Purity Demonstration for Liquid Argon Protection Chamber

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ABSTRACT

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In the field of particle physics detectors, more experiments are turning to the noble gases, specifically argon or xenon to try to detect elusive particles. I have worked on an experiment called the Liquid Argon Time Projection Chamber (LArTPC), which aims to detect neutrinos using ionization and electron drift. Before anything can be detected, it first has to be demonstrated that the argon in this 6 000 gallon tank can be made pure enough to function (with an oxygen level of 100 parts per trillion) without the chamber being evacuated. I have been testing materials and writing programs in order to aid in the construction of the tank and in the demonstration of the argon's purity. I tested several types of G10 material in order to find their individual resistivity so that it could be determined which would work best for the structural components inside the chamber. The material needs to have a large resistance to prevent current flow but which will still allow for some movement, preventing charge buildup. I tested these materials under both room and cryogenic temperatures so as to simulate the conditions in the chamber. I also worked with a xenon flashlamp. The purity in the chamber is measured with a detector which needs multiple but consistent light sources. The light needed is transferred using quartz fibers of from a single xenon flashlamp. I used a device that holds and aims multiple fibers at a central focus and constructed a test to measure the differences in the amount of light traveling through each fiber. In this way I was able to figure out how to use the flashlamp most efficiently. I also spent time with a fellow intern programming a stepper motor and a temperature monitor so as to measure the temperature throughout the chamber, confirm that it is uniform, and therefore rule out the possibility of eddy currents forming. Such currents would affect the function of the chamber (as it depends on electron drift, which the currents would disrupt). We wrote a program for the motor to raise and lower temperature sensors up and down the chamber. These sensors would then be read by the temperature monitor. I was able to find resistivities for the G10 materials, but as our equipment wasn't as sensitive as I could have wished, no conclusive results have been found as to which material should be used in the chamber. I did find, however, the position in which flashlamp works most efficiently, and found that even with multiple fibers, it could be positioned so that there was less than a 30% light loss between the most central and extreme fibers. The process of preparing the chamber will continue into the fall of 2010 and the purity demonstration is scheduled to occur sometime in November. If the chamber can be proven to achieve the appropriate purity without a vacuum, then neutrino detection and study will become a little simpler, hopefully unfogging the fundamentals of the world a little more.

INTRODUCTION

This summer I was employed at Fermi National Accelerator Laboratory in Batavia Illinois, where I worked with a liquid argon neutrino detector in the early stages of its development. This liquid argon time projection chamber (LArTPC) is currently in phase one of its construction, which consists of a demonstration that the argon inside the chamber can be made pure enough without the chamber being evacuated, as had been the procedure previously. I worked with several materials and pieces of equipment to aid in the upcoming purity demonstration.

One of my tasks was to measure the electrical resistance of two types of G10 material, natural G10 and a new electrostatic discharge (ESD) G10. The resistance of these materials is important, as they are both candidates to make up the structural components inside the chamber. These structures would need a resistance that is large enough to prevent current flow but which will still allow for some movement, preventing charge buildup. In order to measure the resistance, and in turn the resistivity of the material, an IPM program intern (Daniel Sandoval) and I exposed the materials to both room conditions and cryogenic conditions similar to those inside the detector. In this way, we were able to measure the uniformity of the resistivity, especially that of the ESDG10.

We also ran tests on a xenon flashlamp. The purity in the chamber is measured with a purity detector, which needs multiple but consistent light sources. The light needed is transferred using quartz fibers from a single xenon flashlamp. These fibers need to be of approximately equal intensity. We used a device that holds and aims multiple fibers at a central focus and constructed a test to measure the differences in the amount of light traveling through each fiber. In this way we were able to figure out how to use the flashlamp most efficiently.

Our final project this summer was to program a stepper motor and a temperature monitor to allow us to check the uniformity of the temperature throughout the chamber and, in this way, verify that no temperature gradients exist, as they would cause eddy currents in the chamber. Such currents would affect the function of the chamber (as it depends on electron drift, which the currents would disrupt). Therefore, it is important to verify that these conditions aren't present. We had to write a program for the motor to raise and lower sensors throughout the chamber, which would be read by the temperature monitor. We also programmed the monitor in a way so that recording and comparing its measurements would be simple.

METHODS

We tested two different types of G10 material, the first of which was a 31 x 11.5 x 0.14 cm board consisting of 61 latitudinal stripes of alternating pale G10 and copper. We connected this to a high-voltage power supply, which can reach up to about 2500 V. Attached to this supply was an ammeter which we used to read off the current. In order not to break the circuit at such high voltage, we attached a 100 MΩ resistor and across this we attached a voltmeter in parallel, with an internal resistance of 10 MΩ (see Figure 1).

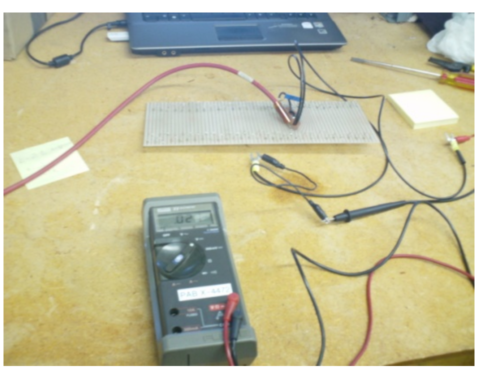


Figure 1: Our circuit. The high-voltage power supply is not pictured.

We also tested a plate of black G10 material, measuring 15.3 x 7.0 x 0.3 cm. We first tested this board under room conditions measuring the voltage per unit of length along the current path. We then fabricated a tool that consisted of a block of Teflon, which held two stainless steel needle probes a distance of 1.85 cm apart. This device was used to test the uniformity of the voltage drop along the board. It should be noted that we had difficulty in making an electrical connection to the board. For the first test, we used small C clamps to secure metallic tape to the surface of the ESDG10. For the second test, we drilled through the ends of the material so as to place a tightened bolt and lock washer for a more secure connection (see Figure 2). After making a connection into the board, we were able to attach the ESDG10 to a 30 V maximum power supply and measure the voltage drop across the material. In order to make a connection with our test probes, we needed to scratch the surface of the plate. Differences in the amount of scratching may have affected our readings, although we attempted to keep the amount of scratching constant. After performing our room condition tests, we then submerged both of our G10 boards into liquid nitrogen (77 K) to simulate the cold conditions of a particle detector. This test only measured resistance.

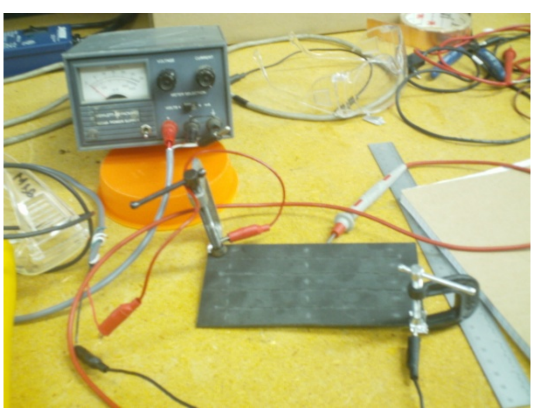


Figure 2: The plate of ESDG10 and our clamped connections.

In our next set of measurements we examined a xenon flashlight, which can be adjusted to have different flashing frequencies and light intensity levels (see Figure 3). According to the maker, the arc gap of the bulb is about 3 mm and we found that the position of this bulb could be controlled using knobs on the external housing. In order to capture the light emerging from the bulb we used a 0.70 mm diameter quartz fiber with a cleaved end. Since we wanted to capture the most light, we used a porcupine-like device which held seven fibers at the same focus (see Figure 4). The light transferred through the fibers was measured using a Hamamatsu phototube, which was attached to a power supply. This supply was set to give out 40 V, creating an electric field inside the phototube to drift the electrons. The output signal was connected to a Tektronix Digital Storage oscilloscope, which read the voltage across the phototube as a function of time.

Figure 3: The xenon flashlamp.

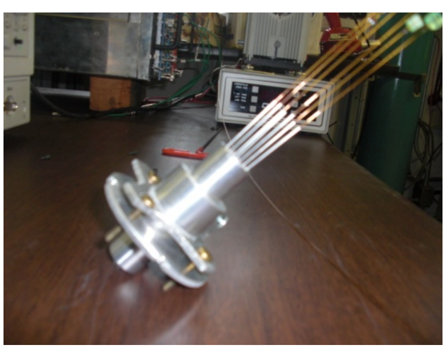


Figure 4: The device which held and aimed our fibers.

Our objective was to find the position of the bulb where the fibers picked up the most light and to see the percentage of light lost in the outside fibers compared to the middle one. We began by placing our test fiber in the middle position, with the bulb at the position where the knobs were completely loosened. We placed the fiber in such a manner that it was just touching the bulb. Then, we adjusted the position of the bulb so that the fiber could pick up the most light. We kept track of the bulb´s position by counting the amount of turns we tightened the knobs. We labeled the bulb´s vertical movement as movement along the y-axis, the horizontal movement as movement along the x-axis and the backwards and forwards movement as movement along the z-axis. We kept the "z" knob fixed at its loose position and instead moved along the z-axis by moving the porcupine´s position. Our first step in finding the peak light intensity was to adjust the bulb´s position on the y-axis. This was done by tightening the knob one turn at a time and then reading the light intensity off of the oscilloscope after each turn. In this way we found the position of the bulb where the most light was transferred (12 turns). We then tested the light transfer through all seven fibers, comparing the percent they dropped from the middle fiber. The x-axis was adjusted in the same manner, except the y-axis was kept at the 12-turn position. Our maximum occurred after three turns. We again tested the seven fibers in the same manner. We adjusted the z-axis by sliding the porcupine closer and further from the bulb, and once the peak was found, tested the fibers the same way we had done previously.

Finally, we worked with a SureStep-Pro Motor 23079 and a LakeShore Temperature Monitor 218E in an attempt to start them running, understand the commands to control them, and write up a program to allow us to determine temperature gradients in the argon chamber. We first began by installing the software that came with the motor equipment. Once we completed this, we continued by making the appropriate connections between the motor, the drive, the computer and the power supply as described by the *SCL Manual*. We also connected two limit switches to arrest the movement of the motor in either direction. We used a 5 volt power supply with these micro-switches and put the wires on the normally closed position of the switches. After this, we proceeded by making the connection between the drive and our PC and made sure that we were able to communicate and configure the motor. We set up the motor by clamping it to the table, attaching a threaded metal rod to the rotating cylinder and then winding a cable about this rod. We attached a weight to the end of the cable and then let it hang off the edge of the table (see Figure 5.) We then familiarized ourselves with the commands to control the motor and observed the different features on the motor. It should be noted that we found several ways to communicate with the motor, through the software it came with, through the TeraTerm window and through MATLAB.

Figure 5: The SureStep motor.

Once we had successfully connected to the motor, we then set up the temperature monitor in a similar manner. In order to make sure that we understood how to take measurements, we soldered a resistor to one of its sensors and practiced taking measurements of temperature. We tried this at room conditions and then under both boiling water and liquid nitrogen. We also connected the monitor to both the HyperTerminal and MATLAB, where we familiarized ourselves with the commands to collect data.

Once we had both pieces of equipment working properly, we were able to connect them both to MATLAB and write a program integrating both. We have our motor lower the resistor attached to the monitor and then pause. During the pause, the monitor gives us a reading of the temperature, which is sent directly to an Excel spreadsheet. This process then repeats.

RESULTS

The results from our first set of tests follow:

Voltage vs. current for the pale G10 under room conditions (Figure 6)

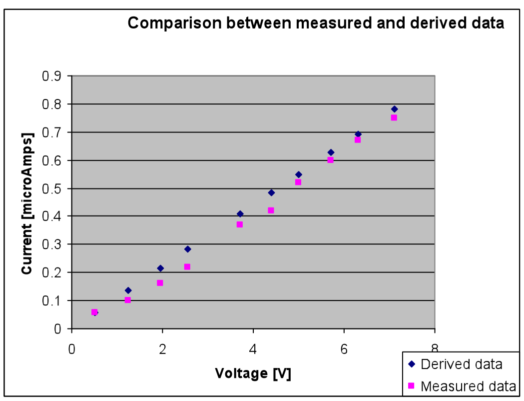


Figure 6: Note: The slope of the graph yields a resistance (342 ± 30 MΩ).

From the voltage drop (read from the voltmeter) across the 100 MΩ, we derived a value for the current of the circuit. We then compared these derived currents to the currents that we had read off of the high-voltage power supply. We saw that the derived current differed from the measured current by an average of 0.036 µAmps with a standard deviation of approximately 0.19.

After cleaning the board with alcohol and baking it at 60 °C for 20 minutes, we ran the same test with the following results (see Figure 7).

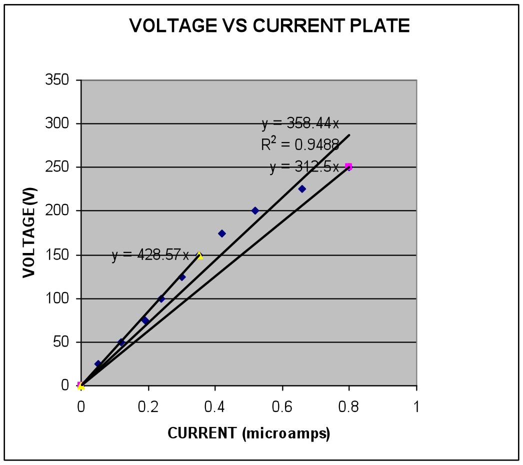


Figure 7

From this measured resistance we were able to calculate the resistivity of 1020 MΩ*m. When we placed the board in cold conditions, the voltmeter (set at 300 mV) jumped about between 0 and 1.2 mV continuously, even at a voltage above 1000 V. If we had seen a constant reading of over 2 mV, then we would have considered there to be current flowing.

For voltage vs. distance along the conductor of the ESDG10 plate we found the following results when the power supply was measured to 5.02 V supplied to the circuit (see Figure 8):

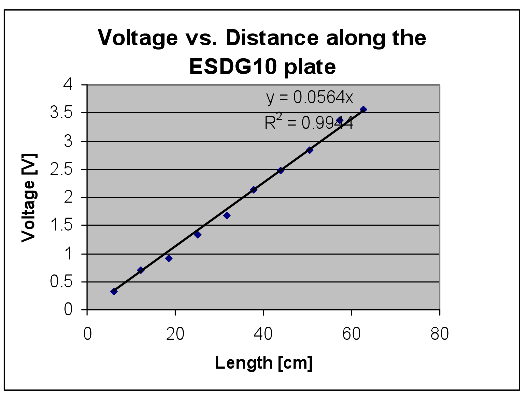
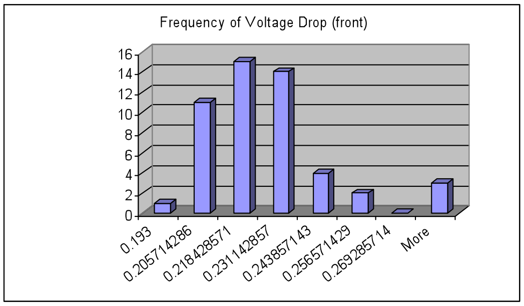


Figure 8

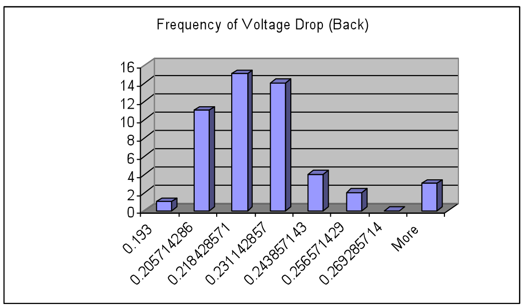
For the second test, in which we measured the voltage drop over a constant distance, we found that across our 50 test regions the average voltage was 0.219 V with a standard deviation of 0.02 on the front side of the board.

On the back side of the board we found the average voltage was 0.196 V with a standard deviation of 0.025.

The histograms below show the uniformity of the data (see Figure 9).



Note: Voltage drop on x-axis and frequency on y-xis.



Note: Voltage drop on x axis and frequency on y axis.

Figure 9

Finally, we measured the resistance across the board under cold conditions (submerged in liquid nitrogen). Before submersion the resistance was approximately 266 kΩ under room conditions. While in the liquid nitrogen bath (about 77 K), the resistance was about 464 kΩ.

The results from our tests with the flashlamp follow:

In order to find the light transferred, we recorded the voltage difference between the pulse (peak of the graph on the oscilloscope) and the ground state of the system (see Figure 10).

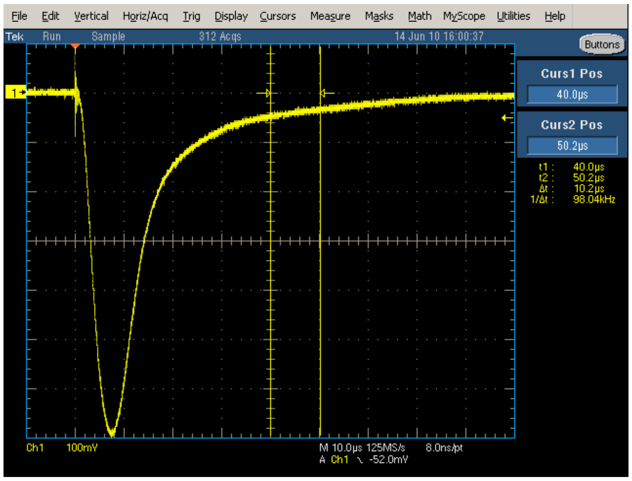


Figure 10: Graph of the oscilloscope reading of one of our measurements.

Figure 11 shows how we recorded the measurements from the oscilloscope.

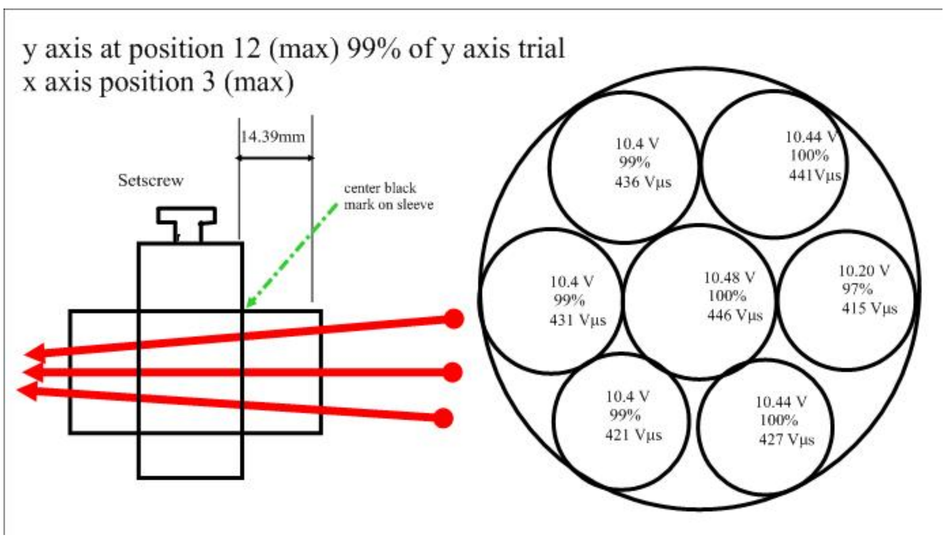


Figure 11: Schematic of our readings when z = 14 mm.

Tests were also done in the oxygen monitor with our flashlamp, and the same procedure was followed. The obtained measurements showed that the percentage of voltage difference between the middle hole and the surroundings was at most 25%.

The results for our motor are unavailable at this date, as the temperate sensor test will not be run until this fall. Our personal results, however, include abworking program and a much better knowledge of MATLAB.

DISCUSSION AND CONCLUSIONS

We first saw that the voltage increased linearly with the distance for the ESDG10. Thus, the resistance was uniform and wasn't subject to much variation. Our second testing technique confirmed this, although we did notice that the ends closest to the contacts had a higher voltage than the rest of the board. This occurred on both the front and back sides of the board. Under cold conditions, we found that the resistance doubled from 266 kΩ to 464 kΩ.

When working with the xenon flashlamp, we can conclude that the outside fibers of the porcupine were within our target limit of 30% light loss in both of our measurement sets, the oxygen monitor and the test setting one. Although more loss was measured during the oxygen monitor test, we still found this loss to be less than our 30% limit.

Even though there is no data to report for the stepper motor test, learning how to hook up the equipment and then write a program for it was very educational. We spent the most time on this project, as we knew very little about programming before starting this internship. I have now developed a new and useful tool which, to me, is valuable to report. I have learned many things this summer that are not taught in the classroom and have also expanded the knowledge that I came with.

ACKNOWLEDGEMENTS

I would like to thank the Department of Energy and Fermilab, especially Eric Ramberg, Roger Dixon and Carol Angarola, for making this internship possible. I would also like to thank Stephen Pordes [1] and Hans Jostlein for providing an endless amount of information and support. Finally, I would like to thank Daniel Sandoval, who put an incredible amount of work and effort into this internship. The only reason our summer project was successful was because of everything that he put into it.

REFERENCES

[1] S. Pordes, "Talk to CDF students on LAr," June 2009, http://lartpc-docdb.fnal.gov/cgi-bin/ShowDocument?docid=436.