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THE UNIVERSITY OF MANITOBA CYCLOTRON FACILITY

I.Gusdal, J.Anderson, J.Bruckshaw, V.Derenchuk, F.Konopasek, J.Lancaster, S.Oh, C.A.Smith, H.Uzat, M.Yoon and J.S.C.McKee

University of Manitoba Cyclotron Laboratory, Winnipeg, Manitoba, R3T 2N2, Canada

Introduction

The University of Manitoba Cyclotron has completed an extensive major upgrading that has resulted in a virtually new and different facility.

Construction of the original four sector, spiral-ridge cyclotron was completed in 1965 [1]. It was designed primarily to accelerate H^- ions with a provision to accelerate D^- ions. The cyclotron originally operated with an internal ion source, which was subsequently replaced with an axial injection system in 1976 [2,3]. At this time, D^- ions were successfully accelerated and extracted for the first time. Since then, both unpolarized an polarized H^- and D^- ions have been injected into the machine [4]. Polarized D^- ions were successfully accelerated, however a resonant depolarization of H^- ions prevented the extraction of polarized H^- beams.

Prior to the present development program, H^- ions were axially injected at 11 kV and deflected through ninety degrees by an electrostatic mirror. The ions were then accelerated by a two dee RF system operating at 28.48 MHz in push-pull mode (dee voltage 180 degrees out of phase) with a peak voltage of 29 kV. D^- ions were injected at 5.5 kV and accelerated at 14.24 MHz also in the push-pull mode at a peak voltage of 14.5 kV. These parameters have been changed as a result of the present upgrading (Table 1).

The magnetic field has an average strength of just under 2 Tesla and is trimmed by 64 temperature controlled blocks of INVAR, equally divided under the 8 hills. The accelerated beam is extracted by the use of a stripping foil, with the final deflection from the machine being made by a combination magnet at the exit port.

The original design parameters called for variable energy proton extraction from 22 to 50 MeV and variable energy deuteron extraction from 12 to 24 MeV. While the cyclotron had been reliable at lower energies, the beam intensity dropped rapidly above 42 MeV, with a maximum extracted proton energy of 48 MeV. The deuteron mode was rarely used because of low beam intensity, a maximum energy of 19 MeV, very poor beam quality, and RF heating of the rear half of the vacuum chamber due to the position of the dee tuning bar.

The latest modification has involved reshaping the magnetic field through the use of iron shims, the design and installation of a completely new Dee and RF system and the construction of an Ehlers type ion source. Only the main magnet and hill assembly, and the injection line were retained. All design and construction was done "in-house". The details of the modification have been described elsewhere [5,6,7]. The intent of this paper is to describe the new machine parameters and to give an overview of the machine performance to date.

Design Goals for the Modification

The major design goals for the present modification were:

1. Increase beam quality and intensity at all energies.
2. Obtain reliable acceleration up to 50 MeV for protons and 26 Mev for deuterons.
3. Make the deuteron acceleration mode equally as efficient as the proton mode.
4. Enhance deuteron beam quality to the point where single turn extraction up to 15 MeV is possible.
5. Provide a successfully accelerated polarized deuteron beam.

Modification Parameters

The modification basically consisted of reshaping the magnetic field to improve isochronism and focussing, replacing the half wavelength dee system with two quarter wavelength dees independently driven by separate RF systems and constructing a new ion source.

The predicted and achieved machine parameters are listed in Table 1.

RF and Dee System

The RF and dee system was installed in June and July of 1984. Many problems were experienced in bringing this system into operation [6], as must be expected during such a dramatic change. However, by mid December we were finally able to hold 35 kV on the dees. An H^- beam was injected into the machine and accelerated beam was immediately visible on an internal fluorescent probe. The basic design concept had been proven and over the next few weeks machine parameters were tuned and minor modifications completed which yielded a useable extracted beam.

The RF system is now extremely stable, reliable and easy to use. The experience gained in operating the RF showed that the automatic control system could be more simple than was imagined and peak dee voltages of 43 kV are easily achieved at 2/3 the maximum available input power (see Table 1). This compares with a previous maximum dee voltage of 32 kV running flat out on the old system.

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TABLE 1

Machine Parameters		OLD	NEW
Injection Voltage	H^-	11 kV	12 kV
	D^-	5.5 kV	15 kV
Dee Voltage	H^-	29 kV	40 kV
	D^-	14.5 kV	40 kV
R.F. Power		20 kW	2 x 20 kW
Frequency	H^-	28.480 MHz	28.296 MHz
	D^-	14.240 MHz	30.500 MHz In Phase
Dee System		2 x λ/2	2 x λ/4
Beam Energy	H^-	22-48 MeV	22-50 MeV
	D^-	12-19 MeV	12-26 MeV
Beam Current	H^-	10 μA,max	20 μA,design
		4 μA,av.	6 μA,prelim
	D^-	2 μA,max	20 μA,design

Machine parameters before (OLD) and after (NEW) the present modifications.

Deuteron Mode

To convert from the proton to the deuteron mode of operation one must replace the central region dee tips, axial injection mirror ground housing and retune the RF from 28.296 MHz push-pull to 30.500 Mhz push-push. All these are simple procedures, but require the machine to be vented for the exchange of the central region as it is not possible to compromise the central region design in order to have a bifunctional component, and still maintain the required beam quality.

The RF system has been tested in the deuteron mode and operates as efficiently as in the proton mode. Conversion to deuteron operation will take place in September 1985, and based on the results of the present proton mode of operation, the design parameters of the deuteron beam should be readily attainable.

Operating Experience and Beam Properties

The cyclotron has now been in operation since mid February with beam being available about 50% of the time to mid April. Since mid April the cyclotron has worked quite reliably, and with continuous operation, the beam properties improve steadily. One reason for the steady improvement with operation is due to the decrease in pressure in the vacuum system as the outgassing of the new machine components takes place. Since this is a negative ion machine, any improvement in the vacuum decreases the gas stripping of the beam and as a result there is a much more dramatic increase in beam intensity.

Figure 1 is a comparison of the beam intensity versus beam energy for the cyclotron before and after the present modification. One of the major design goals was to improve the beam performance above 42 MeV and, in particular, obtain 1 μA of extracted beam at 49 MeV. As shown in Figure 1, there is a great improvement in beam intensity above 42 MeV, with beam having already been accelerated out to 50 MeV. We have also accelerated 1 μA of beam at 49 MeV without the Ehlers source being used and with little difficulty.

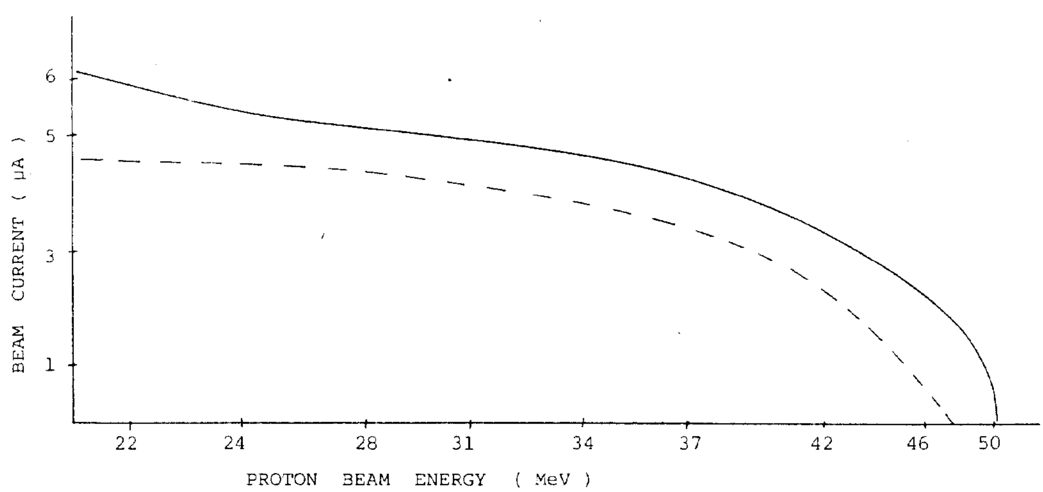

Figure 1

Proton beam energy vs beam current
Dashed line represents the optimal performance prior to modification.
Solid line shows the present operating beam performance.

It should be noted that the machine operation has not as yet been optimized in the high energy region. It was decided to allow a few weeks of operation to permit maximum stabilization of the machine components before the final optimization of the RF and magnetic field parameters was tackled. Since the initial beam parameters are already superior to those in the previous system, this is not a high priority.

While the emittance measurements have not as yet been made, the quality of the beam has noticeably improved. This conclusion is based on the ease and efficiency of transporting the beam through the beam lines and onto target. The minimum size of the beam spot at the irradiation cube on the zero degree beam line is also much smaller than previously attainable.

Conclusion

The conversion of the cyclotron from the old to the new system was an extremely challenging project, both in the planning and final implementation stages. The initial operating performance has already met, and in some cases exceeded, our initial design goals. The cyclotron is operating very well on proton acceleration, awaiting the final optimization of machine performance. It is already obvious that 50 MeV beams are now an operational reality.

The deuteron mode, including polarized deuterons, and the Ehlers source will be made operational in the early fall of this year. Based on the manner in which the proton performance met the design parameters, we feel quite confident that the deuteron mode will operate with equal success. Single turn deuteron extraction will be delayed until the other modifications are completed.

References

1. J.J.Burgejon, B.Hird, F.Konopasek and K.G.Standing, IEEE Trans. Nucl. Sci. Sci. NS-13(1966)422.

2. R.A.Batten, J.Bruckshaw, I.Gusdal, G.Knote, A.McIlwain, J.S.C.McKee, S.Oh, Nucl. Instr. and Meth. 145(1977)403.

3. I.Gusdal, G.Knote, A.McIlwain, J.S.C.McKee, S.Oh, H.W.Uzat, Nucl. Instr. and Meth. 136(1976)393.

4. S.Oh, J.Birchall, M.DeJong, I.Gusdal, A.McIlwain, R.Pogson, J.S.C.McKee, 9th Int. Conf. on Cyclotrons and their Applications, Caen(1981)293.

5. J.Anderson, J.Bruckshaw, V.Derenchuk, I.Gusdal, G.Knote, F.Konopasek, J.Lancaster, S.Oh, C.A.Smith, H.Uzat, M.Yoon and J.S.C.McKee, 10th Int. Conf. on Cyclotrons and their Applications, East Lansing (1984)461.

6. H.Uzat, I.Gusdal, V.Derenchuk, J.Lancaster and F.Konopasek, "Implementation of the University of Manitoba RF System". This conference.

7. V.Derenchuk, J.Bruckshaw, I.Gusdal, J.Lancaster, A.McIlwain, S.Oh, R.Pogson, J.S.C.McKee, Computing in Accelerator Design and Operation, Lecture Notes in Physics, Springer-Verlag Berlin(1983)411.