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ECR2 PERFORMANCE UPGRADES AT ATLAS

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Abstract

The user requests for higher beam energies and intensities have driven the decision to upgrade the ECR2 ion source at the Argonne Tandem Linac Accelerator System. Multiple upgrades are in progress with the expected outcome of dramatically increased ECR2 beam intensities and charge state capabilities. The magnetic upgrades include integrating an improved hexapole permanent magnet array that provides the ion source radial fields, reworking the magnetic materials surrounding the plasma chamber, and installing a new cooling system for the electromagnetic solenoids that govern the ion source axial fields. The new hexapole and higher solenoid magnet operating currents will increase the ion source magnetic fields and support the use of 18GHz RF heating, further increasing the ECR2 beam capabilities. Following these improvements and subsequent source performance, simulations of beam transport devices on the ion source platform will need to be revisited for transmission of high intensity beams. Details of these upgrade projects and simulations of the ion optics are presented.

INTRODUCTION

ECR2 at The Argonne Tandem Linac Accelerator System (ATLAS) was commissioned in 1997 [1] and has since delivered the majority of the delivered ion beams for the internationally supported user facility. The electron cyclotron resonance ion source (ECRIS) has a normal running condition that includes multiple frequency heating of nominally 12 GHz and 14 GHz at powers up to 1100W using frequency generators that feed into traveling tube wave amplifiers (TWTA). The ECR2 configuration includes two water cooled solenoids to produce the axial magnetic fields, an open hexapole permanent magnet assembly to provide the radial magnetic fields in the plasma chamber, and turbomolecular pumps to pump on the plasma chamber, both axially and radially through the open ports in the plasma chamber, made possible with an open hexapole design. Lastly, gaseous material can be easily introduced to the plasma chamber through the vacuum system or solid materials can be introduced radially through the hexapole ports with either an oven or sputter rod that is biased to release material from the probe.

Since 2015, ECR2 was the exclusive ECRIS at ATLAS until the commissioning of ECR3 [2], an entirely permanent magnet ECRIS. This ion source does not have the same level of flexibility that ECR2 leverages for a few reasons. The solenoid magnets are not adjustable, the hexapole is not upgradeable, the plasma chamber has a smaller volume, and there is not radial access to the plasma chamber for material introduction. However, the performance of the ion source is sufficient for many of the requested ion beams at ATLAS, especially the requests for species that can be introduced in gaseous form. For this reason, a two-source dynamic is utilized to allow for both ion sources to be properly maintained and consistently upgraded without jeopardizing the beam hours that the facility delivers annually.

The ATLAS facility continues to make improvements, including the capabilities of the superconducting linac and target stations. The beam requests for higher energies and intensities have followed suit. Although the ion sources have been able to keep up with the requests, there are an increasing number of requests that exceed the capabilities of even ECR2 in its current configuration. It is decided to upgrade ECR2 to produce these increasingly difficult beams. The plan is to support 18 GHz operation of ECR2 while keeping a room temperature design [3]. Other facilities' results from similar upgrades [4,5,6,7] would all achieve the intensities that are needed, further justifying that this path forward will meet our operational goals of doubling the intensities that we currently produce. The upgrade projects that are needed to support this goal were a redesign of the hexapole permanent magnet array and corresponding plasma chamber, an improvement of the magnetic materials surrounding the plasma chamber, a solenoid magnet cooling upgrade, and an improvement of the transport capabilities of the ion beam directly downstream of ECR2.

MAGNETIC UPGRADES

The first and most complicated technical upgrade needed is the hexapole magnet array. The same hexapole has been used in ECR2 since 2005 and produces a simulated B_{rad} of 0.98 T. For this reason, ECR2 typically runs at 14 GHz for peak performance but would not be able to run at 18 GHz. A hexapole upgrade that could produce a B_{rad} of 1.18 T would optimize performance at 14.5 GHz and support operation of an 18 GHz driving frequency. To satisfy the ECRIS scaling laws, the axial magnetic fields must also increase. The extraction iron was modified slightly, and the injection iron was upgraded to incorporate a vanadium permendur cap and a thinner boron nitride insulation disk behind the biased disk, bringing the iron closer to the plasma chamber. Figure 1 shows the upgraded axial magnetic field from these modifications with the solenoid magnets set at 500A each.

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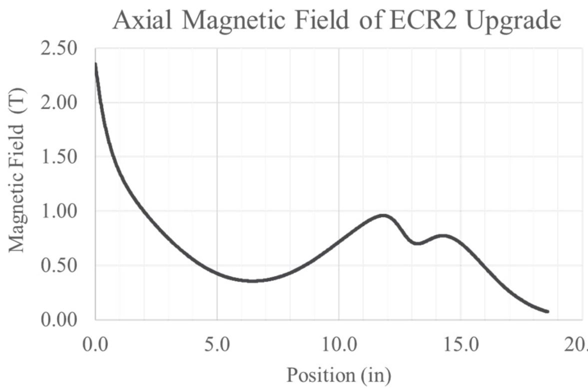

Figure 1: Axial magnetic field profile of the ECR2 upgrade.

The pre-upgrade hexapole incorporated 6 magnet bars, each with two segments. The upgrade hexapole magnet bars make use of 4 segments per bar with a new magnetization vector configuration and have a larger total volume than the previous version of the hexapole [3]. The new hexapole was originally considered using the same material as is currently used and yielded a 3D simulated B_{rad} of 1.18 T, but the risks associated with demagnetization were considered too high to move forward with the material. Additional materials were considered, and demagnetization analysis was completed for a new material, Vacodym 745 HR with a surface diffusion treatment of Vacodym 745 DHR [8]. The results yielded similar magnetic fields as the current material, but the demagnetization fields are far less concerning. Table 1 shows a comparison between the old hexapole and the upgrade hexapole.

Table 1: Magnetic Parameters of the ECR2 Upgrade

Parameter	Current	Upgrade
B_{inj}	1.85 T	2.44 T
B_{min}	0.34 T	0.36 T
B_{ext}	0.92 T	1.00 T
B_{last}	0.85 T	1.00 T
Coil currents	500 A / 500 A	525 / 525 A
B_{rad}	0.98 T	1.18 T
Plasma chamber radius	38.1 mm	38.1 mm
Plasma chamber length	297 mm	297 mm
Hexapole inner radius	42.4 mm	42.4 mm
Hexapole outer radius	74.7 mm	79.7 mm

SUPPORTING UPGRADES

To supplement the magnetic redesign work, components surrounding the plasma chamber needed to be revisited and redesigned. The first modification that was made accommodated a larger magnet volume. The plasma chamber outer diameter was expanded by 0.5 inches. Next, the cooling channels within the plasma chamber were updated. After having difficulty with consistent hermetic welds on the aluminum plasma chamber base, it was decided to explore alternative options that would decrease the risk of a leaking aluminum weld. The plasma chamber design retained the aluminum construction for the plasma facing surface and through the bulk of the material that was designed to conductively cool the plasma chamber and the magnet bars. The decision that would yield a higher success rate for these hermetic welds was the application of explosion bonding the aluminum body of the plasma chamber to a stainless-steel endcap. The stainless-steel endcap encompasses all the welds to ensure a high success rate of hermeticity, leveraging the experience of the machinists with stainless steel welding. Figure 2 highlights the transition region between the aluminum and stainless steel after explosion bonding the two materials.

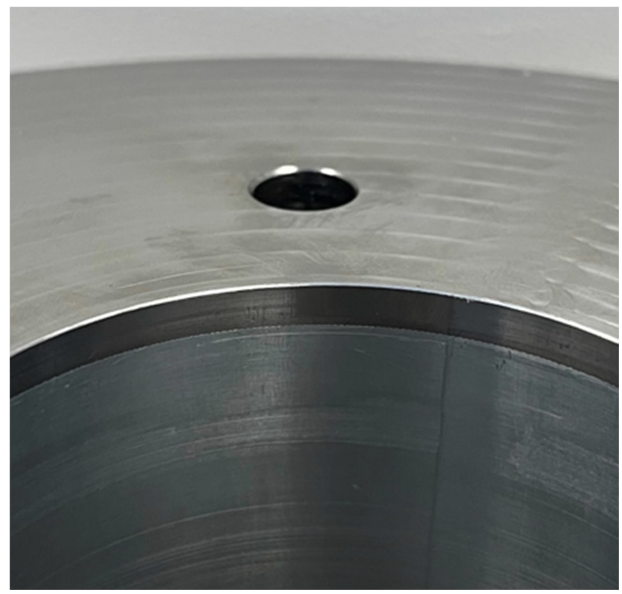

Figure 2: Aluminum and stainless-steel explosion bonded together.

With this new plasma chamber that is slightly larger than the original design, the high voltage insulation must be revisited. ECR2 has incorporated CPVC as a main insulating material since its inception and will continue to use it for its standoff capabilities and mechanical strength. A new CPVC tube and ring will be used around the extraction assembly to support the extraction region hardware as well as serve as the main high voltage standoff between the plasma chamber and the ground potential electrodes of ECR2. Additionally, an aluminum oxide insulator will be used to similarly standoff the plasma chamber potential from other nearby components at ground potential, as well as provide a vacuum sealing surface with two o-rings.

Finally, to support operation of the solenoid electromagnets on the injection and extraction sides of the ion source at higher currents than we are currently capable of, a deionized water system upgrade is being installed. The solenoid magnets are actively water cooled, but do not receive sufficient cooling to operate higher than 475A with their present cooling system. The upgraded water skid will be capable of supplying the required cooling for the upgrade

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that will require the solenoids to run up to 550A to achieve the fields needed for 18GHz operation.

ION BEAM TRANSPORT

The present ECR2 intensities do not pose any beam transport issues with the use of a glaser solenoid optical device and simple magnetic steerers in the beamline directly downstream of the extracted ion beam. Simulations of the ion beam transport were carried out in IGUN and show that up to 100% of the ion beam is transported to the first faraday cup after the analyzing dipole magnet for 100uA of 16/4+. An additional simulation at 1 mA, seen in Fig. 3, showed 81% transmission to the faraday cup with much of the lost beam being lost in a long drift space after the analyzing magnet but before the faraday cup. From top to bottom shows the simulation from extraction to the faraday cup.

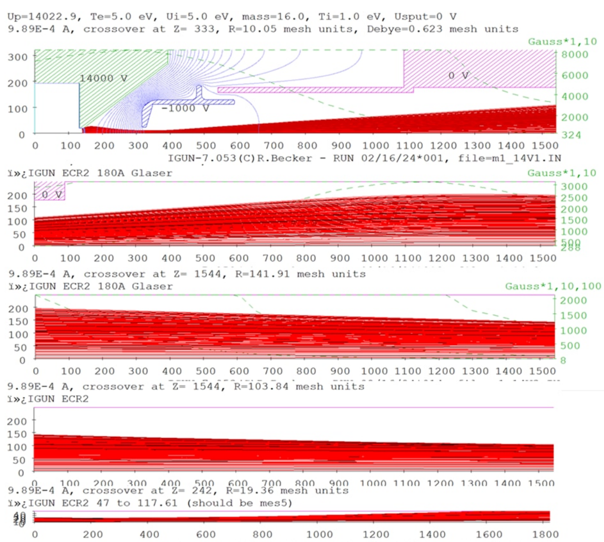

Figure 3: Beam transport from source to the first faraday cup after the analyzing magnet.

A simple solution of adding an einzel lens in the drift space before the analyzing magnet allowed for the 81% transmission to increase to 100%. Then, the extraction voltage was increased from 14 kV to 20 kV, and the beam current was increased to 3mA. Without the use of the einzel lens at 11 kV, the transmission was 44%. However, this increased to 100% with the einzel lens contribution. With the intensity improvements of this ECR2 upgrade, it is expected that the extraction potential will need to increase and the einzel lens will need to be added to the beamline to maximize the deliverable intensities for the ATLAS program. Figure 4 shows the simulation with the expected operational conditions after the ECR2 upgrade.

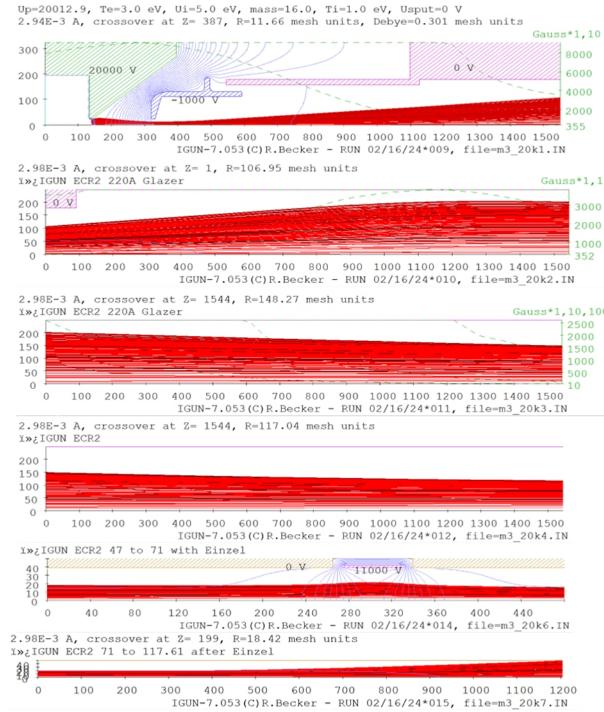

Figure 4: Beam transport from source to the first faraday cup after the analyzing magnet with the added einzel lens, increased intensity, and increased extraction potential.

CONCLUSION

ATLAS is continuing to improve the experimental areas and linac capabilities, which in turn attracts new users and experiments. These new experiments require higher beam intensities and energies, which demand higher charge states than ECR2 can produce. To provide these intensities and charge states for the facility's future, ECR2 must undergo an upgrade. This upgrade will increase the operating frequency of the ECRIS to 18 GHz, which has yielded sufficient increases in intensity and charge state at other facilities. The radial and axial magnetic fields are redesigned to accommodate 18 GHz operation. A completely new hexapole is designed for the radial fields, whereas the axial fields leverage vanadium permendur's high magnetic permeability and saturation flux density to produce the 18 GHz fields. The supplemental subsystems of ECR2 were all reevaluated and modified as needed including the plasma chamber, the cooling water skid, the high voltage insulation, and beam transport. This upgrade is expected to be capable of producing all the ion beams that are required for the upcoming experiments at ATLAS.

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