HTS-110

Technical Manual

MODEL 3 T Relaxometry Magnet

SERIAL

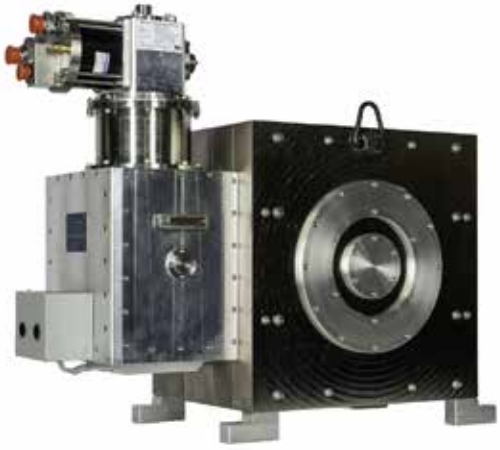
DATE

VERSION

This manual provides specifications for your 3 T Relaxometry magnet. It provides a guide for facilities requirements, installation, and operation and includes factory test data and specifications.

Also included are sections on safety and the procedures required to care for and maintain the magnet. **It is strongly recommended that the manual should be read in its entirety before any operator uses the magnet.**


HTS-110

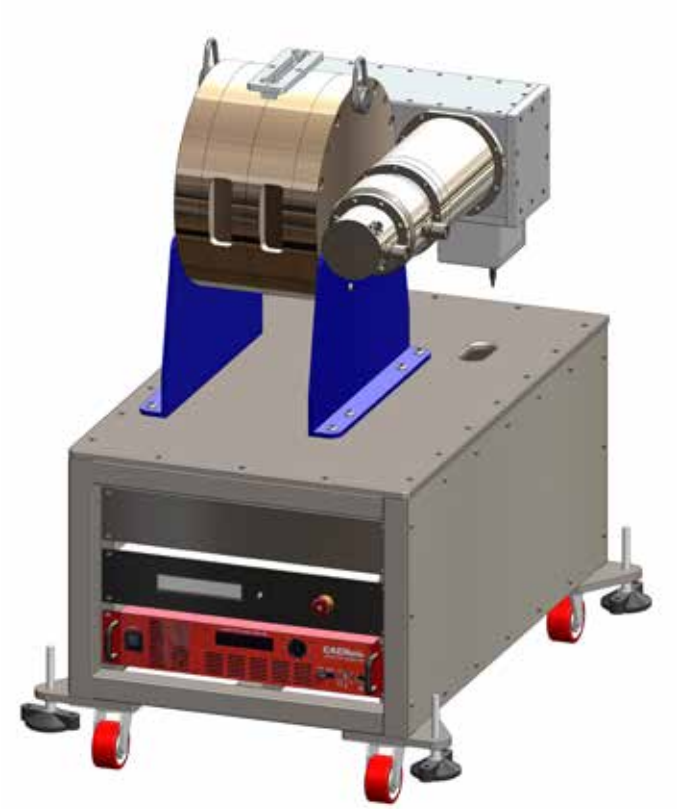


3 T NMR Relaxometry Magnet Specifications

Physical Parameter		Value
Weight (excluding compressor system, vacuum fittings, trolley)		185 kg
Overall Height		530 mm
Overall Width		455 mm
Access Port	Width	25 mm
	Height	150 mm

This superconducting magnet consists of the following elements:

- HTS coil: split pair conduction-cooled coil designed to generate a central field of 3 T.
- Integrated cryostat and return yoke forming the magnet chassis.
- Gifford McMahon cryocooler, manufactured by Sumitomo Heavy Industries; separate operating manual supplied.
- Power supply, one CAENels 150 A, 10 V.
- System Magnet Monitor for monitoring coil operating temperatures and voltages, with safety interlock to the power supply for automated shutdown in the event of abnormal operating condition.
- Dump resistors for emergency de-energisation of the magnet.
- Over-current prevention system to safeguard the magnet.



Introduction

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Information Icons

Information Icon. This icon indicates that the information is important to the optimum running of your magnet.

Caution Icon. This icon indicates that the information is important and where failure to observe instructions or precautions could result in damage to your magnet and associated equipment or void of any warranty.

Warning Icon. This icon is used in this section and through the text of the manual where failure to observe instructions or precautions could result in a risk to health or safety.

Personal injury Warning. This icon indicates that the information is important and where failure to observe instructions or precautions could result in personal injury.

Safety and Care in Operation

Emergency Shut down

In case of emergency, the magnet can be shut down by switching off the Magnet Monitor (this can be done either by flicking the switch on the front panel of the Monitor or by removing the Monitor from the mains). This will immediately disable the power supplies and the magnet will ramp down in field. Please note that it may take several seconds for the inductive power in the magnet to dissipate and for the field to drop to zero.

Safety

The magnet and associated equipment should only be operated by trained personnel. Incorrect operation may result in injury or death. Please read the manual in its entirety before any attempt is made to install, operate, or work in the vicinity of the magnet. **Some magnets may have hazards not described in this Safety section – always check the Operating Parameters table in the Operating the Magnet section of the Manual for information specific to this magnet before operating the magnet.**

Fringe Fields. During operation, significant fringe fields may be present. At maximum operating field the 5 Gauss (0.5 mT) limit is approximately 1600 mm out from the surface of the magnet in the axial direction, and approximately 1300 mm out from the surface of the magnet in the radial direction. Note that the fringe field extends in all three dimensions. The modelled fringe field maps are shown below and are associated with a central field of 3.0 T.

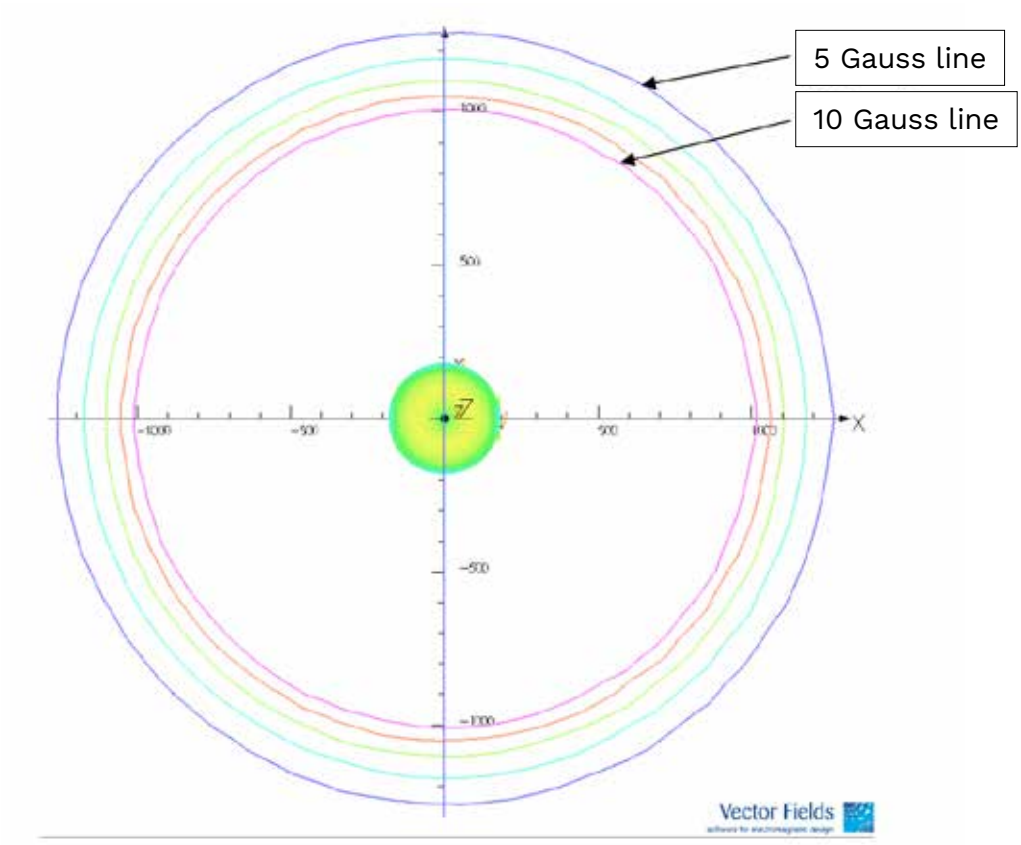


Figure 1: A contour map of the modelled fringe field on the X-Y plane. The field range is from 10 to 5 Gauss. The distances are measured in mm from the magnet central working volume.

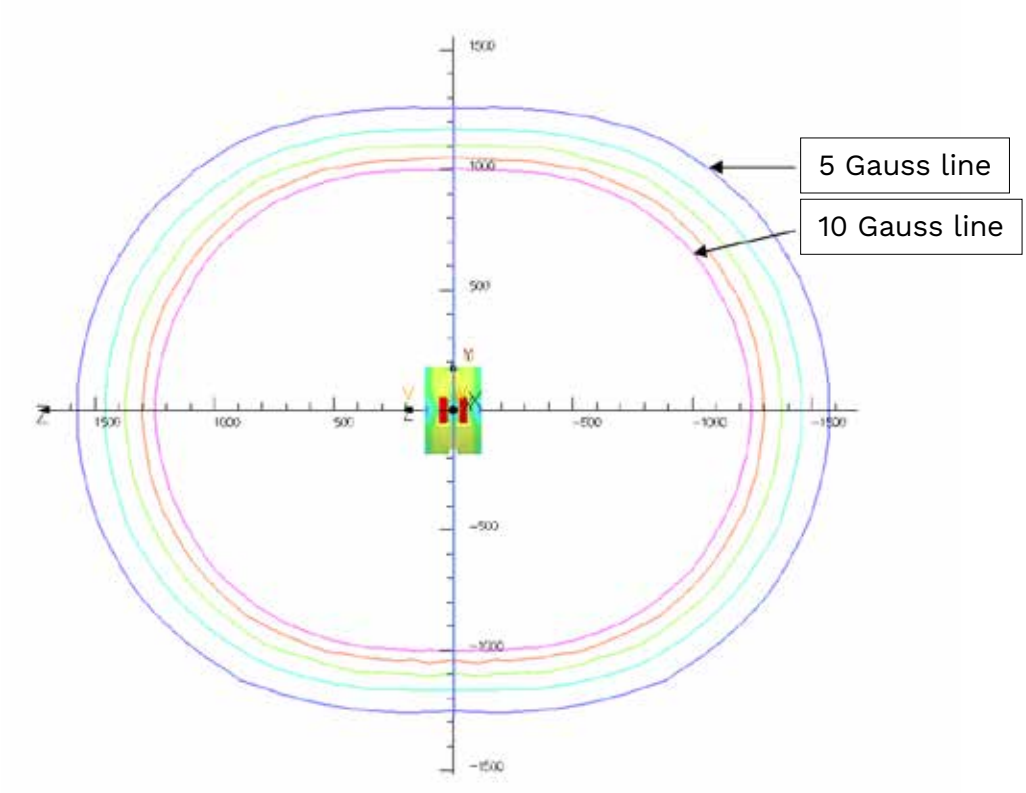


Figure 2: A contour map of the modelled fringe field on the Z-Y plane. The field range is from 10 to 5 Gauss. The distances are measured in mm from the magnet central working volume.

People with cardiac or other medically active implants must be prevented from entering the fringe field area. The fringe field zone should be indicated by signs and/or physical barriers. It is dangerous to attempt to restrain ferromagnetic objects by hand, therefore no ferromagnetic objects should be allowed near the magnet while it is energized. Fringe fields may be sufficient to wipe credit cards and disk drives, or to cause electrical and/or mechanical equipment to malfunction. All such equipment should be kept out of the fringe field region to avoid damage or malfunction.

Mechanical Hazards. HTS magnets typically utilise an iron yoke and can be very heavy. It is important to ensure that the magnet does not become a tipping hazard (for example – in the event of an earthquake). The magnet should never be operated without being suitably restrained. It is strongly recommended that the site manager takes into consideration all local regulations that may be relevant to the mechanical stability of the magnet.

Electrical Hazards. Although the magnet is driven at a low voltage, a potential up to 50 V may momentarily develop across the current terminals in case of sudden loss of power to the magnet. In addition, compressors, power supplies and other equipment may be electrically hazardous if operated incorrectly. Do not touch the current terminals when the magnet is in operation. Operators should read all manuals for electrical equipment included with the magnet. It is strongly recommended that only authorised personnel install or connect electrical equipment and that the site manager take into consideration all local electrical regulations.

Compressed Gasses. The interior of the magnet cryostat is normally at vacuum but in rare fault-conditions this volume could become pressurised. A pressure-relief valve is incorporated into the cryostat to minimise danger. Please keep face and hands away from the valve during magnet operation. Never open the cryostat vacuum isolation valve to atmosphere if the magnet is cold. The cryocooler flexible Helium hoses operate at high pressure. Please read the compressor manual before attaching or removing hoses or operating the compressor.

Care in Operation

The magnet and associated equipment should only be operated by trained personnel. Incorrect operation may result in damage to the magnet, associated equipment and/or surrounding plant, and may void any warranties for the system. Please read the manual in its entirety before any attempt is made to install, operate, or work in the vicinity of the magnet.

Most magnets may have operational requirements not described in this Care in Operation section – always check the Operating the Magnet section of the Manual for information specific to this magnet before operating the magnet.

Moving the Magnet. HTS magnets typically utilise an iron yoke and can be very heavy. Most of the components attached externally to the yoke, including cryocooler, cryostat, dump circuit etc., are not weight-bearing components. The magnet should only be lifted by the provided lifting eyes. The magnet should not be tilted during lifting. Please ensure that both lifting eyes are used equally. Care should be taken that straps, chains, or wires do not press on any part of the magnet other than the yoke.

Operating Parameters. The power supplies supplied with this magnet are capable of operating at currents and/or voltages in excess of the magnets specified limits. Exceeding the specified values, or other incorrect use of the power supplies, may cause significant damage to the magnet and void all warranties. Ensure only trained personel can operate the supplies or change supply parameters.

System Requirements. Before operating the magnet or any associated equipment, please confirm that the appropriate electrical and cooling water specifications have been met for each device. These specifications can be found in the *Component Dimensions and System Requirements* section in the Manual.

Power Supply andCcables. Do not remove power cables connecting the magnet to the power supply or switch off the supply when the magnet is at current. An energy dump circuit is incorporated in the magnet to protect it from inductive voltages, but this is designed for emergency shut down only.

Magnet Monitor. Do not apply current to the magnet unless the Magnet Monitor is connected to both the magnet and power supplies by the supplied cables. Failure to follow this procedure will result in the magnet operating without quench protection. This may result in significant damage to the magnet and will void all warranties. A quench in the HTS magnet should be strictly avoided. If the HTS magnet quenches there is a high likelihood of damage to the coil packs.

Magnet Monitor Warnings. If the Magnet Monitor detects an over-temperature or over-voltage condition in the magnet it will immediately disable the power supplies to protect the coils from possible quench. If this occurs the Monitor status light will switch from steady blue to steady red. Any such event should be considered as evidence of a possible fault and should be investigated immediately, to determine and remedy the fault, before continuing operation of the magnet.

Maintenance. Maintenance on the magnet should only be carried out after the current has been reduced to zero and the power supplies switched off.

Compressor. Note that while some compressors are capable at operating at a range of line frequencies, some need to have the helium pressure altered to suit the frequency. Failure to operate at the correctly set helium pressure can damage the compressor and/or cryocooler (Note: the compressor will be shipped at the correct helium pressure for the line frequency described in the System Requirements Section of the Manual). The compressor should not be tilted on an angle of more than 30° from vertical as per Compressor Operating Manual.

Cryostat Vacuum and Vacuum Pump. Under normal circumstances the cryostat pumping valve should never be opened when the magnet is cold unless a suitable vacuum pump is in operation on the other side of the valve (a suitable pump should be capable of taking the vacuum down to better than 10^{-6} mbar and must be oil-free or utilise a cryogenic oil trap).

System Requirements

The following describe component dimensions and the electrical and cooling water supply requirements for operating the magnet.

Electrical Requirements

Component	Voltage	Phase
SHI CH208L/ F40	415 V ±10%, 4.8 kW, 9 A at full load	3, Delta-connected
CAENels FAST-Bi-1K5	90-240 V, 50/60 Hz, 2000 VA max	1
Magnet Monitor Electronics	110-230 V : 50/60 Hz	1
Current Terminal Heaters	110-230 V : 50/60 Hz	1

Cooling Water Requirements

Component	Flow rate	Water temperature
SHI F40 compressor	≥ 4 l/min (≥2.3 G/min)	≤ 25 °C (≤ 80 F)

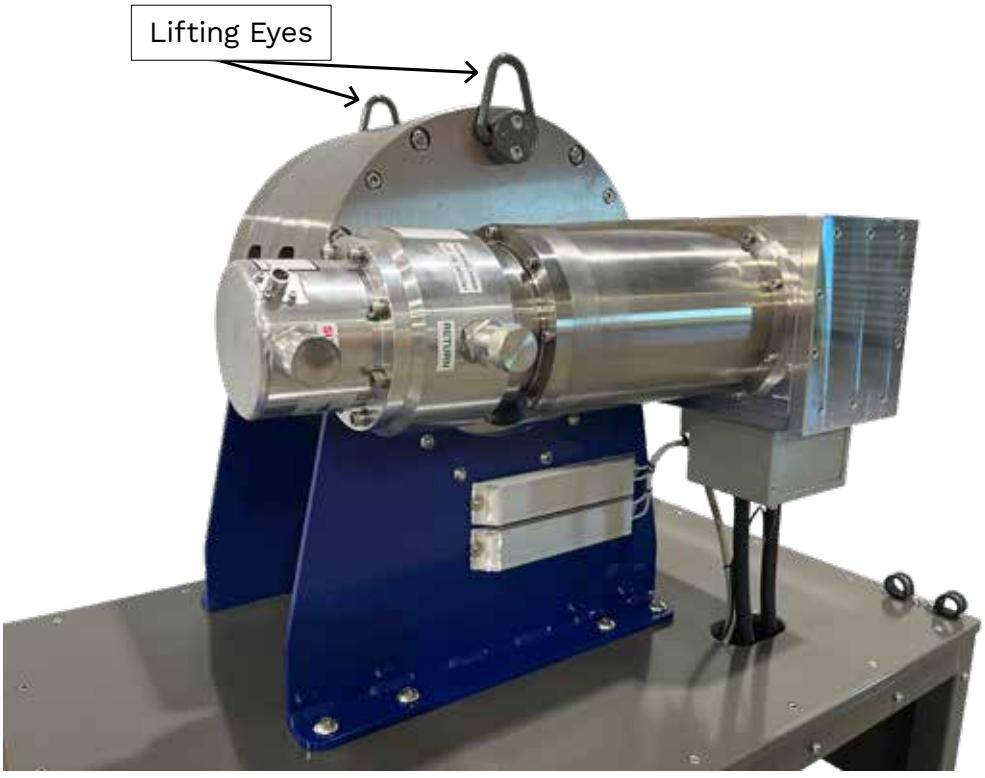
Please read all of the instructions before you commence

Unpacking Instructions

1. Inspect all crates for damage and confirm that Shock-Watch and Tip-Detection monitors have not been tripped. If these monitors have been tripped, please stop unpacking and contact HTS-110 immediately.
2. As each crate is opened check that the contents match the attached shipping lists. If you believe contents are missing please contact HTS-110 immediately.
3. Remove all bolts attaching the magnet stand to the floor of its crate.
4. Attach hooks or lifting straps to the lifting eyes mounted to the magnet yoke and, with a crane or other suitable lifting mechanism, move the magnet into place. This magnet has two lifting eyes. The magnet should not be tilted during lifting. Please ensure that both lifting eyes are used equally. Ensure only the lifting eyes are used to take the weight of the magnet and that strops do not come in contact with other parts of the magnet.
5. Other components can be unpacked by taking standard procedures for delicate and/or heavy instrumentation.

The magnet must only be lifted by use of the lifting eyes built onto the magnet yoke. The lifting chains or straps must not come into contact with, or exert force on, the cryocooler or its housing. Under no circumstances should any of the weight of the magnet be taken by the cryocooler, cryocooler housing, manifold, current-leads, or vacuum tap. The magnet should not be tilted during lifting. Please ensure that both lifting eyes are used equally.

HTS magnets typically utilise an iron yoke and can be very heavy. Incorrect handling while unpacking the crates or moving the magnet can cause damage to the magnet or injury to personnel.



Magnet Setup

Site Preparation

1. Ensure that the appropriate electrical and cooling water supplies (as described in the *Components Dimensions and System Requirements* section of the manual) are available. In some cases, components may arrive with electrical plugs removed or incorrect for your local supply. In this case appropriate fittings should be attached by authorised personnel only.

System Interconnection

2. Refer to the SHI user manual for complete instructions.
3. Remove the shipping bolt from the compressor where applicable.
4. Attach water cooling lines to the compressor.
5. NOTE: Compressor power lead does NOT include the power plug. Attach an electrical plug to the power lead.
6. Using wrenches from the SHI toolkit, attach the helium flex-lines between the Coldhead and the compressor; please note the high and low pressure sides; these are clearly marked on the compressor and Coldhead.
7. NOTE: Please ensure the flexible lines are not sharply bent (radius less than 35 cm) at any point in their path as this will reduce their efficiency and may damage the lines. Ensure that the Helium pressure lines do not apply excessive force to the connection at the coldhead.
8. Attach the motor drive cable between the compressor and coldhead motor.

CAENels FAST-Bi-1K5 Power Supplies

9. Install the CAENels supply, as shown in the photo below (Figure 3).
10. Connect the PSU Interlock cable to the IO Connector port on the back of the supply.
11. Connect the magnet negative power cable to the negative output terminal of the supply.
12. Connect the positive output terminal of the master supply to the IN terminal of the Magnet Monitor.

Magnet System Supervisor

13. Attach the 25pin end of the magnet data cable to the magnet and tighten the screw clamps
14. Attach the 37pin end of the magnet data cable to the Magnet Monitor (“Analog Inputs”). Tighten the screws.
15. Attach the Monitor interlock cable, tighten the screws.
16. Attach the magnet positive power cable to the Magnet Monitor out terminal.

Magnet Terminal Heaters

17. Locate the heater power cable (Figure 8 cable) and connect to the terminal heater power supply located at the rear of the magnet trolley.

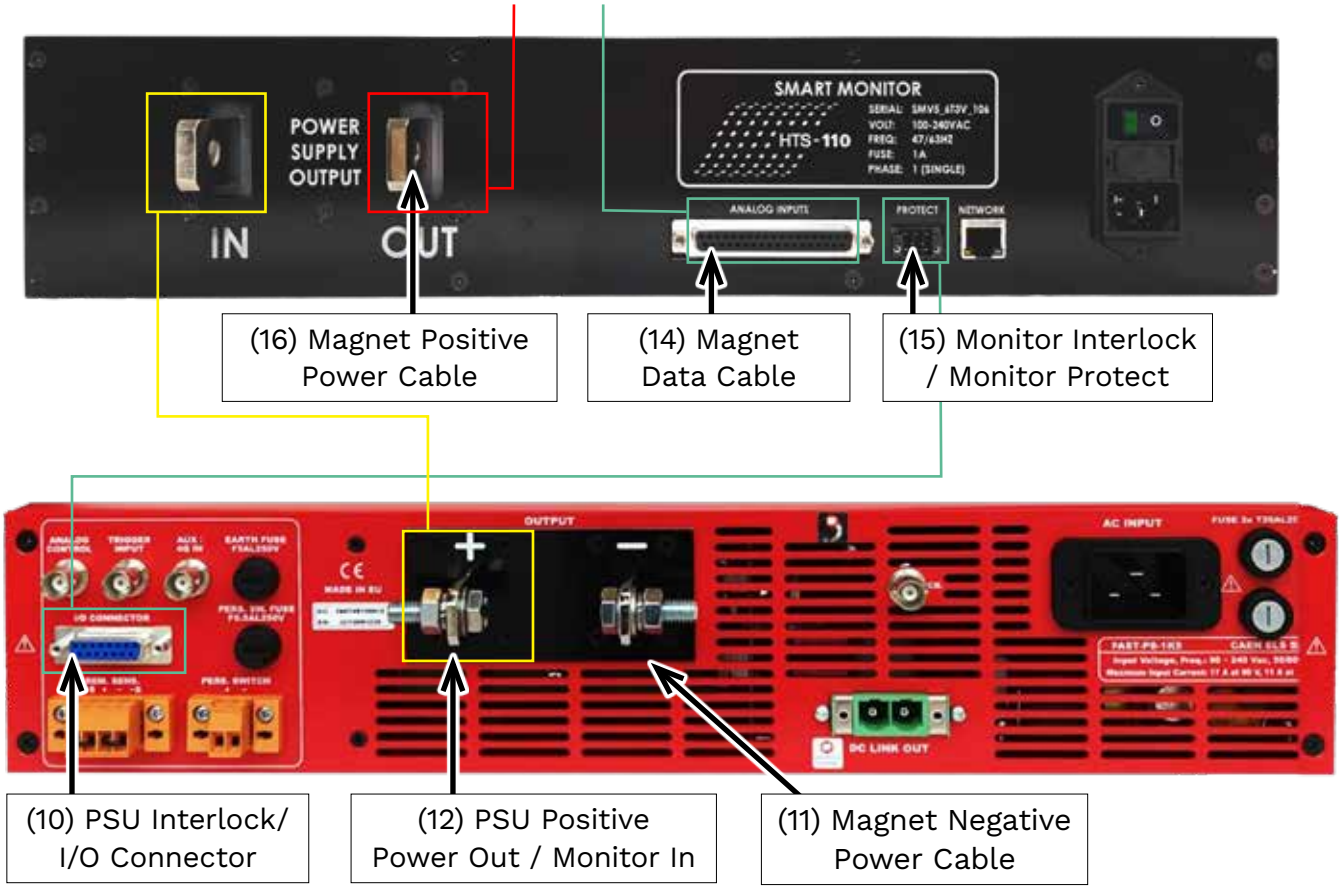


Figure 3: Interconnection diagram for the power supplies and Monitor.

Magnet Cool Down

Vacuum

Vacuum Pump Configuration

A good vacuum in the cryostat is essential for the magnet system to reach its normal operating temperatures. The pumping system must be sufficient to bring the cryostat vacuum down to $1x10^{-6}$ mbar or better. This can be achieved by either a vacuum-pump station or an in-house vacuum line.

The performance of the cryogenic system may also be impeded by contamination such as back streaming oil vapour which will condense on the cryogenic manifold. For this reason a turbo molecular pumping station should be used which utilises an oil free backing pump or, alternatively, an in-line trap between the backing pump and the turbo-pump.

Recommended Pump Operation

The magnet will need to be pumped in the following situations:

- **Initial installation.** The magnet is shipped in the evacuated state but the vacuum will have degraded due to slow diffusion through o-ring seals and out-gassing of internal components; the cryostat must be pumped according to Procedure a) Vacuum pumping for an as-shipped magnet system (evacuated state).
- **Normal maintenance.** During normal operation the cryostat will require occasional re-pumping to maintain optimal vacuum and performance of the magnet. The required interval may vary from magnet to magnet but we recommend pumping at monthly intervals as part of a standard maintenance schedule. This can be carried out on the magnet while it is operating according to Procedure c) Vacuum pumping while the cryocooler is running.
- **Cryostat exposed to atmosphere.** If a warm magnet has been exposed to atmosphere the cryostat must be pumped according to Procedure b) Vacuum pumping when the cryostat is at atmospheric pressure. Note: if a cold (<273 K) magnet is exposed to atmosphere the advice of HTS-110 should be sought before attempting to pump or operate the magnet.
- **Cold magnet after extended period at zero or low field.** If the magnet is left cold for an extended period (7 days or more) either without the application of current or at a very low current it is possible for gases within the cryostat to cryo-pump onto the internal current leads. These gases may evaporate as the leads heat during re-energisation and temporarily degrade the cryostat vacuum. We recommend that the magnet should be pumped during re-energisation according to Procedure c) Vacuum pumping while the cryocooler is running.
- **Cold magnet being warmed (i.e. if the cryocooler is turned off).** If the cryocooler is turned off and the magnet allowed to warm it is essential that the cryostat is pumped while warming to remove gases that could have cryo-pumped onto cold surfaces during operation. Failure to do so could result in high gas pressures developing within the cryostat. In this case follow Procedure d) Vacuum pumping if the cryocooler is turned off.
- **Degraded performance.** If the magnet temperature begins to rise above its normal operational temperatures and/or the outer walls of the cryostat manifold exhibit condensation or weeping then it is possible that outgassing or diffusion through O-ring seals has degraded the vacuum quality. In this case the cryostat should be pumped down according to Procedure c) Vacuum pumping while the cryocooler is running. If magnet performance does not improve after this procedure we recommend the magnet should be raised to room-temperature to allow contaminants to be flushed from the system. In this case read Procedure e) Warming the magnet, then follow Procedure d) Vacuum pumping if the cryocooler is turned off followed by Procedure a) Vacuum pumping for an as-shipped magnet system (evacuated state).

Vacuum Pumping Procedures

a) **Vacuum pumping for an as-shipped magnet system (evacuated state).** Connect the pumping station to the vacuum valve on the magnet via the flexible stainless steel hose and turn on the pump. Wait until the turbo-pump indicates that it has reached full speed (displayed on the pump's DDU) then carefully and slowly open the vacuum valve on the magnet and pump to remove any gases that have leaked into the system or out-gassed from the walls.

   It is recommended to pump on the system for a minimum of 3-4 hours and until a vacuum of $\leq 5x10^{-4}$ mbar is measured. If possible, pump on the system overnight before the cryocooler is turned on. We recommend leaving the vacuum pump running while the magnet is cooling down.

   Once the magnet is at its operating temperature (a steady blue light showing on the Magnet Monitor) the magnet should be ramped up to full field and held there until the coil-pack temperatures stabilise (this may take up to 2 hours), after which the vacuum valve can be closed, the pump turned off, and the magnet de-energised.

b) **Vacuum pumping when the cryostat is at atmospheric pressure.** When the cryostat is at atmospheric pressure, open the pumping valve fully before turning on the vacuum pump. If the cryostat has been exposed to atmospheric pressure it is strongly recommended that it should be pumped for at least 12 hours to minimise outgassing before the cryocooler is turned on.

c) **Vacuum pumping while the cryocooler is running.** HTS-110 recommends pumping on the cryostat once a month or if a temperature rise across all temperature sensors is observed. Once the vacuum pump is at speed, slowly open the vacuum valve on the magnet and leave the system pumping overnight. When finished, close the vacuum valve and then turn vacuum pump off. A vacuum of around 10^{-6} mbar should be observed and the temperatures should drop to their normal values.

d) **Vacuum pumping if the cryocooler is turned off.** It is essential that the vacuum pump is used on the system if the cryocooler is turned off for any reason or if there has been an extended power outage. In this situation it is recommended to allow the magnet coils to warm to a temperature of at least 90 K while vacuum pumping on the cryostat before the cryocooler is turned on again.

e) **Warming the magnet.** The magnet can be allowed to warm by simply turning off the cryocooler; however it will take a considerable time for the system to warm to room temperature. Some frosting on the exterior surfaces of the magnet may occur but this is no cause for concern. When the magnet reaches room temperature reconnect the vacuum hose to the vacuum pump and pump on the system as detailed in Procedure a) above.

Cryocooler

Cryocooler Start up for CH208L Cryocooler and F40 Compressor

Details for operation and maintenance requirements for your cryocooler can be found in the Cryocooler User's Manual provided with the magnet. In particular, please observe the 30,000 hour replacement interval for the compressor adsorber and the 13,000 hour Coldhead maintenance interval.

Please ensure:

1. The magnet is at vacuum and the vacuum pump is operating.
2. The compressor cooling water is flowing.
3. The helium flex lines are securely attached to the compressor and the coldhead.
4. The coldhead motor cable is connected to both the compressor and coldhead motor.
5. The compressor pressure gauges read 1895-1930 kPa.

Then:

6. Turn on the system by pressing the power switch on the front panel of the compressor.

The magnet will cool down to operating temperature over a period of approximately 30-36 hours. During cool down the status lights on the front of the Monitor will flash blue. The light becomes a steady blue when temperatures all fall below the operation-enable temperatures.

Typical final sensor temperatures at 50 Hz during factory testing were:

Sensor	Reading [K] At Zero Field	Reading [K] at Full Field
T1	##.##	##.##
T2	##.##	##.##
T3	##.##	##.##
T4	##.##	##.##

Operating the Magnet

Preparation

Before Energising the Magnet:

- Confirm the magnet vacuum is in the specified range (< $5x10^{-6}$ mbar). If the magnet has been warm, or if it has been cold but non-operational for 7 days or more, the vacuum pump should be turned on and the pumping valve open (see section on vacuum pumping above).
- Confirm the Monitor status light is showing a steady blue (the status light will flash blue while the magnet is still cooling - see the Magnet Monitor User's Manual for more details).

Power Supplies

The magnet is supplied with a CAENels FAST-Bi-1K5 power supply. Please refer to the CAENels Operator Manual for complete operating instructions.

Field Ramping. When an HTS magnet is ramped, a small amount of heat is generated within the coils. Therefore take care to limit the amount of ramping carried out over a short period of time as this could raise the coil temperatures to above their safe operating limit.

If this does occur during normal use then increase the time between ramps to allow the coils to drop back towards their normal operating temperature.

Operating Parameters. The power supply supplied with this magnet is capable of operating at currents and/or voltages in excess of the magnet's specified limits. Exceeding the specified values, or other incorrect use of the power supply, may cause significant damage to the magnet and void all warranties.

Note that voltage and current limits can be password protected on the CAENels power supply. We advise that end users familiarise themselves with the CAENels User's Manual before attempting to control the magnet manually.

Emergency Shutdown. As the magnet can have a large inductance it can take a significant period of time to ramp down from full field to zero field if controlled by the power supplies. In an emergency the magnet can be ramped down rapidly by switching off, or removing power from, the Magnet Monitor.

This will immediately initate a power dump into the installed dump resistors and the magnet will ramp down from full field to zero field in minutes. This should only be used in an emergency situation, not as a regular means of de-powering the magnet.

Manual Ramping to Field

- Turn on the power supply using the front-panel power switch. The supply will undergo an initialisation procedure which should take about 10-20 s to complete.
- Connect a network patch cable between the supply and a PC (with Visual-PS software installed). Note down the IP address displayed on the master display.
- Open up the Visual-PS software and click the Set IP button on the top left of the screen.
- Enter the IP address you recorded earlier from the front panel of the master display.
- Click Save Configuration – this will save the configuration so you will not need to complete the above steps again.
- Next click the Connection button, this will initiate the communication between the supply and the PC.

CAUTION: the following steps will start outputting current to the magnet. Make sure the magnet is at the correct operating temperature and the dump circuitry is properly connected.

- Confirm Regulation Mode settings are:
  - Trigger OFF
  - Normal (Ethernet Input)
  - Constant Current
- Click the ON button under Unit Controls – this will turn the output of the supplies on.
- You can now enter the desired current in the box labelled Current Set [A]
- Once you have entered the current press the Set Current button to start the ramping to field.

Changing Target Field

- Enter the new desired current in the box labelled Current Set [A] and press the Set Current button to start the ramp between fields.
- The magnet may take approximately 5-10 minutes to ramp to full field. There may be a short settling time after the target current is reached before the field stabilises.

Ramping the Magnet to Zero Current

- To turn the magnet off, enter 0 A into the current setting text box as before and press the Set Current button.
- Once the current has reached 0 A, wait 2 minutes for internal currents to stabilize then you can disable the output by pressing the OFF button.
- You can disconnect the software from the supplies by pressing the disconnect button at the top of the screen.

Remnant Fields

After an excursion to full field the factory-observed remnant field is of the order of 5 mT. This can be offset by application of a small current of opposite polarity, or a degaussing cycle can be implemented if desired.

Operating Limits for the Magnet

In both manual and automated ramps the maximum operating current and operating voltage at any part of the cycle must never exceed the values shown in the following table. Note that the power-supply voltage limit has been pre-set to 2.0 V at HTS-110 – there should be no need to change this value.

Output Limits	
Maximum Current	140.0 A
Maximum Voltage	2.0 V
Hardware overcurrent limit setting	145 A

Note. Even when current is set to zero and/or the Visual-PS software is set to Disconnect, a small current can still be passing through the coils. This can result in a significant magnetic field at the magnet poles. If the operator wishes to confirm that the magnet is unpowered (for example – during maintenance) it is safest practice to:

- Turn the CAENels power supply off.
- Disconnect the CAENels power supply from input power.

- Wait 30 minutes after the supply is turned off.
- Remove one of the current leads from the back of the supply.

External Trip

The magnet is protected by the Magnet Monitor which continuously checks operating voltages and temperatures. The Monitor will not allow the power supplies to operate until temperatures and voltages fall below stable operating limits; if voltages or temperatures rise above the Disable limits, the Monitor will send a disable signal to the power supplies and operating current will drop to zero to protect the magnet from the possibility of quenching.

The limits for this magnet are as follows:

Parameter	Monitor ID	Disable
Stage 1 Temperature	T1	50 K
Stage 2 Temperature	T2	20 K
A Coil Pack Temperature	T3	28 K
B Coil Pack Temperature	T4	28 K
Differential Magnet Voltage	Mv	20 mV
Differential Lead Voltage	Lv	10 mV
Magnet Current	Mc	145 A

If the Magnet Monitor detects an abnormal operating condition the indicator light on the front of the Monitor will switch to a steady red, the power supply external trip is activated, and the magnet will ramp down rapidly via the external dump resistor circuit.

After any trip/disable event the Monitor will reset and allow the power supply to operate when the operating conditions have returned to normal. There is no need to reset the Monitor manually. The power supplies will need to be reset. This can be done by pressing the RESET button on the Visual_PS software. If the system does trip, the operator should determine what event caused the trip (for example: operating at an excessive ramping voltage, requirement for pumping out the vacuum etc.) before operating the magnet again. See the section on Troubleshooting to aid in determining the problem.

System Shut Down

If the system is to be unused for an extended period of time we advise turning off the cryocooler and bringing it up to room temperature, to minimise power usage and wear on the cryocooler/compressor. To shut the system down fully, carry out the following procedures:

1. Ensure the CAENels supply is at zero current.
2. Switch off the CAENels power supply.
3. Attach the vacuum system and evacuate the pumping line.
4. Slowly open the valve until it is fully open.
5. Switch off the cryocooler by pressing the black button.
6. Turn off the cryocooler compressor and turn off the cooling water.
7. The Magnet Monitor may be left operating if desired to give system temperature during warm-up.
8. Do not remove the vacuum system until the minimum temperature (T1 to T4 as shown on the Monitor) is greater than 150 K.

See the Magnet Cool down and Vacuum Pumping Procedures for instructions on how to bring a warmed magnet back to an operational state.

Magnet Monitor

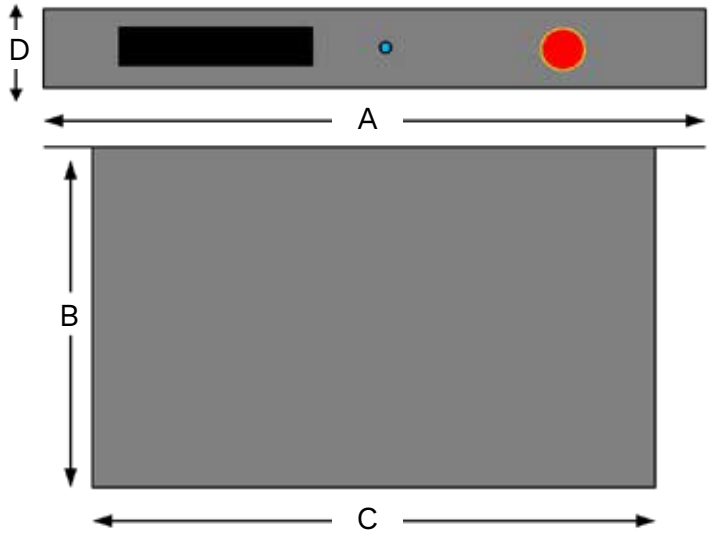
Overview

The Magnet Monitor (Monitor) is designed to monitor and protect a HTS electromagnet during operation. The Monitor is specifically configured for each magnet with the capability to measure up to six temperature sensors and three differential voltage signals simultaneously. Dedicated software limits are programmed into the Monitor for each sensor allowing safe operation of the magnet. If one of these limits is exceeded then the Monitor will automatically disable the power supply and allow power to be absorbed into the dump circuit.

System Requirements:

Specification	Minimum	Typical	Maximum	Units
Operating Voltage	100	230	240	V_{AC}
Operating Current	0.1	0.15	0.4	A
Operating Frequency	47	50	63	Hz
Operating Temperature range	5		35	°C

Dimensions



	A	B	C	D
Dimension	485mm	245mm	435mm	90mm

Front Panel

Display Arrangements

Display Name	Description	Location	Protection Limit
T1	Temperature Sensor #1	1st Stage of Cryocooler Side A	50.0K
T2	Temperature Sensor #2	2nd Stage of Cryocooler Side A	20.0K
T3	Temperature Sensor #3	Side A Coil Pack	28.0K
T4	Temperature Sensor #4	Side B Coil Pack	28.0K
T5	NC	NC	-
T6	NC	NC	-
Mv	Differential Magnet Voltage	Coil pack Side A - Side B	20mV
L1v	Differential Current Lead Voltage	Current Lead A1 – Current Lead A2	10mV
L2v	NC	NC	-
MC	Magnet Current	Contactor Bus Bar inside Monitor	145A

Status LED

Conditions	LED Indicator Colour
Magnet Is At Room Temperature	Green
Magnet Is Cooling Down	Blue – Flashing
Magnet Is At Operating Temperature	Blue
A Fault Has Occurred	Red

Rear Panel

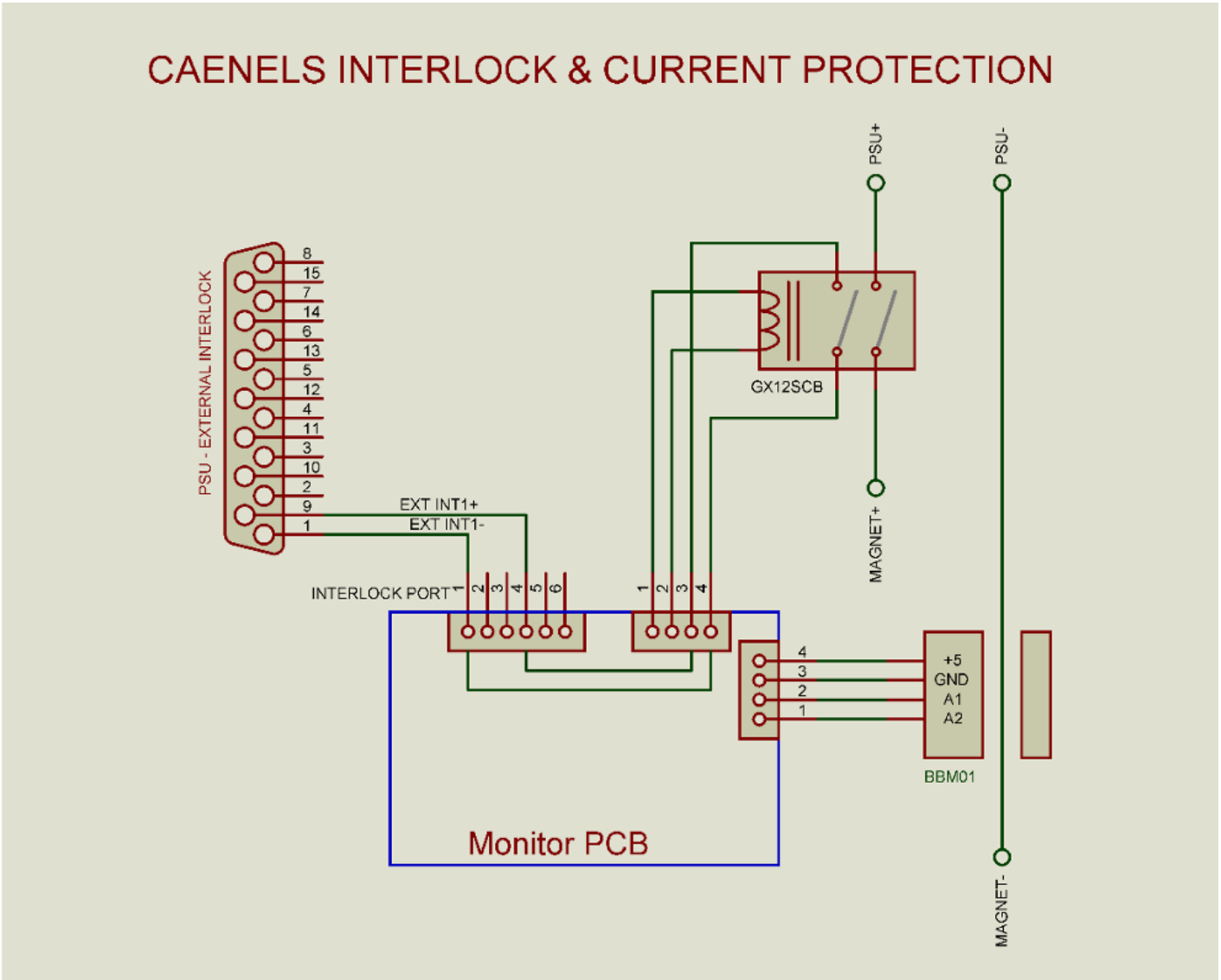
Power Supply Interlock

The magnet is isolated from the supply during a fault via a high current contactor. The Power supply interlock is enabled by the auxiliary contactor connection through pins 1 and 4. The auxiliary contactor is closed when the magnet is at temperature and not in a fault condition.

Pin #	Function
1	Interlock -
2	+12V
3	Relay Isolator
4	Interlock +
5	GND
6	NC

Over Current Protection

This system is also equipped with a high-speed current transducer which will read the output current and trigger the contactor if the current exceeds a specified limit. This circuitry is placed in along with the Monitor to provide a fail-safe magnet protection system.



Remote Communication

The Monitor has two ways in which users can view the status of the magnet.

a. Website:

The Monitor hosts its own internal website which allows users to quickly view the current status of the magnet via a web-browser removing the need for dedicated software.

b. TCP/IP:

This allows users to integrate the Monitor into their system. Simply connecting the Monitor to the local network and sending simple ASCII commands via the TCP/IP protocol can allow users to get the current status as well as the limits for each sensor.

TCP/IP Settings	
Host Name	XXX
Port	XXX

Command Structure	
STAT	Current temperature and voltages from magnet (T1,T2,T3,T4...L1,V2,MV,MC,Date,Clock,Status)
STAT<CR>	30.0,10.0,20.0,20.0,20.0,20.0,0.0,0.0,0.0,0.0,0.0,4,0,0,0<CR>
LIMS	Protection limits
LIMS<CR>	50.0,20.0,28.0,288.0,20.02.0,10.0,10.0,20.0,145<CR>
OPLM	Safe Operating limits (PSU Enabled)
OPLM<CR>	48.0,18.0,26.0,26.0,18.0,18.0,2.0,2.0,2.0<CR>
VER	Smart Monitor Information
VER<CR>	XXX

Analog Port Pin Assignments

Connection to the magnet is made via a D-Sub miniature 37 pin connector, the pin assignments are shown in the table below. Each temperature sensor requires four wires, two for current and two for voltage. Each voltage is differential and split between coil packs and current leads.

Pin #	Function	Pin #	Function
1	T1I-	20	T1V-
2	T1V+	21	T1I+
3	T2I-	22	T2V-
4	T2V+	23	T2I+
5	T3I-	24	T3V-
6	T3V+	25	T3I+
7	T4I-	26	T4V-
8	T4V+	27	T4I+
9	T5I-	28	T5V-
10	T5V+	29	T5I+
11	T6I-	30	T6V-
12	T6V+	31	T6I+
13	BLANK	32	VlB2-
14	VlB2-	33	VlB1-
15	VlB1-	34	VlA2-
16	VlA2+	35	VlA1-
17	VlA1+	36	VmB-
18	VmB+	37	VmA-
19	VmA+		

Cryogenic

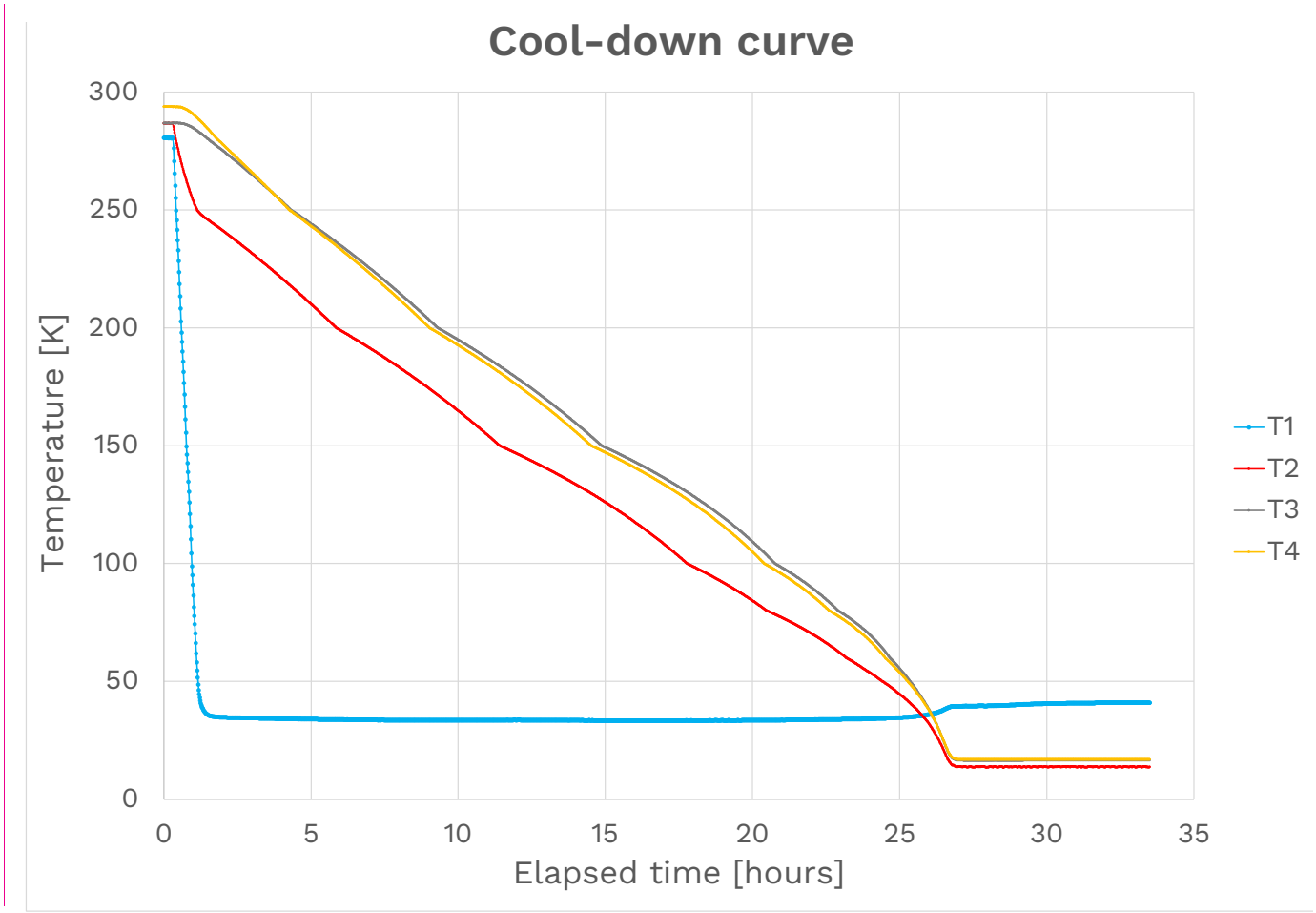


Figure 4: Magnet cool down log (50 Hz)

The magnet cool down curve is shown above in Figure 4. The first stage of the cryocooler will rapidly cool down to ~40 K. The second stage and the magnet coils take much longer to cool down because they are thermally isolated from the first stage (the cooling power of the second stage is approximately 10x less than the first stage).

The expected cool down time is 30 - 36 hours. It is recommended that the cryocooler be operated at all times to ensure that the magnet is always at its operating temperature.

If there are long periods between magnet use (>1 week) then it may be advantageous to switch off the cryocooler.

Note: The magnet must be re-evacuated every time it is allowed to warm up. This is to allow for the removal of any residual gases that may have frozen to the coldhead or magnet whilst it has been kept cold. Failure to do this may mean that the magnet does not achieve its operating temperature.

Magnetic

Magnetic Parameters	Specified Value	Measured Value
Maximum Magnetic Field (H_{max}) at 139 A	+ 3.0 T	3.0 T
Remnant Magnetic Field (H_0)	-	<5 mT

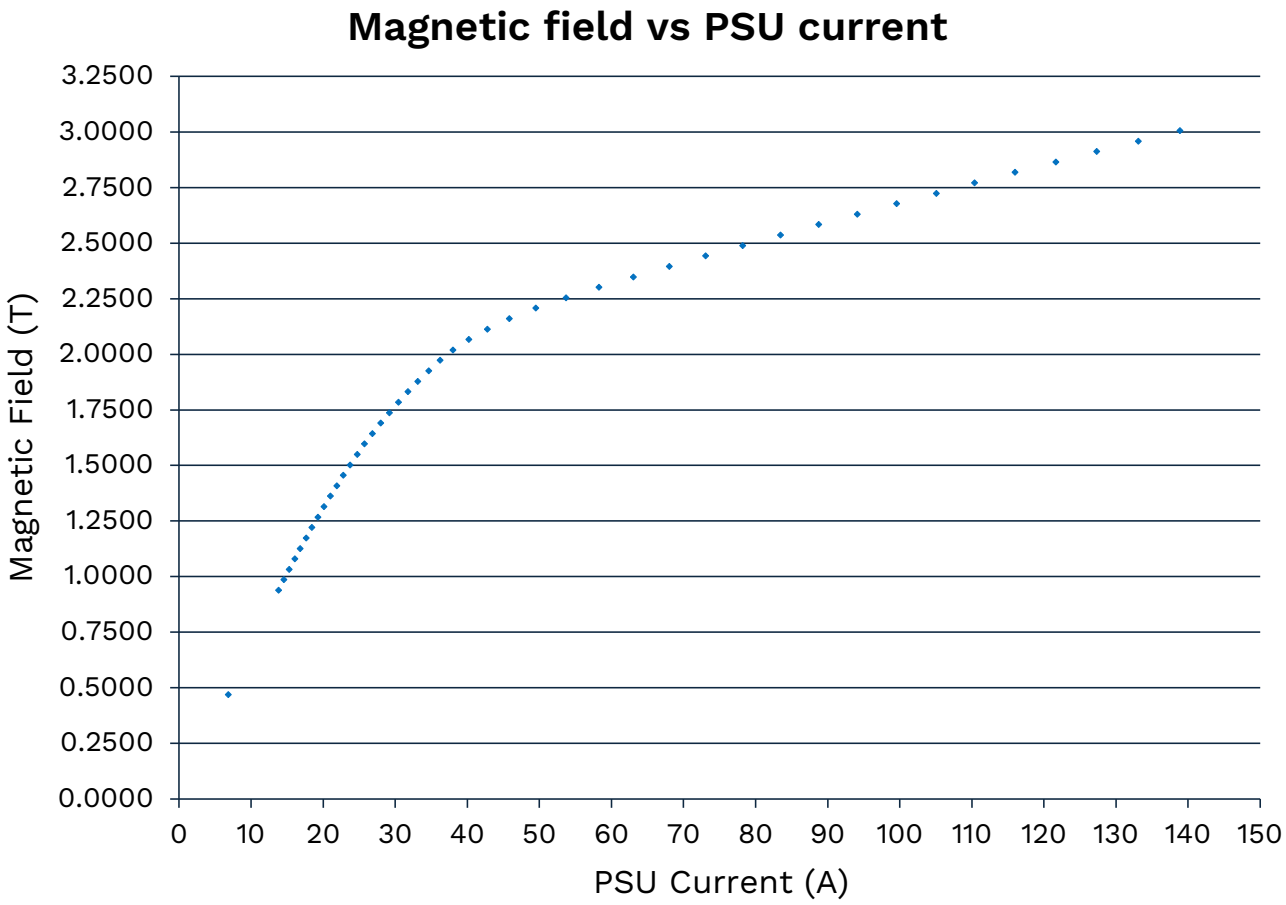


Figure 5: Field (tesla) vs Current (amperes)

Figure 5 shows relationship between the supplied current (from the magnet power supply) in amperes and the magnetic field in tesla.

Field (T)	MHz	Current	Field (T)	MHz	Current
0.986448	42	13.787	2.01987	86	38.01
1.033422	44	14.523	2.066844	88	40.207
1.080396	46	15.263	2.113817	90	42.816
1.127369	48	16.023	2.160791	92	45.851
1.174343	50	16.802	2.207765	94	49.53
1.221317	52	17.604	2.254738	96	53.766
1.26829	54	18.419	2.301712	98	58.346

Field (T)	MHz	Current	Field (T)	MHz	Current
1.315264	56	19.248	2.348686	100	63.138
1.362238	58	20.09	2.39566	102	68.056
1.409212	60	20.954	2.442633	104	73.084
1.456185	62	21.824	2.489607	106	78.21
1.503159	64	22.745	2.536581	108	83.442
1.550133	66	23.691	2.583555	110	88.821
1.597106	68	24.681	2.630528	112	94.193
1.64408	70	25.711	2.677502	114	99.626
1.691054	72	26.792	2.724476	116	105.124
1.738028	74	27.929	2.771449	118	110.404
1.785001	76	29.125	2.818423	120	116.005
1.831975	78	30.386	2.865397	122	121.66
1.878949	80	31.712	2.912371	124	127.379
1.925922	82	33.102	2.959344	126	133.109
1.972896	84	36.19	3.006318	128	139.001

The above table shows the relationship between the input current setting on the PSU and the output field strength of the magnet. Note: These are test values obtained using an input voltage of 230 V 50 Hz, the installed values may change slightly (<1%).

Field Uniformity

Measured uniformity throughout the operating range indicates the uniformity as predicted. The uniformity is measured to be under 50 ppm (FWHM).

Measurements are taken with the Stelar supplied probe while the magnet is energised with a high-stability supply.

System

Vacuum and Cryogenic Parameters	Value
Vacuum pressure before cool down	$<10^{-3}$ mbar
Vacuum pressure after cool down	$<10^{-6}$ mbar
System cool down time (from room temperature to operating temperature)	30 - 36

Troubleshooting Guide

If you have problems with operation or performance of this magnet please read the following guide first. If a solution is not found in the guide, contact us at info@hts-110.com

Vacuum Pressure

Cryostat cannot be pumped down to required pressure (<10^{-3} warm <10^{-6} cold)

- Check all O-ring connections and clamps on the vacuum line between pump and cryostat.
- Confirm vacuum pump is operating normally.

Cryostat pressure rises over a period of weeks

- Reduce period between scheduled cryostat pump-outs (*Vacuum pumping while the cryocooler is running in the Cool down Guide*).

Cryostat shows signs of sweating or icing on exterior surfaces (temperatures may increase)

- Check all O-ring connections and clamps on the vacuum line between pump and cryostat.
- Confirm vacuum pump is operating normally.
- Pump out cryostat immediately according to the *Vacuum pumping while the cryocooler is running* section of the Manual.
- If these processes do not solve the problem then read the section 'Degraded Performance'. Allow the cryostat to rise to atmospheric pressure (*Warming the magnet* in the Cool down Guide) then follow by re-pumping to operating pressure (*Vacuum pumping when the cryostat is at atmospheric pressure* in the Cool down Guide).

Pressure rises significantly when magnet energised

- If magnet has been left cold and non-operational for 7 days or more, operate vacuum pump while energising.

Cryocooler and Temperatures

Cryocooler won't operate or switches off

- Check sufficient cooling water (note that during the initial phase of cooling a warm magnet, the cryocooler may exceed its normal water cooling requirements).

Cryocoolers won't bring down magnet to operating temperatures

- Check cryostat vacuum.

Operating temperatures slowly rise over a period of months

- Check operating vacuum – see above.
- Reduce period between scheduled pumping of the cryostat – see above.
- Check maintenance schedule for cryocooler as described in the Cryocooler User's Guide.
- Read the section 'Degraded Performance'. Allow the cryostat to rise to atmospheric pressure (*Warming the magnet* in the Cool down Guide) followed by re-pumping to operating pressure (*Vacuum pumping when the cryostat is at atmospheric pressure* in the Cool down Guide).

Coil operating temperature rises rapidly while ramping

- Confirm ramping voltages are within set limits.
- Confirm that the magnet is not ramping repeatedly over a short period of time. As a rule of thumb, the magnet should be allowed to cool for a period approximately equal to the ramping time before ramping again.
- Check operating vacuum – see above.

Frosting or sweating of magnet current terminals

- Confirm that terminal heater power supply is plugged in and functioning correctly.

Power Supply

Supply won't output current

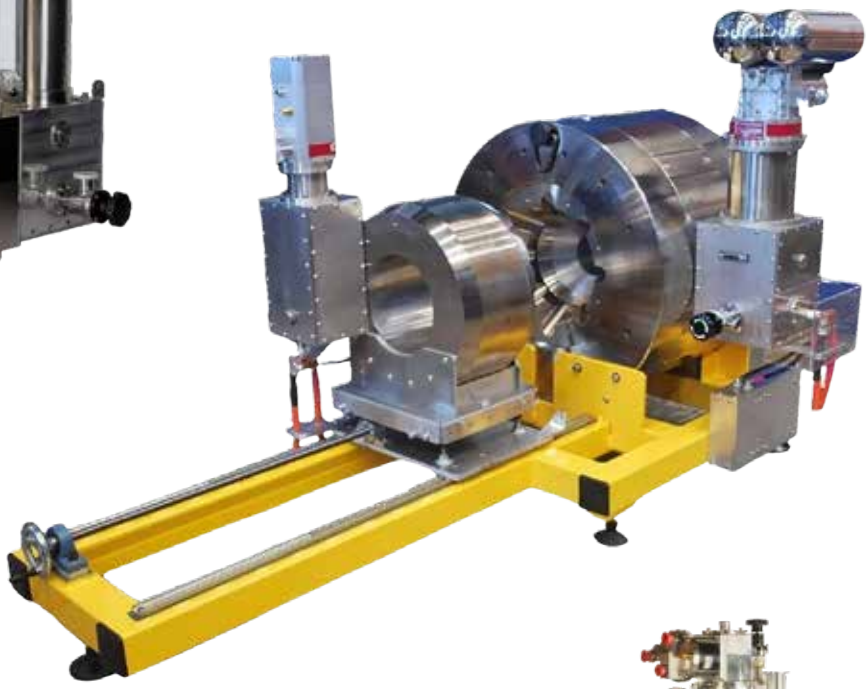
- Check that Monitor is in enable state (status light should be steady blue).
- Check enable/disable cord connections to Monitor, magnet, and power supply.
- Check power supply internal interlocks (See Power Supply User's Manual).

System/Monitor

Magnet disabled by Monitor

- Check operating temperature and ramping voltages are within limits.
- Check cable connections between Monitor and cryostat.

Notes



HTS-110

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