Control system for the ALPHA-g apparatus vacuum heaters

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Student:	Erikas Švažas, Vilnius University, Lithuania
Supervisors:	April Louise Cridland, Swansea University, United Kingdom
	Steven Jones Armstrong, Aarhus University, Denmark
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Abstract

ALPHA collaboration studies the fundamental symmetries between matter and antimatter, or more precisely between hydrogen and its antimatter counterpart - antihydrogen. Prior forming antihydrogen atoms and performing experiments on it, ultra-high vacuum system in the trap has to be prepared as any gas particle left in the vacuum can annihilate the antihydrogen's atom. This report has been prepared on the basis of my work as a summer student in the ALPHA collaboration based at CERN, Switzerland. During my stay, an extension to the ALPHA-2 apparatus, ALPHA-g, was being developed to study the gravitational behavior of antihydrogen atoms in the field of the Earth. The goal of the summer project was to design and assemble the system to control ALPHA-g apparatus heaters for the vacuum system bake out. In other words, to produce the system which allows the cryostat's heaters to be switched on and off. In addition, the project included morning, afternoon or night shifts operating and maintaining the experimental ALPHA-2 apparatus, as well as daily tasks assembling the newest ALPHA-g apparatus. This report covers a brief introduction and motivation behind the ALPHA-2 and ALPHA-g apparatus, explains the work done to control the ALPHA-g cryostat heaters switch system.

1 Introduction to the ALPHA apparatus

ALPHA, an international collaboration, studies the fundamental symmetries between hydrogen and its antimatter counterpart - antihydrogen. As hydrogen consists of a proton and an electron, antihydrogen atom is made up from an antiproton and a positron. This section will briefly cover the ALPHA-2 and ALPHA-g apparatus. More detailed information can be found here [4, 7].

Trapping antiparticles CERN Antiproton Decelerator (AD) provides bunches of antiprotons at relatively low energy (5.3 MeV). This is achieved by letting protons which come from Proton Synchrotron to collide with a fixed metal target. During these collisions, many secondary particles are created, including antiprotons with massive kinetic energy. However, as the newly formed antiprotons have too much energy to be trapped, collisions with a metal foil in a vacuum are used to decelerate these antiprotons down to keV scale. By quickly switching electrostatic fields to induce radial confinement and axial bottling, antiprotons can be caught in Penning - Malmberg (PM) traps and cooled down even more by the collisions with the electrons [7]. On the other hand, the production of positrons is different. Positrons in the ALPHA experiment are obtained from the radioactive beta-decay source containing an isotope of sodium-22 and guided to Penning - Malmberg trap. Since radioactive decay is not timed, buffer gas cooling with the introduced nitrogen gas molecules in the PM trap is used to promote positrons accumulation. The trapped positrons form a non-neutral plasma which rotates around the axis of the magnetic field with a defined frequency. If the plasma rotation speed is increased, due to the conservation of angular momentum, plasma starts shrinking. This technique, known as "rotating wall", is used to control positrons plasma size and number [6].

Formation of antihydrogen The produced antiprotons are transferred to another PM trap, so-called "atom trap", where the collisions with the positrons plasma cloud occur. Consequently,

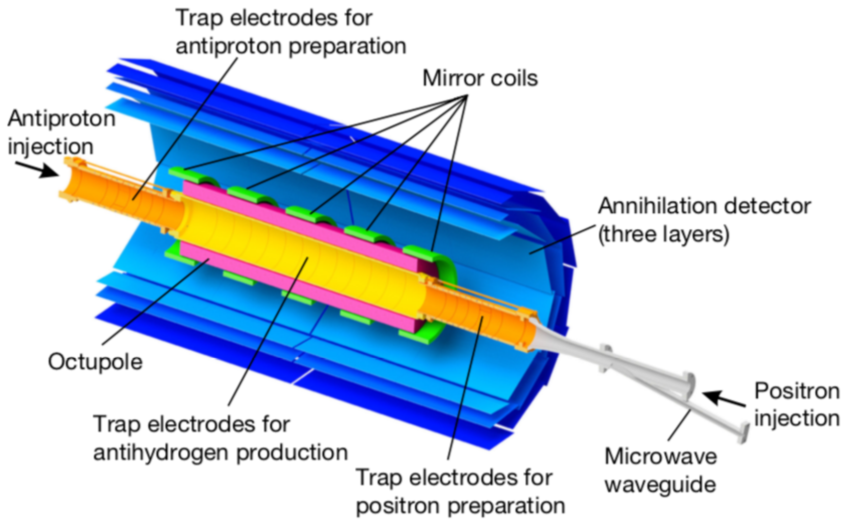

Figure 1: A schematic view of the ALPHA-2 apparatus [2]. Note: the vacuum wall and the cryostat for the superconducting magnets are not shown.

antiprotons lose their energy until they are able to capture a positron and form antihydrogen atoms. An Ioffe trap is used to confine the neutral atoms by the atom's magnetic dipole moment and the magnetic field. This type of atom trap is made of superconducting octupole magnet and five mirror coils (fig. 1). These magnetic fields increase in strength starting from the center point of the trap so that atoms having low enough total energy can be trapped like a marble rolling in a bowl. As these magnets require the use of superconducting wires, magnets are placed in liquid helium.

ALPHA experiments on antihydrogen If antihydrogen atoms are successfully trapped, experiments on them can be performed using various techniques. ALPHA collaboration uses various electromagnetic radiation sources (microwaves, lasers) to do spectroscopy studies on antihydrogen atoms. The first observation of the hyperfine structure of antihydrogen [2] and the first observation of an optical transition of antihydrogen [1] were reported in the recent years by the ALPHA collaboration. This year, Lyman-Alpha transition was observed in the ALPHA-2 apparatus [3], also, this article demonstrated how pulsed laser-light can be used to measure the temperature of the antihydrogen atoms.

Newest ALPHA-g apparatus ALPHA Collaboration was the first one to report the directly measured limits on the ratio of the antimatter's gravitational mass and it's inertial mass [5]. Recently, the extension of the ALPHA-2, ALPHA-g, was proposed and designed [7]. During my stay, the construction work was in progress and I had the opportunity to take part assembling the newest apparatus. It is a vertically orientated magnetic antihydrogen atom trap to study the gravitational interaction of trapped antimatter. This is done by detecting the annihilation products position and time. There are a couple of quantitative goals to be achieved. Firstly, to determine if the gravitational force between antimatter and matter is repulsive or attractive. Secondly, to determine antimatter's gravitational acceleration to a higher precision and compare it with its matter counterpart.

2 ALPHA-2 shift work

During the first five weeks, I was actively involved in the shift work running, operating and maintaining ALPHA-2 apparatus 24/7. There are two types of 8 hour long shifts.

Antiprotons shift This shift takes place only when the antiprotons beam is available from the Antiprotons Decelerator facility. The most important procedures are as follows: steering

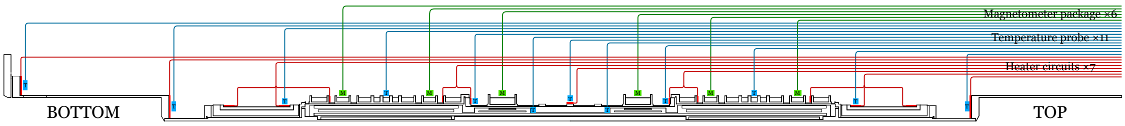

Figure 2: The schematic view of the ALPHA-g cryostat. The red color represents heaters, temperature sensors are marked blue.

the antiprotons beam to the maximum intensity, cool it down by mixing with electrons, kicking electrons out of the catching trap, transferring antiprotons to the atom trap, where they are cooled down by mixing with electrons again. After kicking electrons out of the atom trap, antiprotons are prepared to be mixed with already cooled positrons and the series of potentials are applied to push any remaining charged particles out of the atom trap. This shift includes the majority of experiments done at the ALPHA collaboration.

Cryogenics/lepton shift Trapping magnets take advantages of superconducting wires and they have to be maintained connected to the liquid helium cryostat. During the shift, the continuous supply of the liquid helium has to be ensured and 1000 liters dewar restored to the required level. This is done by connecting liquid helium transfer lines and a helium gas pressurization line to fill the dewar using the smaller 500 liters dewar. In addition, this shift includes the performance monitoring of the catching traps, detector systems and the Carlsberg magnet.

3 ALPHA-g heaters control system

The project goal was to make the electronic system to control ALPHA-g apparatus heater components. However, due to the short project term, assembling of electronics was started, but not finished. This section will briefly cover the motivation behind ALPHA-g cryostat's heaters system, implementation procedures and explain what has been done during the project.

Antihydrogen trapping requires very strong magnetic fields and extremely high currents. Due to this problem, ALPHA experiments use superconducting magnets, however, it requires magnets to be operated at extremely low temperatures. This is achieved by thermally connecting trapping magnets to the liquid helium cryostat. The cryostat is surrounded by the outer vacuum chamber, functioning like a thermos. Inside, the tubes filled with the cold helium gas that evaporates from the liquefied helium are used to cool the heat shields, the high temperature superconducting (HTS) leads that transmit current to the atom trap magnets. The surfaces of the trap vacuum chamber do not outgas if they are held at the cryogenic environment. Instead, they act as the powerful vacuum pumps as the outgassing from the warm surfaces provides a massive gas load for the vacuum system [4]. More importantly, there is a need to heat the internal trap (80 ^{0}C) and the external hardware (120 ^{0}C) to boil off and pump out residual gas particles if the ultra-high vacuum system was opened to the atmosphere to achieve the best vacuum as possible. This is achieved by the heaters system (fig. 2). These heaters can be turned on if the system is cold, and there is a need to warm it up to the room temperature once the entire run is finished. We use temperature sensors (fig. 2) directly connected to each of the heaters to control the temperature changes. As solid state relays (SSR) have a long lifetime and are highly reliable, it is used to act as a switch for each of the heater if the temperature sensor satisfies the given condition.

Controlling heaters and sensors ALPHA-g apparatus uses resistance thermometers to act as temperature sensors. To measure the temperature in the coldest places wide temperature range is needed and PT1000 class temperature sensors are used. PT1000 class is relatively expensive and if the conditions do not require otherwise, PT100 class temperature sensors are used. To control the temperature gradient inside of the cryostat, all of the temperature sensors as well as heaters are connected to the three National Instruments CompactRIO Controllers, cRIO 9045. As it can be seen from figure 3, all the required components, including 2.5A power suppliers and IEC connectors, were purchased, assembled and ready to use. Also, I registered all controllers on the CERN network, provided the IP addresses and installed the required software packages.

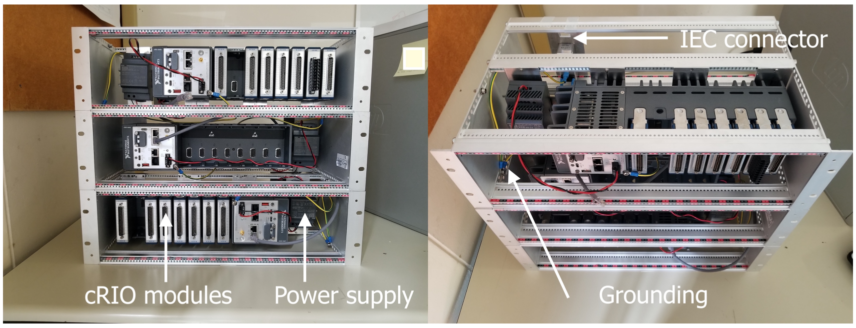

Figure 3: Assembled three chassis boxes containing cRIOs and it's modules, power suppliers, network cables and IEC connectors.

Switching heaters According to the required current and voltage conditions, it was chosen to use OPTO 22 DC60S-5 SSR. 85 SSRs were purchased, assembled and divided into 6 chassis box during this project. As ALPHA-g uses different temperature sensors, two types of chassis box were designed using Autodesk Inventor Professional 2018 program (fig. 4). More detailed view of the middle plate can be seen from fig. 5 and 6.

- 5 units of chassis box with 15 SSRs, power supply (24V, 20 A) each (fig. 4a).
- 1 chassis box with 10 SSRs, 2 power supplies (48V, 10 A; 24V, 12.5 A)(fig. 4b).

To transfer the SSRs generated heat, heat sinks (thermal resistance 2.4K/W) and axial fans (24V) were planned and purchased. As one chassis box was planned to have 48V, 10 Amps power supplier, additional power supply to operate the 24V axial fan had to be added. To turn on/off electronics C14 Panel Mount IEC Connectors were purchased and added to each of the chassis. Also, each chassis contains two DC37 connectors and an Ethernet cable connector as a communication port with the rest of the control system. Through these connectors, a feedback from temperature sensors is sent to the National Instruments CompactRIO Controllers. Depending on the feedback a decision to switch on or off the heaters is made and sent to the SSR's chassis boxes which act as a switch mechanism sending the feedback to the cryostat's heaters.

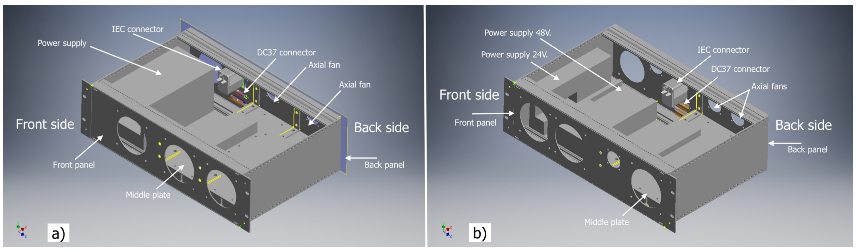

Figure 4: Two types of designed chassis boxes. Each contain: 2 fans, 2 heat sinks, finger guards and L-brackets, DC37 and IEC connectors, middle copper plate, aluminum front and back panels. Additionally, a) 15 SSR, power supply (24V, 20A); b) 10 SSR, power supply (24V, 12.5A), power supply (48V, 10A).

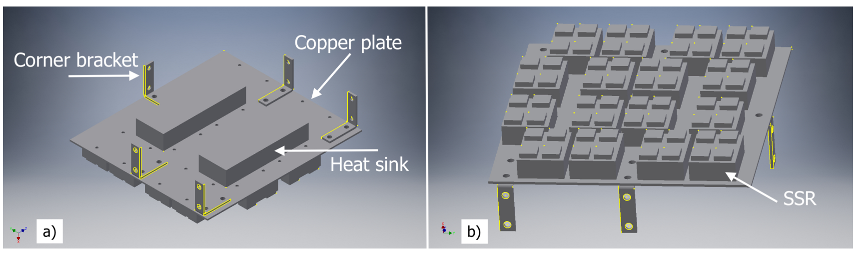

Figure 5: Detailed view of the Middle plate seen in 4 fig. a) part. The combined structure contains: 5 L-brackets, 2 heat sinks, a copper made main plate, 15 SSRs. a) view from the top; b) view from the bottom to show SSRs arrangement.

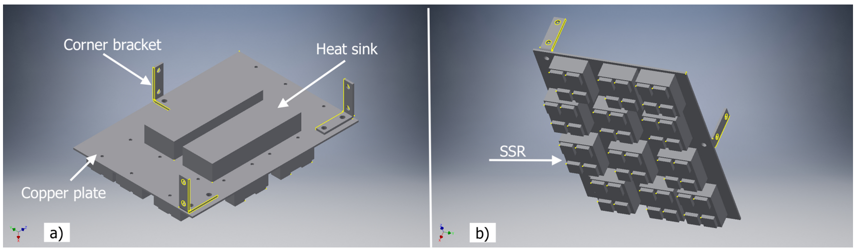

Figure 6: Detailed view of the Middle plate seen in 4 fig. b) part. The combined structure contains: 3 L-brackets, 2 heat sinks, a copper made main plate, 10 SSRs. a) view from the top; b) view from the bottom to show SSRs arrangement.

For better conductivity middle plates (see fig. 4) were designed from copper, while front and back panels - from aluminum. Schematic drawings of these plates showed in figures 7 and 8. The plates were ordered to be cut using a water jet technique. Due to the short project term and late plates arrival, assembling could not be started. However, other parts (axial fans, heat sinks, power supplies, SSRs, corner brackets, and chassis box) were purchased and assembled.

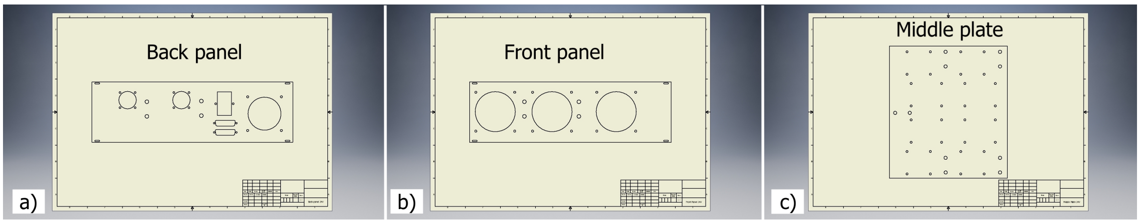

Figure 7: Schematic drawing of the middle plate, back and front panel showed in fig. 4 a).

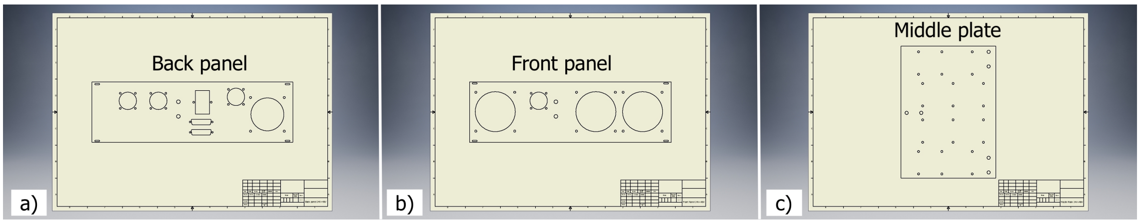

Figure 8: Schematic drawing of the middle plate, back and front panel showed in fig. 4 b).

4 ALPHA-g Gate Valves Controllers

Gate valves, as a part of the beamline, are important features in the ALPHA-2 apparatus. I updated Gate Valves Controllers software written in Labview programming language: included additional read-outs for intermediate Gate Valve Control values, also, updated communication within the network of shared variables. In addition, I checked if the schematics of Gate Valve Control Board are correct by constructing smaller parts on the breadboard. I gave corrections and updated the existing scheme. For example, I corrected mixed pins next to the octocoupler and ensured the required voltage after octocoupler (fig. 9).

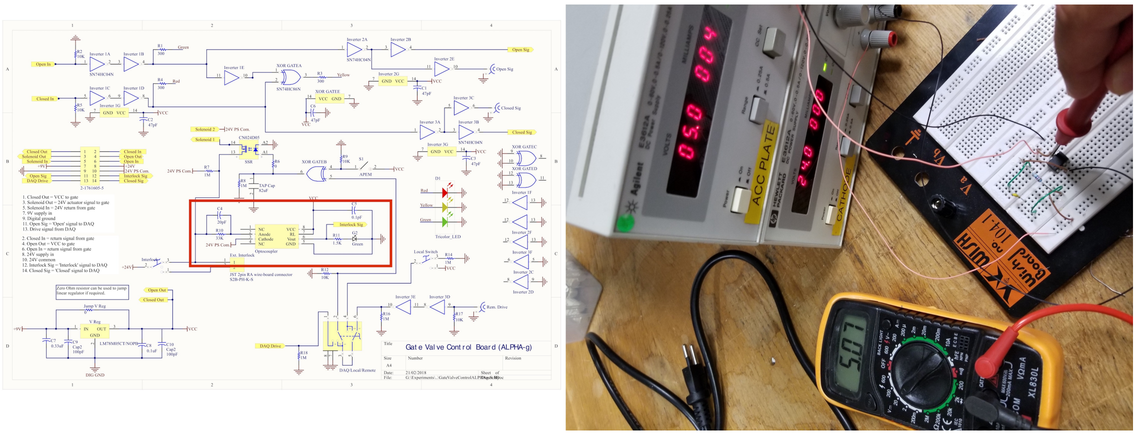

Figure 9: Checking the Gate Valve controllers circuit part (marked as a red rectangular) by the breadboard.

5 Additional work

To avoid people and possessions electrocution, grounding is a must constructing electronic circuits. I connected the new ALPHA-g electronic racks to the ground through thick ground cables and made a network of these cables under the new ALPHA-g platform (fig. 10). Any new electronics on the new ALPHA-g platform can be easily grounded through this network. For example, three cRIOS controlling heaters (fig. 3) will be attached to this network.

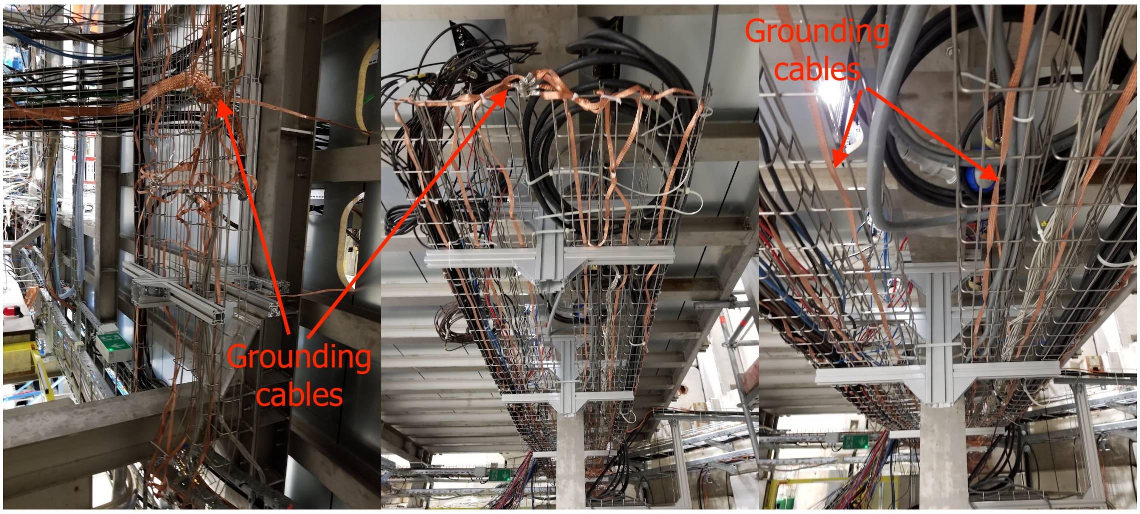

Figure 10: Grounding cables (reddish-orange tinge) under ALPHA-g platform.

6 Conclusions

As a summer student at ALPHA collaboration at CERN, I planned and designed the chassis boxes with the ALPHA-g heaters control system. The boxes were designed using Autodesk Inventor software. In addition, I purchased and assembled all required electronic components and ordered copper and aluminum plates. The system to control heaters and temperature sensors were ordered and assembled. I installed the required software and, by the end of the project, the control system was ready to use. Also, Gate Valve Controllers software and electronics scheme were upgraded using Labview software and breadboards. During the project time, I have been actively involved controlling and maintaining ALPHA-2 apparatus, running the experiments with antihydrogen. Also, I had tremendous experience assembling the newest ALPHA-g apparatus.

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