Commissioning of the Texas A&M ECR Ion Source High B Upgrade.

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Since 1989 a single conventional 6.4 GHz ECR ion source has been used for injection of beams into the K500 superconducting cyclotron at the Texas A&M Cyclotron Institute. The Institute has received funding to upgrade the ion-source capability of the laboratory so that eventually two ECR ion sources will be available for external injection. In the first part of the upgrade, a new stronger hexapole has been installed in the existing source and its steel configuration has been modified to allow operation in the high B mode. In this report the upgrade is described, and the results of the initial operation of the high B version of the source along with injection into the K500 are presented.

1 INTRODUCTION

The Texas A&M ECR ion source was designed in 1987[1] and was first operated in 1989[2]. It employed current-carrying copper coils and a hexapole constructed of samarium-cobalt permanent magnets to produce a minimum-B field configuration with a closed surface resonant at 6.4 GHz for electrons in the second or main stage of the source. The coils also produced a field in the first stage which had a single, unclosed surface resonant at 14.5 GHz. A 6.4 GHz transmitter and a 14.5 GHz transmitter excited the main and first stages, respectively. Its performance[3] was comparable to both the 6.4 GHz ECRIS at Lawrence Berkeley Laboratory[4] and to the 6.4 GHz RTECR at NSCL Michigan State[5], both of which were used as models for the original Texas A&M design.

Anticipating an upgrade, the steel yoke and coils of the Texas A&M source were constructed to provide a magnetic field in the main stage of the source of such magnitude that electrons could reach the resonant frequency of 14.5 GHz. A possible upgrade of the source involving replacement of the hexapole with a hexapole capable of producing 14.5 GHz resonant fields was always considered, but the discovery of the high B mode at the NSCL with the superconducting ion source SCECR[6] greatly simplified our considerations.

The SCECR in the high B mode produces beams of much higher intensity than the other 6.4 GHz sources. Light ion beams and mid-charge-state heavy ion beams from the SCECR are an order of magnitude more intense than those from the RTECR. For high-charge-state heavy ions the increase approaches two orders of magnitude with even higher charge states appearing where none were detectable before. It was quickly realized that the coils of our source could produce fields only somewhat lower than those at which the SCECR runs in its 6.4 GHz high B mode and that the addition of some extra steel would produce a close match. Also, just by substituting neodymium-iron-boron for samarium-cobalt the hexapole strength would be approximately the same as that of SCECR. The hexapole would be longer, however, so a new plasma chamber holding the longer hexapole would have to be constructed.

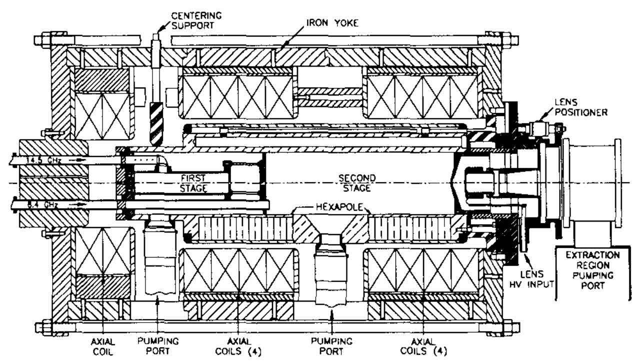

Figure 1: Original ECR source design.

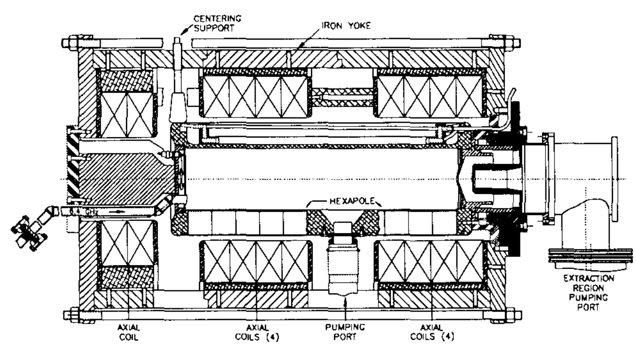

Figure 2: Upgraded ECR source design.

The design of the upgrade is explained in ref. 7 and is basically an effort to match the magnetic fields of the SCECR in its 6.4 GHz high B mode. Figures 1 and 2 show lengthwise cross-sections for the design of the original source and for the design for the upgraded source. The yoke and coils are not changed. The modifications are: 1) the hexapole and plasma chamber are now longer, 2) instead of a first stage there is now a negatively biased disk, and 3) new steel has been added to the injection end and to the extraction end. The steel plug on the injection end must touch the plasma chamber, so it is insulated from the yoke. Table 1 lists the parameters of the design versus those of the SCECR in 6.4 GHz high B mode operation. It should be noted that the Texas A&M fields are at their maximums while the SCECR fields are not. Also, the Texas A&M

Table 1: Source design parameters.

Hexapole	TAMU design	SCECR[6]
Pole strength of the magnetic field at wall	0.50 Tesla	0.44 Tesla
Bore diameter of plasma chamber	13.2 cm	14.0 cm
Axial Field		
Peak at extraction	0.64 Tesla	0.65 Tesla
Peak at injection	1.24 Tesla	1.25 Tesla
Inter-mirror distance	58.7 cm	61.0 cm

hexapole is constructed of six rectangular bars of uniformly magnetized Nd-Fe-B material. Two of the central coils have their currents reversed to produce the minimum of 0.15 Tesla at the source center.

The high-B mode upgrade was finally decided upon because it represented the least expensive, easiest to accomplish and least disruptive alternative. Following evidence that the use of aluminum in the plasma chamber enhances the production of high-charge-states[8], the material for the plasma chamber was changed from copper to aluminum. The old plasma chamber and hexapole will be used as the basis for a second source.

2 CONSTRUCTION

The major item for construction was the new plasma chamber. The chamber was machined from a solid bar of 6061-T651 aluminum. The aluminum was first bored and then turned on a lathe for inner and outer diameters. Slots were machined for the permanent magnets and for water-cooling tubes to be added later, and the side ports were drilled. Figure 3 is a photograph of the plasma chamber after machining. The completed aluminum was shipped to the company responsible for supplying and installing the permanent magnets, Magnetic Component Engineering, Inc. in Inglewood, California.

Before this time the company had prepared the individual Nd-B-Fe magnets through grinding and drilling. Personnel from MCE and from Texas A&M then assembled the individual magnets into the six bars which form the hexapole. Each of the six 57.15 cm X 4.83 cm X 4.95 cm bars of the hexapole was built up of six segments. The magnetized segments were pressed and glued together in a special screw press. Stainless steel straps which fit over stainless steel dowels in the drilled holes in the magnets were also glued on. Finally four thin sheets of stainless

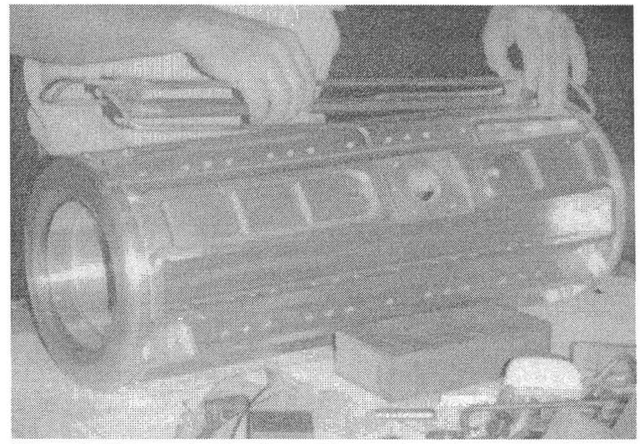

Figure 3: Plasma chamber being fitted with cooling tubes.

steel were glued to the sides of each bar to ensure structural stability and to insulate the bars thermally from the plasma chamber. Immediately after assembly each bar was lowered into its slot in the plasma chamber using the press on a milling machine. Set screws were used to secure the bars in the slots. The completed assembly was then shipped to Texas A&M.

The hexapole field strength was measured by running a hand-held Hall probe down the length of each bar along the inner wall of the plasma chamber. The average field strength at the wall was 4.77 kilogauss, about 5% lower than the design calculation. The bars were approximately equal in field strength.

At Texas A&M the copper, water-cooling tubes were shaped to fit on the chamber, and a stainless steel cover was fitted to surround this assembly. Also at Texas A&M the new steel plug was machined from a single piece of Intrak low-carbon steel (1001-1005), and the vacuum port, ion-gauge port and solid-feed port were constructed. The injection end flange was machined from stainless steel and the microwave guide was silver-soldered to the steel flange. An aluminum plate was machined to cover this flange on the inside and face the plasma. A 12.7 mm diameter hole was drilled through the center of the aluminum plate to expose an aluminum disk, negatively biased, to the plasma. The end flange was also drilled for a gas inlet.

3 SWITCH TO HIGH B MODE

The plan for the conversion of the source was to make it rapid enough that there would be only minimal interruption in the experimental program for the cyclotron. Before the conversion the power supplies and coils were checked for their ability to handle the required currents. Several supplies had to be reset for higher maximum currents.

At the scheduled time the source was turned off, and the beam pipe near the extraction end and the first focussing solenoid were removed. The extraction insulator and electrode were removed as well as the injection end steel plug and the first stage. The plasma chamber was then removed through the extraction end of the source. The new steel plug was placed temporarily in the injection end along with the new steel plate on the extraction end. Current was applied to the coils, and the field levels and directions were checked with a hand-held Hall probe. These were found to be satisfactory, and the new steel was removed before the new plasma chamber was inserted through the extraction end.

When the steel plug on the injection end was mounted in place, the force from the hexapole fringe field on this plug was found to be less than anticipated so that they could be separated by hand. The microwave guide was fitted to the end flange of the plasma chamber through one of the slots in the plug. The extraction end had to be reassembled using the old steel flange due to the late arrival of new metal vacuum seals. Due to this, the field on the extraction end is approximately 425 gauss lower than originally planned. This will be corrected at some point. Finally the vacuum system was remounted. The plasma chamber and the extraction volume are each pumped by a 400 l/s turbomolecular pump.

These modifications took approximately one week before the source was pumped down and the 6.4 GHz microwaves were first injected. In less than one more week the first beams were being extracted.

4 INITIAL BEAMS

The first observation about the performance of the new source versus the old was made upon first injection of microwaves. The pressure rise was dramatically less for the new than for the old source. The source was initially unstable at voltages greater than 3 kV. This steadily improved over the next few weeks. The source was opened a few times in the first week after turn-on to improve the shielding of the injection flange seal from the microwaves. After one week the source could hold 10 kV, the main-stage pressure with no microwave or gas injection was in the low 10^{-6} torr range and the production of $^{16}O^{7+}$ was 11 eμa. By another two and one-half weeks this pressure was down to 3.5×10^{-7} torr and the $^{16}O^{7+}$ production was up to 27.5 eμa. Similar increases were observed with argon beams. From experience with the old plasma chamber it is reasonable to expect an eventual background pressure of 1×10^{-7} torr. Table 2 lists the best beams to date versus the best beams produced by the old version of the source.

The microwave power injected into the source varies from 0.4 kW to 1.1 kW for these beams. The high-density polyethylene microwave window[2], which both isolates electrically and serves as a vacuum seal, has not failed after running at a kilowatt power level for extended periods.

Table 2: Comparison of beams from old and new sources.

Species	Q	old int. (eμa)	upgrade int. (eμa)
^{16}O	6	84	118
	7	11	27.5
^{20}Ne	7	14.5	40
	8	6.6	40
	9	0.4	6.4
^{40}Ar	8	31	51
	9	25	40
	11	12	31
	12	6.5	19
	13	2.0	8.3
	14	0.5	3.6
	16	0.014	0.20
^{58}Ni	17	1.5	5.0
	19	0.06	1.3
	20	0.003	0.20
^{84}Kr	19	2.0	7.4
	20	1.0	4.1
	22	0.175	1.0
^{129}Xe	20	10.6	16.0
	21	8.9	15.0
	22	7.6	13.5
	23	5.4	10.5
	25	2.75	5.0
	27	0.44	1.0

5 CYCLOTRON BEAMS

A beam from the upgraded source was first injected into the cyclotron on August 31 less than one month after the source was turned off for its upgrade. In less than two months it has already had a positive impact on cyclotron operation. One beam run initially for an experiment was a 50 Mev/n neon beam originally developed with $^{20}Ne^{8+}$. Since the upgraded source produces as much $^{20}Ne^{9+}$ as the old source produced 8+, the beam was redeveloped using the 9+ ion with more extracted intensity than before but with significantly lower dee and deflector voltages.

The first beam from a solid material from the upgraded source was run in response to a requirement for a 40 MeV/n beam of nickel. Previously an attempt was made using $^{58}Ni^{18+}$ from the old source. The beam was extracted from the cyclotron, but unfortunately before it could be used the vacuum/high-voltage window failed on the source with the high power. The nickel material was sputtered into the source following a method developed for the Argonne

ATLAS PIIECR ion source[9], and high-charge-states were quickly developed. $^{58}Ni^{19+}$ from the upgraded source was used, and the beam was developed again with less dee and deflector voltage and with more intensity.

6 TWO ECRIS PLANS

Presently a second ECR ion source is being constructed using the old copper plasma chamber and hexapole. Figure 4 presents a length-wise cross-section of the design for this source. The design is close to the previous one except for both the first stage and the steel plug necessary to produce the required ECR field for 14.5 GHz in the first stage. The injection end will be accessible for the insertion of a low temperature oven and a liner for the production of lithium beams, a priority of the laboratory. Using a biased plate instead of a first stage on the injection end, the hope is that the source performance will come close to the old version.

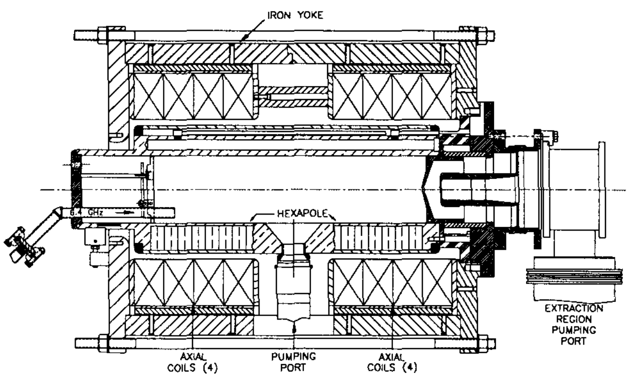

Figure 4: Second ECR ion source.

The two sources will sit next to one another, and their beams will be transported to the cyclotron through the same injection optics after separate analysis systems. In this way, both sources can be tuned separately, and the beam for injection into the K500 can be easily and quickly switched.

7 CONCLUSIONS

The beams produced by our upgraded source are not yet comparable to those produced by SCECR, but the initial performance has been encouraging. High-charge-state intensities have been increased by large factors. The availability of higher intensities has made it possible to run higher intensities out of the K500, to lower the voltages necessary to run the required intensities of certain beams, and to consider the immediate development of higher energy heavy-ion beams from the K500.

The background pressure in the source is still going down. This should continue to improve the performance. Strategies for improving the vacuum and for improving handling of the higher intensities by the optics system, as well as trials of different microwave injection schemes and other ideas can be attempted when the second source is brought on-line early in 1996. Meanwhile, a low-temperature oven, a rod feed and a high temperature oven will be added in order to increase the range of beams. So far the upgrade has been successful both from the standpoint of expense and effort and from the standpoint of maintaining and improving our flexibility in providing beams from the cyclotron.

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