STATUS OF THE LBNL 88-INCH CYCLOTRON HIGH-VOLTAGE INJECTION UPGRADE PROJECT

K. Yoshiki Franzen, P. Casey, A. Hodgkinson, M. Kireeff Covo, D. Leitner, C. Lyneis, L. Phair, P. Pipersky, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, U.S.A.

Abstract

The goal of the project is to design and install a new center region that allows external beam injection at voltages between 20 and 30 kV for high intensity beams. This new center region will make use of a spiral inflector to eliminate the use of a gridded mirror for high intensity beams. At the same time the mechanical design must be flexible enough to allow use of the existing center region for less intense beams. The use of two or more different center regions is necessary to cover the wide range of operation parameter space utilized by the 88-Inch Cyclotron nuclear science and applied research programs. The project also includes HV upgrades to the external injection lines and HV insulation of the AECR and VENUS sources with the goal to provide focusing for beams up to 25 kV or if feasible up to 30 kV. The current spiral inflector design is based on extensive 3D FEM simulations for which results will be presented. In addition results from ongoing efforts to improve on the transport efficiency from the AECR ion source to the current mirror inflector will be discussed.

INTRODUCTION

Beam development experiments at the LBNL 88-Inch Cyclotron using the AECR-U injector source and particularly when using the high intensity beams available from the fully superconducting 28 GHz ECR ion source VENUS have demonstrated that for high intensity beams the space charge effect reduces the injection efficiency into the 88-Inch Cyclotron. At injected currents above 100 eμA the ion beam transmission decreases due to beam losses in the center region of the cyclotron and injection line. While for many experiments conducted at the 88-Inch Cyclotron, ion beam intensity on target is not a limiting factor, luminosity is crucial for the super-heavy element research program. Therefore, this upgrade is mainly focused on increasing the beam intensity of key ion beams in the mid mass range (A=20 to A=136) for the heavy element program at energies around the Coulomb barrier, in particular for ^{48}Ca and ^{50}Ti ion beams.

The goal of the four year upgrade project is to increase the injection energy into the cyclotron to take full advantage of the high intensity beams available from the VENUS ECR ion source. In addition, the project includes an upgrade to the external cyclotron injector beam line. While this upgrade is focused on the BGS ion beam requirements in the mid mass range, a crucial requirement is to preserve the versatility and wide parameter space of beams, intensities and ion beam energies available at the 88-Inch Cyclotron.

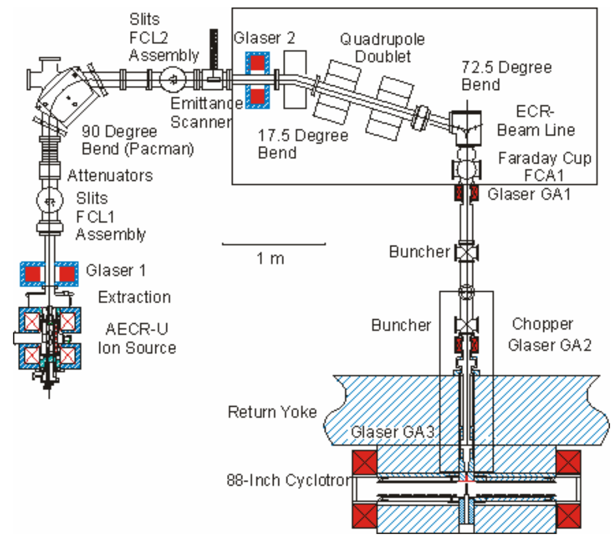

Figure 1. Schematic view of the AECR ion source, the injection beam line and the 88-Inch Cyclotron at LBNL.

DESIGN

Overview

During operation a beam is extracted from either one of the three ion sources and transported through an injection beam line system until it reaches the center region of the cyclotron; see Figure 1 for a schematic view. At the cyclotron mid plane it is necessary to redirect the beam horizontally which presently is done by the use of a mirror inflector. The great advantage of the mirror inflector is its versatility to support all the requested beams of the 88” Cyclotron. As mentioned above the goal of the project is to increase the injection voltage of the beam in order to improve on transmission efficiency at high current operation and reduce the required maintenance time of the inflector. However, due to limitations in vacuum it is not possible to operate the current mirror inflector at higher potentials required for beams injected at higher voltages. The plan is thus to temporary replace the mirror inflector during high intensity operation with a spiral inflector which can be operated at significantly lower voltages. The spiral inflector also does not utilize a grid which in the case of the mirror inflector requires frequent replacement during high current operation. Another equally important advantage of the spiral inflector is that it can be designed to better center the beam which is critical at higher injection energies. It should be emphasized though that the spiral inflector has a limited operating range so the goal is to quickly be able to switch between the two systems by utilizing the existing ion source mechanism which before the early 1990’s was regularly used in a similar fashion when switching between an internal and an external ion source. However, using this mechanism put a severe constraint on the maximum size of the spiral inflector since it has to fit within the existing diameter of the shaft which is only 2.125”.

Spiral Inflector Design

As our target beam we chose Ar^{9+} injected at 25 kV in a magnetic field configuration set to support cyclotron acceleration to 200 MeV. The reason for this choice of ion beam is that the magnetic rigidity and final energy per nucleon is similar to $^{48}Ca^{11+}$ which is one of the most important beams for the heavy element program and is also often used for beam development at the 88-Inch Cyclotron.

The design of the spiral inflector was based on models using the computer code CASINO [1]. This code produces a set of coordinates which describes the center ray trajectory of a particle with a given mass-over-charge ratio and kinetic energy traveling through a spiral inflector situated in a defined magnetic field. By stepping through the spiral inflector parameter space of height (A), magnetic radius (R_m) and tilt (k’) it was possible to find a combination which defines a configuration which 1) fits within the diameter of the shaft, 2) provides a beam which clears the inflector during the first revolution and 3) is centered enough to reach full acceleration. The final parameters are listed in Table 1.

Table 1. Parameters of spiral inflector optimized for injection of 25 kV Ar^{9+} ions into a 14.2 kG center region field.

Parameter	**Value**
A	30.0 mm
R_m	32.1 mm
k’	1.0

From the calculated trajectory data the next step was to define three-dimensional representations of electrodes that produce an electric field distribution which together with the magnetic field would steer the beam into the cyclotron mid plane. A code was developed in Matlab which produced a representation of these surfaces. In addition to the top and the bottom electrodes, grounded entrance and exit electrodes were added to the model. The electrode volumes were represented in STL file format which is commonly used in various CAD and FEM programs, see Figure 2 for an example visualization.

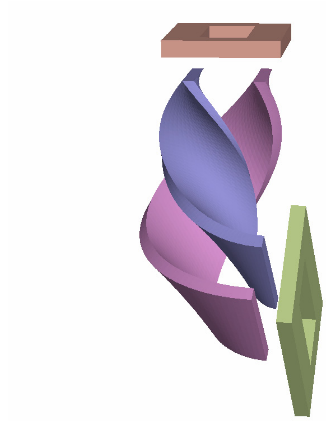

Figure 2. Spiral inflector electrodes (blue: top, pink: bottom, brown: entrance, green: exit).

The next step was to test the defined set of electrodes by using a FEM software package AMAZE [2]. This software creates a mesh representation of the spiral inflector electrode volumes and from the result a corresponding 3D field map was produced. Ar^{9+} ion trajectories were then calculated for 25 kV injection into the system and the results were compared with the output of CASINO. See Figure 3 for an example of trajectories plotted together with a field map solution. When a feasible design was found that fits into the available space of the 88-Inch Cyclotron center region, the STL file representations were used as a basis to produce a model in SolidDesigner compatible with the rest of the system, see Figure 4. In addition, the system was optimized for vacuum compatibility and voltage holding capability.

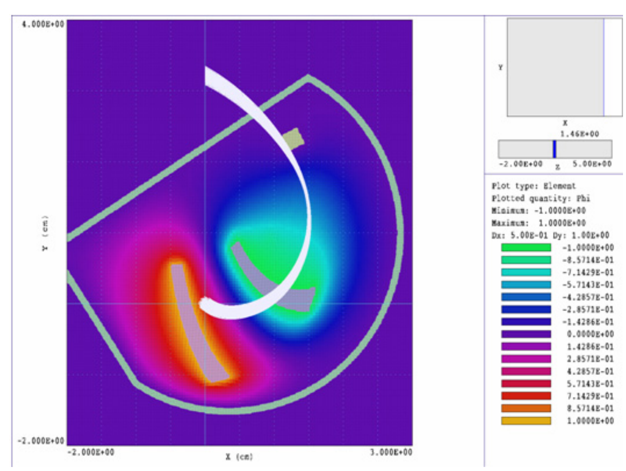

Figure 3. Field map solutions (top view) and 25 kV Ar^{9+} trajectories starting at x=0 cm, y= 0 cm travelling in the negative z-direction. The initial beam diameter is 2 mm. The applied voltages to the top and bottom electrodes are -7.75 and 7.75 kV respectively.

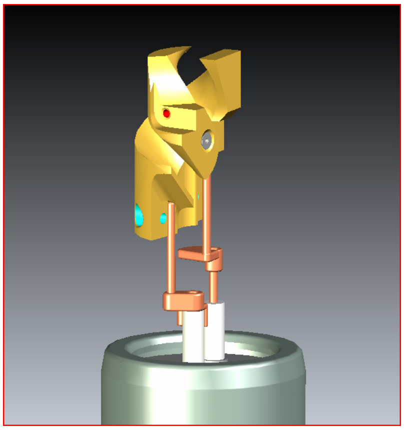

Figure 4. Model of spiral inflector prototype showing the tip of shaft, the high voltage feedthroughs and the spiral electrodes.

Cyclotron Center Region Design

In order to fit the new spiral inflector on the 2.125” shaft the entrance has to be positioned off the shaft axial center. The shaft itself thus has to sit off center from the cyclotron axis and subsequently the present Dee and Dummy Dee inserts have to be modified. Therefore, the original (mirror) center region design was adapted to accommodate the geometry of the spiral inflector, see Figure 5. One major difference is that the space available for the inflector housing is now half-moon shaped in order to position the first accelerating gap closer to the cyclotron center axis. The design was imported into the AMAZE FEM meshing software and an electric potential solution was calculated.

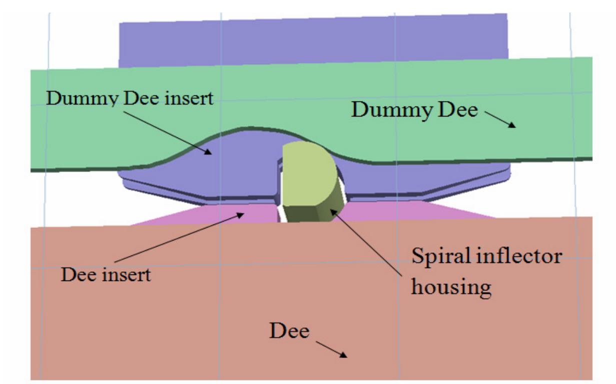

Figure 5. Upgraded Dee and Dummy Dee inserts compatible with the spiral inflector housing.

A magnetic field map was obtained from a code called CYDE which computes the predicted frequency and magnetic field settings (main coil, trim coils) for the 88-Inch Cyclotron from the input data m/q, Dee voltage, harmonic number and desired final energy.

The acquired electric and magnetic field maps were used as input data for the Z3CYCLONE code [3] which calculates the trajectories from the exit electrode of the spiral inflector to the cyclotron extraction radius, see Figure 6 for example results of such calculation.

With the Z3CYCLONE trajectory data it was possible to iteratively optimize the performance of the spiral inflector and the center region. More detailed results will be published elsewhere.

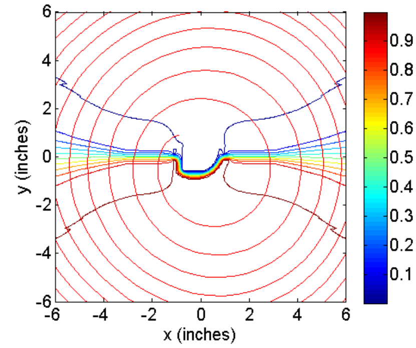

Figure 6. The first few turns of a 25 kV Ar^{9+} ion beam in the new center region of the 88-Inch Cyclotron and equipotential contours of the electric field. Colorbar indicates fraction of Dee voltage.

ONGOING WORK AND INSTALLATION PLAN

The AECR ion source and the injection beam line are presently being tested by 19.5 kV extraction of Ar^{9+} ions followed by transportation down to the mirror inflector. In addition to the goal of increasing the beam current this work aims to verify the current beam line model.

The spiral inflector prototype design is close to being sent off for manufacturing. When ready it will be tested by applying the required voltages while being positioned inside the cyclotron at high vacuum and tuned magnetic field. In addition the new Dee and Dummy Dee inserts will be manufactured and positioned with Dee RF voltage applied. The goal is to have these tests done by the end of the year 2010.

During the spring of 2011 injection will be tested using the spiral inflector. In addition an additional buncher will be installed.

During fall/winter of 2011 the complete system will be tested and improved upon as needed.

CONCLUSION

A design of a spiral inflector together with a matching center region has been produced using a series of simulation codes. The design is optimized to support transmission of a 25 kV Ar^{9+} beam. Manufacturing and testing will begin in the fall of 2010.

REFERENCES

[1] B. F. Milton and J. B. Pearson, CASINO user’s guide and reference manual, TRIUMF, TRI-DN-89-19

[2] Field Precision LLC (http://www.fieldp.com/)

[3] F. Marti, private communication