HELICAL AXIAL INJECTION CONCEPT FOR CYCLOTRONS

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Abstract. A concept for an external beam injection system using a helical beam path centered on the cyclotron axis is described. This system could be used to couple two accelerator stages, with or without intermediate stripping, in cases where conventional axial injection or radial injection are not practical.

1. Introduction - When beams are injected from ion sources such as polarized ion sources, Penning sources, EBIS, and ECR sources, the energy of the injected beam is usually no more than a few tens of kilovolts. In a "Survey of External Injection Systems for Cyclotrons," D.J. Clark cites axial injection, trochoidal injection, and the use of electric fields to cancel the magnetic force as methods of injecting relatively low energy ions.[1] The most frequently used method has been an axial system. As the use of heavy ions increased, the existing 50- to 150-MeV q^2/A machines with internal ion sources were unable to meet the need for higher energy beams. Two-stage systems with interstage stripping were developed, opening up a whole new range of heavy ion accelerator possibilities. These include linac-cyclotron, cyclotron-cyclotron, and tandem-cyclotron systems. In most cases the beam from the first unit is injected into the second, with intermediate stripping between units or in the second stage. Intermediate stripping leads to a much higher beam energy for a given booster cyclotron size. For second stage cyclotrons with circular coils, the injected beam usually must have at least half the magnetic rigidity of the extracted beam. Separated sector cyclotrons with coils around each sector magnet do not have this limitation.

During a study of a heavy-ion cyclotron with circular coils and an energy constant of 3200 ($B\rho$ = 8.1 T•m), it became apparent that injection from the ORIC could not be achieved by the conventional radial method (capture by stripping); a higher energy injector or a different injection system would be needed.

The cyclotron being considered had an average field of about 2.8 T, a hill field of 3.9 T, and a valley field of 1.7 T. In this study the details of the cyclotron beyond the first acceleration orbit are not considered. This first orbit radius in the second stage was set at 2/3 the final radius of ORIC, resulting in the average field of 2.8 T. This is probably about the maximum average field level that can be achieved in a cyclotron where flutter requirements are substantial. A lower average field would result in a larger cyclotron and substantially increase its cost.

Coupled operation of the 25 MV tandem and ORIC gives fully stripped ions up to about mass 40 at energies up to 25 MeV/A and $^{238}U^{44+}$ ions of 3.4 MeV/A.[2] All of these ions have a magnetic rigidity ($B\rho$) of nearly 1.5 T•m and are thus too rigid to be injected axially and bent with conventional 90 degree elements into a 0.5-T•m-radius acceleration orbit of the K=3200 cyclotron. Conversely, the beam from the tandem-ORIC combination does not have sufficient rigidity to reach the center of the second cyclotron even if injected through the 1.7 T valley field. If the energy constant for ORIC is increased to 300 (ORIC Superconducting Conversion), the magnetic rigidity of the unstripped beam from the cyclotron will be increased to 2.6 T•m -- still less than required for conventional radial injection.[3]

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2. (Helical Axial Injection Concept.- A concept (Fig. 1) has evolved that may provide a means for ORIC and other cyclotrons of similar size to serve

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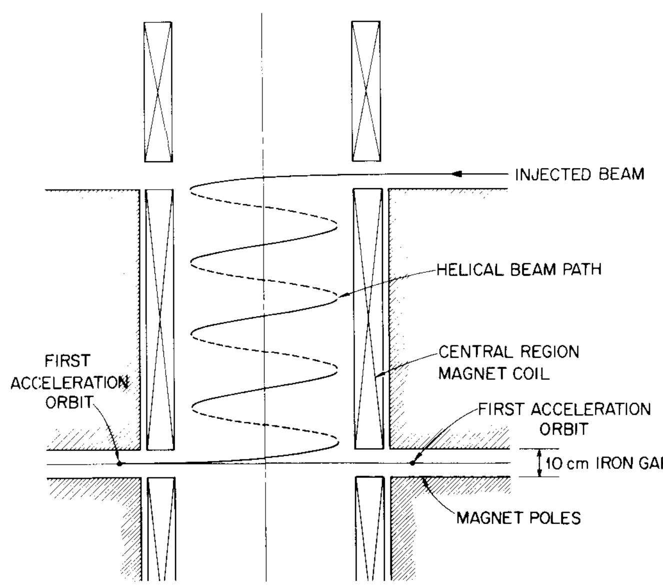

Fig. 1. Elevation view of the injected beam as it enters the central region of the cyclotron. The incoming beam is in a plane parallel to, and 1 m from, the median plane. It is deflected into a helical path, transported to the median plane, and inflected into the first acceleration orbit. The elements that direct the beam into and out of the helical path are not shown.

as the first stage for much larger cyclotrons. Instead of injecting the beam along the axis and bending it with 90 degree elements into the median plane, the beam would follow a helical path around the central axis. This becomes feasible (Fig. 2) when the field along the helical path is made to be about a factor of two higher than the average field at the first acceleration orbit.

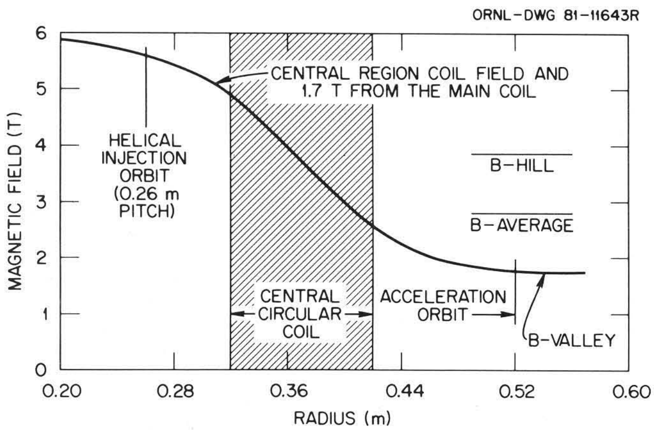

Fig. 2. A central region coil located between the injection orbit and the acceleration orbit provides a field twice that at the acceleration orbit.

It has been assumed that the injected beam will cross the central field in a radial direction in a plane about one meter from, and parallel to, the median plane (Fig. 3). The beam will be deflected onto a spiral with a radius (0.26 m) about half

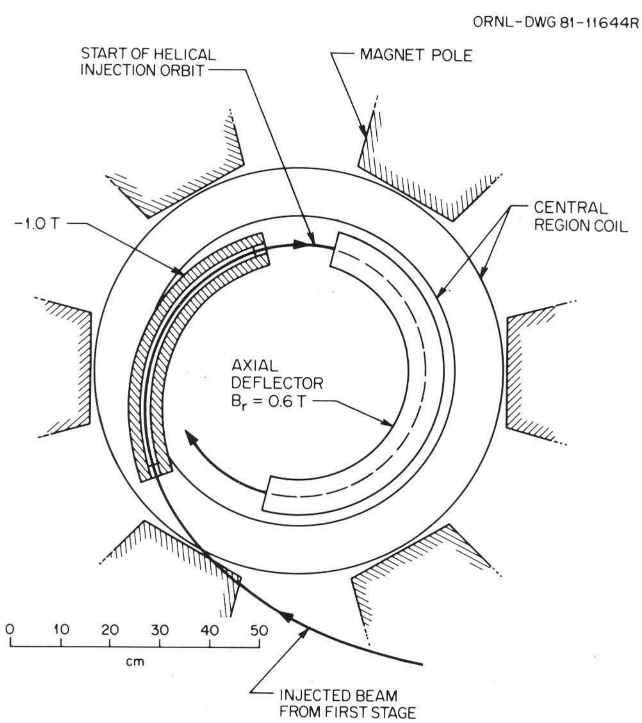

Fig. 3. Plan view of the injection system where the beam enters 1 m from the median plane.

that of the first acceleration orbit (0.52 m). An element with a suitable radial field provides axial motion necessary to place it on a helical path toward the median plane with a pitch of 9 degrees (0.26 m/turn).

After the beam has made a few turns along the helical path, it will approach the median plane where it will be deflected onto the median plane by an element similar to the one used to start the beam on the helical orbit. This element will have a radial field similar to the inflection element but with the field direction reversed.

To extract the beam from the 0.26-m-radius orbit and inflect it onto the 0.52-m-radius acceleration orbit, conventional extraction type elements will be used (Fig. 4). The first of these elements is a

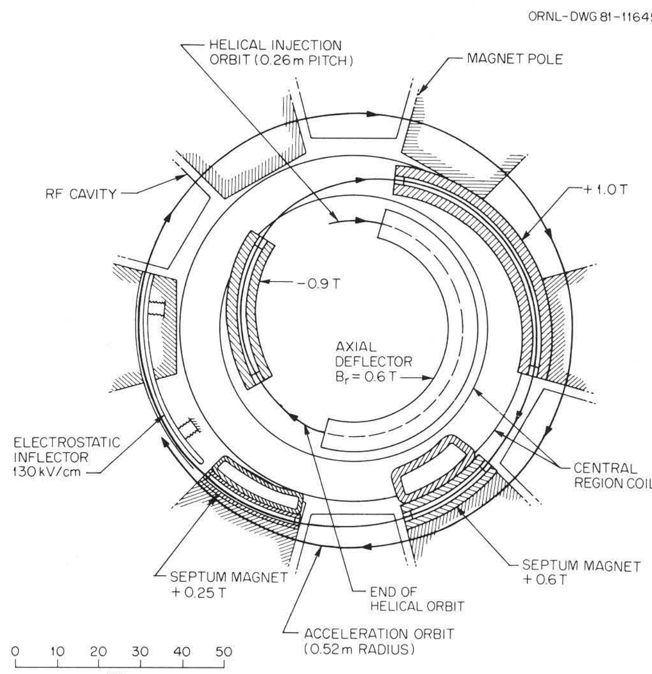

Fig. 4. View at the median plane of the system for deflecting the beam from a helical orbit and inflecting it onto an acceleration orbit.

0.9 T negative field unit. This is followed by a 1.0 T positive field unit, 0.6 T and 0.25 T positive field septum magnets and a 120 kV/cm electrostatic inflector. The electrostatic unit could be replaced by another septum magnet.[4] Detailed transport calculations for this system have not been made; radial gradient compensation may be incorporated in some of these elements or additional gradient field elements may be required. In the present study, separate elements have been used for the various functions of helical injection. In a practical system some of the elements may be combined. The 9-degree helical pitch used in this study results in practical spacings and element strengths. For other accelerators, the pitch could differ substantially.

3. Conclusion. The helical injection concept appears to provide a suitable method of using existing cyclotrons as the first stage for large second-stage heavy-ion cyclotrons. Internal stripping in the second stage is not used for injection in this system. When stripping is used to provide higher charge states for the second stage, it may be done between stages. This would eliminate undesired charge states from the second stage.

When the beam from the K-300 machine is stripped for further acceleration in the larger machine, the magnetic rigidity of the K-300 beam will be nearly equal to that for the K-100 unstripped beam. The K-300 ions can be fully stripped up to about mass 80; uranium ions would have a charge of about 78^+. Thus the same injection system would be suitable for either the ORIC K-300 stripped or the K-100 unstripped beams.

In other situations, helical injection from a smaller cyclotron into a large second stage cyclotron could be used to advantage where ions of charge comparable to the tandem considered here are obtained instead from an ECR or EBIS source.

References

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