RECENT PROGRESS ON THE FACILITY UPGRADE FOR ACCELERATED RADIOACTIVE BEAMS AT TEXAS A&M *

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Abstract

The Cyclotron Institute at Texas A&M University is involved in an upgrade, one goal of which is to provide radioactive ion beams accelerated to intermediate energies by the K500 superconducting cyclotron. The old 88" cyclotron, now the K150, has been refurbished to be used as a driver and also to provide higher intensity, low-energy, primary beams for experiments. Two external ion sources, an electron-cyclotron-resonance ion source (ECRIS) and a multi-cusp negative ion source, have been installed on a new axial line to inject beams into a modified K150 central region. Acceleration of negative ions of protons and deuterons with stripping for extraction will be used in order to mitigate activation of the K150. Beams from the K150 will be used to create radioactive species via a light-ion guide and a heavy-ion guide. Singly charged ions from either ion guide will be transported to an ECRIS that is configured to capture these ions and further ionize them. One charge-state from this second ECRIS will be selected for subsequent acceleration by the K500. Progress on the upgrade, including the acceleration and extraction of both negative and positive beams by the K150, is presented.

INTRODUCTION

Since 2005 the Texas A&M Cyclotron Institute has been extensively upgrading its facility (fig. 1). Described previously [1] this upgrade involves the axial injection of beams from both a 14.5 GHz ECRIS and a multi-cusp negative ion source for acceleration by the recommissioned K150 cyclotron. Although K150 beams will not be as energetic as beams from the K500 superconducting cyclotron, the K150 will be capable of providing much more intense beams for experiments and for the creation of radioactive ions that will then be accelerated by the K500 into an energy range unique for such beams. Two immediate goals for the refurbished K150 are 14 μA of 30 MeV protons and 0.9 pμA of 13.7 AMeV ^{40}Ar. Using intense beams from the K150, radioactive ions will be produced by stopping products from beam-target collisions in helium-filled cells in a light-ion guide, utilizing p, d and α beams, and in a heavy-ion guide. Low-charge-state radioactive ions collected from such a cell will be transported to a charge-boosting electron-cyclotron-resonance ion source (CB-ECRIS). Higher charge-state ions from the CB-ECRIS will then be injected into the K500 cyclotron for acceleration. The CB-ECRIS and its analysis line have been installed and are now being tested [2]. The analysis line will become the first leg of the low-energy-beam transport leading to the existing axial line for injection into the K500 cyclotron.

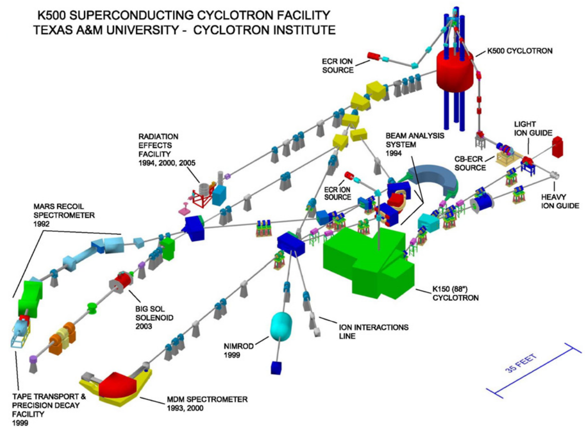

Figure 1: Overview of the Cyclotron Institute Facility.

K150 CYCLOTRON

In late 2007 a beam of protons was axially injected, accelerated to 20 MeV by the K150 and extracted at an intensity of 25 nA with an extraction efficiency of ~10%. This provided a first trial of the extensively refurbished K150, including its new rf system, new magnet power supplies, new vacuum system and new axial injection system as well as its original rf panels and dee, its original mirror inflector and deflector and its original beam probe. A substantial fall-off in intensity from the center to outer radius was observed, presumably due to poor matching in the center region. After some tests the axial injection system, including the upper central steel plug, and the dee were removed so that modifications could be made to improve the transmission. Most recently, a negative-ion, multi-cusp source along with an extraction-by-stripping system were added to the K150.

Axial Injection Line

The injection line (fig. 2) was augmented by the addition of a Glaser lens and steering coils to a new upper steel plug in order to improve beam injection. The upper and lower steel plugs shape the central magnetic field so particular care was taken in alignment with respect to the median plane. Also, extra focusing einzel lenses were added to accommodate the new multi-cusp, negative ion source which was mounted on axis directly above the 90º analysis magnet which bends the beam from the ECRIS onto cyclotron axis.

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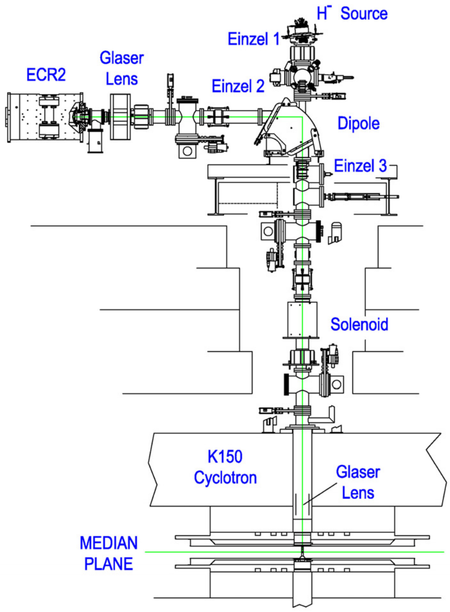

Figure 2: Injection line for the K150.

Central Region Modification

Before the K150 was decommissioned in 1986, beams from polarized ion sources were axially injected, but since internal, off-axis filament and PIG ion sources were still being used, the central region was not optimized for the injected beams. To improve the initial electric focusing and orbit centering, a set of titanium dee inserts, following the design for the LBNL 88" cyclotron [3], were recently constructed and installed (fig. 3). A great deal of effort was devoted to proper alignment of the inserts, both due to its importance to beam acceptance and to the fact that the inserts had to be manipulated from a distance of 1.6 m inside the cyclotron-pole clearance of 15 cm. The dee inserts provide a well-defined electric field near the center of the cyclotron and reduce the gap between the dee and the dummy dee in this region from 5 cm to 0.64 cm. Center region acceleration was studied using the NSCL code Z3CYCLONE with 3D electric field maps produced with TOSCA and magnetic field maps from the LBL orbit code CYDE (fig. 4). It was found that reasonable dee voltages lead to well-centered orbits.

After installation of the dee inserts several test beams were run. Table I lists these beams and compares them to the October 2007 proton beam. All these beams were unbunched and accelerated to an outer radius close to the extraction radius. What is striking is the improvement in the intensity-versus-radius profile for the 20 MeV proton beam as well as a much lower optimized rf voltage. Most of the beams exhibit a good I vs R profile except for the more vacuum sensitive $^{16}O^{5+}$ beam.

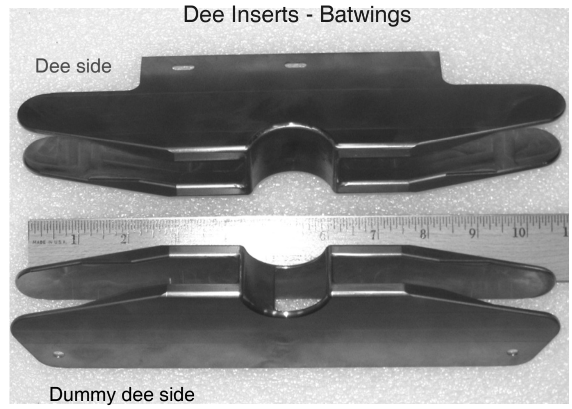

Figure 3: Dee inserts, before installation.

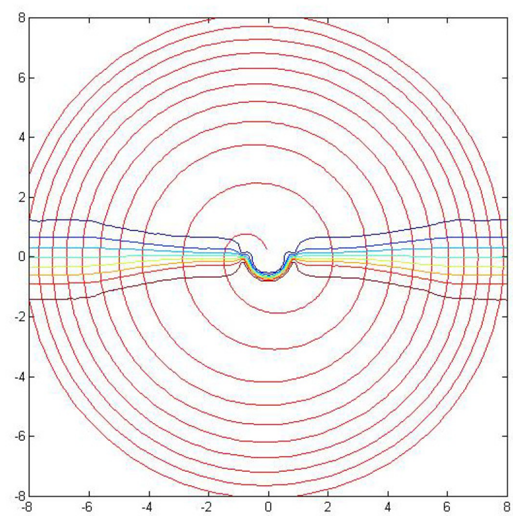

Figure 4: Centered orbits calculated with dee inserts. Scale is inches.

Table 1: First Beams

T/A MeV/u	Ion	Vdee (kV)	I@inj (eµA)	I@infl (eµA)	I@10" (eµA)	I@35" (eµA)
20	P (Oct07)	73 (w/o inserts)			0.65	0.22
20	P	45	29	10	0.33	0.32
25	P	46	23	8	0.56	0.54
30	P	52	25	9	0.40	0.37
7.5	$^{16}O^{5+}$	53	89	35	3.1	1.9
10	$^{16}O^{6+}$	56	132	62	3.9	3.5
12	$^{16}O^{6+}$	65	130		5.0	4.7
14	$^{16}O^{6+}$	65	110		3.4	2.9
14	$^{16}O^{7+}$	65	22	12	0.74	0.67

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Negative Ion Beams

Radiation simulations confirmed that the high intensity light-ion beams required for radioactive ion production would cause high levels of activity in the K150 deflector, which would be a troublesome maintenance issue. Following the successful scheme for H- acceleration by the JYFL cyclotron laboratory [4], it was found that a similar approach would work for the K150: a multi-cusp ion source produces intense H- and D- beams which are accelerated to full radius and then stripped to protons or deuterons and then directed along the exit beam-line by a dipole magnet. Studies showed that there would be sufficient clearance in the K150 beam chamber with the deflector moved to its maximum radius, that an existing port near the exit could be used for the insertion of a moveable carbon foil, that a surplus dipole could be refurbished to provide the maximum 18º deflection required to bring the beam unto the exit beam-line (fig. 5) and that the existing vacuum in the K150 (10-5 torr in the center to 2X10-6 torr near extraction radius) would not cause significant beam loss with resulting activation.

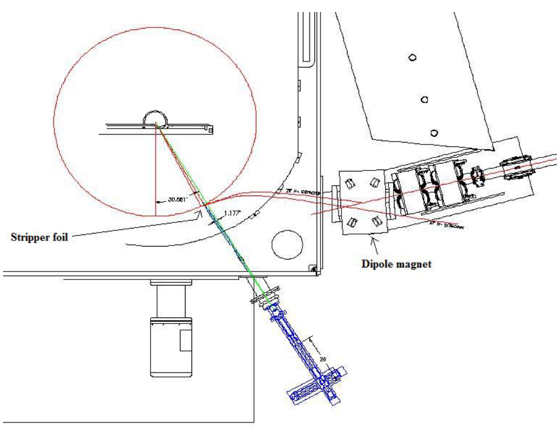

Figure 5: Extraction for H^- and D^- beams.

Testing at JYFL showed that their unused prototype multi-cusp source could produce a sufficient amount of H^- beam for our project. This source was acquired for the K150. With a new source extraction system designed and built by Texas A&M, testing at JYFL showed that the ion source produced up to 1 mA of H^- ions and with an emittance less than 8π mm-mrad. Injection of the H^- beam was studied with the code SIMION (transport plus space charge effects) and two einzel lenses were added to the injection line. The source was mounted and a 1.0 mA current was measured at the analysis faraday cup in the vertical section of the line.

Recently, H^- and D^- acceleration and strip extraction were tested. For H^- the currents in the main and trim coils were reversed and set to the values from the earlier 20 MeV proton run. After some optimization, beams of ~10 µA of H^- were stripped and extracted from the cyclotron onto the faraday cup after the exit dipole. Next, 30 MeV H^- ions were accelerated, and up to 24 µA was obtained on the exit Faraday cup, but this value would slowly decrease to approximately 18 µA as the cyclotron vacuum degraded due the beam heating. In a similar fashion ~1.2 µA of 10 AMeV deuterons was extracted.

With the 30 MeV H- extracted and stopped on the external faraday cup of the K150 cyclotron, secondary radiation levels from neutrons and gamma rays were measured in the cyclotron vault and at the injection line above the K150 cyclotron. Levels of ~1 Rem/hr were measured inside the cyclotron shielding and 2 – 3 mRem/hr were measured at the injection line outside the shielding. These are low values with regard to the safety of the staff working around the cyclotron facility.

FUTURE PROGRESS

Transporting beams from K150 to target for experiments is planned for the near future. An internal LHe cryopanel is being constructed for installation in 2011. The next series of tests will focus on beam-loss of injected negative ions, on extraction of positive ions through the electrostatic deflector, on magnetic field and rf voltage limits for beams and on the ability to predict accurately main-magnet and trim-coil current values for a wide variety of beams. The acceleration of radioactive beams by the K500 is scheduled for late next year.

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