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Dynamically Polarized Target for the g_2^p and G_E^p Experiments at Jefferson Lab¹

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Abstract—Recently, two experiments were concluded in Hall A at Jefferson Lab which utilized a newly assembled, solid, polarized hydrogen target. The primary components of the target are a new, high cooling power ⁴He evaporation refrigerator, and a re-purposed, superconducting split-coil magnet. It has been used to polarize protons in irradiated NH₃ at a temperature of 1 K and at fields of 2.5 and 5.0 tesla. Maximum polarizations of 55% and 95% were obtained at those fields, respectively. To satisfy the requirements of both experiments, the magnet had to be routinely rotated between angles of 0°, 6°, and 90° with respect to the incident electron beam.

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1. INTRODUCTION

Dynamically polarized targets continue to be an important part of the Jefferson Lab physics program. In the past, these targets [1–3] have been used in Halls B and C to measure the spin and electromagnetic structure of the nucleons. The target described here is the first dynamically polarized target used in Hall A. It is built primarily from components used in Halls B and C, modified to meet the needs of two experiments that ran concurrently. Some new components were manufactured, and most of the old ones were heavily modified to repair previous damage, or improve reliability and performance.

2. EXPERIMENTAL OVERVIEW

Two separate experiments requiring a dynamically polarized proton target were approved for operation in Hall A at Jefferson Lab. The first of these aimed to measure the proton’s transverse spin structure function g_2^p at momentum-transfer squared values as low as $Q^2 = 0.02$ (GeV/c)². The second experiment, herein referred to as “ G_E^p ”, measured the proton elastic form factor ratio $\mu G_E/G_M$ in the range $Q^2 = 0.01 - 0.7$ (GeV/c)². The experiments proposed to use the polarized target system that had been utilized in Hall C on three previous occasions as well as at SLAC. This target is described by Averett et al. [1]. However, they required different values for directions of the proton polarization (and therefore the target’s magnetic field) at each accelerator energy setting. For the g_2^p experiment, this direction was 90° with respect to the incident electron

beam, while for G_E^p it was 6°. Additional measurements were made at 0° for calibration of the spectrometer optics. This necessitated frequent rotations of the target magnet. The time required for this procedure has been dramatically reduced to only a few minutes by placing a new, rotary vacuum seal between the 1 K refrigerator and the top of the cryostat, and by constructing a new plumbing manifold between the refrigerator and the pumps. These allow the refrigerator and target insert to remain fixed with respect to the beam line while the rest of the target assembly rotates.

The ammonia samples were polarized at both 5 T and 2.5 T fields. The 2.5 T field was used during the g_2^p runs at the lowest energies despite the lower polarizations obtained at this field. Here a transverse 5 T field would have deflected scattered electrons of interest outside the acceptance of the Hall A spectrometers.

3. POLARIZED TARGET SYSTEM

3.1. Magnet

Unfortunately, we were unable to use the superconducting magnet of Ref. [1] for the Hall A experiments. During the final systems tests before installation in Hall A, the magnet quenched at 3.7 T and was damaged beyond repair. To execute the experiment, this magnet was replaced with a similar 5 T split coil magnet removed from the Hall B polarized target that is described by Keith et al. [2].

3.2. Refrigerator, NMR and Microwaves

A new, high cooling power, ⁴He evaporation refrigerator was constructed to replace the original refrigerator that was damaged during its last use in Hall C. The

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B Field	Beam Flux (e/cm ² s)	P_{\max}	P_{ave}
5.0 T	15.8×10^{10}	92%	70%
5.0 T	2.0×10^{10}	95%	83%
2.5 T	15.8×10^{10}	55%	30%

Maximum and average polarizations at varied field and beam current settings.

new refrigerator is nearly identical to the old, with the only changes being for ease of construction and to meet current safety codes. The design is well established and will not be described here.

An NMR system was used to measure the target polarization throughout the experiment. The NMR [4] system remained basically unchanged from previous DNP targets used at Jefferson Lab and by the University of Virginia Target group. The microwaves necessary for the DNP process were generated by extended interaction oscillator (EIO) tubes². Two EIO tubes were used, one for the 2.5 T (70 GHz) target configuration and one for the 5T (140 GHz) target configuration.

4. TARGET PERFORMANCE AND RESULTS

The two experiments, g_2^p and G_E^p , had different magnetic field and beam current requirements which resulted in varied regimes of target performance. Both experiments took advantage of the higher achievable polarization under a 5 T magnetic field, although g_2^p took a large portion of its data at 2.5 T, sacrificing average polarization to achieve the desired acceptance at very low Q^2 . A need for high precision and an insensitivity at low current of the beam position monitoring system in g_2^p put a lower limit on its beam current at roughly 50 nA. Roughly 142×10^{15} electrons per cm² (hereafter Pe/cm²) of dose from the CEBAF electron beam were incident on polarized ¹⁴NH₃ target samples during the two experiments.

4.1. 5 T Field Results

The polarization performance at the 5 T target field setting were typical of this type of target. The peak

polarization achieved was 95%. When a low electron beam current of 10 nA was feasible due to the high elastic scattering rates during G_E^p , polarizations exceeding 85% were maintained for long periods of time. The charge-averaged absolute polarization for G_E^p , excluding the commissioning irradiation, was 83%.

At 80 nA beam current and above, the polarization results matched the performance of the three previous Hall C experiments using this target. Anneals were performed after the polarization dropped below roughly 65%, which was required after between 2 to 4Pe/cm² dose on target. The charge-averaged polarization for this running was 70%.

4.2. 2.5 T Field Results

Our results at 2.5 T magnetic field exceeded expectations, achieving a record 55% in-beam polarization. We attribute the improved performance over similar results from 1984 [5] to increased microwave power and the pumping capacity to handle the corresponding added heat load.

5. SUMMARY

Even with the unfortunate failure of the original magnet, and the difficult requirement of frequently rotating the magnetic field, the updated DNP target was able to perform well in Hall A for the g_2^p and G_E^p experiments. High polarizations were achieved, and the target ran very reliable in a variety of configurations.

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² Communications & Power Industries LLC.