STATUS OF THE TEXAS A&M UNIVERSITY CYCLOTRON INSTITUTE*

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Abstract

Both the K500 superconducting cyclotron and the older K150 (88”) conventional cyclotron at the Texas A&M University Cyclotron Institute are in constant use for both experimental physics and chemistry as well as for customer-based, radiation-effects testing. In addition, an upgrade program using the K150 as a driver for the production of radioactive beams to then be accelerated to intermediate energies by the K500 Cyclotron is ongoing. Both a light-ion guide and a heavy-ion guide are being developed for this purpose. The status of the cyclotrons and of the associated electron-cyclotron-resonance ion sources (ECRIS) and the H-minus ion source used on the K150 as well as the status of the upgrade are presented.

INTRODUCTION

The Texas A&M K500 superconducting cyclotron was commissioned in 1988, while the Texas A&M K150 cyclotron (formerly the 88”) was recommissioned in 2007. Beams are injected into each cyclotron by dedicated ECR ion sources, while a negative hydrogen/deuterium source injects into the K150, as well. Figures 1 and 2 are representations of the beams run by the K500 and K150, respectively. Figure 3 demonstrates the division of K500 time in the last three years devoted to nuclear physics and nuclear chemistry (8684 hrs.) and to outside use (9567 hrs.), mainly consisting of computer-chip single-event-effects (SEE) testing by a variety of satellite and avionic concerns. In addition, there is an ongoing effort to develop a K500+K150 radioactive-beam capability which will supplement the radioactive beams provided by the momentum-achromat-recoil spectrometer (MARS) [1].

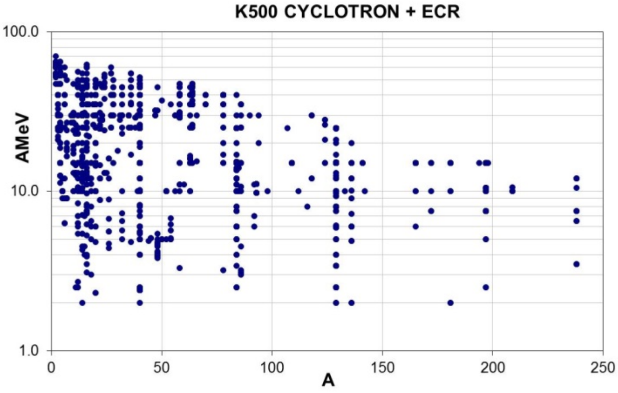

Figure 1: Beams run to date by the K500.

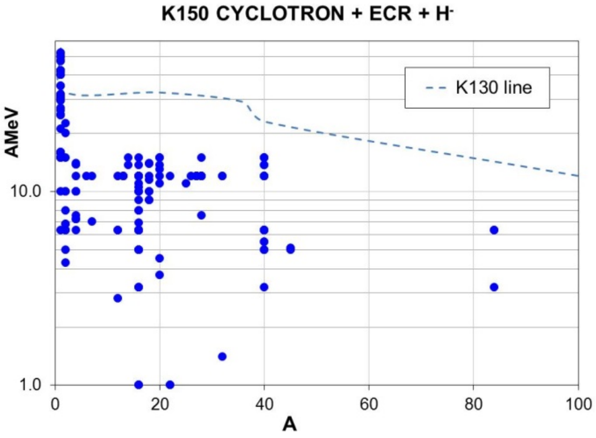

Figure 2: Beams run to date by the K150.

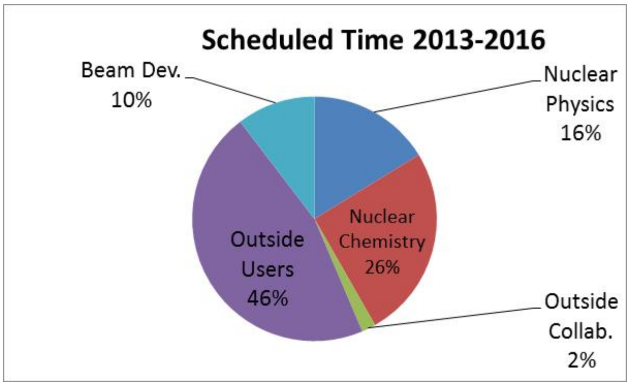

Figure 3: Division of K500 scheduled time.

CYCLOTRONS

The K500 and its injector 6.4 GHz ECRIS (ECR1) continue to operate well, averaging 6212 hours per year of beam-on-target over the last three years. The central inflector was replaced recently with a new one with electrodes fabricated from aluminum. The older tantalum electrodes showed considerable wear from heavy-ion sputtering.

The K150 has just recently come into extensive use although it still suffers from poor vacuum (3 X 10^{-6} torr) since the installed cryopanel remains unconnected to a coolant supply. As previously reported [2] K150 beams are tuned using the trim-coil program CYDE with field maps generated by TOSCA. An analysis of the field by TOSCA with the rectangular yoke included does not yield an appreciable first harmonic in the acceleration region, but both the middle-radius harmonic coils, valley coils 3 and 4, are extensively used for tuning in addition to the central and extraction harmonic coils, valley coils 1 and 5.

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The injector H-minus source for the K150 has operated well with occasional filament replacements and also with the replacement of the filter region permanent magnets which had eroded in their cooling water. The operation of the 14.5 GHz injector ECRIS (ECR2) for the K150 was considerably stabilized with the replacement of the stainless-steel, injection-end flange with one fabricated from copper. A high-temperature oven, similar to one constructed for the LBL VENUS ECRIS [3], has been constructed for this source (see Fig. 4). A crucible fabricated with a tantalum tube is clamped between two water-cooled current leads with current supplied by a 150 Ampere, low-voltage power supply. The oven is mounted axially on a dedicated injection flange. The temperature capability has allowed a beam of titanium to be developed for the source.

Figure 4: The copper clamps and the detached, tantalum crucible for the high-temperature oven.

THE SEE PROGRAM

At present both cyclotrons provide beam for the SEE program, the K500 since 1995 and the K150 only recently. A test station has been installed in the K150 vault for SEE mainly with protons, while a dedicated cave has been outfitted with a test station for K500 beams. Users are interested in the effects of ion beams on individual electronic components, and for this purpose they need a broad variety of beams that can be uniformly spread across the area of a device. Suites of beams at various energies have been developed to provide an array of linear-energy-tranfer (LET) capabilities on-target at low fluxes (10^3 pps/cm^2 or less). To this end three suites of beams have been developed for the K500. The first suite at 15 AMeV consists of alphas, nitrogen, neon, argon, copper, krypton, silver, xenon, holmium, tantalum and gold. The second at 25 AMeV consists of alphas, nitrogen, neon, argon, krypton, silver and xenon. The third at 40 AMeV consists of nitrogen, neon, argon and krypton-78. The energy of these beams allows for a uniform LET across the depth of the device with in-air testing.

Figure 5 shows the test station. Beams can be delivered with a high degree of uniformity over a 1.8" x 1.8" cross sectional area for measurements inside the vacuum chamber and 1" diameter circular cross sectional area for the in-air station. Uniformity is achieved by using a scintillator-detector array. A degrader-foil system makes it possible to set the desired beam LET value at a particular depth inside the target without changing the beam or rotating the target. The beam energy is reduced by means of a degrader system with foils having a suitable thickness and orientation with respect to the incident beam.

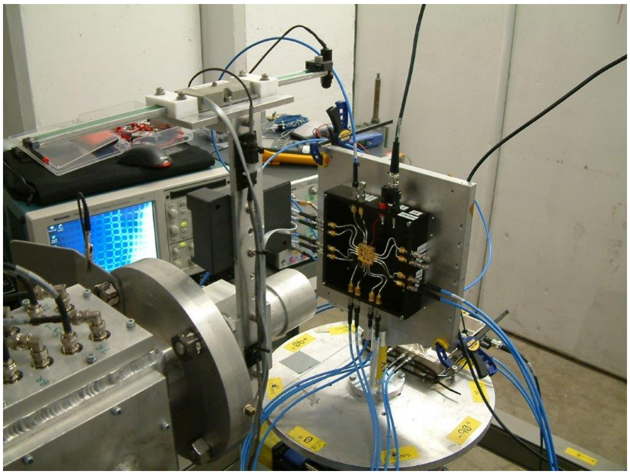

Figure 5: SEE Test station with in-air set-up.

Charge-states for ions in each suite are chosen so that the charge-to-mass ratios (Q/M) are closely grouped so that only small changes in the cyclotron trim-coils and main coil need to be made between the various beams while the cyclotron frequency is left fixed. To save time between beam changes within each suite the injection line which uses only magnetic components is left fixed, and the extraction-voltage of ECRIS is varied to match those components. As a consequence the injected beam energy does not exactly match the inflector/central-region geometry. The time-savings for beam changes is more important to the users than the consequent reduction in flux on target. In fact low flux is usually required, and this is controlled by via attenuators in the injection line.

All the beams from solid materials in these suites are provided by sputtering into the ECRIS. An eight-lead high-voltage feed-through is positioned through a radial port. To switch between solids requires just changing leads and applying the sputtering voltage.

ACCELERATED RIB PROGRAM

Light-Ion Guide

Progress has been made toward a better understanding of the parameters that go into successful operation of the light-ion-guide/charge-breeding ECRIS system (LIG/CB-ECRIS). The flux of radioactive ions from the LIG has continued to improve, and the charge-breeding of radioactive ions has been detected. Recently a short, two-stage sextupole (see Fig. 6) following the design of the University of Jyväskylä Cyclotron Laboratory was installed [4]. An 8mm diameter aperture between the stages blocks a majority of the helium flow from the target cell, and two apertures in the acceleration region further reduce this flow. Figure 7 shows the LIG/CB-ECRIS up through the 90° analysing magnet. The charge-bred ions are directed

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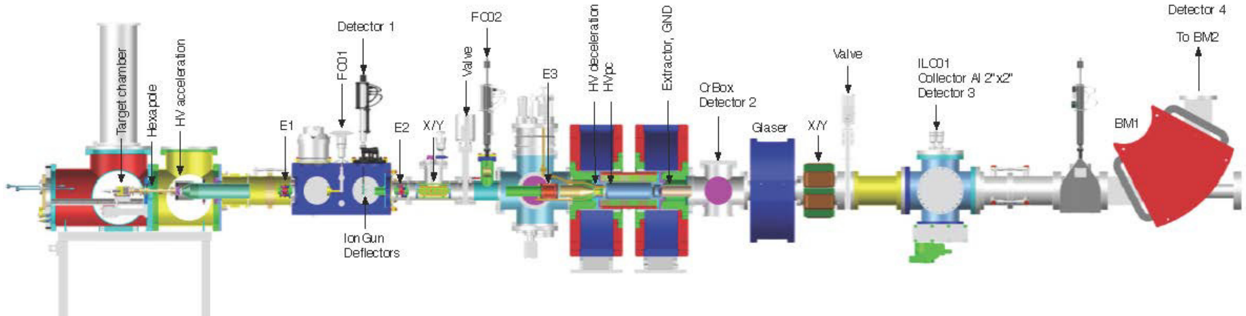

Figure 7: The LIG/CB-ECRIS line from the target-cell chamber to the 90-degree analyzing magnet.

vertically above the shielding for eventual injection into the K500 cyclotron. The target chamber and sextupole are held at high voltage so that exiting ions are accelerated by a grounded puller.

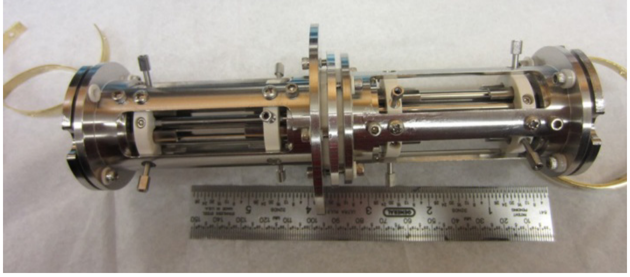

Figure 6: The sextupole.

Two detection stations for betas, each consisting of a rotatable aluminum foil and a shielded silicon detector, were placed in the beam-line, one at a point approximately half-way between the acceleration region and the entrance of the CB-ECRIS and another at a point immediately down-stream of the CB-ECRIS puller. Measurements using a 4.0 µA proton beam and a ^{64}Zn target producing ^{64}Ga via (p,n) gave a calculated flux of 2 x 10^4 pps at the first detection station, although if the beam is not tightly focused on the foil the geometric detection efficiency may be lower, and the actual flux may be higher. For the purpose of determining conditions for charge-breeding of ions coming from the LIG, the one-plus alkali ion source was mounted perpendicular to the beam line in the chamber midway between the LIG and the CB-ECRIS. An electrostatic 90° deflector was mounted in the chamber to steer the ions in the direction of the CB-ECRIS. An aperture was machined into the positive plate to allow passage of the LIG beam. Rubidium from this source could be successfully charge-bred with this system.

Tests with the charge-breeding of the 64Ga beam from the LIG have produced high charge-states, the peak of the distribution being a measured flux of 64Ga12+ at 23 pps with a much lower intensity proton beam. LIG tests with a radioactive thorium source also have yielded a charge-bred beam of 220Rn with a maximum charge of 29+. The fluxes are low at present. One indication of a problem is a measured wide range (~100 volts) of voltage difference between the LIG and the CB-ECRIS in addition to a measured peak of this ΔV at a much higher voltage than for the charge-bred rubidium. This energy degradation and spread of the LIG beam could be due to excess helium gas from the target cell in the accelerated-beam region.

Heavy-Ion Guide

Significant progress has been made in the design and construction of the beam transport system for the heavy-ion guide. To capture radioactive species after the heavy-ion-guide gas catcher and direct them to the different devices, a complex RFQ system has been designed and constructed. The RFQ system consists of a 30 cm long DC-drag cooling RFQ located immediately after the gas catcher's exit hole at a relatively high helium gas pressure zone and a micro-RFQ mounted at the end of the DC-drag cooling RFQ. The micro-RFQ is 2 cm long and has a 4.5 mm exit hole, which is necessary to ensure efficient differential pumping. The micro-RFQ can be coupled individually with three other DC-drag RFQs which are mounted inside a large vacuum chamber on a remotely controlled position system. Two curved RFQs deliver radioactive ions either horizontally to the CB-ECRIS injection line or vertically above the shielding to a superconducting solenoidal Penning trap. Additionally there is a third straight section RFQ that leads to an ortho-time-of-flight (Ortho-TOF) mass spectrometer and a fourth 90° port that points directly to the CB-ECRIS ion source for tuning the injection line with 1+ alkali ion sources.

Logistical problems up to now have prevented the installation of the superconducting solenoidal spectrometer BIGSOL in line with the heavy-ion target cell. For initial testing purposes it has been proposed to use the products from a radioactive ^{252}Cf source.

Pilot-Beam Technique for Acceleration and Transport

Pilot-beams techniques for the acceleration of low flux beams from the CB-ECRIS by the K500 have been explored using the K500 main field to distinguish between species [2]. To prepare for the acceleration and transport to target of extremely low flux radioactive beams, a test was performed using the rf frequency to distinguish between a high and a low-flux beam. A 14 AMeV $^{16}O^{3+}$ (Q/M =.1876, f =12.237 MHz) beam from the CB-ECRIS was tuned in the K500 and transported to a focus at the entrance of MARS. A charge-bred beam of $^{85}Rb^{16+}$

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(Q/M=.1885) mixed with the beam of $^{16}O^{3+}$ was then accelerated in the K500 by raising the rf frequency by 56 kHz. Since all the magnetic components up to the target remained the same, the $^{85}Rb^{16+}$ beam appeared as a focused spot on target. The spectrometer with a silicon-detector telescope in the focal plane, which had been calibrated previously with a 14 AMeV $^{84}Kr^{16+}$ beam, was used to identify the beam as rubidium.

While observing the $^{16}O^{3+}$ beam with a PMT-Scint detector at the MARS focal plane, a 12 kHz shift in the rf was needed to eliminate the beam. So it appears that ions with Q/M differences of less than about one part in 10^{-3} cannot be cleanly separated by the cyclotron. In these cases stripping of the accelerated beam can possibly allow different species to be separated in the beam-line.

FUTURE PROGRESS

The programs at the Cyclotron Institute remain healthy, and with performance improvements in the operation of the K150 the SEE program will expand and the radioactive beam program will be fully supported with driver beams.

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