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UPGRADE OF THE ATLAS 10 GHZ ECRIS

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A major renovation of the ATLAS 10 GHz ECRIS, which began operations in 1987, is in the planning and acquisition phase. The old two-stage source will be converted to a single stage design including a high gradient magnetic field, electron donor disk, large radial ports, and flexible modular design. Eight solenoid coils taken from the existing ECR will produce the axial mirror. The individual coils will be encased in an iron yoke that optimizes the magnetic field. Computer modeling of the magnetic field profile yields a minimum field along the axis of 3.0 kG with mirror ratios of 4.4 and 2.9. An open hexapole configuration consisting of Nd-Fe-B bars enclosed in an austenitic stainless steel housing will be placed in an aluminum plasma chamber that will be water cooled along the poles of the hexapole. The hexapole field at the chamber wall, 4 cm in radius, is expected to be 9.2 kG along the magnet poles and 5.7 kG along the center of the pole gaps, which are 2.4 cm wide. A 3D model produced from individual 2D field profiles was used to check the end effects of the hexapole. Based on the models this new field configuration is capable of supporting a second ECR resonance zone at 14 GHz, which may be implemented at a later date.

1. INTRODUCTION

The ATLAS facility at Argonne National Laboratory provides beams of heavy-ions at energies up to 17 MeV/A for research in nuclear and atomic physics[1]. Beams of any element are potentially available. In a typical year, beams from nearly 30 different isotopic species will be provided from protons to uranium. The majority of the beams have been produced by the ATLAS ECR-I[2] ion source from solid materials.

ECR-I has operated reliably since 1987 and has provided over 30,000 hours of beam for ATLAS. The source dates from the ‘first generation’ period of high charge state ECR ion sources, utilizing a two-stage design and a radio frequency (RF) of 10 GHz. As the only ECR ion source for ATLAS, time for development and source improvements was greatly constrained. Now with the completion of a new, second, ECR ion source[3] for ATLAS it is possible to undertake a significant redesign of the ECR-I source and incorporate many of the new techniques and concepts developed over the past ten years[4] in a newly designed incarnation of ECR-I.

The primary goal for upgrading the ECR-I ion source is to significantly improve the average charge state distribution produced by the source, typically shifting the average charge state up by approximately 10%. A second goal is to increase the total extracted useful beam current by up to a factor of two. These goals are to be achieved while maintaining a source design, which continues to emphasize the importance of solid feed material.

The major features of the new source are:

1. 10 GHz RF operation will be continued, but the magnetic field design will support operation at 14 GHz.
2. Large radial access ports into the plasma region will be maintained but consistent with a strong hexapole field that keeps the ECR resonance zone well confined.
3. A single stage source design with an on-axis electron donor disk replacing the function of the old first stage.
4. Use of an aluminum plasma chamber to make maximum use of the high secondary electron yield of aluminum oxide surfaces.
5. The control system of the new source will be fully incorporated into the main ATLAS VISTA control system.

II. SOURCE DESIGN

The basic structure of this source is shown in Fig. 1. Both the injection and extraction tanks are shown along with the iron yoke surrounding the solenoid coils. The plasma chamber is 30 cm long from the bias disk to the extraction aperture and 8 cm in diameter. The 10 GHz RF line and all of the gas feeds are coupled into the source through the injection tank on the left. Both the injection and extraction coils will be mounted from a common base plate. While the extraction coil and plasma chamber will be permanently fixed in position, the injection coil will sit atop a rail system allowing the

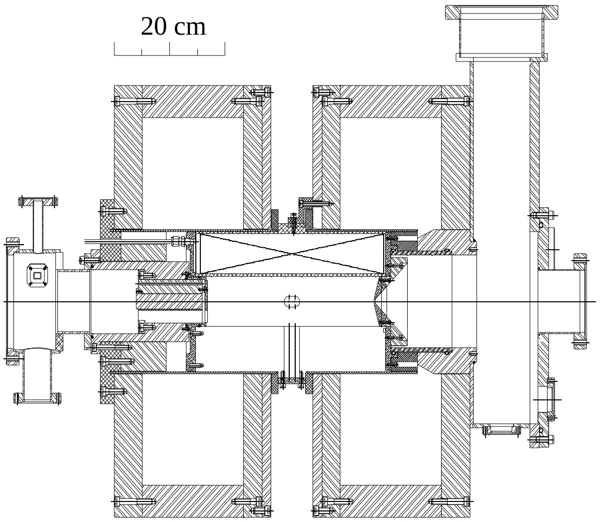

FIG. 1. Schematics of the new single-stage 10 GHz ECRIS with the injection tank on the left.

coil, iron yoke and injection tank to be rolled back from the plasma chamber roughly 1.2 m. To achieve the greatest flexibility the inner iron on both the injection and extraction coils will be partially removable providing a maximum working gap of 10.7 cm between the coils. An open hexapole configuration with radial ports 2.8 cm long and 1.7 cm wide through the plasma chamber allow access to the plasma for solid material feeds, pumping of the source region and plasma diagnostic studies. It is envisioned that pumping of the plasma chamber will be provided through two of the radial ports as well as through the extraction tank.

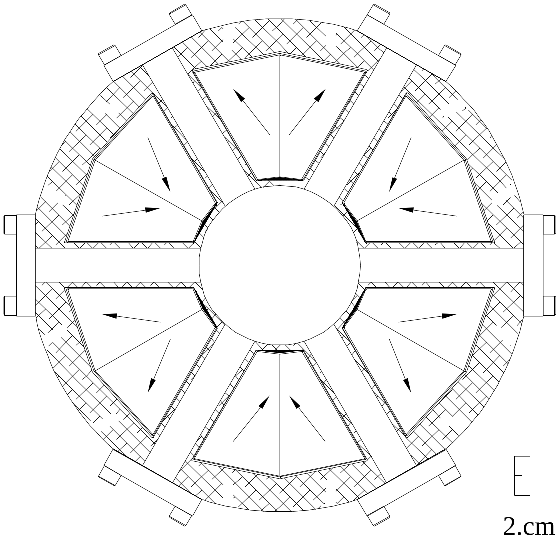

FIG. 2. A cross sectional view of the plasma chamber showing the hexapole magnets within their housing and the water channel along the poles of each magnet bar.

Figure 2 shows a cross sectional view of the plasma chamber including the hexapole arrangement, the water channels at the base of each magnet block and the radial ports. The plasma chamber will be constructed out of 1061 aluminum and have an inner diameter of 8 cm. The inner and outer corners of the magnet blocks are at radii of 4.5 cm and 10.5 cm respectively. The easy axis angles are at 38 degrees relative to the center of each pair of magnet blocks. The hexapole magnet bars will be encased in austenitic stainless steel and then housed in channels within the plasma chamber walls. These same channels will be used for direct water cooling of the hexapole. Neglecting water flow around the magnet bars the effective water channel cross section is 0.38 cm^3. A physical model of this region of the plasma chamber 30.5 cm long was constructed to determine if sufficient cooling to the hexapole is provided. Test data at 1 gal/min and a pressure near 80 psi, with an estimated energy flux of 130 watts, produced a 1° C increase in the water temperature and a 10 to 12° C increase in the external aluminum. Based on a series of these measurements at different flow rates and different external temperatures, the hexapole should remain within a few degrees of the water temperature, even under a 2 kW load. To insure sufficient water flow at the available pressure, three parallel water leads will be installed.

III. MAGNET DESIGN

Eight of the original solenoid coils will be reused to produce the axial mirror. The solenoid field including the surrounding iron yoke was simulated using the POISSON code, available from the accelerator group at Los Alamos National Laboratory (LANL), and the iron was adjusted to produce the maximum field gradients. The resulting axial field for a current of 500 A in both coils is shown in Fig. 3. The minimum-B field between the two coils is 3.0 kG while the injection and extraction mirror ratios (MR) are 4.4 and 2.9 respectively. Additional simulations indicate that the mirror ratios go up as the current is reduced. For example, at the minimum current of 350 A, which insures that there is no 10 GHz on axis resonance zone in the near extraction region, a minimum-B field of 2.2 kG is produced with MR of 4.8 and 3.0. When a second frequency at 14 GHz is added the minimum current needs to be increased to 425 A producing a minimum-B field of 2.9 kG and MR of 4.5, and 2.9. Thus in the case where a lower B-field gradient is desired, which might be the case for producing low charge states, some of the iron around the coils should be removed (see Source Design above). Based on the model, the position of the extraction gap has been placed at the peek of the extraction B field, which minimizes its effects on the plasma.

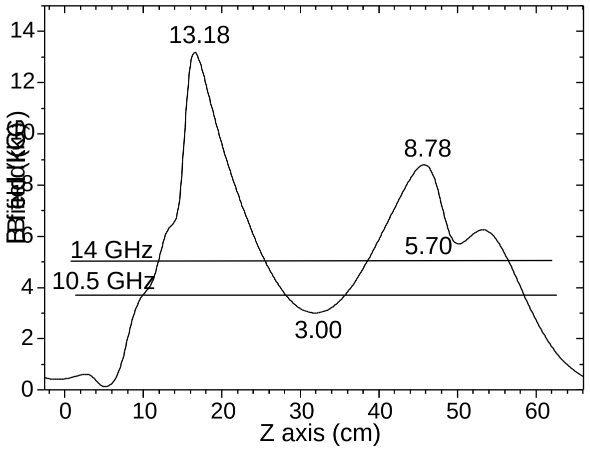

FIG. 3. The axial magnetic field profile for a coil current of 500 A.

The new hexapole magnet design is based on that of ECR-II, which utilizes a large gradient B field in the radial direction. The working principle for the new ECR-I design is to maintain the ability to add a second resonant frequency at 14 GHz while maximizing the effective size of the radial ports. In order to achieve this kind of flexibility, an open hexapole configuration using a high-energy product Nd-B-Fe magnet material was selected. To achieve this goal a significant amount of modeling needed to be done to optimize the magnet shape as well as the easy axis angle. Computer models of this configuration, limited only by the inner diameter of the existing solenoid coils, were produced using PERMAG, provided by Dan Xie, and PANDIRA, available from the accelerator group at LANL. The main distinction between these two codes is that PERMAG is capable of generating 3D fields but does not consider the possibility of demagnetization[5] while PANDIRA includes the coercive force (H_c), accounting for demagnetization effects, but only supplies a 2D-field profile that ignores end effects. With these limitations in mind, an initial 2D model of the hexapole was generated using PANDIRA in order to optimized B_r and B_φ. Figure 4 shows a field profile of the magnet bars at the wall of the plasma chamber as a function of angle starting from the pole gap on the right in Fig. 2. Once the fields were optimized a second model using PANDIRA was generated and it was found to be identical to that shown in Fig. 4. Assuming demagnetization is not a factor for the high H_c material selected, PANDIRA was then used to generate a 3D-field profile so that end effects could be investigated. Without considering the effects of the iron on the hexapole field, a zero order approximation was generated by combining both the solenoid and hexapole field profiles via superposition. The three lines of interest in this model lie along the two magnet poles and along the center of the pole gap. In all three cases, cancellation effects on the extraction side were minimal and well handled by shaping the iron plug forming part of the extraction gap. However, cancellations on the injection side involving magnet bars having their easy axis pointing away from the center of the hexapole were hardest to deal with because of the very strong solenoidal field in that region. The B field as a function of the axial position (z) for three different radial values (r) is plotted in Fig. 5. Ideally the radial field lines should not cross spatially as they do near z = 20 cm, which corresponding to the injection side of the source. In this case, simple shaping of the iron yoke did not modify the field profile significantly. The only thing that made a significant difference was the reduction of the solenoid current but this compromises the peek B field, which

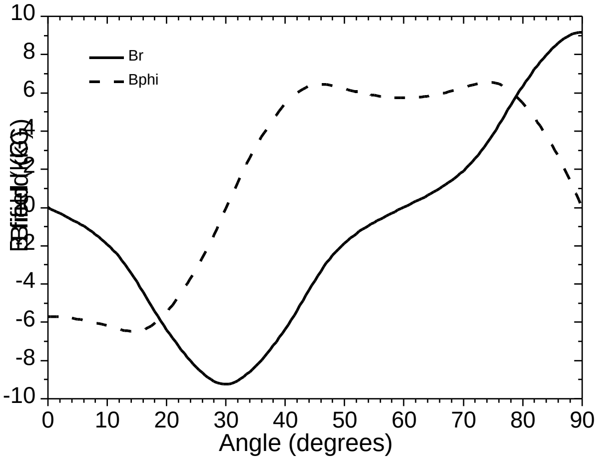

FIG 4. The hexapole field profile at the surface of the plasma chamber for the upper right quadrant of Fig. 2 is displayed counter clockwise.

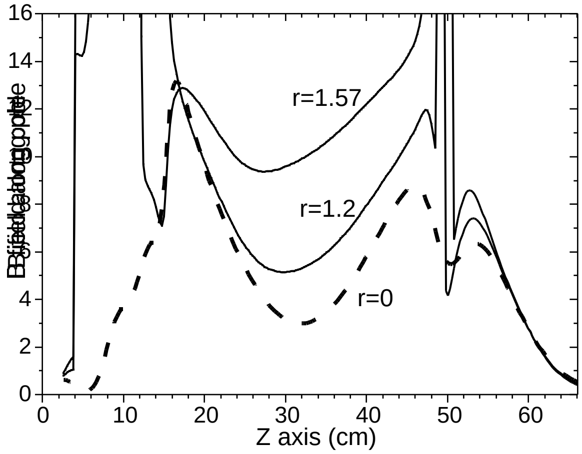

FIG 5. A slice from the 3D magnetic field model showing the spatial overlap of the B field resulting from hexapole end effects. Z = 0 corresponds roughly to the left edge of the injection yoke iron in Fig. 1. The coil current was 500 A.

was deemed more important. The field crossing seen near Z = 50 cm corresponds to an off axis point just outside of the extraction aperture. At 14 GHz a resonance zone will appear in this region with very weak confinement. This effect has been observed in ECR-II, which has a similar iron extraction yoke configuration, but the effect on the extracted ions has not yet been determined.

IV. Current Project Status

Table 1 presents a summary of the ECRIS parameters that have already been discussed. Additional modeling of the extraction region, including electric and magnetic fields as well as space charge effects, is being carried out using PBGUN. Studies of the puller location and configuration will eventually be carried out.

Conversion to the ATLAS master control system is underway but since ECR-I remains in operation this transition has been limited in scope. At present the gas manifold has been successfully interfaced through CAMAC and fiber optic links. Further updates in the control system will take place as scheduling permits.

Table 1: Summary of ECRIS parameters

Microwave Frequency	10 GHz 14 GHz possible
Plasma chamber	
Diameter	8.0 cm
Radial ports	2.8 cm by 1.7 cm
Water channel cross section	0.38 cm^2
Solenoid coils	
Current range for 10 GHz	350 – 500 A
Minimum Field (500 A)	3.0 kG
Injection side MR	4.4
Extraction side MR	2.9
Hexapole	
Length	33.0 cm
Easy axis angle (radial ref.)	38.0°
B_r Pole tip field, r = 4 cm	~ 9.2 kG
B_Φ Gap field, r = 4 cm	~ 5.6 kG
Cooling water	
Input temperature	~ 11° C
Head pressure	80 psi
Max. expected $\Delta T_{hexapole}$ for a 2 kW input	< 10° C at 1.0 gpm per channel
Max. expected ΔT_{coils} for a current of 500 A	< 30° C at 4.0 gpm per coil

Procurement of the hexapole magnets is also proceeding with the intention of purchasing one additional unmagnatized, unassembled bar as a backup. Because the magnet blocks can be magnetized in either direction a single backup bar should be sufficient since a plasma confinement failure is likly to take place in only one location. The plasma chamber and iron yoke are still in the design stages but will be submitted for fabrication as soon as the details are finalized. The decommissioning of the existing 10 GHz ECR is planned for the Fall of 1999 with initial testing of the new ECRIS near the end of the year.

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