STATUS REPORT ON THE UNIVERSITY OF MANITOBA CYCLOTRON

James Anderson, Robert Batten, John Bruckshaw, Mark de Jong,
Irving Gusdal, Gert Knote, Francis Konopasek, Alan McIlwain,
James S.C. McKee, Saewoong Oh and Robert Pogson

ABSTRACT

A comprehensive upgrading of the University of Manitoba cyclotron (20-50 MeV H^-) as a low energy research facility, has been in progress since 1974. When completed, the cyclotron is expected to provide polarised H^- and D^- beams with currents in excess of 15 nA in addition to existing beams of unpolarised ions. Along with a polarised ^{3}He target which is currently under construction this upgrading will add a new dimension to the facility.

1. Introduction

The University of Manitoba cyclotron was originally built for acceleration of H^- ions[1] from an internal ion source. Conversion to the external injection of H^- beam was a necessary first step towards the provision of polarised beams. We reported early results of the progress to the Seventh International Cyclotron Conference[2]. Since then there has been a substantial improvement in the injection system[3]. Lately we have successfully accelerated and extracted both a polarised H^- beam from a test source[4] and an unpolarised D^- beam[5]. Computer control of the injection system is in progress. A nuclear spin filter type Lamb-shift source, which adopts axial velocity differentiation method for removal of the direct H^- and D^- beam component, is nearing completion. We expect to be able to inject a polarised beam from this source into the cyclotron towards the end of this year.

2. External Injection System

The duoplasmatron source of H^- beam was initially placed in the cyclotron vault 1.5m above the cyclotron. In 1976 this was moved up a further 5.5m to a newly built ion source hall. As a temporary measure* the existing injection system was split into two, and only the duoplasmatron source compartment was moved up leaving the remaining part intact. The extended portion of the injection system was then connected by a transport system consisting of a pair of electrostatic (ES) quadrupole triplets. This pair have apertures of 76mm placed 3.5m apart and designed to transport polarised H^- and D^- beams of up to 300mm mrad. Two 2W cryopumps keep this portion of the transport system in a high vacuum and clean. In 1977 a new type of beam buncher[6] was introduced in the system. This operates in the combined first and second harmonic modes and, when tuned properly, results in 40% increase in the beam current over the first harmonic beam buncher. The cyclotron has a magnetic field of 1.87 Tesla at the centre and the injection energy for H^- beam is 11 keV. With the dee voltage only 30 kV (peak to ground) the orbits are pretty tight, being only 8.1mm radius for the first quarter turn, following injection. The 90° ES mirror at the centre of the cyclotron consists of a ground potential electrode with 5.5mm inner radius and 0.5mm thick, in which is housed a -9kV electrode of 4mm radius. The face of the ground potential electrode is inclined at 46.3° and is formed by an array of 0.05mm thick tungsten wires threaded onto the electrode. We reported at the 1975 Conference that the beam transmission efficiency from just before the mirror to the exit port from the cyclotron is 3% and that due to the sputtering process of the metals the insulator which separates the inner and the outer electrodes of the mirror eventually breaks down thus necessitating regular cleaning of the mirror each week. The situation has been improved, and the transmission efficiency from the first beam stop (1.5m above the cyclotron) to extraction is now between 10 and 18%. The mirror can now last a year without servicing. We think that the use of cryogenic pumps contributed significantly to the improvement in the mirror.

The mirror can be quickly taken out and replaced without having to vent the cyclotron. This enabled us to do some beam profile measurements at the mirror and to make a check of the alignment between the geometrical axis and the magnetic axis of the injection system. Thus we tuned the injection system for maximum transmission from the first beam stop to the inner electrode of the mirror. Then the outer electrode was replaced by a similar electrode with a 2cm long aluminum cylinder mounted on it instead of tungsten wires. The injection system was again tuned for maximum transmission onto the inner electrode through the 2mm diameter hole provided along the axis of the cylinder. It was observed that over 90% of the beam could reach the inner electrode through this 2mm hole, when tuned correctly; an indication that H^- beams spiraling downwards has less than a 0.5mm radius of curvature in the angular motion (ignoring any initial angular momentum). To see if this particular beam is also optimum for acceleration we changed back to the original tungsten wire electrode and, without any adjustment in the parameters, then accelerated the beam. It was observed that the beam was very close to optimum. Although these measurements may not be conclusive (they could be interpreted as a 100mm mrad beam with the geometrical axis of the injection system misaligned to the magnetic axis by 1mm, or 400mm mrad beam with the two axis almost perfectly aligned etc.) it implies that the alignment is perhaps within 1mm and that the vertical betatron oscillation frequency is not badly away from the adiabatic transition with the radius in the central region of the cyclotron.

Conversion into the external injection resulted in an improvement in the beam quality. The transmission efficiency through the existing five beam lines has been improved. The improvement is typically by a factor of two for the high resolution beam line or when narrow slits are used. This is an indication that the beam centre spread inside the cyclotron is reduced by one-half after conversion.

3. Polarised Beam

The main objective in the conversion to external injection was to inject polarised beams (H^- and, later D^-). Design of a Lamb-shift source began towards the end of 1976. This is shown in Fig. 1. The source (No. 1 to 11 in the figure) consists of eleven modules as explained in the figure. The duoplasmatron source produces several mA of proton beam. A water jacket provides cooling for coils and for anode. The extractor

Author's Address: Cyclotron Laboratory, Department of Physics, University of Manitoba, Winnipeg, Manitoba, R3T 2N2, Canada.

---

*This temporary measure has been adopted for a little longer than was expected and is, in fact, still in use. In the past we placed a series of apertures along the original portion of the injection system to protect the ES quadrupoles and deflection plates from being bombarded by 11 keV H^0 beams formed when the H^- loses an electron on collision with the residual gas.

0018-9499/79/0400-1976$00.75 ©1979 IEEE

can be positioned in the x-y direction while in operation. A series of cylindrical lenses follows the extractor. The length of each cylinder is short compared to its radius. This enables the variation of the potential along it smoothly, so that the aberrations can be kept to a minimum. The lenses focus in such a way that the beam forms approximately a uniform column between the cesium and the argon canals. The system is, however, flexible enough to focus the beam anywhere between the two canals. After the cesium canal we have bias electrodes, 5a and 5c. Here the direct H^- beam from the canal is decelerated by about 100eV, creating that much difference in the beam energy between the direct H^- and the desired component, H(2s). This energy difference is utilized to remove the direct H^- component at a later stage (7 and 8) by further deceleration. After passing through the argon canal, where the H(2s) is converted to H^-, the lenses in 7 and 8 focus the polarised H^- beam in 9. An aperture will be placed here to help remove some of the background of unpolarised H^- beam arising from H(1s).

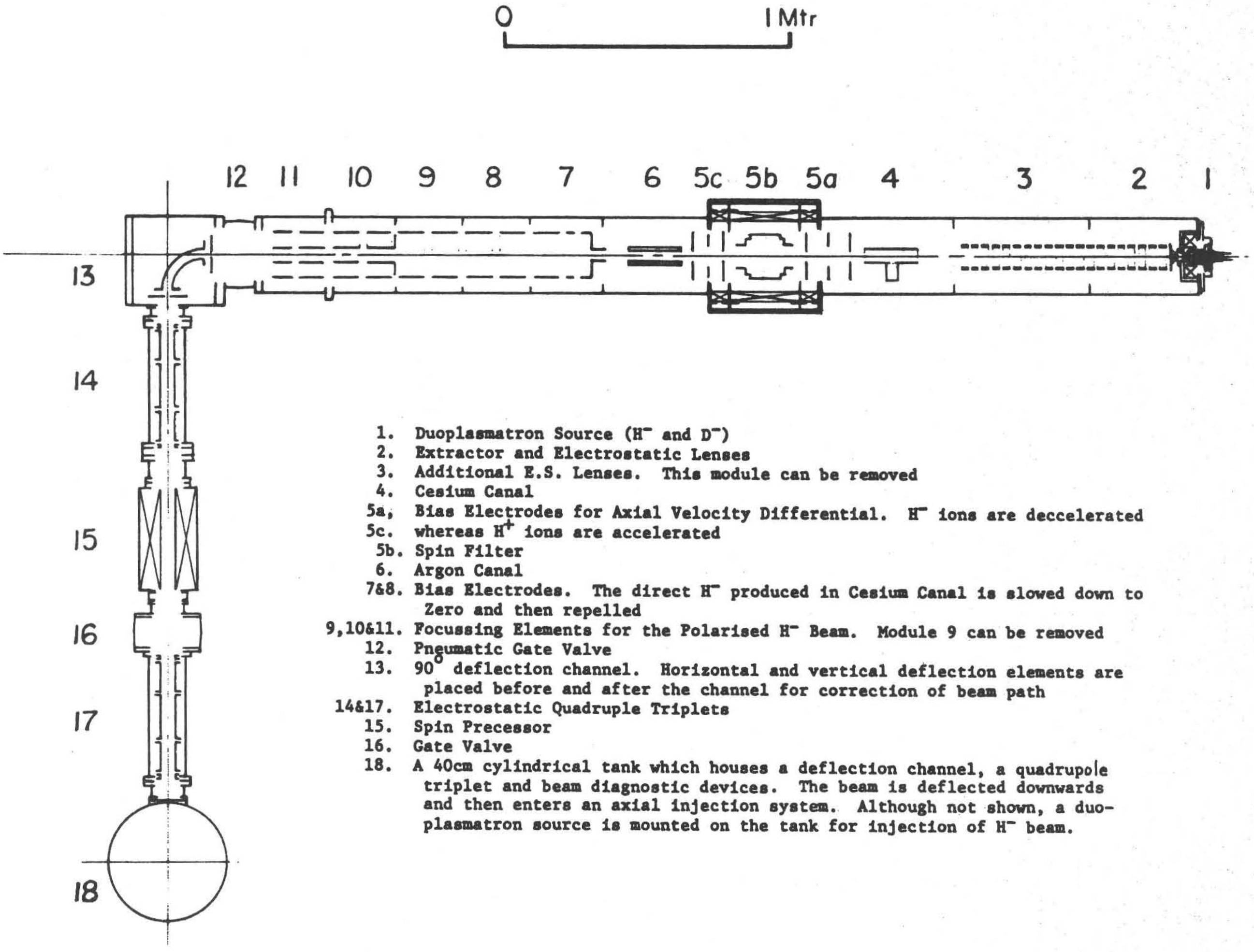
At this stage the beam is polarised along the direction of the Lamb-shift source. Successive 90° electrostatic deflection, 13 and 18, sandwiched by a 90° spin processor, 15, aligns the polarisation with the direction of cyclotron field.

A detailed study has been carried out for the source between the cesium canal and the first deflection channel[7]. From the study we expect that the above-mentioned method of separation of polarised H^- component will be equally effective for the geometrical parameters shown in Fig. 1. For production of polarised D^- beam this source is expected to perform a little bit better than the comparable source with the conventional deflection of unwanted beam. This comparison is, however, rather sensitive to the parameters such as beam size and divergence, the amount of deceleration in 5a and 5c and the degree of space charge neutralization in and before the cesium canal etc. and therefore optimization of this source is expected to take time.

Along with the construction of this source a polarised H^- source, developed at the University of Alberta as a prototype for the T.R.I.U.M.F. polarisation programme, has been adapted to the requirements of the Manitoba accelerator. Injection of polarised H^- beam from this source confirmed that it is indeed possible to inject, accelerate and extract H^- beam without destruction of polarisation[4].

4. Computer Control Of The Injection System

The focusing and steering of the external injection system is subject to drifts due to such causes as mains fluctuation, charging up of insulators, small vacuum leaks etc. Also source conditions may vary from time to time. To help control this problem we are building a set of programmable bipolar power supplies that may be controlled manually or by a microcomputer system. The computer is based on the TMS 9900 which is a 16 bit microprocessor. Ten bit digital to analogue converters are used to give one volt resolution to the one kilovolt supplies. Programmes have been written for this system using the existing PDP15 computer system and a cross assembler. The software will be designed to correct



1. Duoplasmatron Source (H^- and D^-)
2. Extractor and Electrostatic Lenses
3. Additional E.S. Lenses. This module can be removed
4. Cesium Canal
5a, Bias Electrodes for Axial Velocity Differential. H^- ions are deccelerated
5c. whereas H^+ ions are accelerated
5b. Spin Filter
6. Argon Canal
7&8. Bias Electrodes. The direct H^- produced in Cesium Canal is slowed down to Zero and then repelled
9,10&11. Focussing Elements for the Polarised H^- Beam. Module 9 can be removed
12. Pneumatic Gate Valve
13. 90° deflection channel. Horizontal and vertical deflection elements are placed before and after the channel for correction of beam path
14&17. Electrostatic Quadruple Triplets
15. Spin Precessor
16. Gate Valve
18. A 40cm cylindrical tank which houses a deflection channel, a quadrupole triplet and beam diagnostic devices. The beam is deflected downwards and then enters an axial injection system. Although not shown, a duoplasmatron source is mounted on the tank for injection of H^- beam.

Fig. 1 A plan view of the polarised ion source and the horizontal portion of the transport system.

drifts, and maintain beam optics at the optimum conditions set up manually by the operator. We hope that then it will only be necessary to optimize the optics at the start and then leave the computer to close in on the peak and then keep it there by a successive trial and error approach. The system chosen is flexible enough to allow further development of software and to add more analogue imputs and outputs. We estimate that this control will occupy about 10% of the capacity of the computer.

5. Other Development

After completion of the polarised H^- source we plan to redesign the lower portion of the injection system. This system was designed when it was incorrectly believed that the maximum rf voltage on the dees was 50kV peak to ground (it turned out to be 28kV in a subsequent measurement). It will improve the admittance and transmission. A refinement to the cyclotron magnetic field is also planned. Adding a third harmonic to the existing beam buncher is underway. Theoretically this will yield 10% improvement in the beam.

In conjunction with the polarised beam programme the experimental area is modified accordingly. This is shown in Fig. 2. A beam line (second from the top) is totally assigned for polarisation experiments. Both the ^{4}He polarimeter and the ^{3}He polarised target (based on the optical pumping) are near completion. A feasibility study of the electron cooling of polarised proton and deuteron beams in a storage ring is being undertaken.

Applications in Medical Physics and the production of radio isotopes are in progress. We have a separate paper on this topic at this Conference.

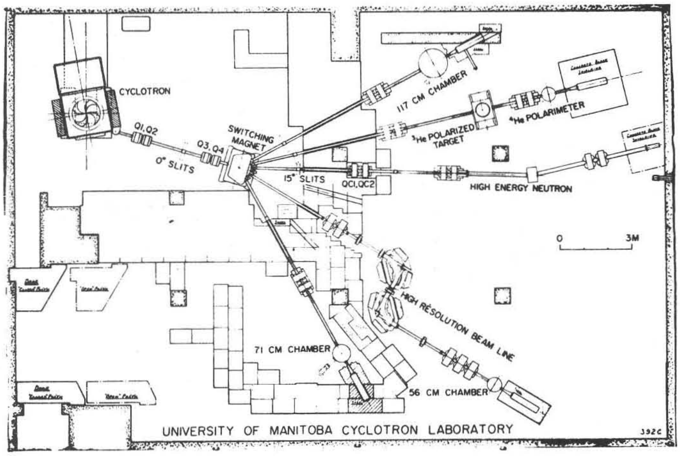


Fig. 2 Layout of The University of Manitoba Cyclotron and experimentary area.

References

1) J.J. Burgerjon, B. Hird, F. Konopasek, K.G. Standing, "The Manitoba Cyclotron", IEEE Transactions on Nuclear Science NS-13, 422-425, Gatlinberg, Aug. 1966.

2) A. McIlwain and S. Oh, "A vertical injection system for the University of Manitoba Cyclotron", Proc. 7th Int. Conf. on Cyclotrons and their Applications", 394-396, Basel, Aug. 1975.

3) R.A. Batten, J. Bruckshaw, I. Gusdal, G. Knote, A. McIlwain, J.S.C. McKee and S. Oh, "Axial injection of H^- ions into the University of Manitoba variable energy cyclotron", Nucl. Instr. and Meth. 136, 15-17, July 1976.

4) A. McIlwain, S. Oh, R. Abegg, R.H. Batten, J. Birchall, I. Gusdal, G. Knote, W. Mulholland, J.S.C. McKee, R. Pogson and N. Videla, "Polarised beam from the University of Manitoba spiral ridge cyclotron", Nucl. Instr. and Meth. 153, 283-284 July 1978.

5) I. Gusdal, G. Knote, A. McIlwain, J.S.C. McKee, S. Oh and H.W. Uzat, "The acceleration of deuterons by the University of Manitoba variable energy cyclotron", Nucl. Instr. and Meth. 136, 393-394, 1976.

6) R. Pogson and S. Oh, "An improvement to the beam buncher of the University of Manitoba cyclotron", Nucl. Instr. and Meth. 145, 403-404, Sept. 1977.

7) To be published.

** DISCUSSION **

G. DUTTO: What amount of polarization do you expect from your source?

S. OH: We expect 80% polarization for protons and 85-90% for deuterons.