AN IMPROVED BIRMINGHAM POLARIZED DEUTERON SOURCE AND INJECTION OF THE BEAM INTO THE CYCLOTRON

G. Guest, W. Hardy, S. Oh and W.B. Powell
University of Birmingham, Birmingham, U.K.

ABSTRACT

The stage one updating programme on the Radial Ridge Cyclotron polarized D^+ source has been recently completed. Initial tests and measurements have been carried out on the improved stability, beam quality and intensity.

Birmingham's first polarized deuteron source which adopted the atomic beam principle was operational in April 1965[1] when a beam of approximately 0.0 nA was measured at the scattering chamber. Since then efforts were made to improve the beam intensity and polarization,[2] which by 1968 gave 1 nA intensity with a polarization of 70% of the theoretical value. Attempts to improve the beam stability met with very little success; these instabilities were due mainly to electron trapping within the five einzel-lens assembly comprising the axial transport system and also problems associated with the ionizer.[3] All these modifications were on a small scale to give minimum interference to the nuclear experimental programme.

However, by 1970, it was obvious that the source was outdated; the advance in technology in this field had made possible beam intensities in some other laboratories[4,5] in the region of 200 nA. Table I shows a few comparisons, and a major modification and rebuild programme was started in September 1970.

Table I

	Other Lab	Birmingham	Factor against Birmingham
Dissociator gas throughput	9000∿15000 cc/h	900 cc/h	∿10
Sextupole strength at 4 mm radius	11000 G	6000 G	∿ 2
Sextupole to ionizer	25 cm	45 cm	∿ 2
Injection system transmission	85%	45%	∿ 2
Extraction efficiency	50 ∿ 70%	35%	∿
Cyclotron ν_z × magnet gap	0.6 × 10 cm	0.14 × 6.3 cm	

As a polarized ^{3}He project was to be mounted in parallel, it was decided to split the updating programme into two parts. The first, whic has recently been installed for operational tests, called for the redesign of the RF transitions, the ionizer and the axial transport system. The main object was to eliminate instabilities and also improve beam quality and beam intensity. It was essential that the redesign of the axial injection system was matched for both polarized deuterons and ^{3}He. The second stage, the redesign of the dissociator and sextupole from which was expected a big factor in beam intensity, was postponed until the ^{3}He project was completed.

Fig. 1 shows schematically the modified Birmingham polarized deuteron source. There are two RF transition apparatus with the vector transition apparatus placed in position in the figure. The RF transition apparatus for a vector polarization has a 20-turn solenoid for the four-level (If) transition at 7.5 MHz ($B_z \approx 0.8$ mT*) and a cylinder-shaped single-turn solenoid for the simultaneous $\phi_2 \rightarrow \phi_5$ and $\phi_3 \rightarrow \phi_6$ transitions at 329.4 MHz ($B_z \approx 1.4$ mT). The apparatus for the tensor polarization has two cylinder-shaped single-turn solenoids for the $\phi_2 \rightarrow \phi_6$ at 340 MHz ($B_z \approx 1.2$ mT) and $\phi_3 \rightarrow \phi_5$ at 315 MHz ($B_z \approx 1.5$ mT). All the transitions occur in a weak static field region. This choice enabled us to reduce the required RF power for hf transitions down to less than 5 W each, at the same time cutting the total length of each transition apparatus down to 95 mm. The static field for the If transition has a positive slope; this ensures that there is no mixing in of tensor component in the beam polarization.[2]

The ionizer has a solenoid and can produce an axial magnetic field of up to 0.2 T at the centre. The electron beam which emanated from the filament is accelerated towards the anode to ~600 eV and oscillates between the two ends of the ionizer until it hits the anode. The anode consists of three parallel tungsten wires with 3 mm spacing and runs parallel to the tungsten filament. This confines the radius of the electron beam in the drift tube to within 2 mm thus reducing the r component in the r-P_r phase space area. The solenoid field is actually modified by the presence of a soft iron above the filament in order to produce a rapidly converging magnetic field towards the anode. This convergence in the field helps in confining the electron beam to a small radius. The filament consists of two tungsten wires each of which carries about 130 A in opposite directions to each other in such a direction that the current further aids the confining effect. The space charge neutralization in the drift tube ("a" in Fig. 1) is essential to keep the phase space area and the energy spread of the deuteron beam within acceptable values. An effort is made to minimize the atomic beam hitting the metal wall of the drift tube and of the auxiliary tube ("b" in Fig. 1) to reduce the background unpolarized beam component. The drift tube has many vertical slots to allow maximum free movement of the residual gas from inside the tube.

* mT stands for millitesla. 1 T equals 10 kG.

The ionizer is followed by two accelerating cylinder lenses. The axial injection system consists of six electrostatic quadrupole triplets, four pairs of electrostatic deflecting plates, a beam buncher, a variable aperture and finally an electrostatic mirror at the centre of the cyclotron. Every effort was made to eliminate the electron trapping along any part of the system. This trapping arises from the fact that the electrostatic field of the lenses is not parallel to the cyclotron magnetic field along the injection system.[5] At the same time the acceptance of the injection system is maximized in order to transport as much ^{3}He beam as possible (the phase space area of the future polarized ^{3}He beam is unknown) down to the mirror. This injection system is designed to accept not only the polarized beams but also the unpolarized beams (^{3}He and ^{4}He) of up to several microamperes at the scattering chamber. The space charge repulsion along the injection system is estimated to be the main limiting factor for the maximum beam current attainable.

We estimated the effect of geometrical errors (machining and alignment) and of ripple contents and instability in the power supplies upon the beam optical property, and every effort was made to meet the requirements.

We first tested the new system in June 1972 and measured 3 nA at the scattering chamber. The current increased to 11 nA by the end of the run. Some quick measurements were taken during this run. As priority is given to the nuclear experiment, detailed investigation of the new system has not yet been done. We found, however, that the solenoid of the new ionizer had an internal electrical defect which resulted in a large deviation of the magnetic field from the expected shape, as the upper half of the solenoid windings were shorted out. It is amazing that the ionizer with such a serious defect worked at all. We expect that the correction of this defect will increase the beam intensity considerably.

As was noticed from Table I we believe we have a factor of 10∿20 in beam intensity in hand and therefore when the upper part is redesigned we expect to get several hundred nanoamperes of polarized deuteron beam at the scattering chamber.

It is appropriate at this stage to mention the Birmingham polarized ^{3}He project. This was started in April 1970 but as priority was given to updating the polarized deuteron beam the project has been delayed considerably. We hope to be able to test the polarized ^{3}He source by the summer of 1973.

We described at the previous conference[6] a combined electro- and magnetostatic regenerator for the extraction of a beam from the cyclotron. We would like to mention that the regenerator has now been replaced by a pure magnetostatic one which has an extraction efficiency of about 35%.

REFERENCES

1. W.B. Powell, IEEE NS-13, #4, 147 (1966)

2. S. Oh, Nucl. Instr. Meth., 82, 189 (1970)

3. W.B. Powell, Int. Conf. on Polarization Phen. of Nucl, Karlsruhe, 1965

4. Private communications with D.J. Clark, Lawrence Berkeley Lab., Univ. of California. See also D.J. Clark et al., Report UCRL-18934, 1969

5. H.F. Glavish, Proc. of Symp. on Ion Sources and Formation of Ion Beams, Brookhaven National Lab., 1970 (BNL 50310)

6. S. Oh and W.B. Powell, Proc. Fifth Int. Cyclotron Conf. (Butterworths, London, 1971) 208

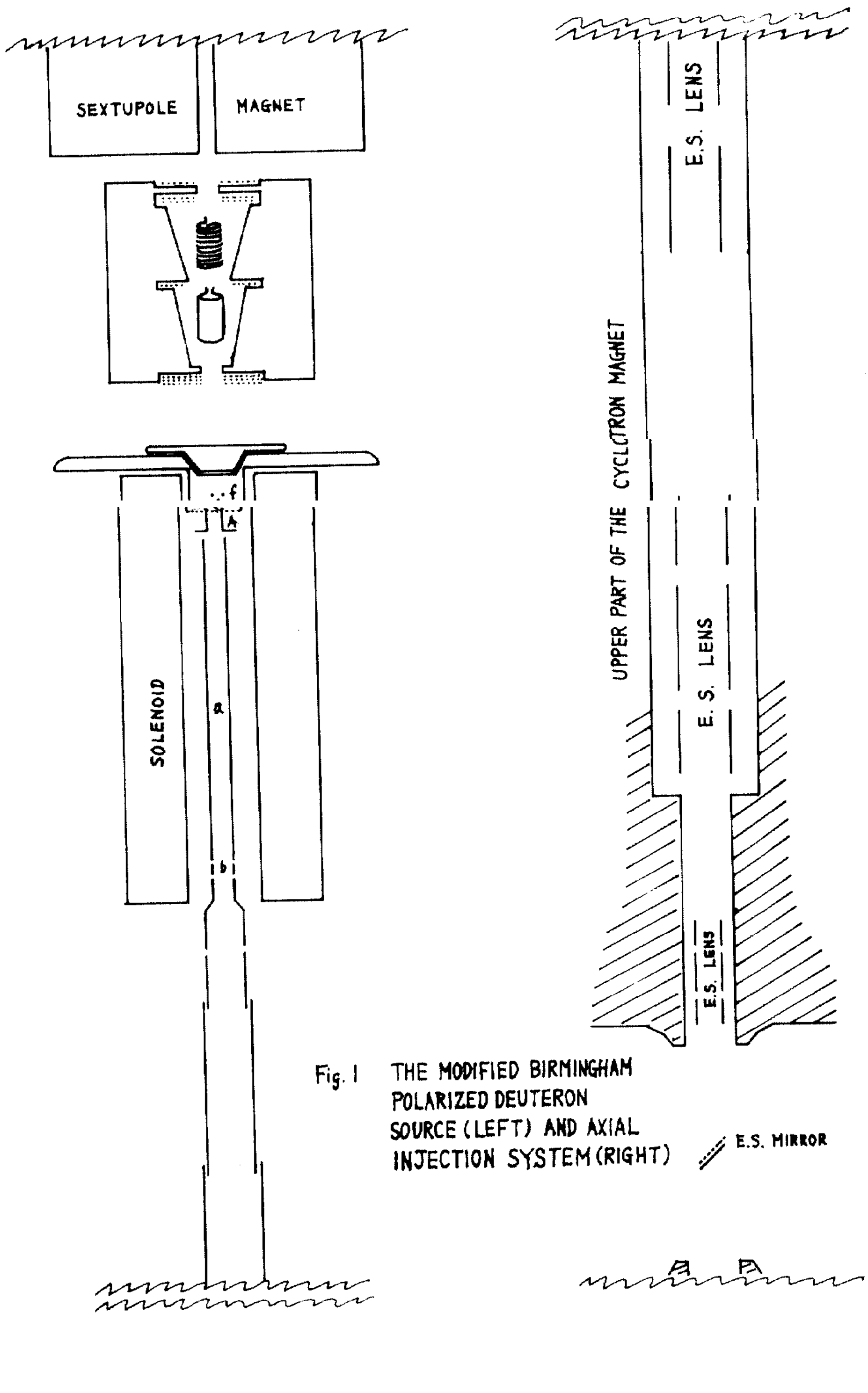

Fig. I THE MODIFIED BIRMINGHAM POLARIZED DEUTERON SOURCE (LEFT) AND AXIAL INJECTION SYSTEM (RIGHT)