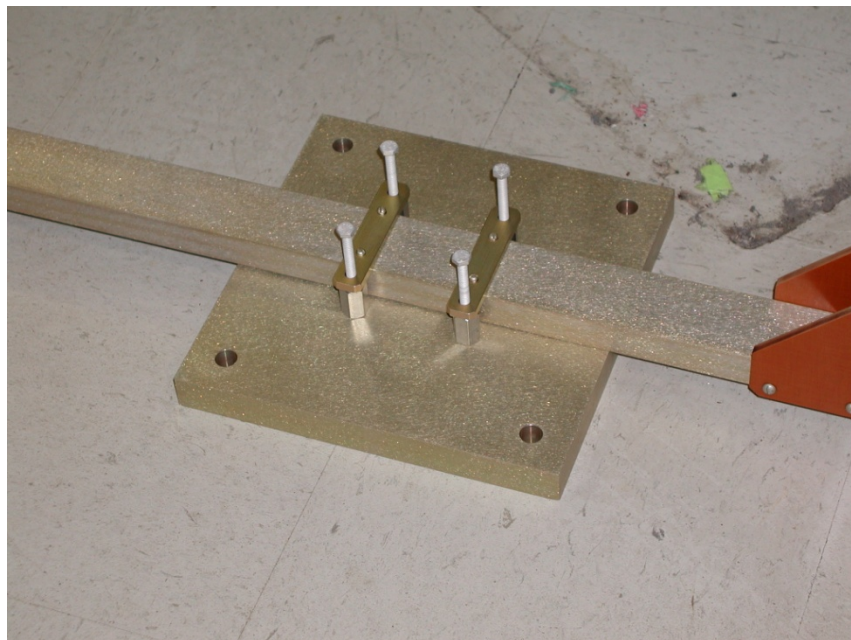


Figure 7 X-axis coil mounted to one of the pads.



Figure 8 X-axis coils in place.

The next step is to insert the Y-axis coils, which are the smallest, inside the X coils, and fasten them to the mounting pads and to brackets that secure them to the X coils at the top.



Figure 9 X and Y-axis coils in place.

The next step is to place the upper of the Z-axis coils around the other coils, and join it to them at eight points with spacers and bolts. Then the lower Z coil is added. The result is the interlocked nest of six coils joined to themselves and to the mounting pads. See Fig. 10.



Figure 10 X, Y and Z-axis coils fully assembled.

Next the pedestal that holds the CCM-3 sensor is bolted to the floor.

Finally, the CCM-3 magnetometer sensor is installed in the pedestal (see Fig. 2), completing the coil system assembly.

Preparation for Coil System Assembly

The site for the installation needs to be chosen with regard to the guidelines given in the Site Requirements section. If a spacer frame is required to separate the coil system from magnetic material in the floor, it should be constructed and the coil system placed upon it. A square frame made from 2"x10" pine is suggested. Use non-magnetic nails or screws to assemble it.

Also attention is traditionally given to the orientation of this kind of system with respect to the magnetic field of the earth. Although this is not required with an automatic feedback system like the HCS01CL, it is probably a good idea to orient the system so that the positive X-axis points north and the positive Y-axis points east. These directions are marked on the coils and drawings. In this way the Y-axis is approximately aligned with the null plane of the Earth's field, which can be convenient for certain tests made with the coil control system inactive.

Pre-positioning of Z-axis Coils

Please refer to Fig. 11.

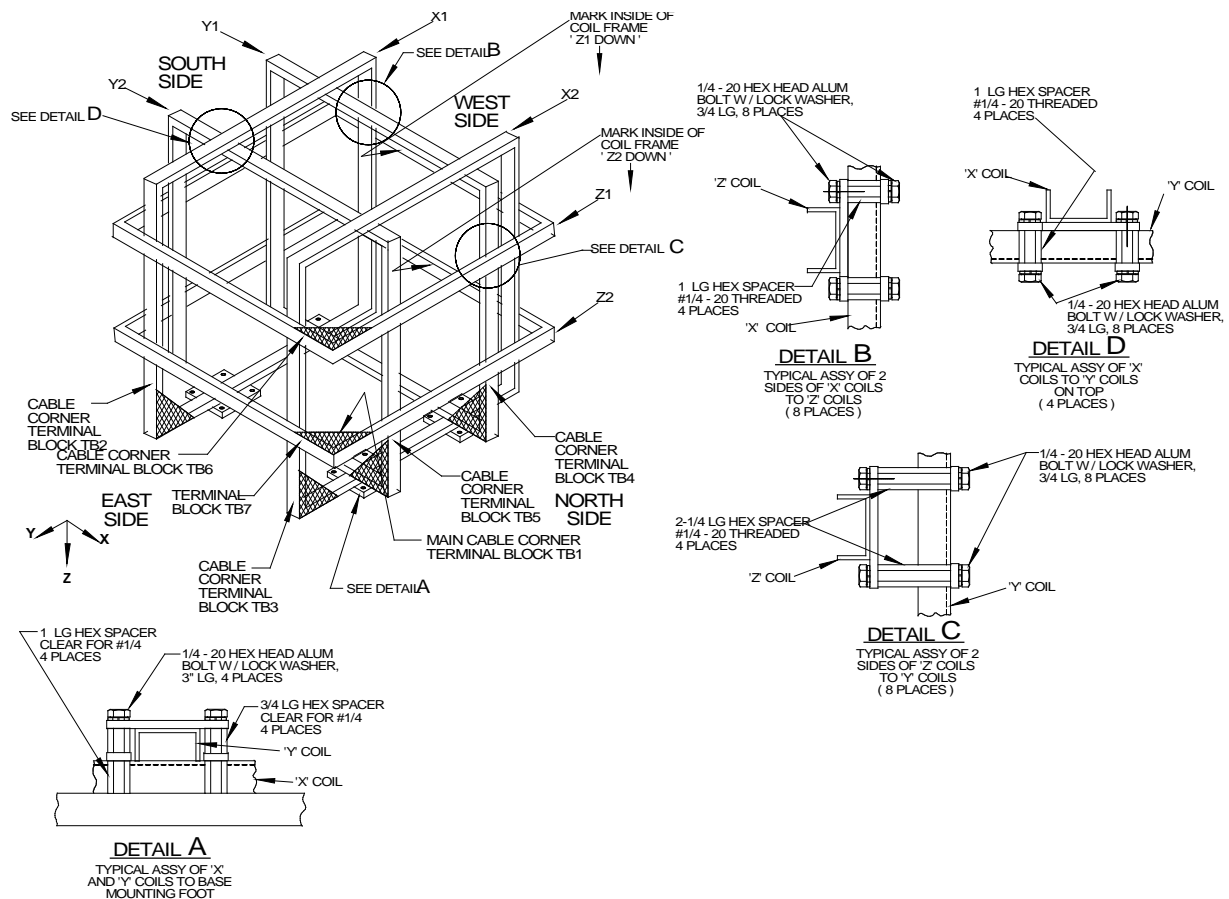


Figure 11 Final Assembly

1. Place the Z2 coil on the floor, orienting it so that the marked arrow points down and the side with the marking on it is adjacent to the west side of the frame, as shown in the drawing. The Main field cable corner marking is on the Northeast corner. The gradient cable corner is on the Northwest corner.
2. Place the Z1 coil over the Z2 coil, orienting it the same way. The cable corner marking is on the Northeast corner.
3. Place a footpad on the floor approximately at the intersection of the lines joining the vertical brackets attached to opposite sides of the Z-coils (four positions).

Assembly of X-axis Coils

Two people are required for the assembly of the coil system, although three will make the job easier. Please refer to Fig. 11. The drawing shows the northeast corner of the coil assembly to be nearest the viewer. This is the corner

from which the electrical drive cable for the field coils will emerge. The electrical drive cable for the gradient coils will emerge from the Northwest corner.

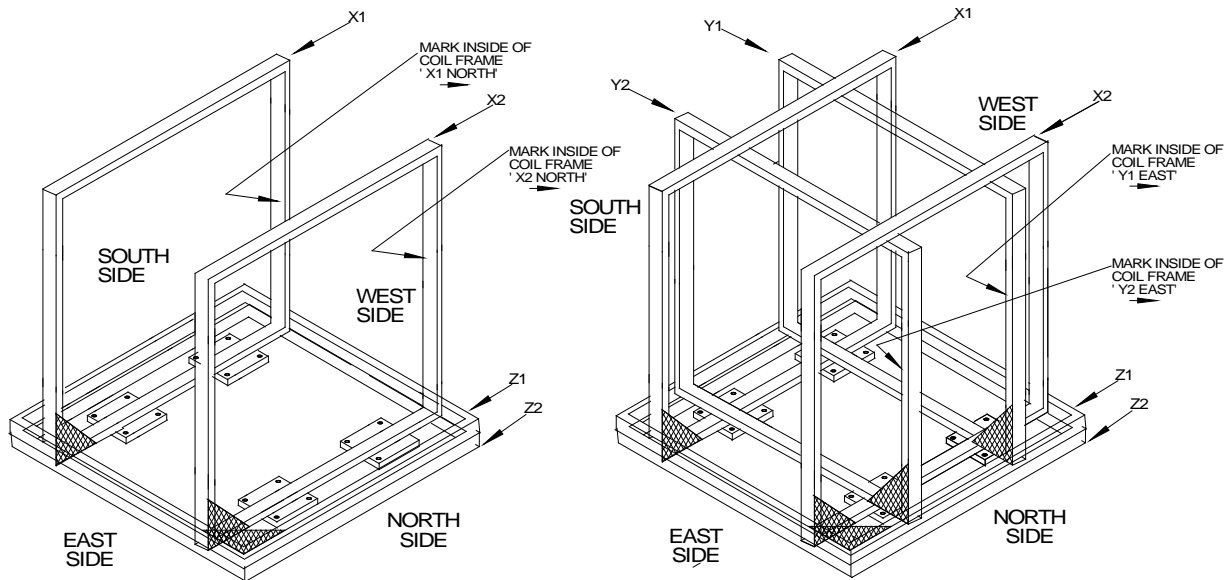


Figure 12 X-Axis and Y-Axis Assembly

1. Place the X1 coil with the marking upright and the marker arrow pointing as shown in Fig. 12. Make sure the coil is resting on the two footpads in line with it.
2. Repeat step 1 for the X2 coil.
3. Have one person hold the two coils upright while two other people performs the Y-axis coil assembly.

Assembly of Y-axis Coils

Please refer to Fig. 11 and Fig. 12.

1. Insert the Y1 coil inside the X coils and over the mounting pads on the west side. The coils fit together closely, requiring care in assembly to avoid marring the finish.
2. Carefully align the mounting pads with the brackets on the X1 and Y1 coils. Insert spacers and screws into mounting pads as shown in detail A of Fig. 11. Align carefully until aluminum screws can be turned by hand.
3. Repeat step 2 for the X2 and Y1 coils.
4. Repeat steps 1 through 3 for the Y2 coil.
5. At the top where the X and Y coils cross, install threaded spacers, $\frac{1}{4}$ -20 x $\frac{3}{4}$ " long hex screws and lock washers to the brackets as shown in detail D of Fig. 11.

This completes the assembly of the X coils to the Y coils.

Assembly of Z-axis Coils

Please refer to Fig. 12.

1. Raise the Z1 coil up around the coil nest into position. It may be advisable to employ a third person for this step.
2. While holding the coil in position bolt it to the X coils with 1" threaded spacers, hex machine screws, and lock washers as shown in detail B of Fig. 11.
3. Secure the Z1 coil to the Y coils with 2 1/4" threaded spacers, hex machine screws, and lock washers as shown in detail C of Fig. 11.
4. Repeat steps 1-3 for the Z2 coil.

This completes assembly of the X, Y and Z coils.

Pedestal Mounting

Please refer to Fig. 12.

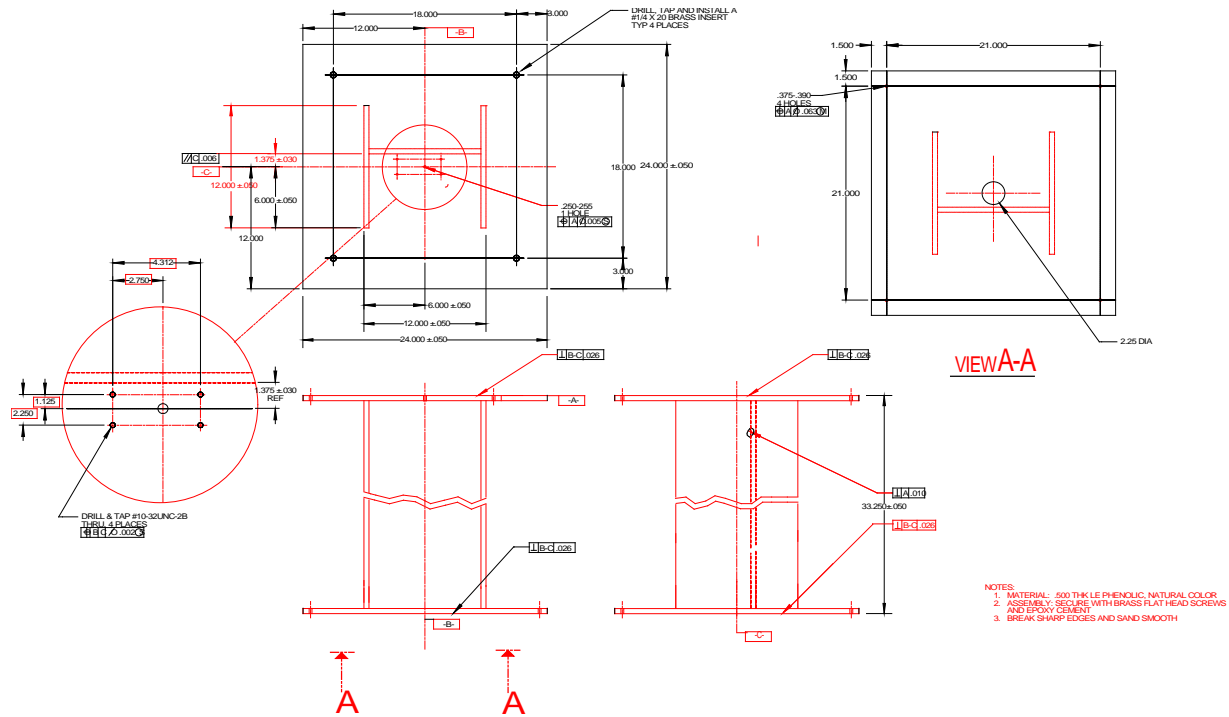


Figure 13 Pedestal general arrangement.

1. Locate the geometric center of the Helmholtz coil system.
2. Place the pedestal at the center of the coil system so that the hole in the center of the pedestal top surface is in line with the Z-axis centerline (vertical axis).
3. Rotate the pedestal about its vertical axis until it is oriented as shown in Fig. 2.
4. Attach the base of the pedestal to the floor using the four mounting holes.

Magnetometer Sensor Installation

1. Remove the four 10-32 3/4" aluminum screws from the sensor mounting holes on the top of the working surface of the pedestal.
2. Carefully unpack the CCM-3 Coil Control Magnetometer sensor and install it on the central vertical upright as shown in Fig. 2.
3. For the time being, leave the sensor cable coiled up inside the pedestal.

Coil System Wiring

Refer to Fig. 14.

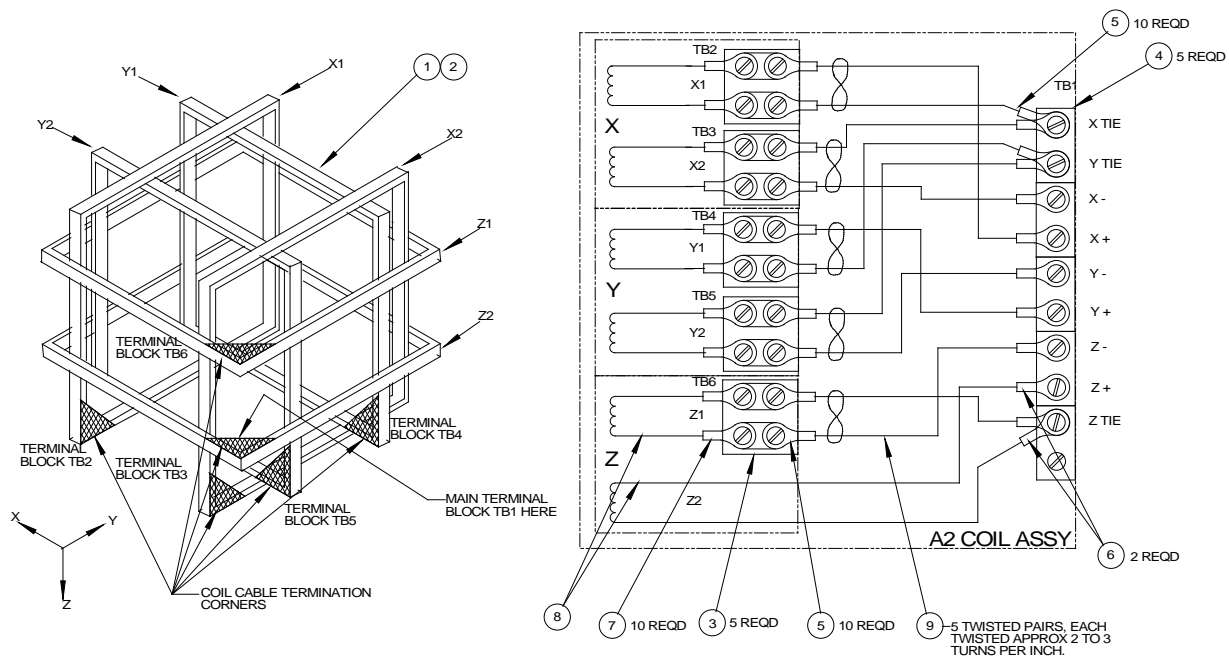


Figure 14 HCS01CL Coil Assembly wiring.

The pairs of wire that connect the coil winding terminal blocks to the main terminal block are all in place on the various coil frames. At the most, cable clamps on the end of the wire segments have been opened to permit separation of the coils. All wire lugs and all terminal blocks have been labeled. Reconnection is a matter of routing the wires over the cable tie wire mounts, connecting them to the terminal blocks, and adding cable ties where applicable.

1. The X1 wire pair will be found secured by four cable clamps to the south or front side of the Z2 coil frame. Connect its left-hand ends to the corresponding terminals on the X1 coil frame. Route it through the cable clamp on the X1 frame and close the clamp.
2. Route the right-hand end through the open clamp on the Z2 frame and connect the +X1 lug to the +X terminal on the main terminal block, tightening the screw. Connect the -X1 wire to the X Tie terminal on the main terminal block, but do not tighten the screw.

4. Route the X2 wire pair through the open clamp on the Z2 frame. Connect the -X2 lug to the -X terminal on the main block and tighten the screw. Connect the +X2 lugs to the X Tie terminal, and tighten down the screw on two lugs.
5. The Y1 wire pair will be found running through four cable clamps on the east side of the Z2 coil frame. Connect its right hand lugs to the corresponding terminals on the Y1 block. Route it through the clamp on the Y1 frame and secure the clamp.
6. Route the left-hand end through the open clamp on the Z2 frame. Connect the +Y1 lug to the +Y terminal on the main block and tighten the screw. Connect the -Y1 lug to the Y Tie terminal, leaving the screw loosely tightened.
7. Route the Y2 wire pair through the open cable clamp on the Z2 frame and close the clamp. Connect the -Y2 lug to the -Y terminal and tighten the screw. Connect the +Y2 lug to the Y Tie terminal and tighten the screw on two lugs.
8. The Z1 wire pair will be found running through four cable clamps on the X2 frame. Run its upper end through the cable clamp on the Z1 frame and close the clamp. Connect the lugs on the upper end to the correspondingly labeled terminals on the Z1 coil.
9. Route the lower end of the Z1 wire pair through the open cable clamp on the Z2 frame. Close the clamp over three pairs of wire.
10. Connect the -Z1 lug to the -Z terminal on the main block and tighten the screw. Connect the +Z lug to the Z Tie terminal and tighten the screw on two lugs.
11. Check that the +Z2 lug is connected to the +Z terminal and that the screw is tight.

Gradient Coil Wiring

The pairs of wire that connect the gradient coil winding terminal blocks to the main gradient terminal block are all in place on the various coil frames. At the most, cable clamps on the end of the wire segments have been opened to permit separation of the coils. All wire lugs and all terminal blocks have been labeled. Reconnection is a matter of routing the wires over the cable tie wire mounts, connecting them to the terminal blocks, and adding cable ties where applicable.

The gradient coil wiring is similar to the main coil wiring. The difference is the XYZ coils are independent of the main coil wiring, and are terminated on a separate terminal block on each coil. A circular orange disc next to the terminal block identifies the gradient coil. The coils are brought together on the Z2 coil frame, on the opposite corner from the main coil wiring. The corner that is designated for the gradient coil termination is identified with 2 orange circular discs on the top of the corner. See Fig. 14 for the wiring of the gradient coils. All gradient coils are marked according to where they come from; example: X1AG etc.

RACK ASSEMBLY

Please refer to Figure 1, 3, 4 and 5.

Overview

The Helmholtz Coil Control electronics are enclosed in a standard 19" equipment rack. The rack can be placed on or beside the table or desk that supports the personal computer that is the system operator interface.

The final rack assembly contains a CCM-3 Coil Control Magnetometer electronics chassis, six Kepco Bipolar Operational Power Supply chassis, and a power distribution unit.

Assembly consists of uncrating the equipment, installing the BOPs in the rack and securing them with screws and washers. Connection of the various system cables is covered below.

Provision must be made for a 30-Ampere twist-lock plug for the system power. The required receptacle is: NEMA L5-30R.

Figure 1 shows the final equipment arrangement.

Rack Assembly

Uncrate the rack and place it in its intended location if possible. It can be moved short distances after assembly, but its weight of about 400 pounds needs to be considered. The CCM-3 Coil Control Magnetometer and Power Distribution Unit are already installed in the rack. The rack also contains the cables that attach the BOPs in the rack to the Helmholtz Coil subassembly. Figure 15 below is a cable diagram for the system.

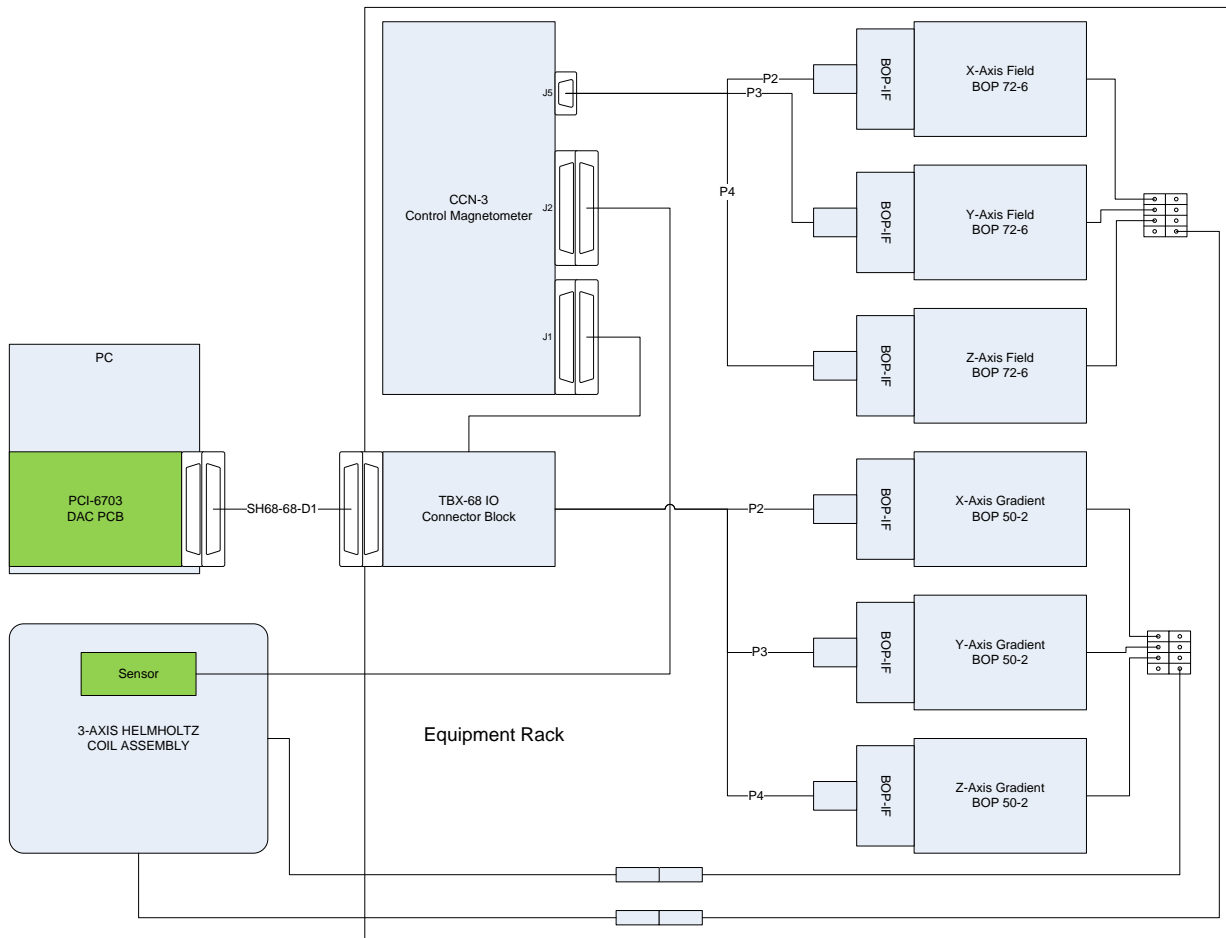


Figure 15 HCS0CL with Gradient cable diagram.

1. Uncrate the Bipolar Operational Power Supplies (BOP).

- Remove the 10-32 screws and plastic backed washers from the tapped holes in the rack where they were placed for shipment. The three field BOPS are identical. They are to be installed in the order: lowest, middle, top. Each power supply has been marked X, Y or Z. They are to be placed alphabetically from the top down as shown in Fig. 1. The power supplies will slide easily into place on the brackets built into the rack. Secure each with four screws and washers.
- Connect the color-coded wires from the terminal boards mounted on the left side of the rack (viewed from the rear) to the BOP TB201 terminals. First, remove one screw used to mount the BOP IF PCB to the BOP. Then rotate the BOP IF PCB to access TB201. Finally connect the wires and reattach the BOP IF PCB.
- Untie the white cable in the rack and connect the Molex connectors to their associated field BOP IF PCBs and the 9-pin D connector to CCM-3 J5 (refer to Fig. 17, 18 and 19).
- Connect the 68-pin connector from the TBX-68 Connector Terminal Block to CCM-3 J1 and the cables with the Molex connectors to their associated gradient BOP IF PCBs.

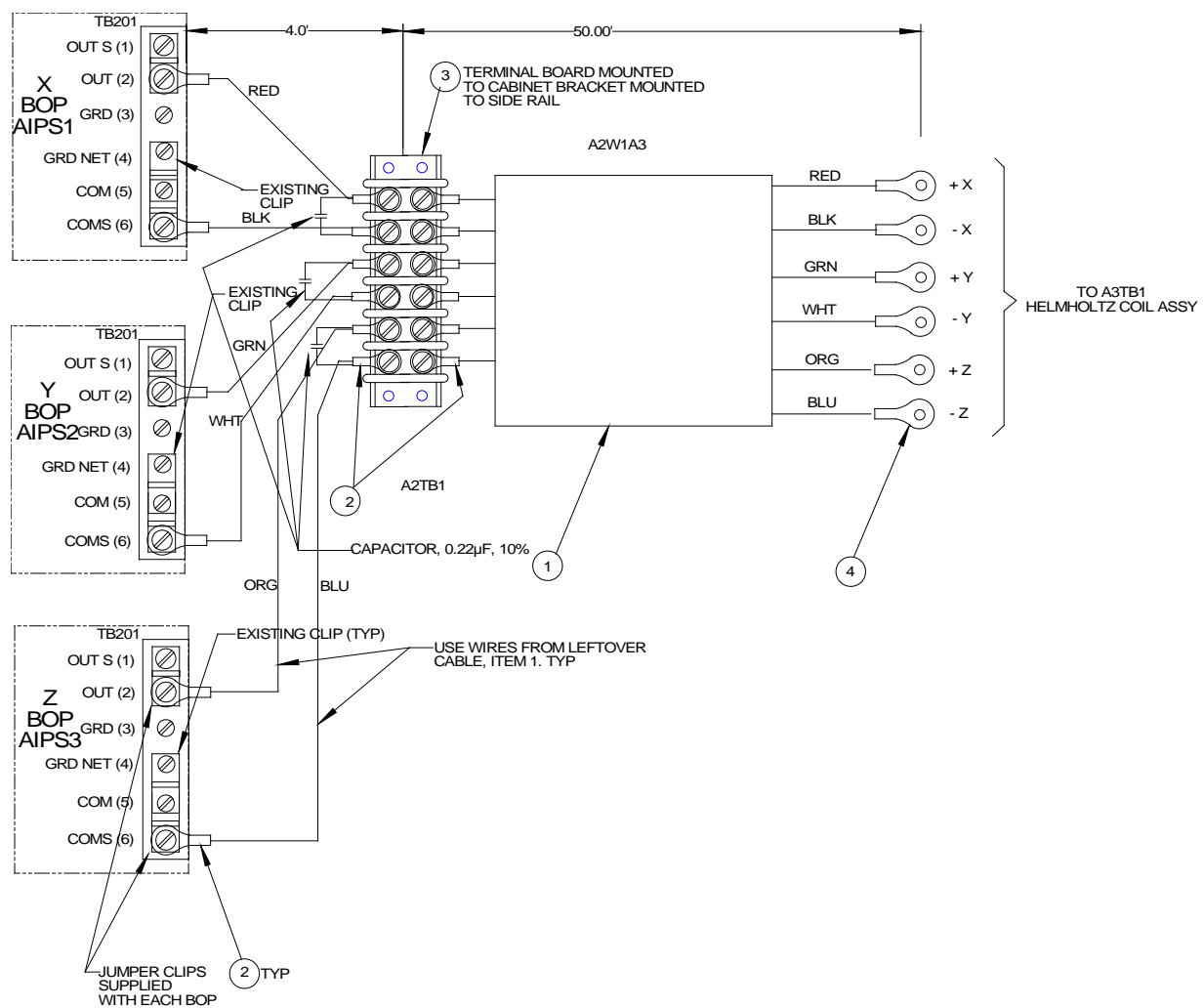


Figure 16 BOP to Helmholtz Coil Assembly wiring.

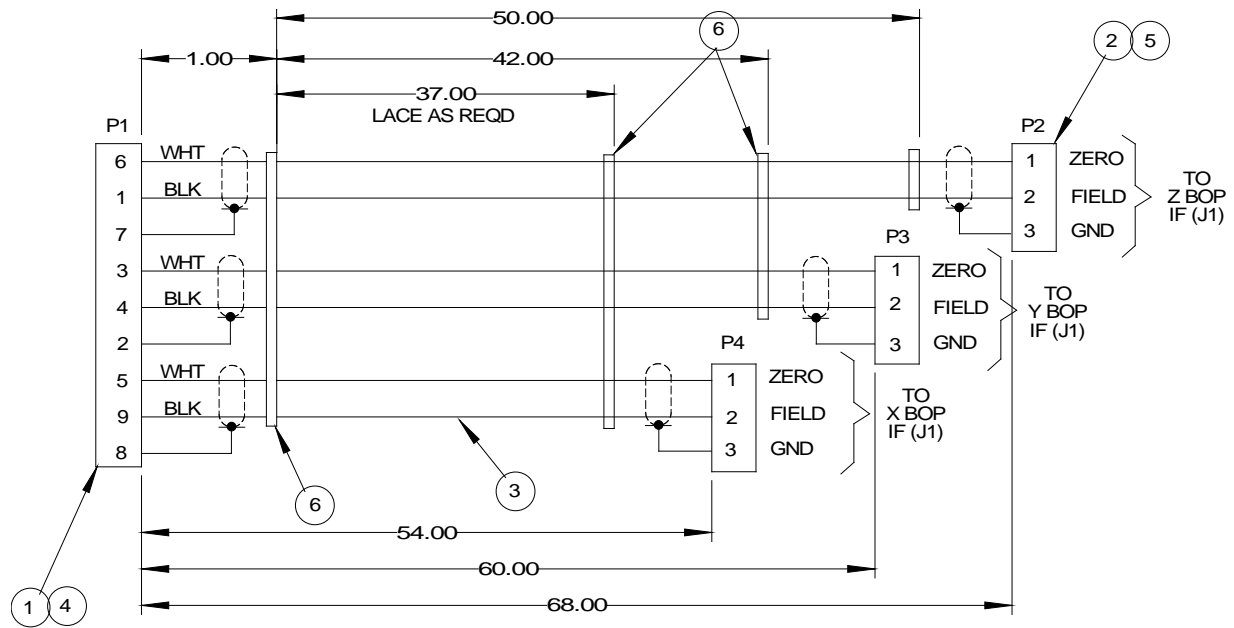


Figure 17 CCM-3 to BOP IF Cable Assembly

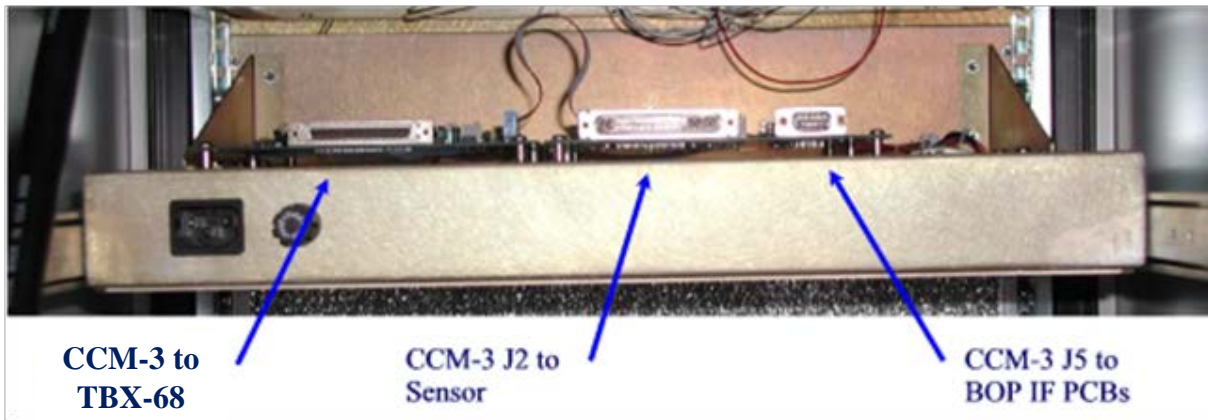


Figure 18 A rear view of CCM-3 chassis.

System Interconnection

Make sure that the main power cord from the power distribution unit is not connected to the wall outlet.

1. Plug the power cords of the BOPs and the CCM-3 into the outlets on the back of the power distribution unit.
2. Connect the 68-conductor cable between the connector of the DAC board plugged into the PC and J1 of the TBX-68 IO connector block mounted to the CCM-3 chassis rear (see Fig. 5).
3. Connect the CCM-3 sensor cable to J2 of CCM-3. The sensor is mounted on the pedestal.

4. Connect the two cables attached to the terminal boards mounted in the rack to their associated cables attached to the coil assembly using the inline connectors. One cable is marked Field and the other is marked Gradient.

PRELIMINARY CHECKOUT

Perform the following steps in the order given to verify that the HCS01CL has been reassembled and is operating properly:

1. Turn off the main power breaker on the power distribution unit (PDU) and the power breakers on the BOPs. Turn off the VDT and PC.
2. Connect the PDU to a 115 VAC 60 Hz 30 Amp power receptacle.
3. Turn the PDU breaker to the on position. The 'power on' light should come on. If it does not then check the power receptacle to verify that it is active.
4. Operate the CCM-3 power switch. The switch will be depressed when power is applied.
5. Check the switch positions on the front panel of the BOPs. The switches should be in the following positions:

<u>SWITCH</u>	<u>POSITION</u>
MODE	CURRENT
VOLTAGE CONTROL	OFF
CURRENT CONTROL	OFF

6. Turn on the VDT and PC. If the display or the PC does not turn on, check to make sure the power cords are properly connected.
7. Start the *HCS01CL Field and Gradient Manager* program (see the **HCS01CL Field and Gradient Manager** section below) and set the zero field adjustment values to 0.
8. Place an RM100 Station Magnetometer Sensor or equivalent at the geometric center of the coil assembly, and align it along the positive X-axis of the coil system (direction of arrows on X coil assembly).
9. Turn the X-axis BOP power on. The field measured by the magnetometer should drop to less than 2000 nT if the X-axis of the HCS01CL is operating properly. The current and voltage meters on the X BOP should deflect slightly.
10. If the deflection approaches full scale and the magnetometer reading increases then it is likely that the X-axis coils connected to the Main field terminal block are reversed. Reverse the present connection and repeat the process described in the above paragraph.
11. Type 80000 into the X-axis Field control and click on the + radio button.
12. The magnetometer should indicate a positive field of approximately 80,000 nT .
13. Click on the – radio button. The magnetometer should indicate a negative field of approximately 80,000 nT.
14. Click on the Off radio button. The magnetometer should return to the original zero field reading.
15. Repeat steps 8 through 14 for the Y-axis and Z-axis.
16. Finally use the up and down arrows of the Zero Adjustment controls to adjust the coil field to zero ± 1.5 nT in all three axes.

The zero offset settings are stored in the registry of the operating system. The registry is updated each time the program is closed. When the *HCS01CL Field and Gradient Manager* is started, the zero settings are read from the registry and the controls are initialized to these settings.

If the above steps were completed successfully, the HCS01CL is ready for final adjustment and calibration using the procedures described in the following sections. A recalibration is in order any time the system is disassembled and reassembled in a new location. The recommended calibration interval is one year.

OPERATION

HCS01CL START-UP

The HCS01CL should be started up using the following sequence, which assumes that the power switches on the PDU and BOPs are in the off position and the CCM-3, PC, and VDT switches are on:

1. Turn on the PDU. This will connect power to the BOPs.
2. Start the *HCS01CL Field and Gradient Manager* program (see the **HCS01CL Field and Gradient Manager** section below).
3. After the *HCS01CL Field and Gradient Manager* screen appears, turn on the BOPs one at a time. The order is unimportant.

The total transient current consumption of the HCS01CL can be high enough to trip a 30-Ampere circuit breaker. The operating current is below the 30 Ampere trip point. The above procedure helps protect against tripping a circuit breaker.

The BOPs should not be turned on until the *HCS01CL Field and Gradient Manager* program has begun execution. When the PC is turned on, it performs some hardware diagnostics. During this time, the state of the digital-to-analog converters (DAC) and the HCS01CL control voltages are indeterminate. This may cause the transient currents of the BOPs to be excessively high when they are turned on.

FIELD AND GRADIENT MANAGER

The HCS01CL comes with the *HCS01CL Field and Gradient Manager* computer program that can be used to control the HCS01CL. See the **HCS01CL Field and Gradient Manager** section for instructions on installing and using the *HCS01CL Field and Gradient Manager* program. The program displays a virtual front panel on the VDT and responds to mouse clicks and keyboard commands. The front panel display is shown in Fig. 19.

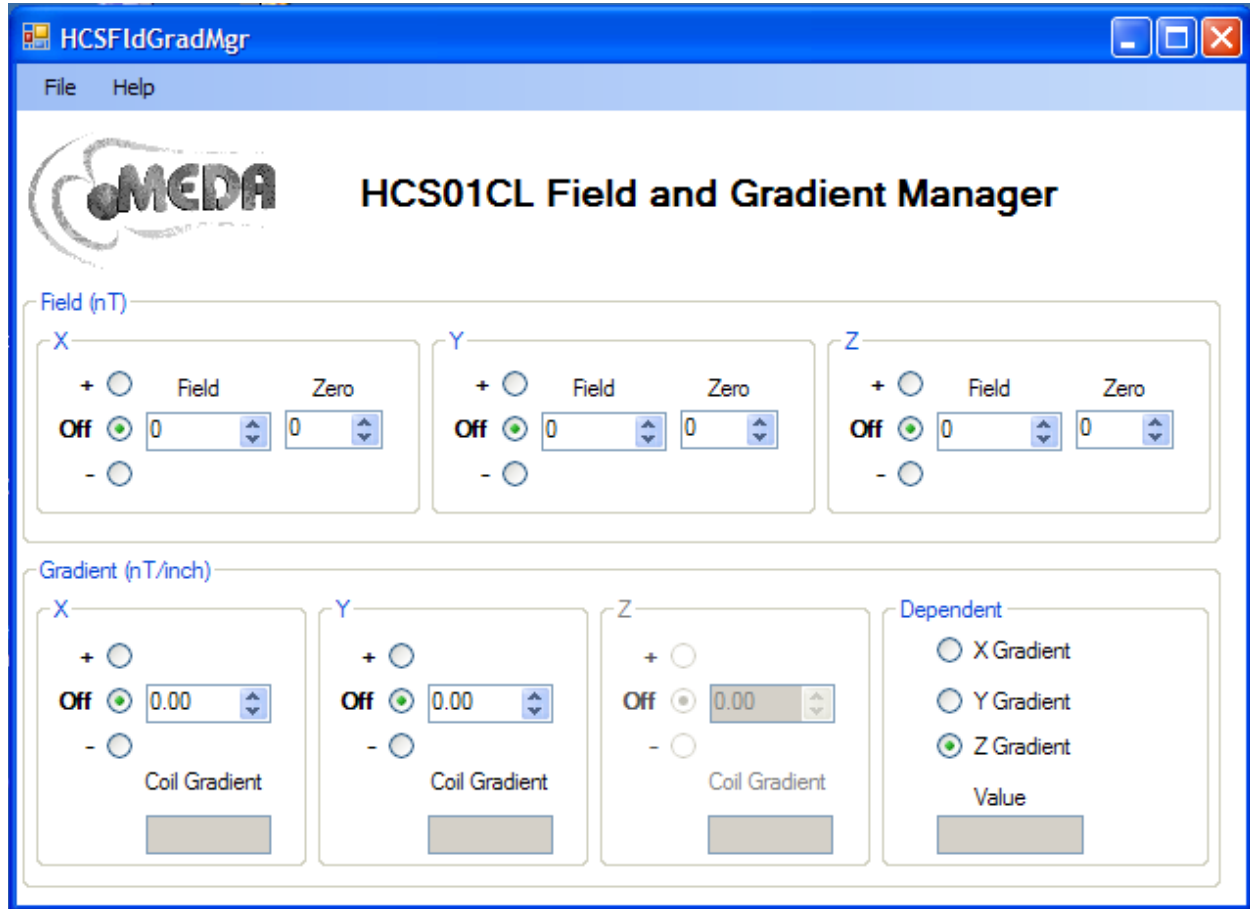


Figure 19 HCS01CL Field and Gradient Manager virtual front panel.

HCS01CL FIELD AND GRADIENT MANAGER PROGRAM

The *HCS01CL Field and Gradient Manager* can be used to apply fields from 0 to ± 100000 nT along any one or all of the reference axes as well as apply gradients from 0 to ± 100 nT/inch along any set of two axes. It can also be used to adjust the zero field value at the center of the coil system. This section describes how to install and use the program.

Minimum computer requirements

The computer requirements are:

- IBM PC compatible computer running Microsoft Windows XP.
- National Instruments PCI-6703 16-channel Digital-to-Analog Converter plug-in board.
- National Instruments NI-DAQmx Version 8.0 or later software package.
- One PCI slot.
- Microsoft .NET Framework version 2.0 or later.

Installing HCS Field and Gradient Manager

The HCS01CL comes with the *HCS01CL Field and Gradient Manager* program preinstalled. Use the following procedure to reinstall the program or install the program on another computer.

All MEDA designed software and manuals are stored on a CD that is provided with the HCS01CL system. The NI-DAQ software package that comes with the PCI-6703 must be installed before the *HCS01CL Field and Gradient Manager* program. To install the *HCS01CL Field and Gradient Manager* program:

1. Place the CD in one of the CD drives.
2. Wait up to 10 seconds for the installation program to start up.
3. Follow the instructions displayed on the screen.

The *HCS01CL Field and Gradient Manager* program, support libraries and source code will be placed in the *C:\Program Files\MEDA\HCSFldGradMgr* directory by default unless a different directory is chosen. Also an *HCS01CL Field and Gradient Manager* shortcut will be placed on the *Start* menu.

If the installation program does not start up automatically, use the following procedure to install *HCS Field and Gradient Manager*.

1. Click **Start** then **Run**.
2. Click on **Browse** and browse to the CD drive.
3. Double click *Setup.exe*.
4. Follow the on screen instructions.

Starting HCS01CL Field and Gradient Manager

HCS01CL Field and Gradient Manager should always be started before turning on the BOP's of the HCS01CL system.

To start the HCSField program:

1. Click on *Start* followed by *MEDA* on the *Start* menu.
2. Select *HCS Field and Gradient Manager*.

The *HCS01CL Field and Gradient Manager* virtual front panel shown in Fig. 20 above will appear. The Zero Adjust controls will contain the values that were present the last time *HCS01CL Field and Gradient Manager* was terminated.

ZERO FIELD ADJUSTMENT

The field at the center of the coil assembly can be adjusted to zero by using the Zero Adjust controls on the virtual front panel. A magnetometer is required to perform this task. Perform the following steps to set the field to zero:

1. Place the magnetometer sensor at the geometric center of the coil system and align it along the positive direction of the axis being adjusted.
2. Turn off all three axes by clicking on the **Off** radio buttons.

3. Use the up and down arrows to the right of the **Zero** control until the magnetometer reads zero within 1.5 nT.

The new zero setting will be saved in the registry of the PC when you exit the program.

APPLYING FIELDS

To apply a field:

1. Type a field value between 0 and 100000 into the Field control(s) or use the up and down arrows to the right of the text box. Do not put in any commas or spaces.
2. Click the mouse in the + or – radio button associated with the axis that is to apply the field.

Clicking on the **Off** radio button will turn the field off along the associated coil axis.

APPLYING GRADIENTS

Gradient fields can only be applied in two independent axes. The gradient in the third axis depends on the gradient selected for the other two axes. The gradient field has the following constraints.

$$G_x + G_y + G_z = 0$$

To apply a gradient:

1. Select the dependent gradient by clicking one of the radio buttons in the **Dependent** group box.
2. Type a gradient value between 0 and 100 into the Gradient control(s) or use the up and down arrows to the right of the text box.
3. Click on the + or – radio buttons to apply the gradient.

The text boxes below the gradient controls display the gradient field settings for the associated gradient coils. The text box in the **Dependent** group box displays the dependent gradient value.

HCS01CL POWER DOWN

The following sequence should be used in powering down the HCS01CL:

1. Turn each of the BOPs off one at a time. The order is unimportant.
2. Turn the PDU switch to the off position.

THEORY OF OPERATION

GENERAL

The HCS01CL with gradient coils is used to apply uniform, accurate and precise magnetic fields and gradients in the central region of the coil assembly and to attenuate external magnetic field sources that might cause a disturbance in the region. The Earth's field is the major source attenuated by the HCS01CL.

The HCS01CL provides separate operator controls for setting the zero fields, applied fields and gradient values. The Earth's field compensation function is controlled through a negative feedback loop that operates automatically without operator intervention.

Figure 20 is a functional block diagram for one axis of the field application circuit. The following sections describe how the HCS01CL performs its operations.

NI PCI6703 16-bit DAC Plug-In

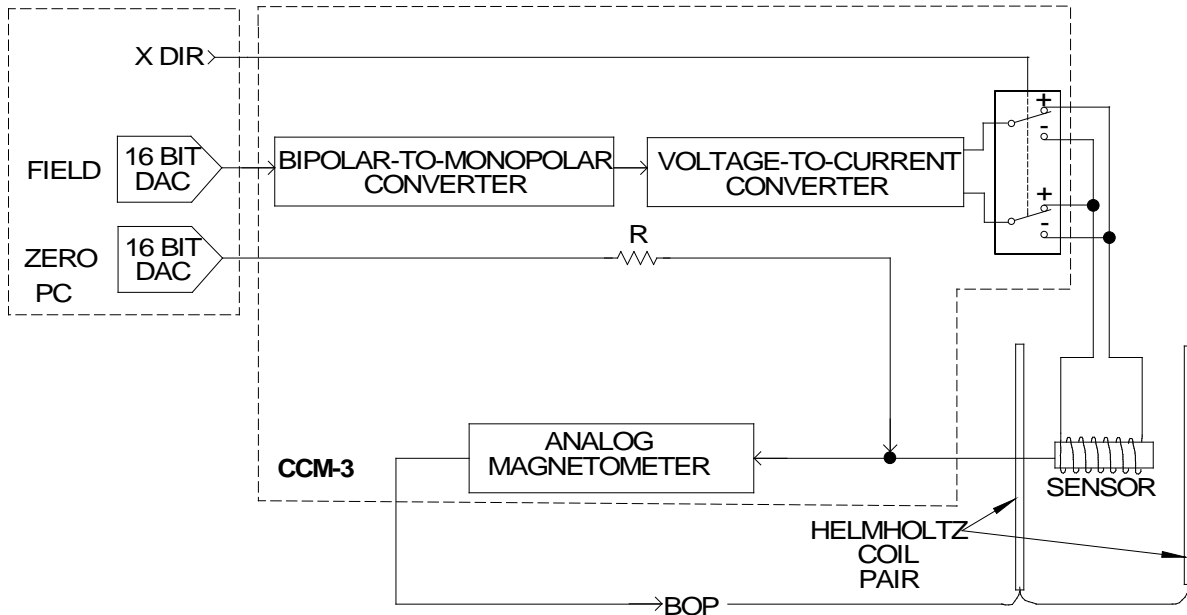


Figure 20 HCS01CL X-Axis Functional Block Diagram.

EARTH'S FIELD COMPENSATION

The overall operation of the HCS01CL is based on a negative feedback loop which forces the magnetic field at the sensor near the center of the Helmholtz coil assembly to approach zero. The sensor of the control magnetometer is placed near the center of the Helmholtz coils. The output of the sensor is the sum of the ambient field and the Helmholtz coil field. It is processed and amplified by the magnetometer electronics and then applied to the input of a bipolar operational power supply (BOP). The BOP output drives the Helmholtz coils to produce a magnetic field at the sensor that opposes the ambient field. This causes the net field inside the Helmholtz coils to approach zero.

The forward gain of this negative feedback loop is very large. As a result, the large field of the Earth (50,000 to 75,000 nT) is reduced to only a few nT at the sensor location.

Because the control sensor is offset from the geometric center of the coil assembly, the field at the center may not be zero. The HCS01CL has a control that can be used to adjust for this difference. This is discussed in the Zero Field Adjustment section above.

Any changes in the Earth's field are automatically compensated through this negative feedback mechanism. In fact, any external disturbance that causes the ambient field to change uniformly will be attenuated. Thus the field at the center of the coil assembly will be quite stable for large variations caused by external sources.

FIELD APPLICATION

The negative feedback loop forces the field at the sensor to a null. This characteristic is used to force the feedback loop to generate desired fields in the center of the coil assembly. A solenoid surrounding the sensor is driven by a stable voltage-to-current source. This produces a field at the sensor that the feedback system nulls. Since the solenoid field is local to the sensor (not present outside the solenoid), this process results in a field at the center of the coil assembly that is almost equal to the solenoid field. The difference (less than 1%) between the two is a result of the displacement of the sensor from the center of the coil assembly. This difference is eliminated through adjustments (see the Maintenance section).

The solenoid and current source used in the HCS01CL are very stable and produce very linear and accurate fields. One 16-bit DAC of the PCI-6703 located in the PC drives a bipolar-to-monopolar converter circuit that converts the ± 10 Volt DAC output voltage range to a 0 to 10 Volt range at the input of the voltage-to-current converter. A relay connected between the solenoid and the voltage-to-current converter, driven by a digital output of the PCI-6703, controls the direction of current flow through the solenoid thus changing the polarity of the field. The result is a 17-bit resolution magnetic field control source.

ZERO FIELD ADJUSTMENT

A 16-bit DAC of the PCI-6703 connected through a resistor to the sensor input provides a fine adjustment of the zero fields at the center of the coil system. The current through the sensor signal winding creates a small local field at the sensor that the feedback system nulls, causing the field at the coil assembly center to change. The range of this fine adjustment is about ± 4000 nT.

GRADIENT APPLICATION

The gradient fields are produced by applying precision currents through Helmholtz coils that are wound on top of the Helmholtz coils used to generate the precision uniform field. The gradient field is produced by connected these coils in opposition. Three 16-bit DACs on the PCI-6703 PCB control the magnitude and polarity of the gradient. These DACs drive the gradient BOPs directly through the BOP IF PCBs. A variable resistor on the BOP IF PCB controls the scale factor (nT/inch) of the gradient coils.

The gradient produced by the gradient coils is given by the following equation:

$$\vec{G} = \begin{bmatrix} 1 & -0.5 & -0.5 \\ -0.5 & 1 & -0.5 \\ -0.5 & -0.5 & 1 \end{bmatrix} \vec{G}_c$$

Where G is the applied gradient vector and G_c is the coil gradient vector. The matrix connecting these two vectors is singular so there is no inverse. That means that it is not possible to independently set all three gradient field components. The constraint is $G_x + G_y + G_z = 0$.

One other issue has to do with the change in the field at the center of the coil system when a gradient is applied because the feedback control sensor is offset from the center. The feedback system adjusts the field value so that the

field at the sensor is essentially zero. The **Zero** controls correct for the fact that the field at the sensor is not the same as the field at the center of the coil system. This zero field value is independent of the applied field value. This is not the case when a gradient is applied. When one of the gradient coils is turned on it produces a gradient field that is seen by the feedback sensor. The feedback will then adjust the field to cancel the affect at the sensor location. If not corrected, this will cause the field at the center of the coil system to change since there is now a defined gradient between the control sensor and the center of the coil system. This relationship can be expressed by the following equation:

$$\vec{H}_{center} = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{ee} \end{bmatrix} \vec{G}_c$$

Where H_{center} is the field vector generated at the center of the coil system caused by the gradient coil vector G_c . The matrix connects the gradient field vector to the center field vector and its coefficients have the dimension of inches. The matrix coefficients are measured during the calibration process and stored in the registry. When the *HCS01CL Field and Gradient Manager* starts up it reads in these values and uses them to automatically correct for the zero shift caused by the application of a gradient.

The X and Y axis sensors in the control sensor are very close to being in the central plane of the Helmholtz coil pair associated with them so the X and Y gradient coils produce only a small change in the field at the center. The Z axis sensor is displaced by about 11 inches from the central plane of the Helmholtz coil pair associated with it so it has the greatest affect on the shift in field at the center.

Let x_0 be the offset of the X sensor from the X-axis central plane; y_0 be the offset of the Y sensor from the Y-axis central plane; and z_0 be the offset of the Z sensor from the Z axis plane. Then the shift in field at the center of the coil system will be approximately:

$$\vec{H}_{center} = \begin{bmatrix} x_0 & -0.5x_0 & -0.5x_0 \\ -0.5y_0 & y_0 & -0.5y_0 \\ -0.5z_0 & -0.5z_0 & z_0 \end{bmatrix} \vec{G}_c$$

The coefficients in one column of the matrix are determined by measuring the change in the magnetic field at the geometric center of the coil system caused by the associated gradient coil pair.

MAINTENANCE

GENERAL

The HCS01CL requires very little maintenance. The major maintenance activity is the periodic calibration of the system. All replaceable parts are at the printed circuit board module level or higher. In the event of a failure, the HCS01CL can be repaired quickly by substituting a spare unit for the failed module. It is highly recommended that a complete set of spare modules be maintained on site. This will reduce down time.

System recalibration is necessary after replacement of any module. Certain modules such as the bipolar power supplies should not affect the calibration, but maintenance of calibration integrity dictates that a recalibration is in order.

The following sections provide information that is required by qualified technical personnel to adjust and calibrate the HCS01CL. Any questions about these procedures should be directed to MEDA, Inc.

ADJUSTMENTS

HCS01CL Scale Factor and Zero Adjustment

The HCS01CL scale factors should be adjusted after replacing, repairing or adjusting any module in the system. Scale factor adjustment involves the application and measurement of magnetic fields and adjustment of variable resistors.

The scale factor and zero adjustments require a very accurate magnetometer. The recommended magnetometer is an RM100 manufactured by MEDA, Inc. It has a full-scale range of $\pm 100,000$ nT and an accuracy of 0.01% of the reading. These adjustments should be made after the HCS01CL has been warmed up for at least 30 minutes. The facility should be at its nominal temperature.

Below is a picture of the interior of the CCM-3 control magnetometer.

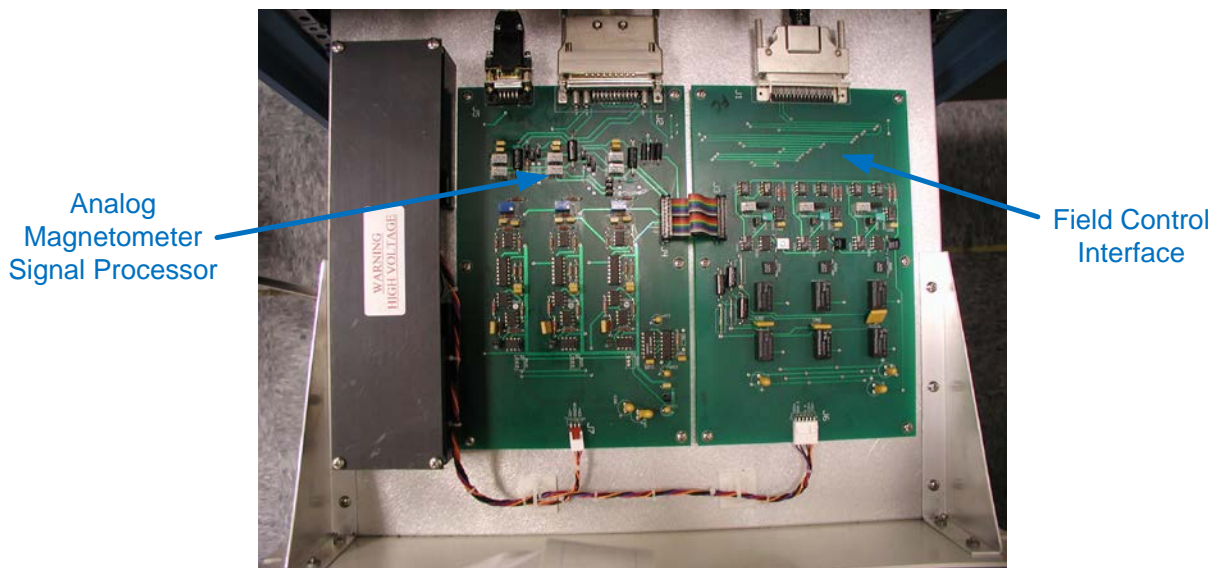


Figure 21 View of the inside of the CCM-3

All adjustments are made on the Field Control Interface printed circuit board.

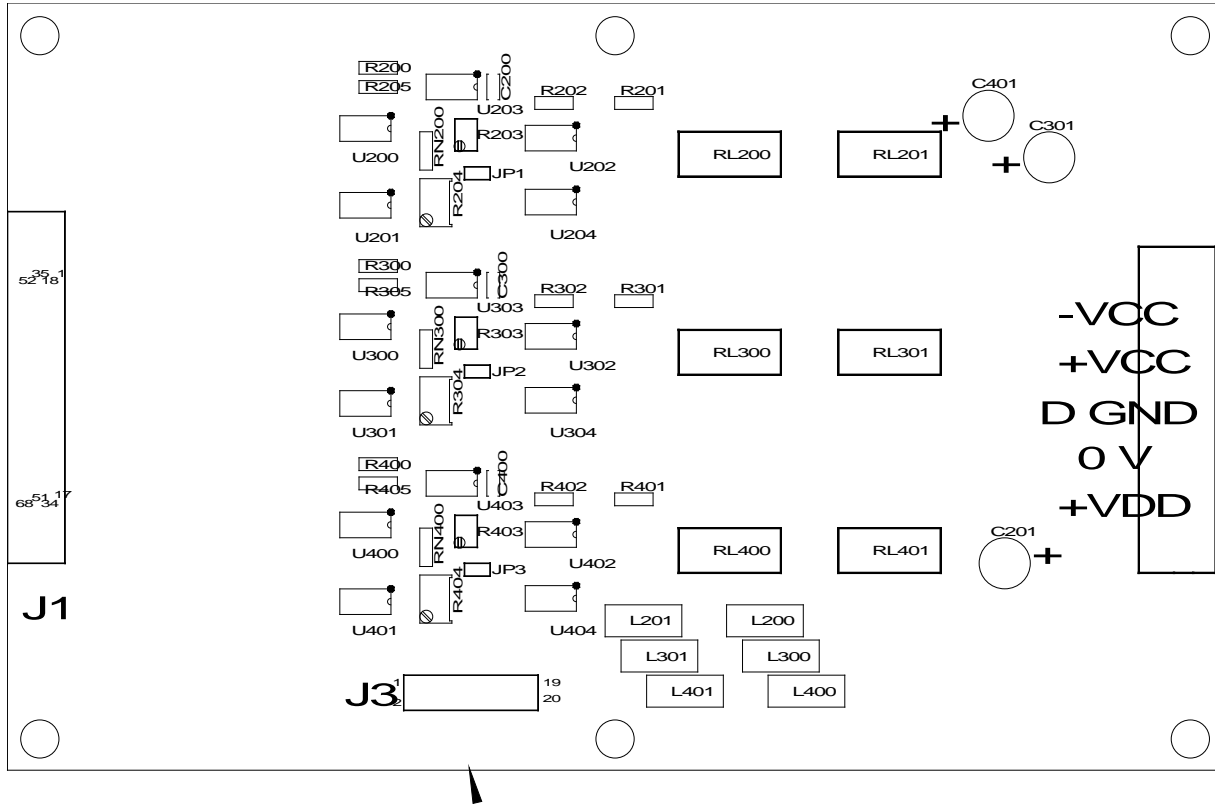


Figure 22 Field Control IF PCB

Zero Adjustment

1. Start the National Instruments *Measurement and Automation Explorer* program and turn on the system. Leave the gradient BOPs off but turn on the field BOPs.
2. Mount an RM100 sensor at the geometric center of the coil system and orient it along the X-axis datum.
3. In *Measurement and Automation Explorer* select **My System->Devices and Interfaces->NI-DAQmx Devices->NI PCI-6703: "Dev1"**.
4. Select **Test Panels** (see Fig. 23 below).
5. Set the output voltages of Dev1/ao0 through Dev1/ao2 to +10 volts.
6. Set the output voltages of Dev1/ao3 through Dev1/ao8 to 0 Volts.
7. Select the **Digital I/O** tab of the Test Panel (see Fig. 24 below) and set **Port Line Direction** to output.
8. Set **Port Line 0, 2 and 4** to **High** and click on **Start**.
9. Press the **Null** key on the RM100 to null the RM100.
10. Set **Port Line 1** to high and note the change in field.
11. Adjust R204 until the reading is half the noted value and press the **Null** key on the RM100.
12. Set **Port Line 1** to low and note the change in field.
13. Adjust R204 until the reading is half the noted value and press the **Null** key on the RM100.
14. Repeat steps 9 through 13 until switching **Port Line 1** between low and high causes a change in field reading of less than 1.5 nT.
15. Rotate the sensor so that it is aligned with the Y-axis.

16. Repeat the above adjustments using **Port Line 3** and adjusting R304.
17. Rotate the sensor so that is aligned with the Z-axis.
18. Repeat the above adjustments using **Port Line 5** and adjusting R404.

At this point the HCS01CL zero has been adjusted and the HCS01CL scale factor adjustment can be made.

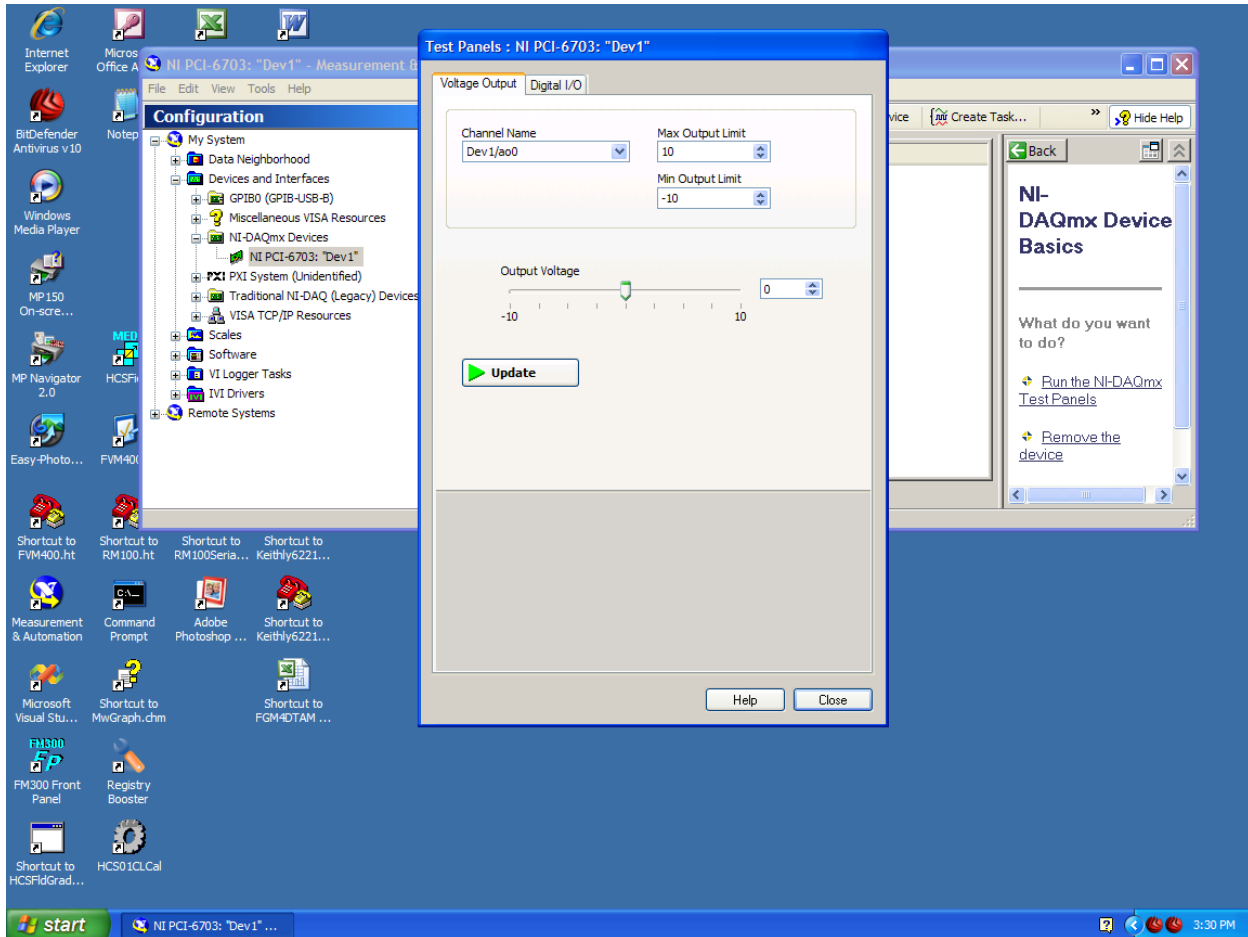


Figure 23 Measurement and Automation Test Panel voltage output display.

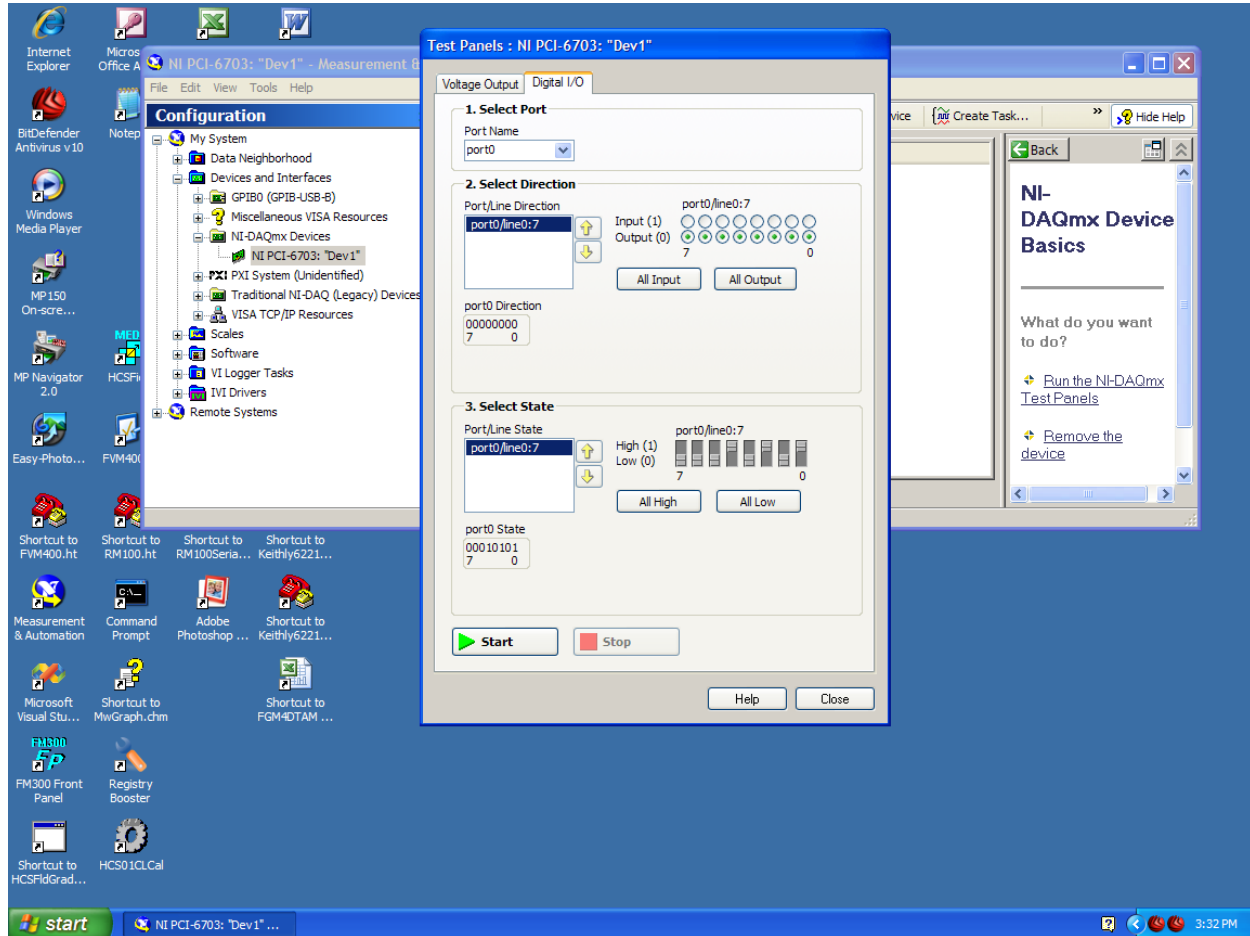


Figure 24 Measurement and Automation digital output display.

Scale Factor Adjustment

The zero adjustment must be performed before adjusting the scale factor.

1. Perform steps 1 through 9 of the Zero adjustment procedure.
2. Set the RM100 in **Auto Null** node by pressing the **Shift** key followed by the **Auto** key.
3. Note the resulting measured field value.
4. Set the Voltage output of Dev1/ao0 to – 6.0 volts.
5. Adjust R203 so the change in field is 80,000 nT within 50 nT.
6. Set the Voltage output of Dev1/ao0 to 10 volts.
7. Rotate the sensor into the Y-axis.
8. Repeat steps 4 through 6 using Dev1/ao1 and R303.
9. Rotate the sensor into the Z-axis.
10. Repeat steps 4 though 6 using Dev1/ao2 and R403.

At this point the HCS01CL is ready for tuning and calibration using the utility program *HCS01CLCal* that is provided on the *HCS01 Field and Gradient Manager* CD.

Tuning

The above described adjustments usually only need to be performed once or after a PCB in the control magnetometer has been changed. The following procedures need to be performed whenever the system has been moved to a new location or the system has failed the calibration test. The provided *HCS01CLCal* utility program can be used to perform this task. To install this program:

1. Place the *HCS01CL Field Manager* CD into a CD drive.
2. Click **Cancel** to stop the installation of the *HCS01CL Field and Gradient Manager* program.
3. Use *Window Explorer* to locate subdirectory **HCS01CLCal** on the CD and double click on **Setup.exe**.
4. Follow the instructions that are presented on the screen.

The following screen will appear when **HCS01CLCal** utility program is started.

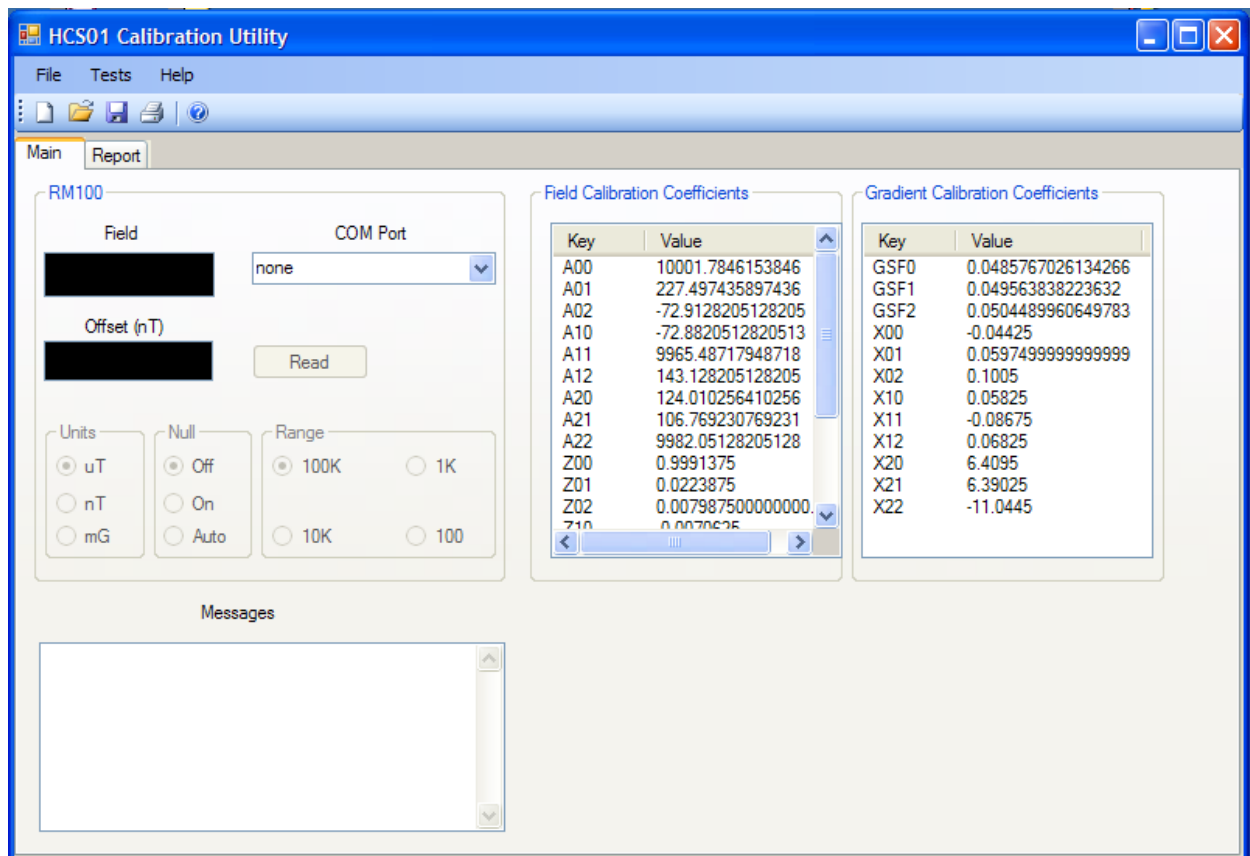


Figure 25 HCS01CLCal utility program start-up screen.

The current field and gradient calibration coefficients are displayed in the tables to the right.

The RM100 must be connected to a serial port before running any of the tuning or calibration procedures. To activate the serial connection use the COM Port drop down menu to select the serial port to which the RM100 is connected. If the connection is successful the **RM100** controls will be enabled.

The customer must provide a fixture to which the RM100 sensor can be mounted. The RM100 sensor will be rotated into each of the three orthogonal reference coordinate axes during the tuning and calibration procedures. Axis orthogonality depends on the orthogonality of the reference coordinate system established by the test fixture.

Field Alignment

The following procedure is used to align the system to the customer specified reference coordinate system.

To determine the alignment calibration coefficients A00 through A22 (refer to figure 26 below)

1. Start the *HCS01CLCal* utility program.
2. Select **Test->Tune->Field->Field Alignment**.
3. Follow the on screen instructions.

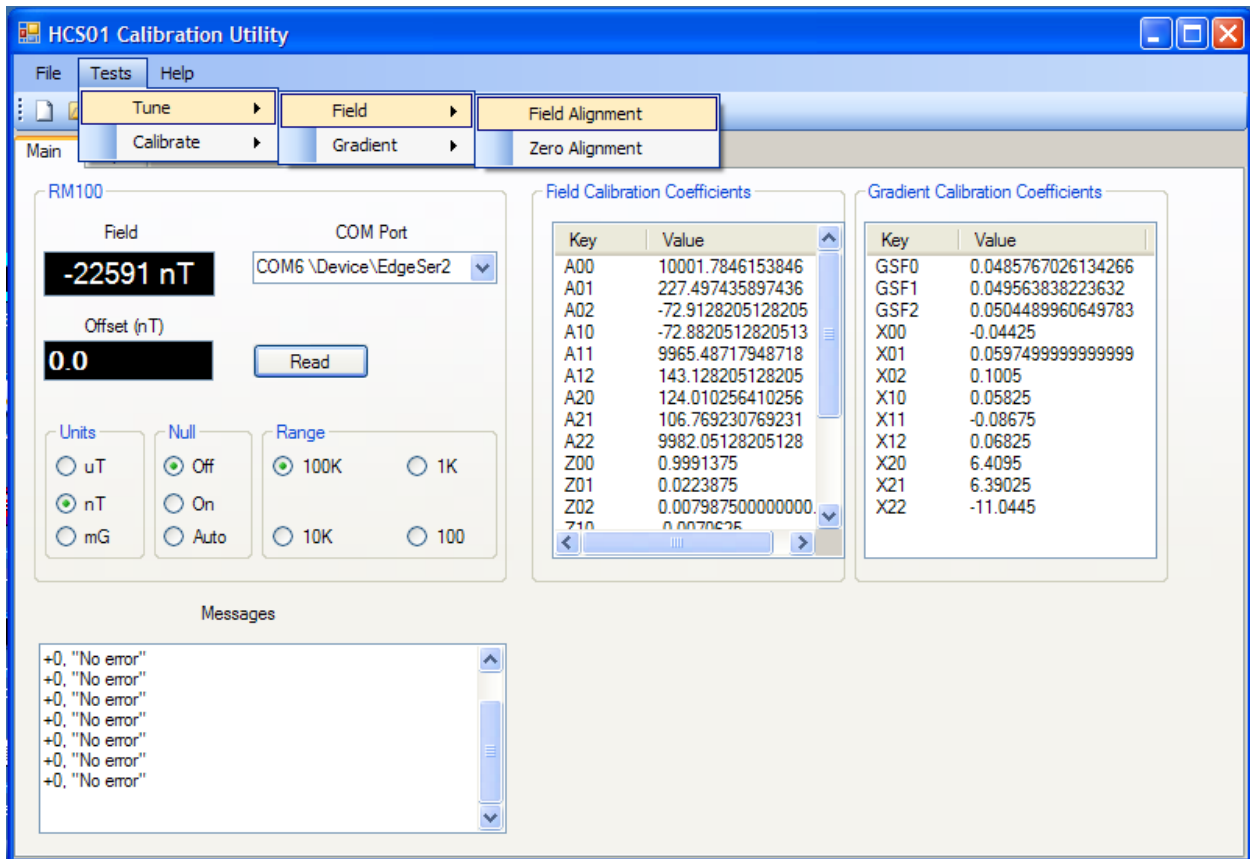


Figure 26 Select Test->Tune->Field->Field Alignment to measure the field alignment calibration coefficients.

Interim results will be displayed in the Messages text box. When the procedure is finished it will place the new A00 through A22 values in the **Field Calibration Coefficients** table. The registry will not be updated until the **File->Save** menu item is selected.

Zero Alignment

The following procedure is used to measure the zero adjustment alignment coefficients for the user defined coordinate system.

To determine the zero alignment calibration coefficients Z00 through Z22 (refer to figure 27 below)

1. Start the *HCS01CLCal* utility program.
2. Select **Test->Tune->Field->Zero Alignment**.
3. Follow the on screen instructions.

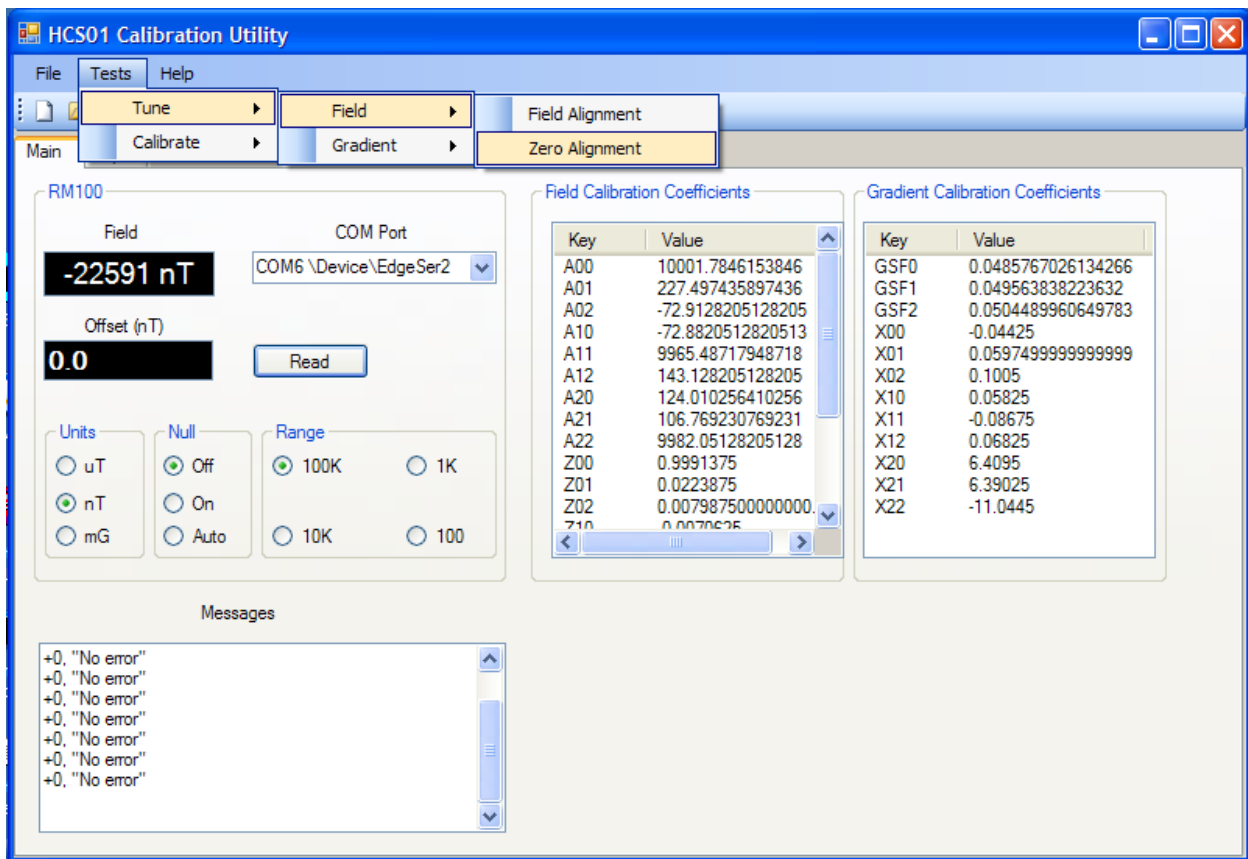


Figure 27 Select Test->Tune->Field->Zero Alignment to measure zero alignment coefficients.

Interim results will be displayed in the Messages text box. When the procedure is finished it will place the new Z00 through Z22 values in the **Field Calibration Coefficients** table. The registry will not be updated until the **File->Save** menu item is selected.

Gradient Scale Factors

The following procedure is used to compute the scale factors for the application of gradient fields.

To determine the gradient scale factors GSF0 through GSF2 (refer to figure 28 below)

1. Start the *HCS01CLCal* utility program.
2. Select **Test->Tune->Gradient->Scale Factors**.
3. Follow the on screen instructions.

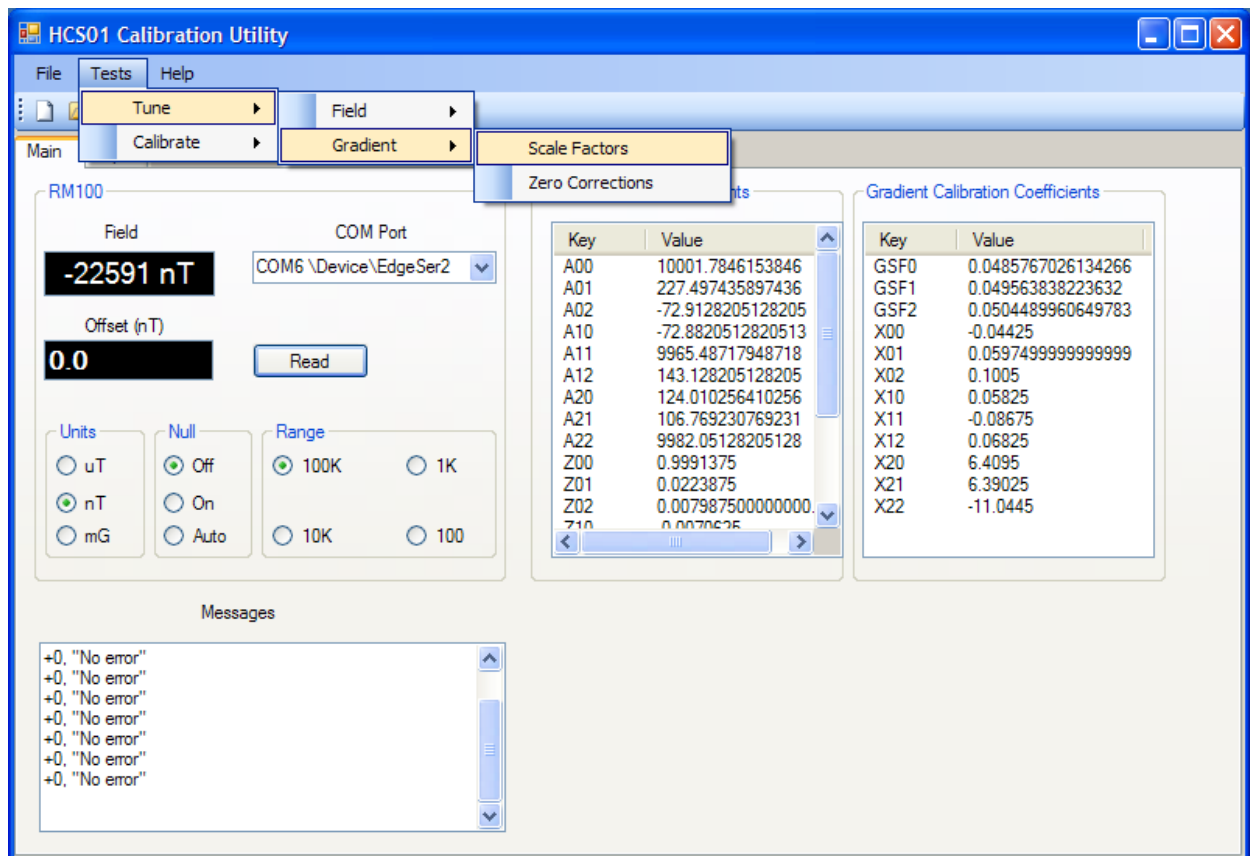


Figure 28 Select Test->Tune->Gradient->Scale Factors to measure the gradient field scale factors.

Interim results will be displayed in the Messages text box. When the procedure is finished it will place the new GSF0 through GSF2 values in the **Gradient Calibration Coefficients** table. The registry will not be updated until the **File->Save** menu item is selected.

Gradient Zero Corrections

Use the following procedure to compute the gradient zero correction coefficients.

To determine the gradient zero correction coefficients X00 through X22 (refer to figure 29 below)

1. Start the *HCS01CLCal* utility program.
2. Select **Test->Tune->Gradient->Zero Corrections**.
3. Follow the on screen instructions.

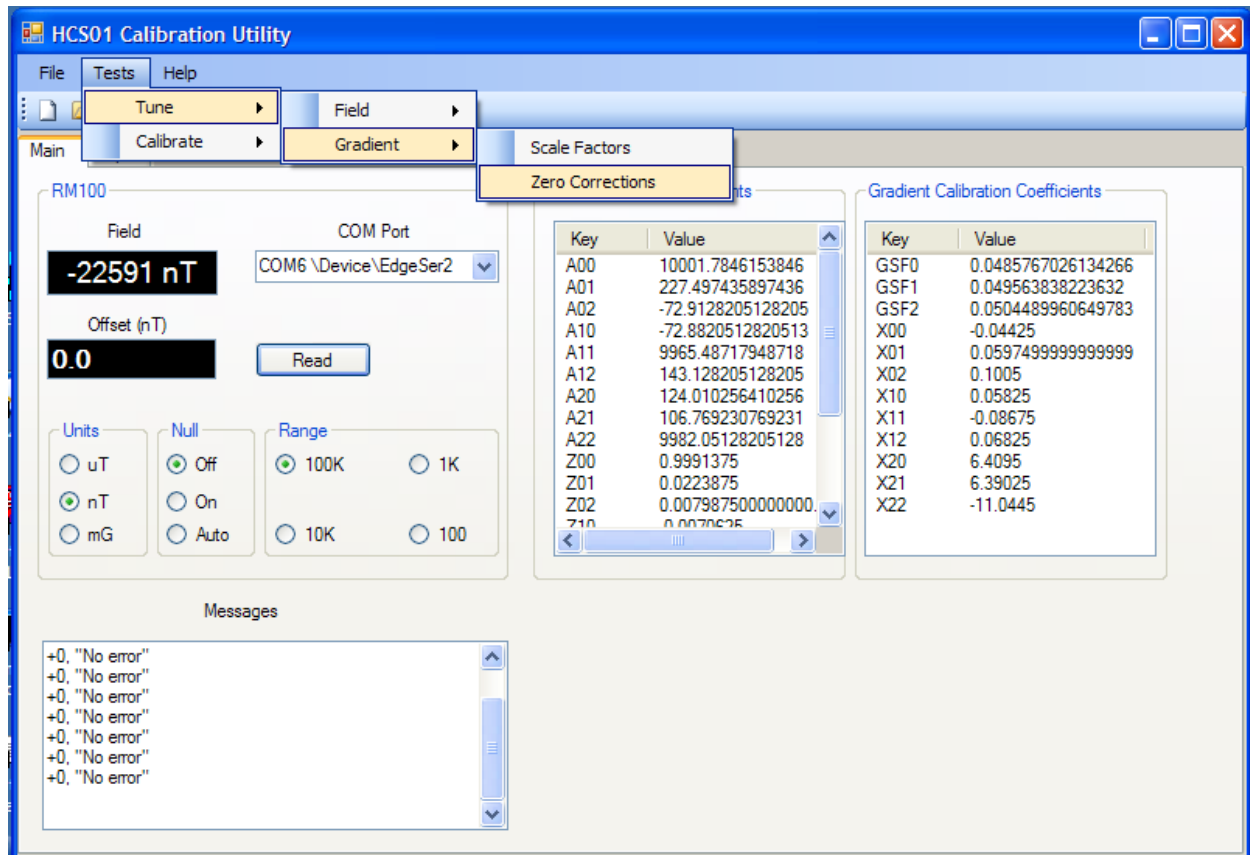


Figure 29 Select Test->Tune->Gradient->Zero Correction to measure the gradient zero correction coefficients

Interim results will be displayed in the Messages text box. When the procedure is finished it will place the new X00 through X22 values in the **Gradient Calibration Coefficients** table. The registry will not be updated until the **File->Save** menu item is selected.

Calibration

Once the tuning procedures have been completed, use the following procedures to calibrate the system. The new calibration coefficients must be saved using the **File->Save** menu command in *HCS01CLCal* to update the registry before performing these procedures.

Field Calibration

Use the following procedure to calibrate the magnetic field application part of the HCS01CL.

To calibrate the HCS01CL magnetic field application subsystem (refer to Fig. 30 below)

1. Start the *HCS01CLCal* utility program.
2. Select **Test->Calibrate->Field**.
3. Follow the on screen instructions.

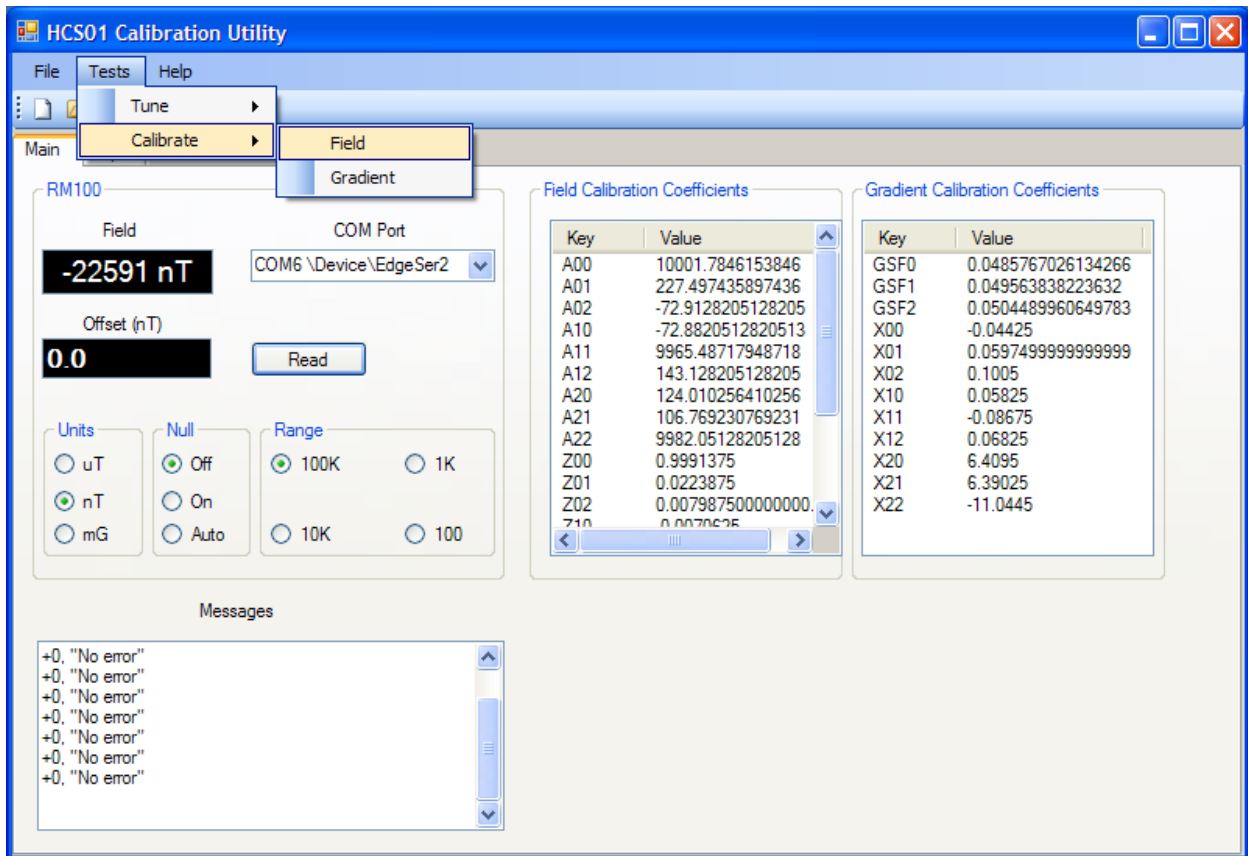


Figure 30 Select Test->Calibrate->Field to calibrate the magnetic field part of the HCS01CL.

Interim results will be displayed in the Messages text box. When the calibration is completed the screen will switch to the Report tab and display the calibration report. Figure 31 is an example report.

The screenshot shows the 'HCS01 Calibration Utility' window. The 'Report' tab is active, displaying a 'Field Calibration' report. The report includes the following information:

SN: TIAX Technician: Steve Macintyre
Date: 11/25/2007 3:05 PM
RM100 SN: 5648 Cal Due: 3/31/2008
Temperature: 22 C Humidity: 43 %
Comments: Preliminary calibration of TIAX system in Dulles, VA.

The report also contains a table titled 'X Axis' with the following data:

Applied (nT)	Measured (nT)	Tolerance (nT)
99950	99968	99898 to 100002
90000	90008	89953 to 90047
80000	80000	79958 to 80042
70000	69996	69963 to 70037
60000	59994	59968 to 60032
50000	49992	49973 to 50027

Figure 31 Example field calibration report.

To save the report to a file select **File->Save** from the **File** menu. The file will be saved in html format and it can be read using *Internet Explorer* or any program that can accept html formatted files. To print the report select **File->Print** from the **File** menu.

Gradient Calibration

Use the following procedure to calibrate the gradient field application part of the HCS01CL.

To calibrate the HCS01CL gradient field application subsystem (refer to Fig. 32 below)

1. Start the *HCS01CLCal* utility program.
2. Select **Test->Calibrate->Gradient**.
3. Follow the on screen instructions.

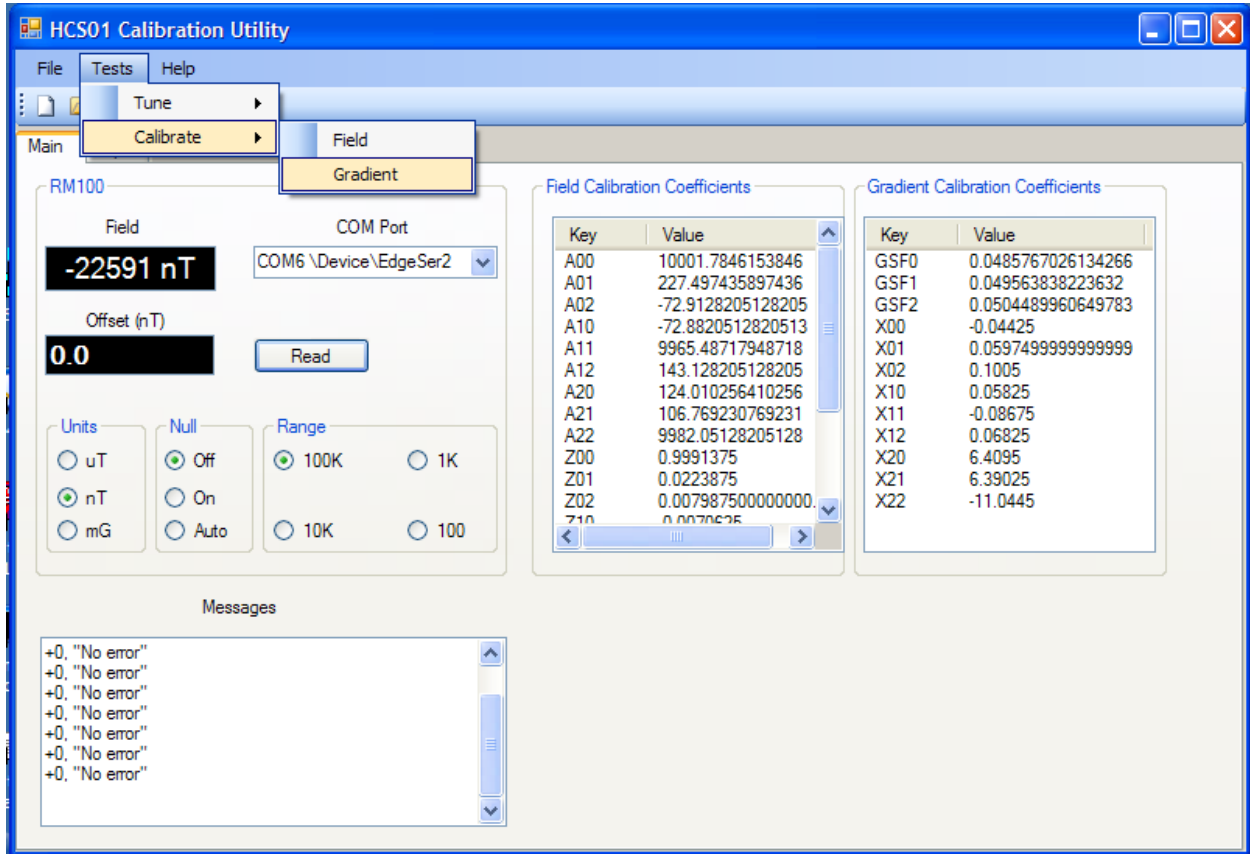


Figure 32 Select Test->Calibrate->Gradient to calibrate the gradient field subsystem.

Interim results will be displayed in the Messages text box. When the calibration is completed the screen will switch to the Report tab and display the calibration report. Figure 33 is an example report.

HCS01 Calibration Report

SN: TIAX Technician: Steve Macintyre
 Date: 11/25/2007 3:45 PM
 RM100 SN: 5648 Cal Due: 3/31/2008
 Temperature: 22 C Humidity: 43 %
 Comments: Preliminary calibration of TIAX system in Dulles, VA.

X Axis

Applied (nT/in)	Measured (nT/in)	Tolerance (nT/in)
200.00	200.36	197.60 to 202.40
180.00	180.24	177.80 to 182.20
160.00	160.00	158.00 to 162.00
140.00	140.32	138.20 to 141.80
120.00	120.36	118.40 to 121.60
100.00	100.28	98.60 to 101.40
-- --	-- --	-- --

Figure 33 Example gradient calibration report.

Although the full scale magnitude of the gradient specification is 100 nT/inch, each gradient coil set needs to generate fields of up to 200 nT/inch to achieve this specification (see the discussion in the **GRADIENT APPLICATION** section).

To save the report to a file select **File->Save** from the **File** menu. The file will be saved in html format and it can be read using *Internet Explorer* or any program that can accept html formatted files. To print the report select **File->Print** from the **File** menu.

This completes the calibration of the HCS01CL. If any measured field value is outside the tolerance range listed under the Tolerance heading, the HCS01CL calibration is out-of-tolerance, and a failure report shall be prepared and issued to the appropriate test, metrology, and quality control personnel.

TROUBLESHOOTING

The HCS01CL is a complex feedback control system. Personnel assigned to troubleshoot and repair the HCS01CL should have a thorough understanding of electronic feedback systems and how the HCS01CL works. Troubleshooting should be limited to isolating the module that is causing the failure. The module manufacturer is the best one to perform repair of the module.

The BOP manual does provide detailed information that may be used to perform repairs. This is a complex piece of equipment and MEDA recommends that, unless there are trained personnel on site who are familiar with this equipment, the BOP should be returned to KEPCO for repair.

The same can be said for the CCM-3 coil control magnetometer. This unit should be returned to MEDA for repair.

Some troubleshooting information is available for the PC. This information can be used to isolate the failed PC module and, in some cases, the module can be replaced or repaired by on site personnel. Refer to the PC documentation for troubleshooting information.

Unless the failure is catastrophic, such as a BOP voltage or current overload, it may be difficult to detect a system failure. Periodic health tests, using a high quality magnetometer such as the RM100 or FVM-400 manufactured by MEDA, are the best way to detect system failures. The frequency of the health tests must be determined by the test facility needs. Unexpected behavior of a device under test should also alert test personnel that a HCS01CL failure has occurred.

Once a failure has been detected, a magnetometer is usually needed to troubleshoot the system. The troubleshooting procedures described in the following sections assume that a magnetometer is available along with a digital multimeter.

Zero Adjustment Out of Range

The field at the center of the coil assembly cannot be set to zero using the *HCS01CL Field and Gradient Manager Zero* controls. One or more axes could have this problem. This can be caused by one of the following failures:

1. BOP or CCM-3 failure that causes the feedback loop to open.
2. A failure in the DAC that is used to set the zero.
3. A failure in the CCM-3 Field Control IF differential amplifier that interfaces the DAC output to the CCM-3.

Use the following procedure to identify the cause of the problem.

1. Disconnect the cable between the PC and the CCM-3.
2. Turn the BOPs off and measure the field components at the center of the coil assembly.
3. Turn the X-axis BOP on and measure the X field component at the center.
4. The X field component should be significantly less than the value measured in step 2 (at least 50 times less). If little or no change occurs then the feedback loop is open. In this case go to step 6.
5. Repeat step 4 for the Y and Z axes.
6. If the feedback is open then continue else go to step 8.
7. Replace the BOP and repeat step 3. If the results are the same then the CCM-3 has failed, otherwise the BOP has failed.
8. Check the DAC using the manufacturers recommended procedure. If the DAC is OK then the CCM-3 Field Control IF differential amplifier for the channel (or channels) has failed.

The zero adjustment could also be out of range if a ferromagnetic object had been placed in the vicinity of the coil assembly that caused a large gradient between the CCM-3 sensor and the center of the coil assembly.

No Response to Zero Field Adjustment

The field at the center of the coil assembly is within the zero adjustment range, but nothing happens when the *HCS01CL Field and Gradient Manager Zero Adjust* control is exercised. Make sure the cable between the PC and CCM-3 is properly connected. If the problem persists then the DAC or CCM-3 Field Control IF board may be the cause of the problem.

1. Disconnect the cable between the PC and the CCM-3.
2. Check the DAC using the manufacturer's recommended procedure.
3. If the DAC is OK then the CCM-3 Field Control IF board is the cause of the problem. Replace the differential amplifier (AMP 03) of the channel that has failed.
4. Replace the DAC if it has failed.

No Response to Polarity Function

Pressing + or - key causes the front panel display to indicate a change in polarity, but the field does not change. The magnitude of the field is correct. The cause of the problem can be a failure in the DAC or the CCM-3 Field Control IF board. Make sure the cable between the PC and the CCM-3 is connected properly. If the problem continues then perform the following procedure:

1. Remove the cable between the PC and CCM-3.
2. Check the DAC digital output using the manufacturer's recommended procedure. If the DAC fails then replace it else continue.
3. If the DAC is OK then the relay driver or the relay in the CCM-3 has failed. Replace or repair the CCM-3 Field Control IF board.

Cannot Apply Field

The front panel indicates that a field should be present in the coil system, but none can be detected. Changing field values has no effect. A failure in the DAC or CCM-3 Field Control IF can cause this symptom. Make sure the cable between the PC and CCM-3 is properly installed. If the problem persists then perform the following procedure:

1. Remove the cable between the PC and the CCM-3.
2. Check the DAC using the procedure recommended by the manufacturer. If it fails then replace or repair the DAC else continue.
3. If you made it here then the relay driver(s) or relay(s) has failed in the CCM-3 Field Control IF board. Replace or repair the CCM-3 IF board.

Miscellaneous Problems

There may be other problems that have symptoms and solutions other than the ones described above. In general check the cable connections, DAC, and CCM-3 Field Control IF board whenever an unexplained problem occurs. If the cause of the problem cannot be determined then call MEDA, Inc. for assistance.