Study of the New Pulse NMR System for the Jefferson Lab Helium-3 Polarized Target

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Abstract

The polarized Helium-3 target is used to study the neutron because the Helium-3 nucleus behaves like a neutron in terms of spin. To measure the target polarization, a technique known as pulse Nuclear Magnetic Resonance (NMR) was tested. The new polarized cell has a design that induces convection of ^{3}He; therefore, a flexible polarimetry method, such as pulse NMR, can help researchers understand the dynamics in the cell. Pulse NMR can perform polarimetry in less time; however, there are limitations. The focus of this project is to find noise in the Pulse NMR signal and to compute the calibration constant to make the polarization easier to deduce. First, Pulse NMR calibration tests were performed by doing a field sweep NMR measurement followed by a Pulse NMR measurement controlled by LabView while varying independent variables. These include the temperature of the convection heater, the status of the oven, and the status of the heater. Data analysis, using MATLAB, was done by fitting the pulse NMR signal from the oscilloscope and using the Fast Fourier Transform to analyze the frequencies in the signal. Systematic errors, such as noise, were quantified by identifying their frequencies and amplitudes. The calibration constants were affected by the status of the laser, temperature of the oven, and the operation of the heater. The calibration constants of the target chamber and pumping chamber were closer together with convection. Also, convection decreased the value of the pulse NMR calibration constant for both chambers. Noise was found after analyzing the Fast Fourier Transform and fittings. These results will enable researchers to calculate the polarization with pulse NMR by itself. Knowing the noise frequencies can provide insight as to where unwanted background noise is originating. More importantly, pulse NMR will provide a flexible and viable method to measure the target polarization.

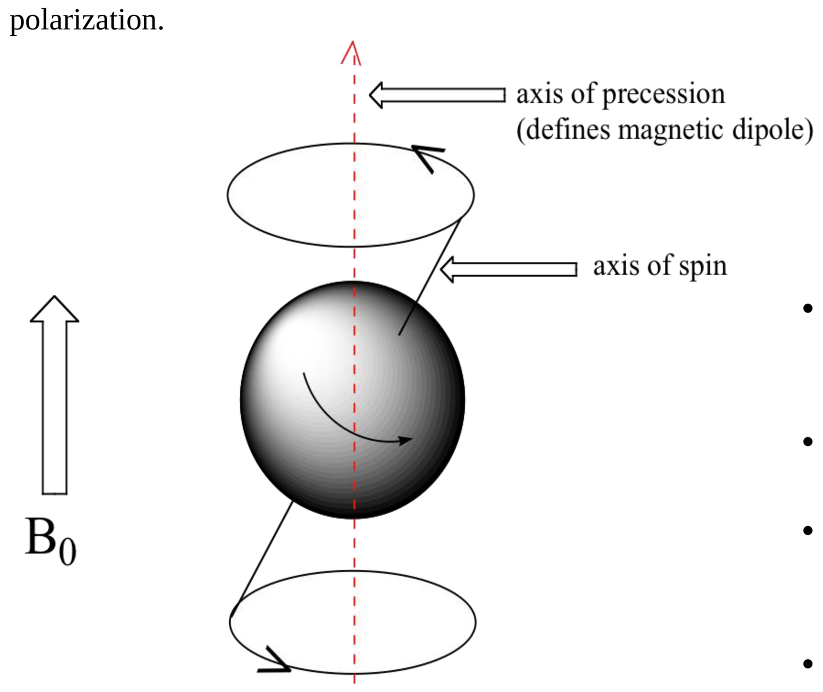

Figure 1. Diagram of magnetic moment in the presence of magnetic field [1]

How Pulse NMR works

- Radiofrequency (RF) pulse is tuned to the Larmor frequency of He-3 to achieve resonance
- Spin vector gets tipped at an angle and it decays after RF is turned off
- Signal is detected through magnetic field generated by oscillatory motion of nuclei [2]
- Signal shape is described by Free-Induction Decay (FID) [3]

Experimental Set-Up

Figure 2. Set-up of the three lasers and the optical equipment

Figure 3. The target cell apparatus with Helmholtz and RF coils

- Consists of target cell, an oven, air flow, Helmholtz coils, a pulse NMR coil, and pick-up coils.
- Three infrared high-powered lasers at 25 Watts are used for optical pumping
- The target cell itself contains a pumping chamber, a target chamber, and transfer tubes.

Figure 4. The new Helium-3 target cell that induces convection

Methodology

$$AFP\ NMR\ Signal \sim \frac{\omega_1}{\sqrt{(\omega-\omega_0)^2+\omega_1{}^2}} \qquad \text{Constant} = \frac{pNMR\ amplitude}{afpNMR\ amplitude}$$

- AFP NMR sweeps and pulse NMR sweeps.
- ‘Spin up’ means the laser is on and the polarization in the cell is increasing
- ‘Spin down’ means the laser is off and the polarization in the cell is decreasing
- The heater enabled convection to observe the effect of gas movement on calibration constant

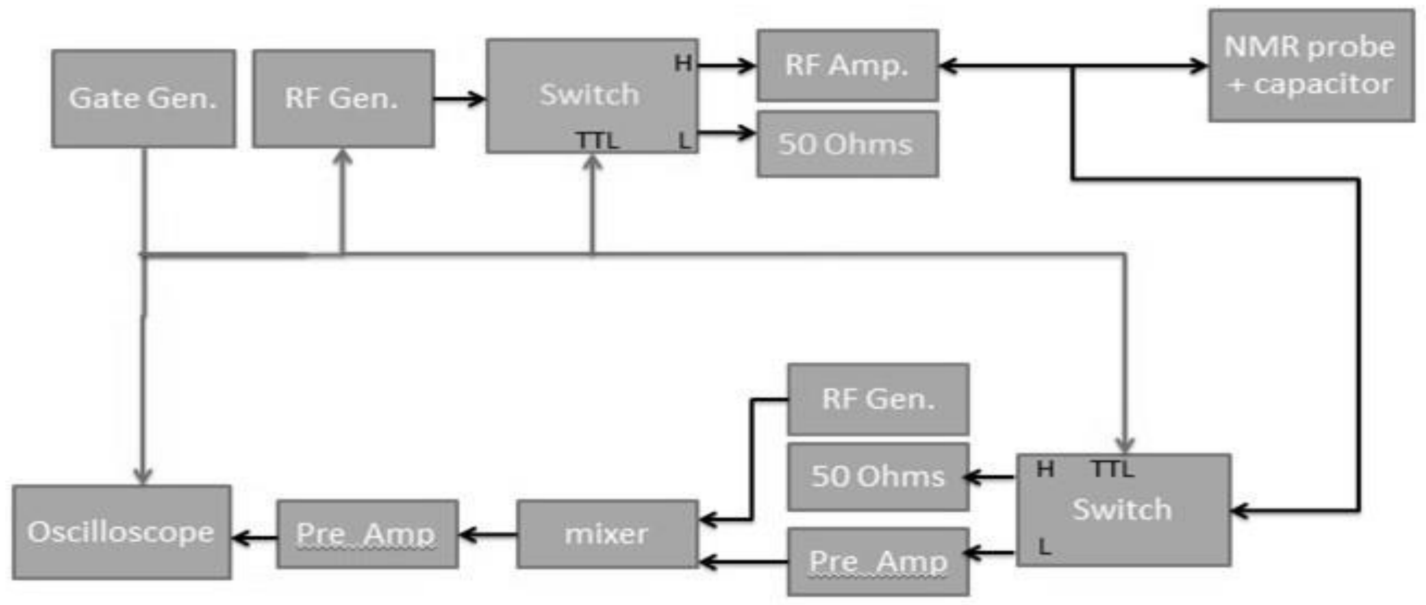

Figure 5. Design of the Pulse NMR system [4]

Signal Results

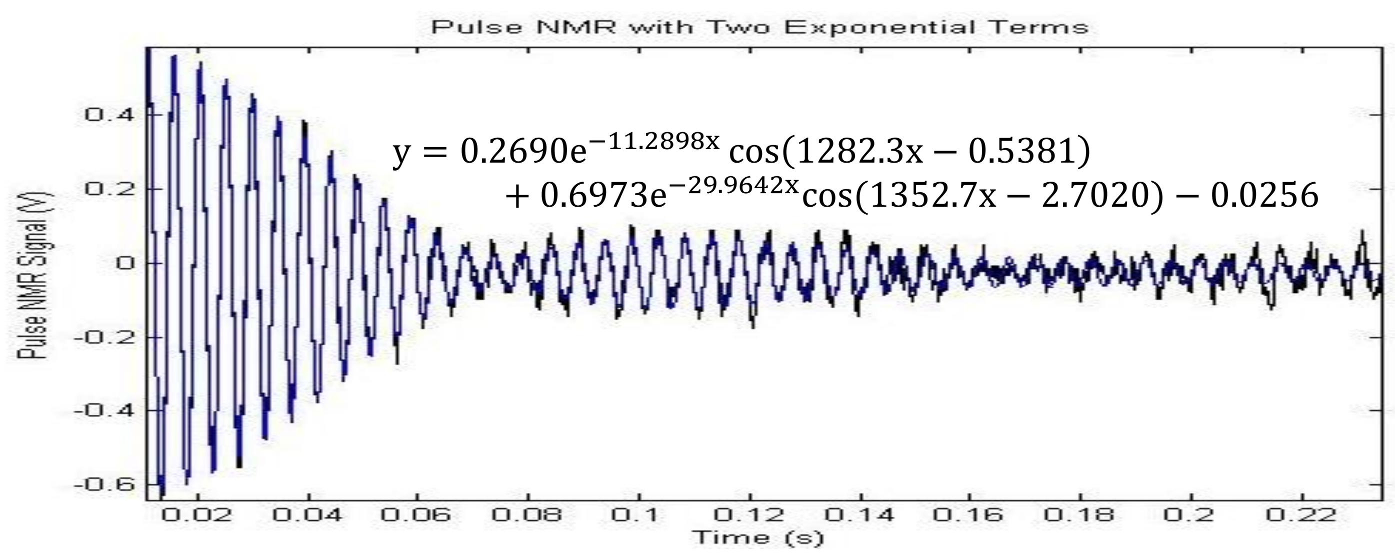

Figure 6. Pulse NMR data in black and fitting in blue

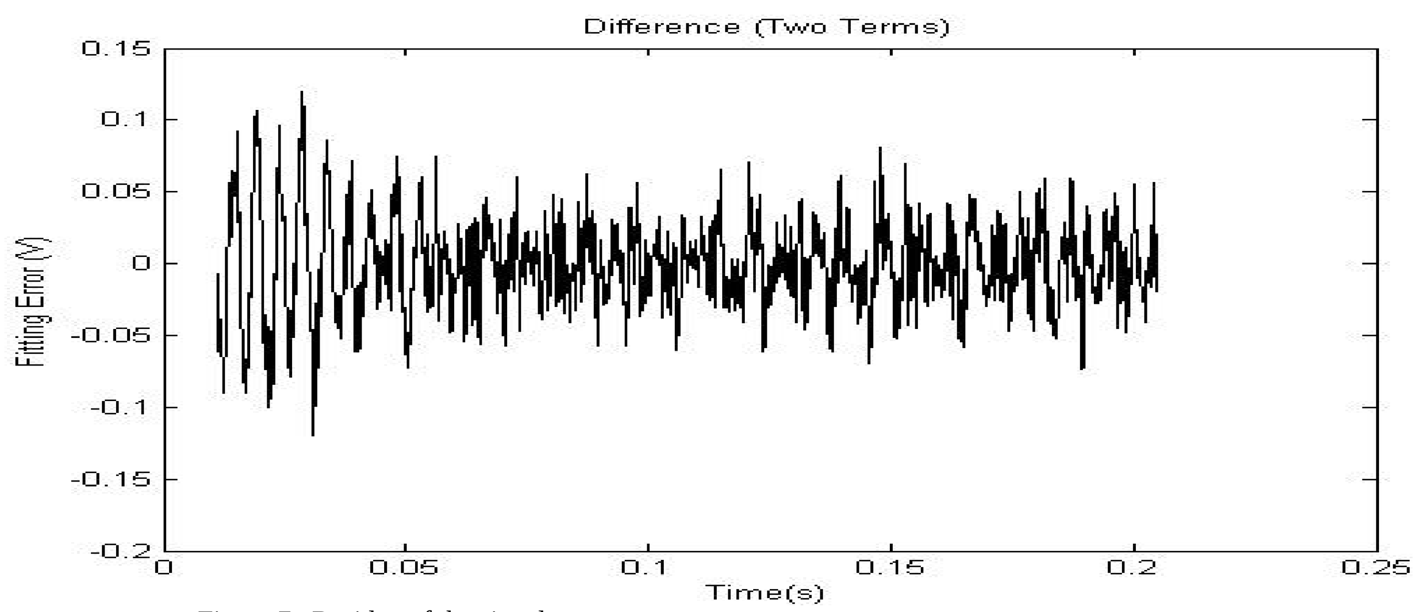

Figure 7. Residue of the signal

AFP NMR in Pumping and Target Chambers

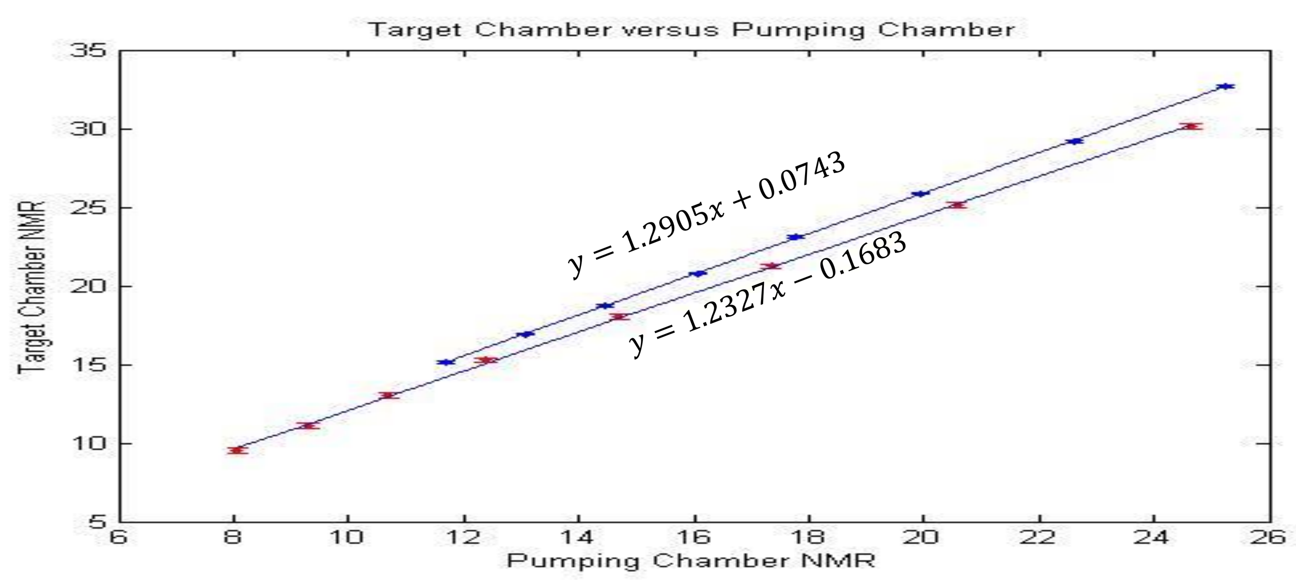

Figure 8. Blue is without convection and red is with convection

Pulse NMR Calibration with Convection

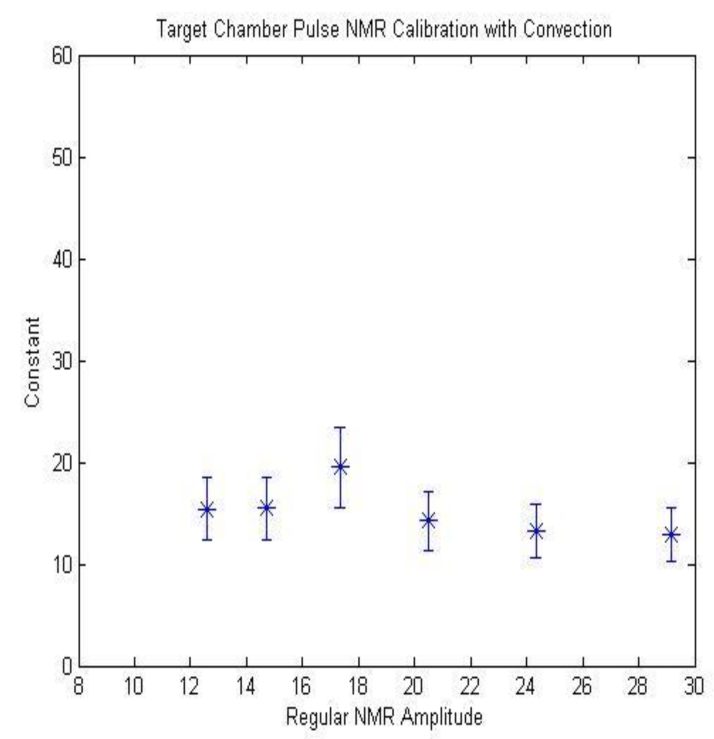

Figure 9. Target Chamber with Convection

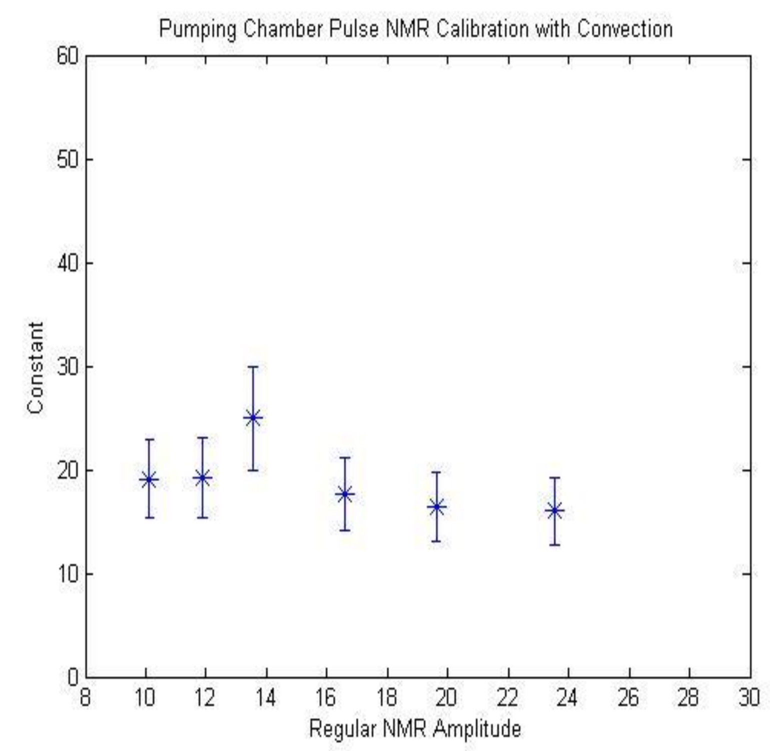

Figure 10. Pumping Chamber with Convection

Pulse NMR Calibration without Convection

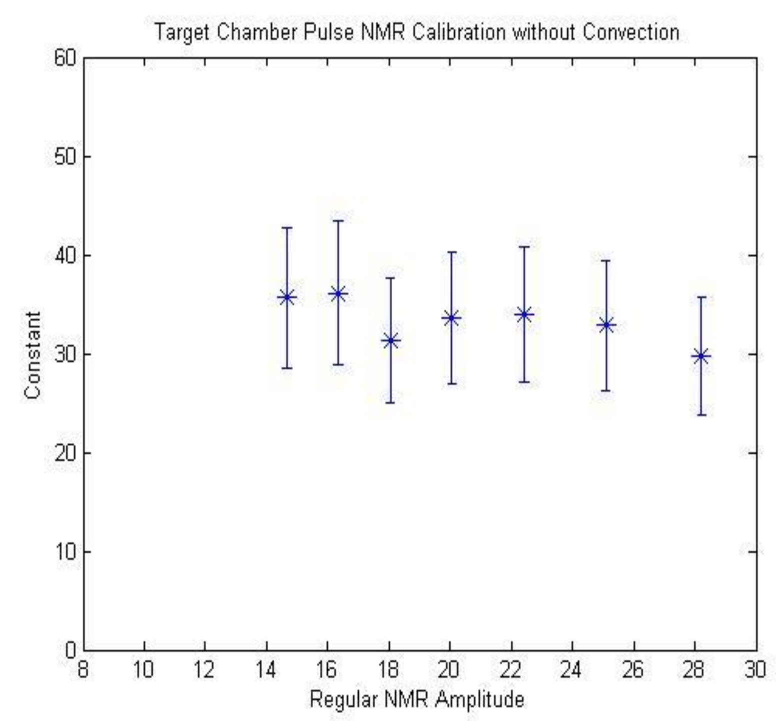

Figure 11. Target Chamber without Convection

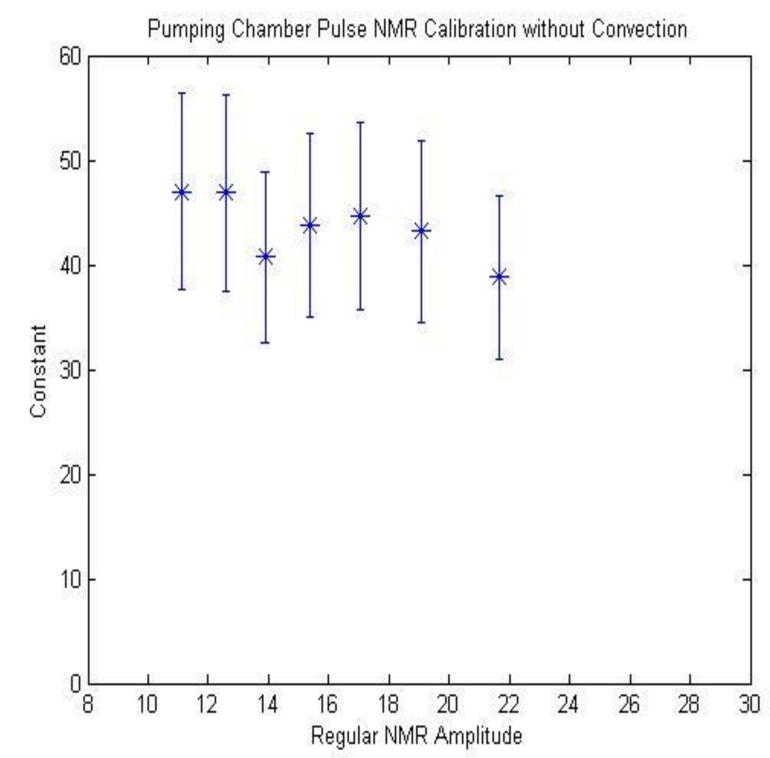

Figure 12. Pumping Chamber without Convection

Discussion

The pulse NMR signals contained significant noise based off the amplitudes of the two terms of the fitting. It is possible that one of the terms is the noise and the fittings show that the amplitude of one term is relatively close to the other. In addition, the residue displayed a certain amount of noise that we do not understand yet. The calibration constants were affected by convection. The calibration constants were closer together when convection is induced and further apart in the absence of convection.

Conclusion/Future Steps

Since the residue and the fitting both contain parts of the noise, there needs to further study on the source and nature of the noise in order to make pulse NMR analysis more meaningful and accurate. The calibration constants will be used to measure the relative polarization. Afterwards, the absolute polarization can be measured by calibrating it to electron paramagnetic resonance (EPR) and NMR water testing.

References

[1] http://chemwiki.ucdavis.edu/@api/deki/files/9271/=image004.png
[2] J. Singh, “Alkali-Hybrid Spin-Exchange Optically-Pumped Polarized Helium-3 Targets Used for Studying Neutron Structure,” Ph.D Dissertation, Dept. Phys., University of Virginia, Charlottesville, VA, 2010.
[3] S.T. Rohrbaugh, “Evidence for Relaxation of Xenon-125 By Paramagnetic Impurities on RbH Surfaces,” Ph.D Dissertation, Dept. Phys., University of Virginia, Charlottesville, VA, 2008.
[4] “Hall A Collboration Meeting” by Jie Liu, June 13, 2013.

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