DESIGN OF AN ION CYCLOTRON RESONANCE ACCELERATOR FOR EXPERIMENTAL STUDY

C.T. Ramsell, T.L. Grimm, R.C. York, and S.A. Rice

The ion cyclotron resonance accelerator (ICRA) is a novel concept for accelerating ions that is based on the operating principles of cyclotrons and gyrotrons. Designs for 10 MeV, 1 MeV, and 50 keV proton models have been investigated. The 10 MeV design would be useful for production of radioisotopes, as an accelerator based neutron source, or for some material science applications. The 1 MeV ICRA was designed to use an 8 Tesla superconducting magnet, and be built as an experimental demonstration [1,2]. However, due to the availability of an existing 3 Tesla superconducting magnet, the demonstration model has been scaled back to a 50 keV proton design which is currently under construction.

Background

In a cyclotron, ions are axially confined to the median plane within a magnetic field and are accelerated in the azimuthal direction. In a gyrotron the energy of a dc electron beam is converted into microwaves in a resonant cavity. Within the cavity, the electron beam spirals around magnetic field lines but is allowed to drift axially. The ICRA is similar to the cyclotron in that ions orbit around magnetic field lines while being accelerated azimuthally. However, in the ICRA the beam is not axially confined so that ions are allowed to drift along magnetic field lines, similar to the trajectory used in a gyrotron. The ICRA differs from the cyclotron primarily in this lack of axial focusing and in the type of rf accelerating structure.

Jory and Trivelpiece used cyclotron resonance acceleration in 1968 to produce a 10 mA beam of 460 keV electrons [3]. However, this method of acceleration has not yet been demonstrated for ions. The ICRA would extend cyclotron resonance acceleration to ions by using a superconducting solenoid together with an rf magnetron structure operating at a harmonic of the cyclotron frequency. Since the magnetron structure is basically a lumped circuit it can be small enough to fit into a solenoid of reasonable diameter [4].

A computer model for the ICRA has been developed which tracks particles from the ion source, through the injection, acceleration, and extraction regions, to the target face. Many single particle trajectories were used to map out the acceptance phase space, allowing the accelerated beam current to be calculated.

50 keV Design

In order to demonstrate the ICRA concept at low cost, the 8 Tesla, 1 MeV design has been scaled back to a 50 keV proton model that is compatible with an existing 3 Tesla superconducting solenoid available here at the NSCL. Scaling was done by holding the trajectory geometry constant while reducing the energy appropriately for the lower magnetic field and shorter interaction length. Design parameters are listed in Table 1.

A cutaway view of the 50 keV proton ICRA design is shown in Figure 1. The main components of the design are as follows. An ion source provides a proton beam, which is extracted along a magnetic field line. Electrostatic bending plates bend the beam onto the injection orbit with the desired ratio of momentum perpendicular and parallel to the magnetic field ($p_\perp/p_{\parallel}$). A superconducting solenoid provides the dc magnetic field. A magnetron structure supplies rf electric fields for accelerating the ions azimuthally, and an rf power source to drive electromagnetic fields in the magnetron structure. An electrical schematic is shown in Figure 2.

Table 1. Design parameters for the 50 keV ICRA

Design Energy	50 keV
Injection Energy	6 keV
Ion Beam	protons
Current Accelerated	[a]1mA protons
Magnetic Field	2.53 Tesla
Cyclotron Frequency	38.5 MHz
Harmonic Number	4
RF Frequency	154 MHz
RF Power	< 60 Watts
Cavity Voltage	3 kV peak
Number of Turns	5
Cavity Length	5 cm
Cavity ID at Entrance	1.1 cm
Cavity ID at Exit	4.0 cm

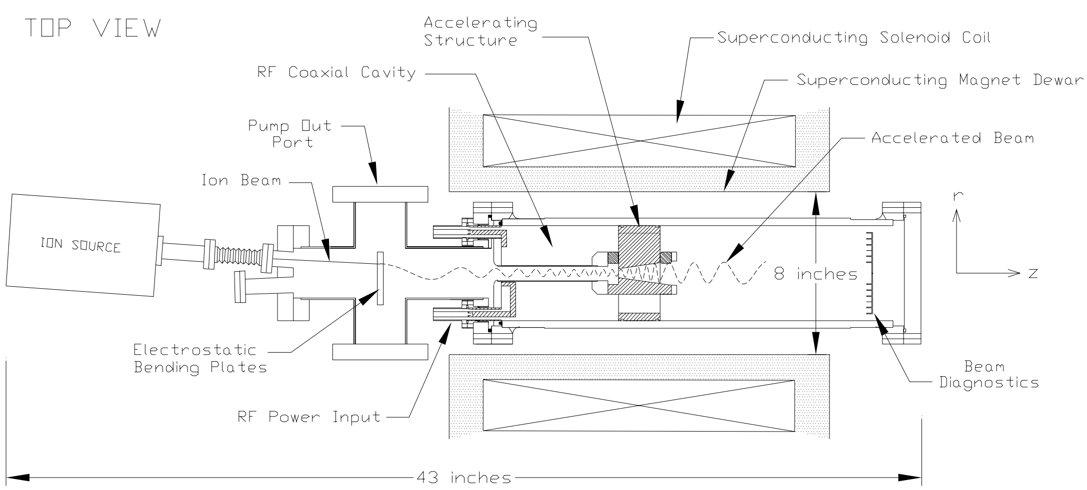

Figure 1. Cutaway view of the 50 keV ICRA.

The superconducting solenoid was made by Intermagnetics General Corp. Mapping of the magnetic field was completed in the fall of 1997. Results confirmed that the central high field region does have a field flatness of $\Delta B/B_O < 0.005$, necessary for resonance over the Z = 5 cm acceleration region. Mapping the fringe fields was necessary to predict beam trajectories in the injection region.

The lower rf frequency (154 MHz) imposed by lowering the magnetic field from 8 to 2.5 Tesla means that the inductive components of a magnetron structure would extend out too far in the radial direction to fit into the 8 inch bore of the superconducting solenoid. For this reason, the accelerating rf cavity was redesigned so that the inductive component extends in the axial direction. The result is a shortened section of a quarter wave coaxial cavity with magnetron vanes mounted across the open end as shown in Figure 3. Notice that the aluminum outer conductor doubles as the vacuum wall. Also notice that the outer vanes of the magnetron structure are electrically connected only to the outer conductor of the coaxial cavity, while the inner vanes are connected only to the inner conductor of the coaxial cavity. The added capacitance of the magnetron structure means that the coaxial section must be shorter than a quarter wave cavity with the same resonant frequency. The accelerating voltage is 3 kV, so the electric field will reach 15 kV/cm across the 2mm gaps between the inner and outer vane. This cavity has been built and initial low power tests indicate a Q of about 2000, meaning that it will require about 55 watts to reach the full 3 kV accelerating gap voltage. Full power tests and vacuum tests will begin in June 1998.

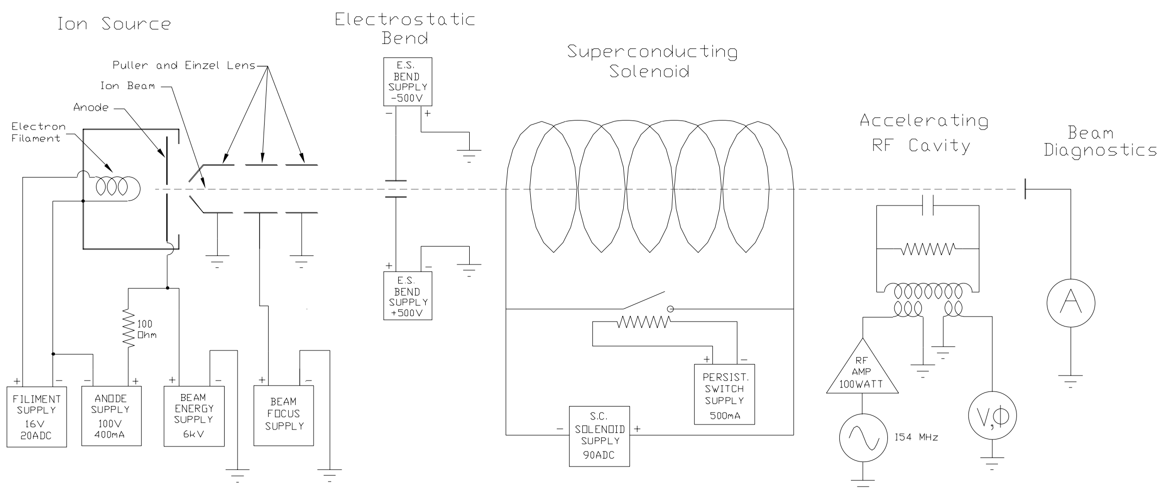

Figure 2. Electrical schematic for the 50 keV ICRA

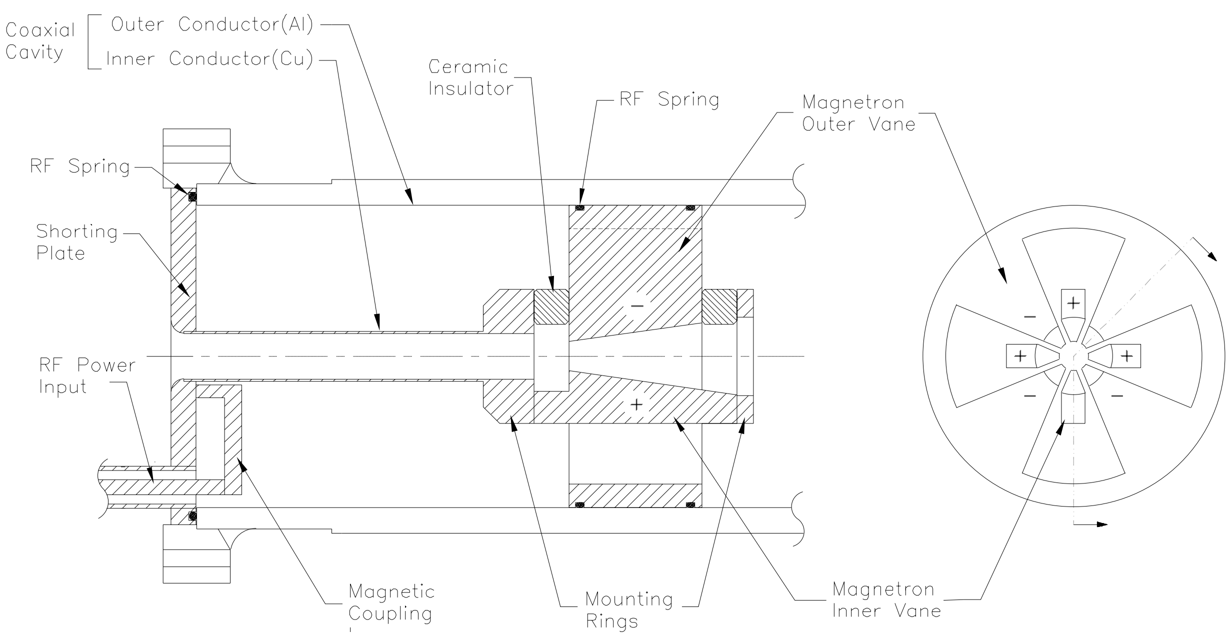

Figure 3. Two views of the hybrid coaxial - magnetron rf cavity which provides the azimuthal electric fields for acceleration.

A simple electron filament ion source from Colutron Research Corp has been purchased which will produce a 10μA beam of H^+. The next task will be to install the ion source as well as to build and test all beam optics necessary to focus and bend the injected beam for the proper trajectory into the high magnetic field region. Beam diagnostics will be designed so that the required injection trajectory can be verified. The entire system should be operational near the end of 1998, at which time measurements of accelerated beam current and energy distribution will be made.

References

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