# McGILL SYNCHROCYCLOTRON IMPROVEMENTS*

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## Abstract

Engineering improvements to the McGill synchrocyclotron to enable routine production of nuclei far from beta stabilities are listed. Modifications to accelerate particles other than protons are described and a new approach to the central region problems of a synchrocyclotron, with possible applications to the acceleration of heavier ions, is presented.


## Introduction

Construction of the McGill Synchrocyclotron was started in 1946 and the machine became operational in 1949. Originally conceived as a proton accelerator to produce new radioactive species of nuclei, it became very productive and many of the early identifications of radioactive isotopes were carried out with this facility.

During the early sixties, interest in nuclear physics shifted toward the study of direct particle reactions and a beam of protons was extracted from the machine and the laboratory facilities extended to engage in this work. A great deal of early work on inelastic proton reactions on light nuclei (including p-p bremsstrahlung) was carried out at this laboratory. However, newer machines with much better beam characteristics for this work then became available and work in this field at this laboratory declined.

At about this time, the discovery of beta-delayed proton radioactivity by Barton et al.[1] at this facility sparked new interest in the use of the facility for the production of short-lived radioactive nuclei far from beta stability. Work by Hardy et al.[2] using the internally circulating beam of the synchrocyclotron showed that the machine was a prolific source of such activity in a form suitable for study,and interest in the laboratory shifted to the development of experimental apparatus and techniques for the study of these activities. As the experiments and the necessary apparatus became more and more sophisticated, the potential reliability and ease of operation of the synchrocyclotron became very attractive features, particularly for a university-based team with limited resources. Consequently an improvement program was launched to make full use of the synchrocyclotron's inherent capabilities.

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## Engineering Improvements

Since the McGill synchrocyclotron is now 30 years old, reliable routine operation and ease of maintenance required that many of the cyclotron components had to be modernized. A new magnet coil cooling system was installed using electrically insulated cooled sector plates sandwiched between the coil pancakes. The vacuum tank was overhauled and the vacuum pumps relocated to allow more access to the internal beam by experimentalists. A modern oscillator tube and power supply (supplied by Continental Electronics of Dallas, Texas) was installed, with new r.f. feed lines and a new dee system. The rotating capacitor and its vacuum system were completely overhauled. Finally the external beam magnet power supplies were replaced and the controls of the cyclotron completely revamped and modernized. These changes were all engineered with the aim of allowing operation of the accelerator by any member of the laboratory and achieving routine reliable operation after minimal training.

## Acceleration of Particles Other Than Protons

The new r.f. system has been designed to accommodate the acceleration of particles other than protons. This is achieved by simply extending the feed lines to achieve a line resonance at the frequency required for acceleration of a particular particle (Fig. 1). To accelerate $^3He^{++}$ the lines must be extended by 1.0 meters and to accelerate deuterons or $^4He^{++}$ the lines must be extended by 2.2 meters. This extension is achieved by using rapidly demountable rolled copper sheets for the outer lines, and rapid disconnect internal line and cooling water connections. Conversion of the cyclotron from the acceleration of one particle to another takes about 2 hours.

Deuteron beams of 50 MeV have been accelerated to intensities equal to that of the proton beam. Trace quantities of $^3He^{++}$ and $^4He^{++}$ have been accelerated, but usable beams await the development of a more powerful ion source. This source has been built and will shortly be placed in operation.

## Ion Source Pulser

A pulsed cold-cathode Penning Ion Gauge (PIG) source has always been used in this synchrocyclotron, and prior to modification it produced peak arc currents (of $H^+$ ions) of the order of 1 ampere and required striking voltages less than 2 kV. It was found that the low striking voltage could not produce reasonable arc currents of the doubly charged ions ($^3He^{++}$, $^4He^{++}$), and a new ion source supply has been designed to provide striking voltage of 8 kV, with arc peak currents up to 10A.

In some isochronous cyclotrons such as ORIC[3], a tetrode tube is used as the current controlling and regulating element; the same principle is used in the present pulsed version. Under normal conditions, this cyclotron requires ion pulses of 50 μsec, at a pulse repetition rate of 400 P.P.S.

A simplified schematic is shown in Fig. 2. Current for the source is supplied from the charged 1 μF capacitor when the tetrode grids are pulsed from cutoff (-350 v.) to 0 v. A convenient feature of the circuit is the independent control of striking voltage and arc current. The current is set by the tetrode screen supply voltage, and is essentially constant during the pulse, while the striking voltage depends on the anode supply voltage. Input gating pulses (-5 v.) drive the single transitor switch for the tube grids.

This pulser has been tested to full power with resistive loads, and has been operating reliably at the low currents required for the $H^+$ arc. Tests with the doubly charged ions will be completed following the installation of a new water cooled PIG source.

## Central Region Modifications

The design and installation of the new dee led us to consider once again the problem of the limitation of a synchrocyclotron beam by space charge in the central region (MacKenzie[4] and Lawson[5]). The profound effect of increasing the accelerating voltage of our machine is shown in Fig. 3 where it is seen that the orbiting beam current at a usable radius increases approximately as the square of the dee voltage. This led us to consider ways to increase this voltage.

Since it requires considerable engineering effort to substantially increase the r.f. power on the dee of a synchrocyclotron, we have attempted to achieve more rapid particle acceleration through the space charge limiting region of our machine by substituting for the grounded "dummy" dee a small central region dee (15 cm radius) facing the main dee and powered at 180° phase relative to it (Fig. 4). This makes the synchrocyclotron a somewhat conventional cyclotron in its central region and, in this region, effectively doubles the accelerating voltage without substantially increasing the total r.f. power required.

We have operated this small dee at r.f. ground and the synchrocyclotron performs at least as well as with the normal dummy dee. This proves that there is no need for a dummy dee outside the central region. We will be activating this small dee as soon as its r.f. drive becomes operational.

Making the central region of a synchrocyclotron a conventional cyclotron should, in principle, greatly improve the capabilities of the accelerator. By using a completely separate central dee system as shown in Fig. 4, it should be possible to achieve peak accelerating voltages up to 50 kV in the central region. A voltage gain of 100 kV in the first orbit would allow axial injection of heavy ions from an external source. This would remove yet another problem from the synchrocyclotron, the poor vacuum caused by the central ion source. Vacuums of the order of $10^{-8}$ Torr could then be achieved and phase stable acceleration of partially ionized heavy ions would be feasible. This would make the synchrocyclotron an inexpensive, convenient heavy ion acceleration facility for the production of short-lived radioactivity by heavy ion reactions.

## References


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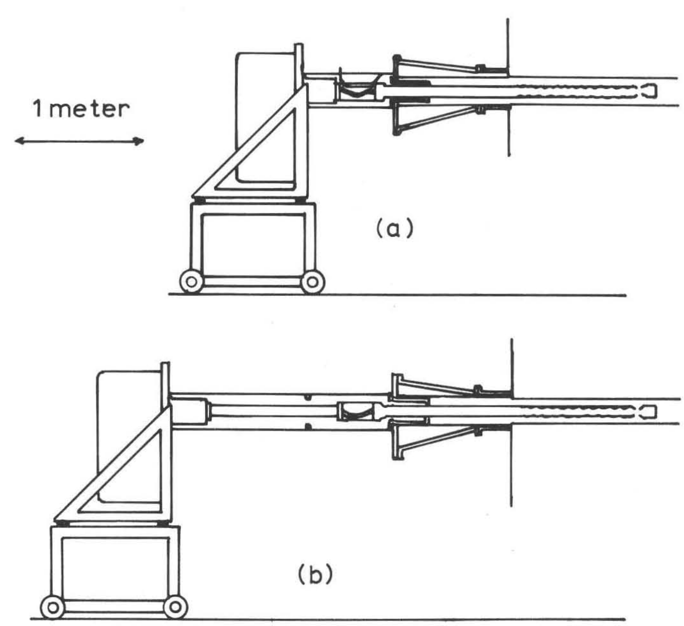


*Figure 1* R.F. Line Configurations: (a) Protons, (b) $^3$He.

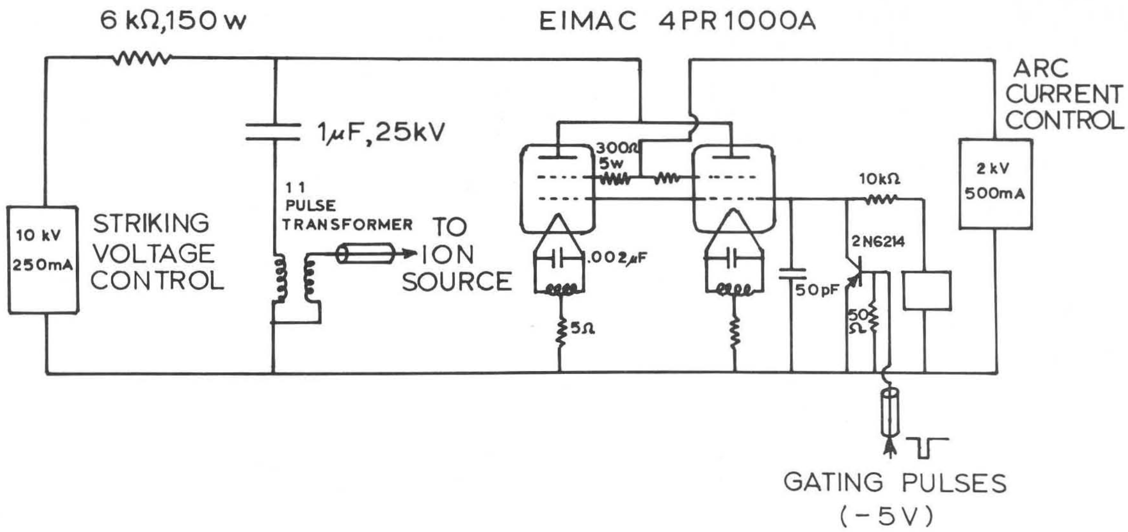


Fig. 2 Ion Pulser Schematic.

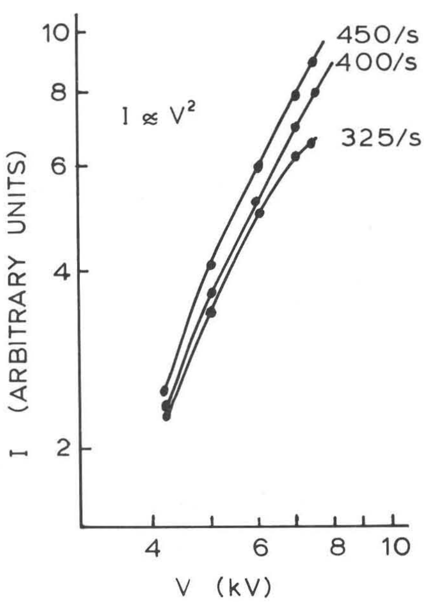


Fig. 3 Synchrocyclotron Beam Current as a Function of Dee Voltage Amplitude for 3 Repetition Rates of the R.F. Sweep.

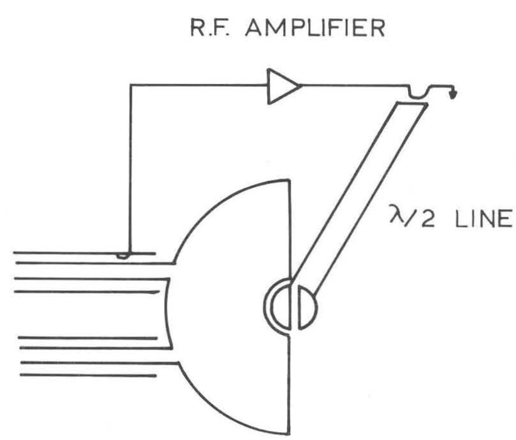


Fig. 4 Proposed Configuration for Independent Central Region Acceleration in a Synchrocyclotron.



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