ALPHA-G Magnet Controls and Preparation

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The ALPHA experiment traps antihydrogen ($\overline{H}$) atoms in a magnetic potential well, releases them, and detects their annihilations with the walls of the trap. The new ALPHA-G apparatus will be used to measure the gravitational interaction of $\overline{H}$. The ALPHA-G superconducting magnets require fast-responding and fine-tuned systems. During my internship I engaged with the assembly and testing of the control systems for the $\overline{H}$ magnetic trap in ALHPA-G.

I. INTRODUCTION AND BACKGROUND

Antihydrogen is the antimatter counterpart of normal matter hydrogen, and consists of a positron bound to an antiproton. In the ALPHA experiment, $\overline{H}$ is created by combining cooled antiprotons from the antiproton decelerator with positrons obtained from a decaying ^{22}Na source. $\overline{H}$ is then contained using its intrinsic magnetic moment and a magnetic trap. The trap consists of an octupole and two mirror coils enclosing a vacuum chamber (Fig. 1).

The electromagnets form a potential well in both the radial and axial directions, trapping $\overline{H}$ atoms within the vacuum chamber. The magnetic moment of $\overline{H}$ is very small, so trapping antihydrogen atoms requires very strong magnetic fields and very high currents through the octupole and mirror coils. Such high currents are not achievable in conventional conductors, so the magnets are made of superconducting material and cooled below their superconducting transition temperature using liquid helium.

Once trapped, the $\overline{H}$ can be detected through release and annihilation. The magnetic trap is ramped down and the potential well removed, allowing the $\overline{H}$ to expand outward and collide with the electrodes that line the vacuum chamber. The positrons and antiprotons annihilate with electrons and protons in the electrodes, releasing gamma rays and pions respectively. The paths of these particles are detected using a silicon detector surrounding the apparatus. By tracing these paths to their intersection, the existence of the antihydrogen within the trap and the location of the annihilation event can be determined.

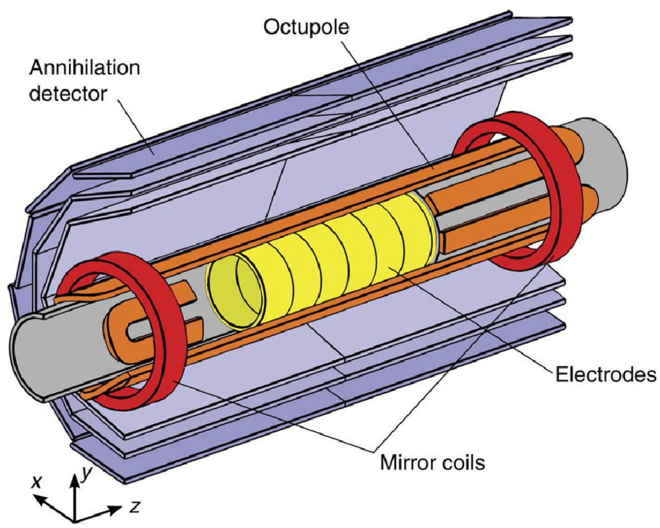


Fig. 1[1] The ALPHA-2 apparatus magnetic trap. Positrons and antiprotons are controlled axially within the trap by the electrode potentials and contained radially by a background magnetic field from an external solenoid (not shown). Antihydrogen, with no net charge, is unaffected by electric potentials and constant magnetic fields. $\overline{H}$ is instead contained by the magnetic field gradients from the quadrupole and mirror coils. Particles and gamma rays produced by $\overline{H}$ annihilation are detected as they pass through the three-layer annihilation detector.

II. ALPHA-G

The ALPHA collaboration is currently constructing a new apparatus, known as ALPHA-G, that will be used to take precision measurements of the gravitational acceleration ($g_{\overline{H}}$) of antihydrogen. Using a previous apparatus, the ALPHA experiment set limits on $g_{\overline{H}}$ of between -65 and 110 times the gravitational acceleration of regular matter[1]. Using ALPHA-G, the ALPHA collaboration hopes to improve the precision of that measurement by several orders of magnitude, and determine for the first time the sign of $g_{\overline{H}}$; whether antimatter is attracted or repelled by normal matter through gravity.

ALPHA-G will have a similar structure to the previous ALPHA apparatus, but oriented vertically. Cold $\overline{H}$ will be trapped in the center of the ALPHA-G magnetic trap and then released. Even at temperatures below 1K, the kinetic energy of individual $\overline{H}$ atoms dominates the energy of its gravitational interaction, so atoms will scatter and annihilate throughout the vacuum chamber. The location of the $\overline{H}$ annihilation events will be compared to simulations of antihydrogen dropped with various values of $g_{\overline{H}}$, and a value and uncertainty for $g_{\overline{H}}$ will be extracted.

III. MAGNET CONTROLS

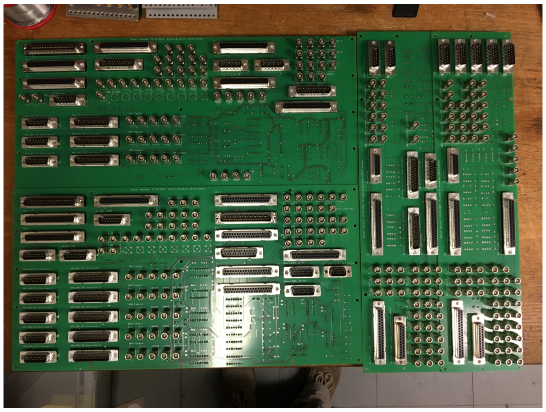
The superconducting magnets in the $\overline{H}$ trap have special operating requirements. Their current magnitudes must be constantly updated to counter fluctuations and maintain stability. The magnets must also be capable of shutting off their current and eliminating their magnetic fields on the order of milliseconds. These capabilities protect the magnets in the event of a quench, or sudden transition from superconductivity to normal conductivity. If the electromagnets could not immediately shut down following a quench, the high currents and sudden jump in resistivity would cause overheating and damage to the magnets.

These capabilities are also important for the initial verification of antihydrogen production within the trap. By quickly ramping down the magnetic potential well, the antihydrogen atoms within the trap are released and annihilate within a short time-span, producing a high and narrow peak in detected particles. A slower release of antihydrogen can be more difficult to distinguish from noise, background radiation, and cosmic rays.

The operating requirements of the system are met by the use of fast-response power supplies, signal conditioners, and CompactRIO controllers. Current and voltage data from the magnets are supplied to the signal conditioners, which adjust the input data to levels the CompactRIOs can handle. The CompactRIOs interpret the state of the system and send update signals to the power supplies. The FPGA modules within the compactRIOs are optimized just for input, output, and simple processing, producing the quick response time required to respond to a magnet quench. Unlike computers with standard operating systems, the FPGAs can also run for weeks or months with no interruptions, an important feature for long experimental runs.

During my internship I installed and tested four of the CompactRIO and power supply systems using LabView software (Fig. 2). I began the assembly process for the signal conditioners and wrote testing code for them as well. I soldered connections on the power supply and quench protection breakout circuit boards, and designed front panels for them using Inventor (Fig. 3,4). I also assisted with various tasks involved in the preparation of the experimental zone for the main ALPHA-G apparatus and cryostat.

Fig. 2 A CompactRIO controller. The seven attached modules are used to communicate with signal conditioners and electrode/magnet power supplies. The back half of the chassis contains the CompactRIO power supply.



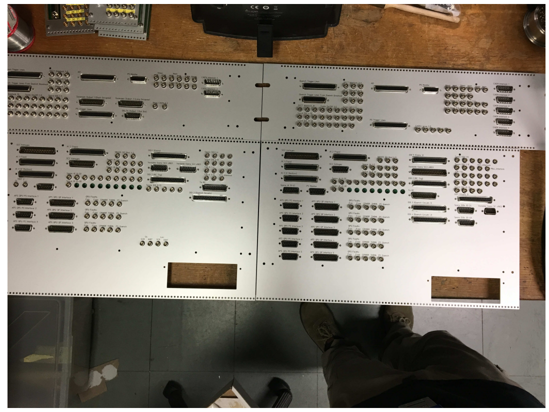


Fig. 3 and 4 Power supply and quench protection breakout circuit boards, with and without front panels.

A. References

1. The ALPHA Collaboration and Charman, A.E. Description and first application of a new technique to measure the gravitational mass of antihydrogen. *Nat. Commun.* **4**, 1785 (2013)

B. Acknowledgments

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