HYDROGEN/DEUTERIUM POLARIZED TARGET AT MIT-BATES

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MIT-Bates Linear Accelerator Center conducts experiments with polarized internal target in the electron storage ring. The target includes Atomic Beam Source (ABS), a storage cell and a polarimeter. Bates ABS is the first installation of the kind operated inside magnetic spectrometer in the presence of magnetic field exceeding 2 kG. The paper describes the specific features of the ABS operation in magnetic field. High ABS intensity ($2.5 \cdot 10^{16} at/sec$) and high polarization ($\approx 70\%$) inside storage cell have been achieved.

1. Introduction

Recently, experiments with internal target in the storage ring started at MIT-Bates. The facility includes polarized electron source, linear accelerator with a recirculator and South Hall storage ring (SHR). The experiments are conducted at electron energy of 850 MeV. The injected current into the ring is 150-170 mA, and the average current is 110-120 mA. Siberian Snake built in Budker Institute for Nuclear Physics (Novosibirsk) was installed in the ring. It allows to keep the longitudinal beam polarization in the internal target area with average polarization of 67%. BLAST (Bates Large Acceptance Spectrometer Toroid) magnetic spectrometer [1] is used to detect scattered electrons and secondary particles in coincidence. BLAST is an open geometry detector with a toroidal magnetic field. The experiments are conducted on polarized Hydrogen and Deuterium targets. ABS produces a jet of polarized atoms and injects it into the T-shaped storage cell (60 cm length, 15 mm diameter) cooled to about $100^o K$. The surface of the cell is coated with drifilm to minimize wall depolarization. Small outlet allows some fraction of the jet to go through the cell for polarization analisys in Breight-Rabi Polarimeter (BRP).

2. The Atomic Beam Source

The ABS is of a convenient design. Atoms leave RF dissociator through 2.1 mm nozzle, followed by a skimmer and a diaphragm. The focusing system consists of 2 sets of permanent sextupole magnets. MFT transition unit is located between the sextupoles, SFT and WFT units follow the second sextupole. For Deuterium target, we switch between 3 target states:

(1) Vector + : Pz=1, Pzz=1

(2) Vector - : Pz=-1, Pzz=1

(3) Tenzor - : Pz=0, Pzz=-2

The ABS was originally designed and build in Amsterdam [2]. It was shipped to Bates after AmPs was closed. However most of the ABS components had to be redesigned due to unique environment. The ABS is located inside BLAST magnetic spectrometer which produces severe space restrictions and a necessity to function in a strong magnetic field.

These conditions narrowed our choice of vacuum pumps. Large turbopumps don't fit into the available space, and they don't work in magnetic field. Still they are the best pumps for the first stages of ABS, where the gas load is high. We installed 4 turbopumps with a total pumping speed of 5240 l/sec outside the magnetic field and shielded them to reduce the residual field. Those turbos pump the first two stages of ABS via long (1.5 m) pipes of very large diameter (30 cm).

In the past the sextupole magnet chamber was pumped with 2 NEG pumps with pumping speed 1300 l/sec each. However, the use of NEG pumps might be dangerous, since they can overheat permanent magnets during the activation. Also, we found that they do not operate with specified pumping speed in our environment. The pumping speed degrades fast after the activation, and the pumps saturate much faster than they should. We attribute these effects to poisoning of the NEG surfaces by non-hydrogen species originated from degasing of coils in RF transition units. Lately, we replaced NEGs with cryopumps of compact design and high pumping speed (3000 l/sec each). It should be noted that these cryopumps break beyond repair in a strong magnetic field (demagnetization of the valve mechanizm) and needed to be shielded to reduce the effective field below .5 kG.

We observed an interesting effect of BLAST magnetic field affecting the focusing in sextupoles. Although the BLAST field is rather uniform, and it doesn't change the amplitude or direction of the gradients in sextupole magnet, it changes the direction of magnetic momentum of the atoms relative to the direction of the gradient. Generally, the force acting on the magnetic dipole is $\vec{F} = \vec{\nabla} \cdot (\vec{\mu} \cdot \vec{B})$, and since dipoles follow the direction of the magenetic field $\vec{\mu} = \mu \cdot \vec{B}/B$, $\vec{F} = \mu \cdot \vec{\nabla} B$.

In ideal sextupole ($B_x = G(x^2 - y^2)$; $B_y = -G \cdot 2xy$) with no external field the force has only radial component: $\vec{F} = 2G\mu\vec{r}$; $\frac{\vec{F}}{F} \cdot \frac{\vec{r}}{r} = 1$. External magnetic field B_0 applied in x-direction (so now $B_x = G(x^2 - y^2) + B_0$) doesn't affect the amplitude of the force, but it does change it's direction: $\frac{\vec{F}}{F} \cdot \frac{\vec{r}}{r} = \frac{1+b\cdot\cos(2\theta)}{\sqrt{1+b^2+2b\cdot\cos(2\theta)}}$,

where b is a ratio of external field and sextupole field at the given point $b = B_0/B_6$ and θ is a polar angle. One can see that in the regions where external field exceeds sextupole field, the y-component of the force changes sign and becomes defocusing! Since the BLAST field is over 2 kG, and sextupole field is 0 at the center of sextupoles, and about 10 kG at the pole tip, the effect is very significant and reduces the ABS intensity by factor of 2. We encased our sextupoles in magnetic shields and reduced the effect to less than 10%.

3. The Breight-Rabi Polarimeter

The convinient BRP with a permanent sextupole magnet, a chopping wheel and quadrupole mass analyzer (QMA) could not be used in our environment. QMA doesn't work in strong magnetic field, unless it was placed at the very bottom of BLAST pit, some 2 m away from the target. So far away the signal was to weak for reliable measurements. The only natural way to enhance the signal - compression tube - has too slow response time to be combined with a chopping wheel.

Instead, we used BRP with dipole magnet. The magnet has very strong (about 2.5 kG/cm) and uniform gradient and was placed after a small (2 mm) diaphragm below the outlet of the storage cell. 3 compression tubes (CT) have been installed 1.5 m below the magnet. With magnet off, the central CT collects both atoms and molecules. With magnet on, atoms are deflected into the left or right CT depending on their polarization. Our BRP allows to measure both degree of dissociation in the discharge tube (ABS sextupole magnets have been moved out for these measurements) and polarization in the jet. Morever, we could monitor the polarization of the atomic beam during the production run observing the signals from the left and right CTs. The drawback of the system is that only the central trajectories of the atomic beam are sampled in BRP, and therefore absolute measurements of polarization contain significant systematic errors.

4. The Ion Polarimeter

The Ion Polarimeter was designed and build in Amsterdam, and it was implemented at Bates only partially. The electron beam ionizes atoms and molecules in the storage cell. A set of electrostatic lenses extracts ions from the cell and accelerates them to 2.5 kV. Spherical deflector guides ions into the Wien filter, where they are mass analyzed. The full version includes deuteron ions scattering on Tritium target to measure the polarization, but these apparatus was not installed at Bates. Even the limited version allowing to analyze the mass spectrum of the ions and therefore to measure the atomic fraction in the target proved to be very useful. At the early commissioning phase we detected very low atomic fraction (less than 50%) for both Hydrogen and Deuterium, which explained low asymmetries we measured at that phase. We identifyed the problem as a damage to the cell surface caused by either Synchrotron Radiation (SR) or charge particles during the injection flash.

Later we removed the Ion Polarimeter and installed tungsten collimator just upstream the storage cell. It has an internal diameter just smaller than that of the cell, and it's shape was designed to protect the cell from the SR and charge particles and also minimize the background rate of the detectors. With collimator in place, we run for several months and do not detect any degradation of the cell.

5. The Target Performance

Target intensity and polarization are monitored on daily basis by measuring rate and asymmetry of the elastic and inelastic scattering. The ABS flow into the cell for both Hydrogen (1 state) and Deuterium (2 states) was about $2.5 * 10^{16} at/sec$ which produced target thickness of $7 * 10^{13} at/cm^2$. The measured polarization of the Deuterium target was Pz$\approx$ 72%, Pzz$\approx$ 68%. Polarization of the Hydrogen target was Pz$\approx$ 78%.

References

1. Proceedings of the 2nd Workshop on Electro-Nuclear Physics With Internal Targets and the BLAST Detector, May 1998, Cambridge MA, *World Scientific Publishing; ISBN: 981024004X*
2. Van Buuren L.D. etc, *NIM* **A474**,209 (2001).