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A COMPARISON OF SONA AND SPIN-FILTER POLARIZATION SCHEMES FOR A LAMB-SHIFT POLARIZED ION SOURCE

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Summary

Presently operating Lamb-shift polarized ion sources use either the Sona or the spin-filter polarization method. The University of Washington Lamb-shift source operated according to the Sona (diabatic field-reversal) method until late 1976. At that time we installed a spin-filter system and associated apparatus required to implement the rapid spin-reversal system of McKibben and Potter.[1] This conversion was motivated by a desire to reduce systematic errors in analyzing-power measurements below the 10^{-4} level achieved with the Sona scheme. This is of importance in our continuing efforts to measure parity-violating effects in ^{19}F and in other ongoing experiments. We report here a comparison of the performance of these two ion-source versions and construction costs of the spin-filter system. We also compare spin-correlated beam motion for the two systems. We find that the benefits associated with the spin-filter installation are well worth the cost.

Sona Source

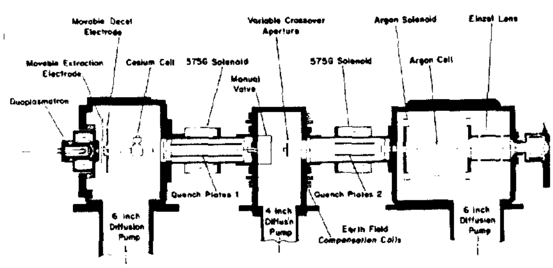

Fig. 1. Sona Lamb-shift Source.

The Sona version of the UW Lamb-shift source is shown in Fig. 1. This design was the result of a two-year development program and represented almost complete reconstruction of the ion source originally installed in 1971. The design was considerably influenced by the possibility of eventually installing a spin-filter system. Thus, a modular structure was chosen.

Of principal interest are the two 575 G solenoids and "crossover box". The latter provides pumping and serves as a support for Helmholtz coils used to cancel transverse fields in the diabatic field-reversal region. The 575 G coils are wound on split bobbins, and these are in turn mounted on thin-wall stainless steel tubes continuous with the vacuum system. This construction greatly reduces eddy currents and allows field reversal in about 12 ms. The solenoid around the argon cell is similarly constructed.

Spin reversal was affected in this system initially by reversing currents in all solenoids at about 3 Hz. Analysis of spin-correlated beam modulation indicated that such modulation could be significantly reduced if the 575 G solenoids alone were reversed and the argon field was turned off. The argon field was the dominant source of beam motion because this field is necessarily large ($\sim$150 G) for the Sona scheme and the beam is charged and has its largest diameter in the argon region. If the coil is not truly coaxial with the beam significant steering results. The beam polarization with the argon field off falls to about 60% of normal but the beam current almost doubles because of improved emmitance. Therefore, IP^2 is more than 1/2 the former value. The great reduction in spin-correlated beam motion with this final system (position shift and angle change) are $5\pm2 \times 10^{-6}$ radians and $4\pm1 \times 10^{-4}$ cm for a typical data-collection period.

The final version of the Sona source produced target proton beams in the 100-200 nA range with 75% polarization (quench ratio $\sim$ 6). Deuteron currents were similar with $P_z \sim 0.50$ and $P_{zz} \sim 0.60$.

Spin-Filter Source

The spin-filter version of the ion source is shown in Fig. 2. This design follows closely the "short cavity" system of Hardekopf.[2] Only the 575 G coils and associated drift tubes were discarded from the Sona version. Spin-filter solenoids were designed to be

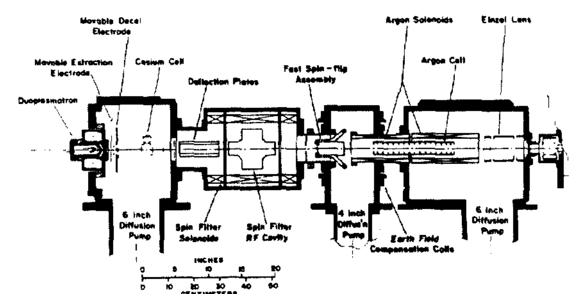

Fig. 2. Spin-filter Lamb-shift Source.

compatible with existing power supplies and the crossover box was retained for use with the rapid spin-reversal system described below.

The main solenoid, shown in Fig. 3, is a single unit of welded construction about 36 cm long which slides into an outer can. The coil is freon-cooled, and the solenoid bobbin is continuous with the vacuum system, eliminating the chance of freon leaks. All steel has been annealed before final machining, and critical areas are fabricated of Armco[3] steel. The completed coil bobbin has been treated with a "black oxidizing" rust preventive process before coil winding.

The rf cavity is 14.6 cm in major diameter and the central region is 9.5 cm long. The end sections are isolated to provide a uniform dc electric field over the cavity length. General construction principles have been described previously.[4]

The rf field distribution in the cavity has been determined by a bead-pull technique. The axial magnetic field is made uniform to ±0.3 G in 600 G over the entire 12.7 cm rf region by adjustment of three trim coils. The cavity Q is about 2200 when installed.

The rf oscillator is a solid-state, 1 watt, 1.6 GHz model produced by Aertech Industries.[5] The frequency stability is about 20 kHz after 10 minute warm-up. The stability of the cavity resonant frequency is about the same. Frequency drift effects are not noticeable in practice. Desired cavity power level is determined by a PIN-diode attenuator at the cavity input controlled in a feedback loop by a thermistor power meter connected to a cavity pickup loop. The oscillator and associated electronics are mounted on a stand directly above the spin-filter to reduce cable losses. Maximum power delivered to the cavity drive loop is about 300 mW. Normal operating power level is about 10 mW.

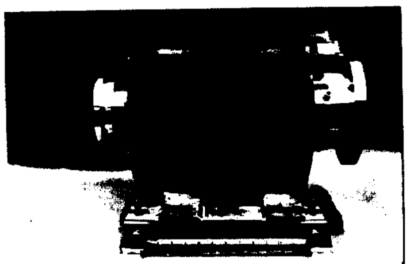

Fig. 3. Spin-filter Solenoid

The spin-filter source delivers typical target currents of 50-60 nA with a polarization of 0.83. With the fast spin-reversal system the average polarization falls to 0.77. However, this figure is expected to increase to 0.78-0.80 as proper adjustment of the rapid-reversal system is completed.

The reduction in beam current compared to the Sona version is associated with the elimination by the spin filter of one of two metastable atomic state transmitted by the Sona scheme. Some of this loss is compensated by ionization in a very weak argon field and associated emittance improvement. However, the quench ratio is reduced also. In order to produce reasonable polarization cesium and argon pressures must be reduced, with accompanying loss in beam intensity. We find that the typical reduction factor in intensity

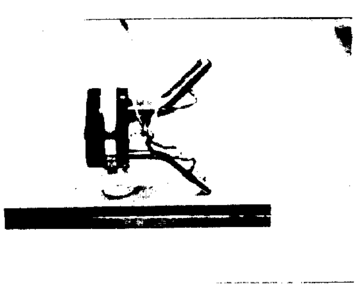

Fig. 4. Transverse field coils.

from Sona to spin-filter version is somewhat greater than two for comparable quench ratios (about 6).

Rapid Spin-Reversal System

The rapid spin-reversal system described here was first developed by McKibben and Potter at LASL. Generally speaking the system involves selection of metastable hydrogenic atoms in the $m_I = +1/2$ state by the spin filter. These atoms then pass through a diabatic field-reversal (as in the Sona scheme) between spin filter and argon regions. In the absence of transverse fields the atomic spins are undisturbed. If, however, a small (1.5 G), carefully shaped transverse field is applied in the crossing region the atomic spins precess in such a way that a reversal is accomplished. The system is operated with the transverse field alternately on (either polarity) and off at a rate of about 1kHz. The transverse field coil is shown in Fig. 4. Note that the coil forms are split at one end to eliminate eddy currents. The forms, together with compensating electric-field plates are mounted on an epoxy flange which allows arbitrary orientation of the transverse fields.

The electric field adjustment permits reduction of the average spin-correlated Lorentz force on charged

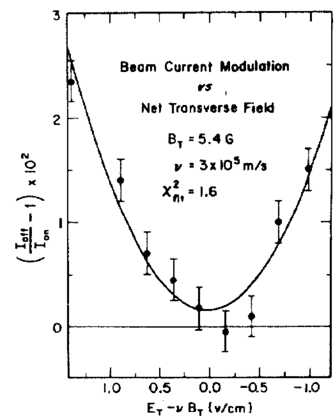

Figure 5.

particles passing through the crossover region to zero. Spin-dependent quenching of metastable beam depends quadratically on the net transverse fields and therefore can never be reduced to zero to the extent that these fields are non-uniform across the beam diameter. This quadratic dependence is illustrated in Fig. 5. These data correspond to a transverse magnetic field about 4 times larger than normal to enhance sensitivity. The quadratic fit indicates a maximum spin-dependent current modulation of 1.6×10^{-3} at this field strength or 1×10^{-4} at the operating point. This number may be improved by better matching of E and B fields along the beam axis.

A schematic representation of the spin-reversal process is given in Fig. 6. The spin precesses about the vector difference between the instantaneous total magnetic field vector and the angular velocity of this rotating vector. The axial and transverse field components must be shaped so that the spin is just antiparallel to the beam axis when the transverse field returns to zero. Results following a preliminary field shaping are given in Fig. 7. Polarization with transverse field off is 0.80 and with the field at the operating point is -0.75. The critical spin-reversal fields are generated by one transverse and four axial coils. Only a small region of this parameter space has been explored in our initial diagnostic runs. We expect some improvement with more experience.

Spin-correlated beam motion with this system is less than 7×10^{-4} cm and 2×10^{-5} radians with reversal fields parallel to the scattering plane and four times normal magnitude. With normal values and rotation of the fields normal to the scattering plane we expect a reduction factor of 200-400 in effective beam motion. This corresponds to upper limits of 3×10^{-6} cm and

1 x 10^{-7} radians, far better than our present requirements. Further diagnostic runs should reduce these statistical upper limits.

Construction Costs

Construction and installation of the spin filter required eleven months from initial design to beam on target. This work was facilitated by simultaneous use

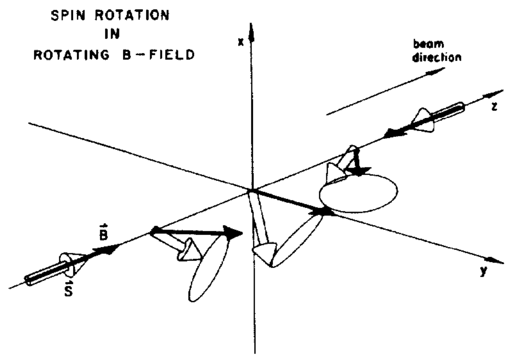

Figure 6.

of several machine shops on the UW campus. Total project shop time was 480 hours at a cost of $6000. The rf system, including the rf oscillator, Hewlett-Packard PIN modulator, power meter, heterodyne frequency converter and associated equipment, cost $5000. Technical staff salaries and other costs brought the total to about $15,000. This is to be compared with a $10,000 price for the rf system alone in an earlier spin-filter system.[6]

Conclusion

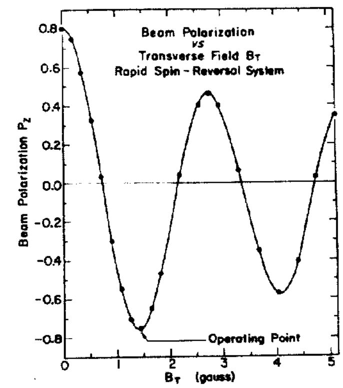

Figure 7.

Our experience with the completed spin-filter has been very satisfactory. The operating parameters are essentially unchanged since the initial setup, and the rapid spin-reversal system has exceeded our requirements for reduced instrumental asymmetries. We greatly benefited from the previous work of and communication with Dr. J. L. McKibben and Dr. R. A. Hardekopf of LASL.

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