Recoil Mass Separator Hysteresis Measurements and Germanium Detector Development

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Abstract

A recoil mass separator, St. George, was proposed to study nuclear reactions that control the energy production and nucleosynthesis in stellar and explosive helium burning in inverse kinematics. Dipole magnets will be used to separate out the charged states of the reaction products and filter out background radiation. It is not possible to measure the full magnetic field within these dipole magnets without interfering with the ion beam. For this reason a hall probe was used to measure the magnetic field outside of the strongest magnetic field region of the dipole magnet. Data taken comparing the magnetic field reading on the hall probe to that on a nuclear magnetic resonance probe in the center of the magnet, show the hall probe is sufficient to determine the magnetic field inside the dipole magnet.

Complementing the St. George mass separator is the Georgina project. This project will be used to study stellar burning by efficiently detecting low energy gamma rays from in-beam experiments. In order for the germanium detectors to operate correctly they need to be cooled down to liquid nitrogen temperatures. This is done by filling the detectors with liquid nitrogen and refilling the detectors every six hours. To allow for continuous use of the Georgina project, Labview code was printed on a CampactRIO system to fill the germanium detectors at specified offset times.

Introduction

The Nuclear Science Lab at Notre Dame focuses on nuclear astrophysics. This is the field of study that links nuclear physics to astrophysics by studying the nuclear processes that occur in stars and supernova. The Nuclear Science Lab is specifically interested in studying stellar nucleosynthesis. This is the process in which most elements heavier than hydrogen are formed. The goal of the lab is to determine the origins of elements and to further understand the universe [3].

The Strong Gradient Electromagnetic Online Recoil separator for capture Gamma Ray Experiments or St. George was designed to study stellar helium burning. St. George is a recoil mass separator located in the Nuclear Science Lab at Notre Dame. This separator will be used to study low energy reactions in inverse kinematics for beam masses with an atomic number as high as 40. Alpha capture reactions are important in stellar helium burning and affect the formation of heavy nuclei through nucleosynthesis. Low energy proton or alpha particle beams are traditionally used to study these reactions. The St. George provides the possibility to use heavy ion beams to bombard a ^{4}He jet gas target; the heavy ion recoil nuclei produced by alpha capture reactions in the gas jet are separated from the intense primary beam by the St. George separator. St. George is made of six dipole magnets, eleven quadrupole magnets, a Wien filter, and a detection system [1]. The project is broken into three sections. The first section chooses a certain charged state from the heavy ion recoil beam. Once the heavy ion beam collides with the helium gas target, the small percentage of heavy ion recoil products are of many different charged states. The first section on the St. George allows only the selected charged state to pass. This is done using dipole magnets to bend the other charged states too little or too much. Section two separates the heavy ion recoil from the original heavy ion beam by selecting only particles of a certain velocity. Due to conservation of momentum, the heavy ion recoil and the original heavy ion beam have the same momentum after the initial collision with ^{4}He jet gas target. The recoil product, however, has a higher mass and therefore a slower velocity than the starting ion beam. This makes it possible to separate the two beams by using perpendicular electric and magnetic fields. The final section of St. George is the detection stage. This section uses two targets to further filter the heavy ion recoil from the beginning heavy ion beam. The first target starts timing once the total beam collides with it and the second target, a distance away from the first target, determines the energy of the total beam. The amount of heavy recoil can then be

determined, using the time and distance to get to the second target along with the energy of the beam.

Georgina, which stands for Ge-detector Online aRray for Gamma ray spectroscopy In Nuclear Astrophysics, was designed to efficiently detect gamma rays from in-beam experiments. Georgina will also be a part of the Nuclear Science Lab at Notre Dame. The Georgina project will give additional data on low energy stellar burning experiments, which St. George cannot supply. Georgina can be used in alpha capture reactions along with St. George, and Georgina can collect data on proton capture experiments, which St. George cannot supply information on. Georgina consists of five germanium detectors which can be arranged in different formations to reduce background interference and more efficiently detect gamma rays [2]. Georgina and St. George will broaden the experimental techniques at the Nuclear Science Lab and help further understand fundamental concepts of the universe.

Georgina Code

The Georgina computer code is written to start experiments, continuously run experiments, and be accessible anywhere in the Notre Dame network. This code is written in Labview using a while loop to ensure the program runs continuously. The code also consist of a series of nested while loops to starting filling tanks with liquid nitrogen, set an offset time between the time the liquid nitrogen tanks are filled, indicate if a failure has occurred, and to reset the program. The program is written to fill the five germanium detectors one at a time, and then wait a set amount of time before refilling the detectors. LEDs are used as sensors to tell the program when the tanks are full of liquid nitrogen. When liquid nitrogen cools the LED sensors the resistance across the LEDs decreases which raises the voltage read by the program. Once the voltage is above 2.2 volts the program reads the tanks as being full. To ensure that the LEDs do not falsely indicate that the tanks are full, the program requires the tanks to fill a minimum amount of time before they can be considered full. This means the LED sensors must go off and the minimum amount of time specified must be reached before the next tank can fill. Additionally if the tanks take too long to fill, meaning a problem with the filling has occurred, the program will skip through any tanks left unfilled and indicate a failure has occurred.

Failure

The failure loop was written to prevent liquid nitrogen from being wasted in the case that a tube unconnected or an LED breaks. The failure indicator can be undone by pressing the reset button. The program will run in the failure loop until the reset button is pressed allowing for time to fix problems with the filling system.

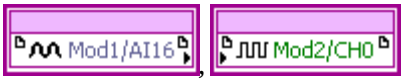
Start and Reset

The start and reset button was added to allow for manual changes in the program during the filling process. Upon starting the program the start or reset button will need to be pressed to start the tanks filling. No offset time occurs between start and the first filling. After the first filling is started the start button becomes a reset button. Pressing the reset button after a failure occurs starts the program at the beginning of the offset time. This means the program will take the specified offset time to start filling tanks again. Pressing the reset button during the offset time of the program starts the first tank filling again. This means pressing the reset button twice after a failure will cause the tanks to start filling again. Pressing the reset button while the tanks are filling stops the tanks from filling and sends the program back to the beginning of the offset time.

Labview Functions

Loop timer 

The loop timer function begins timing in milliseconds upon being called and continues timing throughout the duration of the program. When entering a new loop the loop timer continues to count but will not display the counting change in the new loop. This means a loop timer in a previous loop will only display the time at the start of the new loop on an indicator in the new loop. When using multiple loop timers, once the first loop timer is called all future loop timers also begin timing. This timing function only keeps track of the amount of milliseconds after it was called and does not work for determining the time of the day.

FPGA I/O Node 

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The FPGA I/O Nodes are used to either monitor the voltage in series with the LED or to turn on an LED indicator on the CompactRIO. Modulus 1 is used to monitor voltages using AI0 through AI4 to determine if the tanks are full and AI16 as the start and reset button. Modulus 2, channels 0 through 3 and modulus 3, channel 0 are used to indicate that a tank is filling.

St. George Dipole Magnets

The six dipole magnets on the St. George will be water cooled to 55 degrees Celsius and will be able to provide a magnetic field up to 0.6 tesla [1]. This will ensure that all the heavy ion recoil charged particles, remaining in the beam, have the correct charged state. The Lorentz force is responsible for bending the moving particles and the first two dipole magnets are used to ensure the Lorentz force thoroughly filters the ions. The particles with the specified charge state will be bent an angle of 26 degrees while all other charged states will be bent more or less and not make it through the exit aperture [1].

St. George Hysteresis Measurements

It was proposed to use a Hall probe to determine the magnetic field that influences the charged particles within the dipole magnet. To prevent the Hall probe from interfering with the ion beam, the Hall probe will be permanently mounted a fixed distance outside the region where the particles travel. The Hall probe will be placed approximately 5.5 inches from the center of the magnet. This position was chosen because a strong magnetic field still resides there while deflected particles will not collide with the probe there. To map out the change in the magnetic field with respect to the distance from the center of the dipole magnet and determine the magnetic field at the position the Hall probe will be mounted, a Hall probe was attached to a linear positioner. The magnetic field was then measured in 0.2 inch increments, up to ten inches, from the center of the magnet. These measurements were performed at five currents corresponding to five different magnetic fields. These currents started at a maximum of 120 amperes and decreasing by 20 percent of the maximum current down to 24 amperes. As shown in figure 1 the magnetic field is uniform near the center of the magnet and then drops off nonlinearly. The region of homogeneous magnetic field is the region where the ion beam will

travel. The position where the Hall probe will be mounted is in the nonlinear region of the magnetic field and is outside the region where the ion beam will travel. The nonlinearity of the magnetic field, in this region, makes it impossible to replace the Hall probe with a more precise Nuclear Magnetic Resonance (NMR) probe. This is because an NMR probe cannot resonate and give accurate results in a nonlinear field.

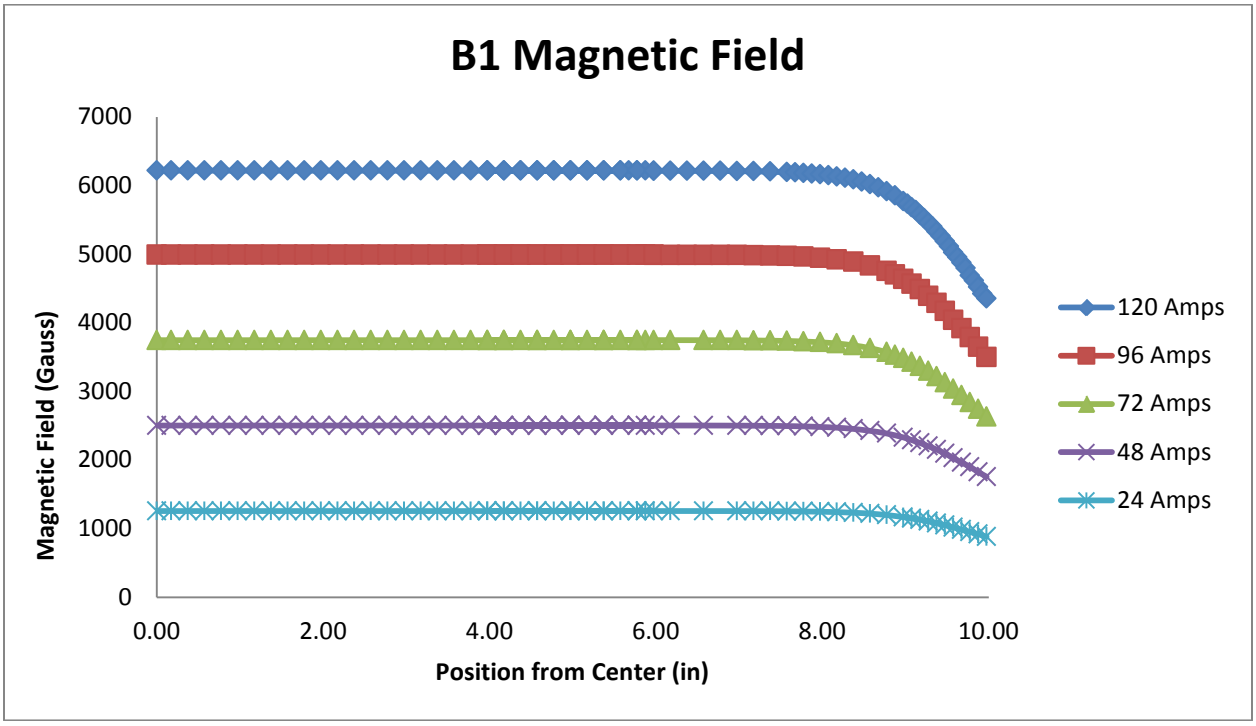


Figure 1. This shows the change in the magnetic field of dipole magnet B1 with respect to the distance from the center of the magnet. The different line graphs represent different currents.

The magnetic field, inside the dipole magnet, does not vary perfectly linearly with the current through the magnet. This is due to the hysteresis of the dipole magnet. In order to stay on one hysteresis curve and make measurements on the dipole magnet, it was propose to vary the current in one direction only. This means the current must either start at zero amperes and always increase or the current must be increased to the maximum current and then always decreased. When varying the current, the magnetic field must first stabilize at the most extreme current before increasing or decreasing the current.

To determine if a Hall probe mounted 5.5 inches from the center of the dipole magnet is sufficient to determine the magnetic field charged particles experience in the center of the dipole magnet, an experiment was conducted with an NMR probe in the center of the magnet. For this

experiment an NMR probe was held fixed at the center of the dipole magnet and a Hall probe was held fixed in its permanent position approximately 5.5 inches from the center of the magnet. The current through the dipole magnet was then varied and the magnetic field readings on the Hall probe and the NMR probe were recorded. To show the hysteresis of the magnet, the current was varied by deceasing from the maximum of 130 amperes to the minimum of 0 amperes and by increasing from the minimum current to the maximum current. This procedure was done by varying the current in 2 ampere units. This experiment was conducted on the B1 and B2 dipole magnets of the St. George. Figures 2 and figure 3 show that on both magnets the field reading on the Hall probe varies linearly with the reading on the NMR probe. This means that a Hall probe mounted approximately 5.5 inches from the center of the magnet is sufficient to determine the magnetic field within the center of the magnet.

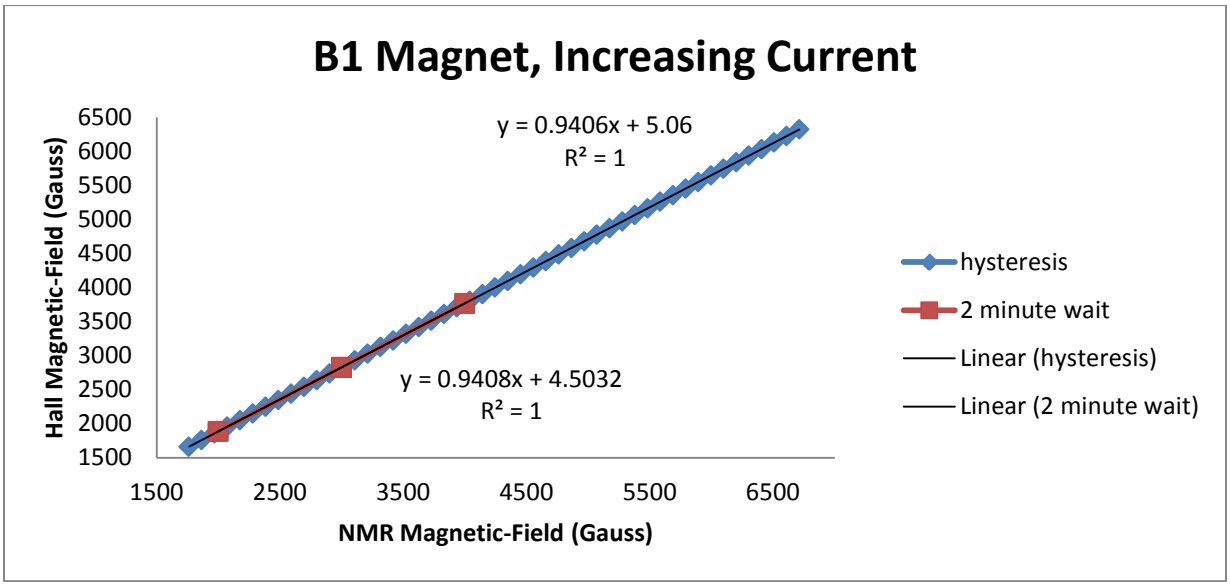


Figure 2. Magnetic field reading on an NMR probe versus the magnetic field reading on a Hall probe and corresponding linear fits of the B1 magnet. 2 minute wait plot corresponds to waiting two minutes at zero current before increasing the current to the chosen magnetic field.

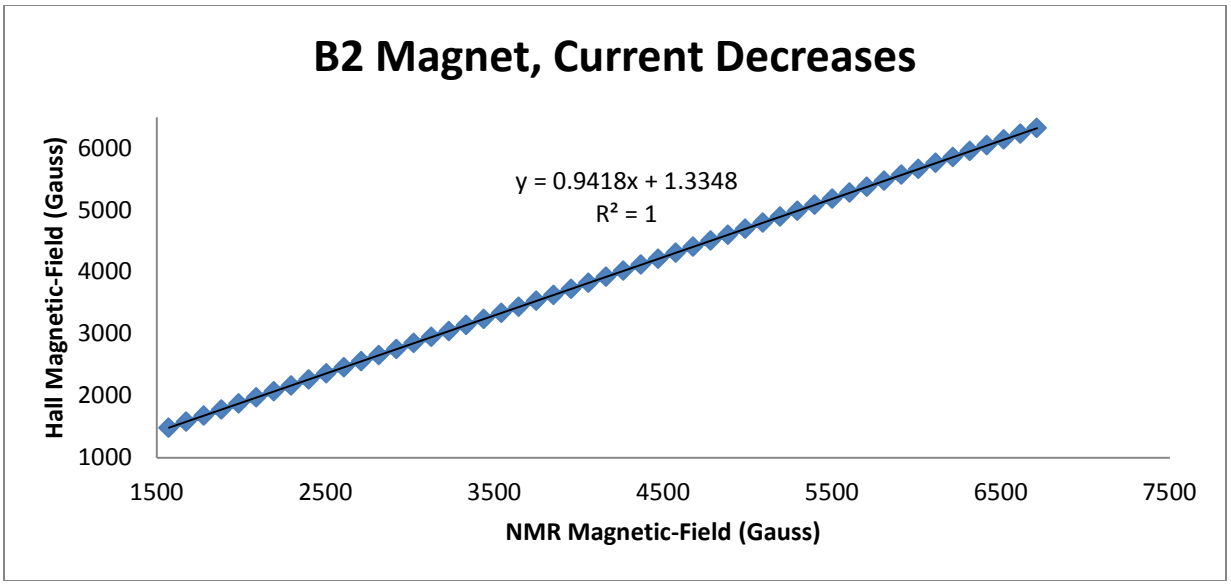


Figure 3. Magnetic reading on an NMR probe versus magnetic field reading on a Hall probe and corresponding linear fit of the B2 magnet. The current always decreased in developing this figure.

An additional experiment was conducted to determine the amount of time needed to allow the magnetic field within the dipole magnet to stabilize. This experiment was preformed to find the minimum amount of wait time needed to stabilize the dipole magnetic field. This was done by starting at either 0 or 130 amperes and waiting a specified time before increasing or decreasing to a desired magnetic field. This process was repeated several times waiting ten minutes, five minutes, and two minutes before changing the current. The process was repeated twenty five times for a two minute wait. Figure 2 shows the data from waiting two minutes falls on the hysteresis curve and has a linear fit close to the linear fit of the hysteresis curve. This means waiting at 0 or 130 amperes for two minutes is sufficient time to ensure accurate readings on the magnetic field probes.

Conclusion

The Georgina project is ongoing due to equipment needs and further testing. With the code written for Georgina however, the project only needs minor equipment assembling to begin experiments. St. George is also an ongoing project. Equipment malfunctions have slowed down the development of the project. However, with experimental evidence validating the use of a permanently fixed Hall probe and the hysteresis data on two of the dipole magnets, experiments can be conducted much quicker once the project is completed. Once the Georgina and St. George projects are fully operational the Nuclear Science Lab will be able to perform a wider

range of tests and will have a combination of experimental techniques incomparable to that of any other lab in the world.

References

[1] M. Couder et al. “Design of the recoil mass separator St. George.” *Science Direct.* (2007): 35-45. Print

[2] Garg, Umesh et al. “Development of GEORGINA.” (2009): Print

[3] "Experimental Research, Institute for Structure and Nuclear Astrophysics (ISNAP), University
of Notre Dame." University of Notre Dame. Web. 18 July 2011. <http://www.nd.edu/~nsl/html/research_exp.html>.