EQUIPMENT

I.Power Supply.

Figure 1, magnet power supply

Current is supplied to the magnet via a 6260B Hewlett-Packard power supply (Fig. 1). This power supply is configured to run in current controlled mode—that is, the power supply will vary the voltage until the target current is achieved. The “target current” in this case is dictated by the RAMP GENERATOR.

It should be noted that this power supply (and most power supplies, for that matter) do not deal well with inductive loads. In a purely resistive circuit at constant voltage, the current in the circuit will be equal to V/R. If the resistance is fixed, we can alter the current simply by changing the voltage until the current reaches the desired level. In a purely inductive circuit, however we have (from Faraday’s Law):

$$V = L\frac{dI}{dt}$$

If we change the voltage linearly from $V_1=Vt_1$ to $V_2=Vt_2$, than by integration:

$$\int_{t_1}^{t_2} V(t)dt = \int_{t_1}^{t_2} L\frac{dI}{dt}dt$$

$$\frac{1}{2}V(t_2^2 - t_1^2) = LI$$

$$\frac{V\Delta(t^2)}{2L} = I$$

If the power supply raises the voltage, a current will be created, and the power supply will stop raising the voltage. This will lead to further increase in current, and the supply will respond by again altering the voltage. This will lead to a recognizable oscillatory behavior in the power supply voltage, and most likely a magnet quench.

II. RAMP GENERATOR

Figure 2, Ramp Generator

In order for the power supply to increase the current in a linear, controlled fashion, something needs to tell it what current to put out when. This something is the RAMP GENERATOR (See fig. 2). On the rear of the ramp generator are two connections of importance: the current shunt, and the control. The control leads should be connected to the POWER SUPPLY. It is important that correct polarity is observed in this connection, else a quench will occur. The current shunt is what allows the ramp generator to operate in a closed loop: the generator tells the power supply to create a certain current, and the current shunt tells the ramp generator if the power supply is doing so correctly (there are situations where this control scheme goes awry—see the discussion of inductance under POWER SUPPLY).

There are four controls of importance on the ramp generator:

Ramp rate: this control consists of two knobs. One is a range setting, with positions at 0.1, 1, and 10. The variable rate knob sets the increment between these numbers. For example, if the range knob is set at 0.1 and the variable rate knob is set to 1, than the ramp rate will be 0.01 amperes per second.

Voltage limit: in some circumstances, the desired current will necessitate a higher voltage than is healthy for the power supply to deliver. In these cases, the voltage limit control can be used to stop the RAMP GENERATOR from instructing the power supply to create a voltage that would be damaging to the supply. In this experiment, the currents required are not high enough for this to be a problem.

Current limit: while the voltage limit is not a concern in this experiment (the power supply is capable of a much higher output than we will ever use), the current limit is of great importance. If the magnet is ramped to a higher field than its rated value, a quench will occur, resulting in possible physical harm to the researcher and damage to the magnet. Neither of these is desirable. The magnet in use is rated to 69.6 Amperes, however the current limit control is not exactly reliable. It is recommended to set this control to around 65 Amperes on the first ramp up, and when the current limit indicator (the red LED next to the knob) lights up, SLOWLY increase the current limit until a value of no more than 69.6 appears on the FIELD DVM. The field digital voltmeter (FIELD

DVM) measures the current through the superconducting solenoid producing the magnetic field.

POLARITY SWITCH:

Figure 3, Polarity switch

The power supply used in this experiment is unable to reverse polarity: the positive output is always positive, and the negative output is always negative. However, it is sometimes desired that the field of the magnet be reversed, hence the POLARITY SWITCH (See fig. 3). The switch controls three relays in the energy absorber that reverse the polarity of the current. More importantly, the polarity switch also monitors the current in the magnet circuit, and will not allow the polarity to be switched if said current is non-zero (try it—at some no-zero current, flip the polarity switch. An alarm will sound, and the polarity will remain unchanged).

ENERGY ABSORBER:

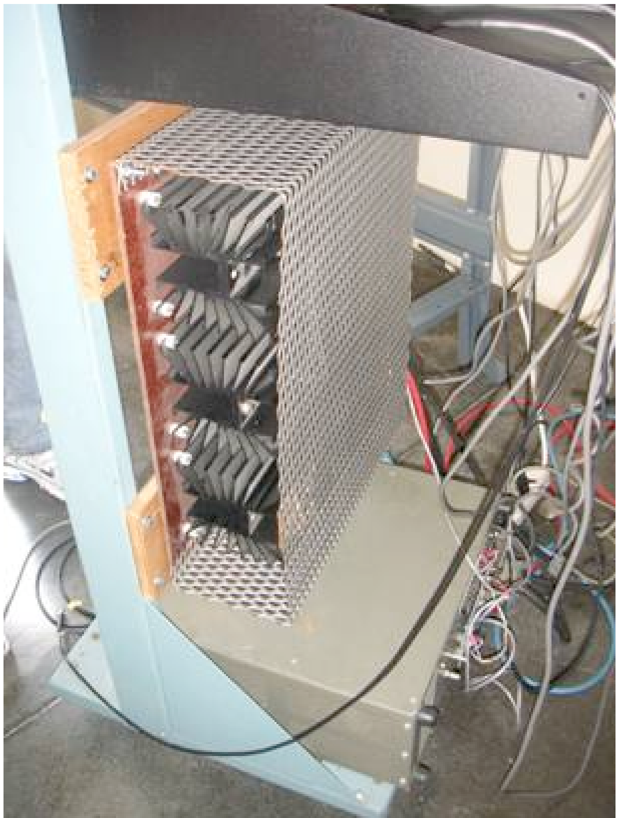


Figure 4, Energy Absorber

The energy absorber contains the relays necessary to flip polarity, three diodes and two thyristors. The three diodes serve to give the power supply some resistance, because, as previously mentioned, the power supply cannot handle a purely inductive load.

The "energy absorption" is accomplished by means of the two thyristors (also known as silicon controlled rectifiers, or SCRs). SCRs are basically solid state relays—on a given signal, they make a connection, in this case to ground. A small monitoring circuit (the small boards next to the thyristors) will detect a quench in the magnet (a large voltage develops in the circuit when this happens). Rather than have all the current flow back into the power supply (and possible damage it), the thyristors will fire and sink the current to ground.

SUPERCONDUCTING MAGNET:

The QHE experiment utilizes an 8 Tesla superconducting solenoid. The advantage of a superconducting solenoid is that, by shorting the coil with a superconducting shunt, any current present in the coil will circulate indefinitely, thus maintaining an extremely stable, perpetual magnetic field. However, the inclusion of this superconducting shunt creates a problem: any current we attempt to put through the coil will simply travel across the shunt, bypassing the coil, and thus not creating a magnetic field. To solve this problem, there is a small resistive element in close proximity to the shunt, known as the PERSISTENT SWITCH. When current runs through this resistive element, it heats up, and raises the temperature of the shunt above the critical temperature. The shunt is no longer superconducting, and current will flow through the coil. Once the desired field is created, we can turn off the persistent switch, and the magnet will enter persistent mode, where current is trapped in the coil/shunt assembly. It is of great importance that the persistent switch be turned on ONLY when the output of the power supply matches the current already in the magnet. Otherwise, the attempt to change the current so rapidly will result in a large back EMF. The output of the power supply will be dropped entirely across the shunt, quite possibly destroying it, and quenching the magnet in the process.

DIGITAL VOLT METERS (DVMs):

Figure 5 , Hall DVM, (middle), FIELD DVM (bottom), and PERSISTANT SWITCH BOX (r., w/ key)

Two DVMs are used in the QHE experiment. The FIELD DVM measures the voltage drop across a 1 mΩ resistor located in the ENERGY ABSORBER. The current in the magnet can then be read directly off the DVM (just multiply by 1000, or simply ignore the exponent). In order to determine the field, one needs only to multiply the current by 0.1149 T/Ampere, the current/field ratio of this particular magnet.

The RESISTANCE DVM is used to measure the Hall voltage, or the magnetoresistance of the sample, depending on what wiring geometry is used.

CRYOSTAT:

The magnet is contained within a 10L helium dewar. There are three layers to the dewar:

-a vacuum layer to thermally isolate the central helium section
-a liquid nitrogen jacket that absorbs any radiation
-the helium section itself, which contains the magnet

This system is well suited to holding helium—the Dewar is capable of holding the magnet at helium temperature for upwards of 5 hours.

MAGNET INSERT:

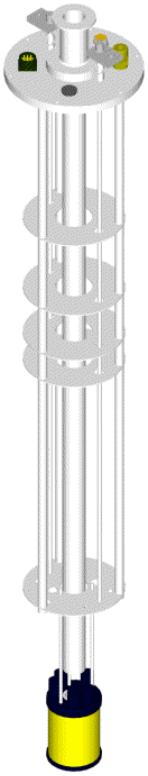


Figure 6, magnet insert. The Superconducting Magnet is the yellow and blue cylinder situated at the bottom of the structure

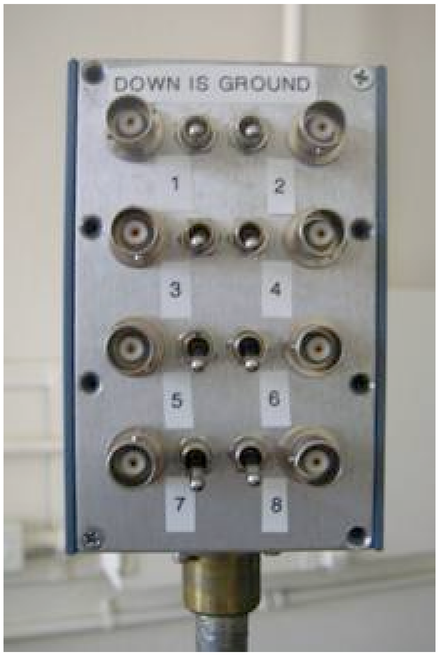
The magnet is suspended in the helium by an insert that also contains a guide tube, which serves to guide the PROBE into the magnet bore, and the helium LEVEL METER. A series of baffles above the magnet prevents radiation from reaching the liquid helium.

LEVEL METER:

The level meter Probe is no more than a 24” piece of superconducting wire. The portion of this wire that is immersed in helium will be superconducting, while the remainder of the wire has some non-zero resistance. Thus the total resistance of the wire serves to give an indication of how much helium remains in the dewar. The superconducting wire is attached to a meter that translates the resistance detected into a percentage value. The wire is mounted on the insert in such a way as to indicate zero percent when the helium level is just above the magnet. This way, the experiment can be run to zero percent without the magnet quenching.

PROBE:

Figure 7. Probe Switch box



The switchbox mounted on one end of the probe allows for electrical contact to be made to the sample. Each BNC connector has a corresponding grounding switch. All switches should be set to ground before any connections are made or broken.

On the other end of the probe is a brass assembly that protects the sample. To change the sample, unscrew the brass fitting to expose the sample holder—the small black phenolfiber mount. Care should be taken when re-attaching the brass fitting such that the sample holder pins are not damaged.

If the sample is changed mid-experiment, it must be carefully dried before reinsertion into the helium. When the probe is initially removed and exposed to air, moisture will rapidly begin to condense upon it. If the probe were to be reinserted without drying, this water would freeze, possibly cracking or otherwise damaging the probe. It is best to warm the probe up in an atmosphere of pure nitrogen to minimize the amount of moisture that condenses on it.

SAMPLE POWER SUPPLY:

This unit supplies the current that will flow through the sample itself. We want the current to be constant, even though the resistance of the sample will change as we ramp the magnet. To do this, we supply a constant voltage from a battery and put it through a resistor that has a resistance several orders of magnitude greater than the average sample resistance. That way, when the sample resistance changes due to magnetic field, the percentage change in the total circuit resistance will be minimal. For example, if the sample resistance is around 10kΩ and the load resistance is 1MΩ, a 10% change in the sample resistance (a change of 1kΩ) corresponds to a total load change of a thousandth of a percent.