THE ECR HEAVY-ION SOURCE FOR ATLAS

R. C. Pardo and P. J. Billquist
Argonne National Laboratory
Argonne, IL 60439

Abstract

The ATLAS PII-ECR ion source is the first ECR ion source to be designed for operation on a high voltage platform. The source system is required to provide beams of heavy ions with a velocity of 0.01c for subsequent acceleration by the superconducting ATLAS Positive Ion Injector Linac. At present, the ability of the system to provide high charge state ions with velocities up to .01c is probably unique and as such has generated significant interest in the atomic physics community. A beamline for atomic physics has been installed and is now in use. The source began operation in October, 1987. The source capabilities and operating experience to date will be discussed.

Introduction

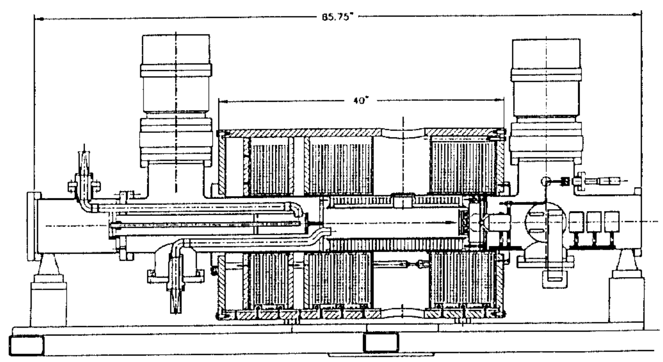
The Argonne Positive Ion Injector project [1,2,3] combines the high charge state, intense beams from an ECR ion source mounted on a high voltage platform with the high accelerating voltages possible from superconducting resonator technology and individual, independently phased resonator cavities to produce an accelerator concept with a unique combination of properties. The superconducting resonators and the high voltage preaccelerator produce a system which operates in the continuous wave (100% duty factor) mode. Beam quality is expected to be excellent, possibly better than that presently obtained from the tandem injector to ATLAS. The beam quality is determined by: the linac design which separates the accelerating field region from the magnetic focusing region, the large acceleration boost in the early stages of acceleration from the large ($\lesssim$4 MV/m) accelerating fields, the high charge state of the ions from the ECR source, and the beam quality from the ECR source.

The ECR ion source has a number of properties in addition to the production of large currents of high charge state heavy ions which make it an attractive device for heavy-ion accelerator facilities. The device has extremely high reliability because it has no electrodes and is in no way self destructive, especially when used with gas feed material. The source is extremely versatile; beams from solids as well as gases can be obtained. Essentially any ion species can be obtained from such a source with varying degrees of ease. The beam properties of the sources are also quite attractive. The power delivered into the source does not couple directly into the ions and as a result the ions are relatively cold. This fact results in good transverse emittance ($\gamma\beta\epsilon \approx 0.2\ \pi$ mm-mr) as well as low energy spread ($\Delta E \approx 5q$ ev). Such properties allow the overall accelerator system to deliver beams of high quality. In the remainder of this paper, the PII-ECR ion source system will be described and the operating experience of the system will be discussed.

The Argonne PII-ECR Ion Source

The goal of the Argonne PII-ECR ion source project was to develop a source with the good charge state and current characteristics of the large ECR sources presently operating at several laboratories. The additional important features of ECR sources important for our application are good transverse emittance, low total energy spread, production of ions from solid materials, and low consumption rates. The power requirements of the source system also must be held to a minimum because the source is operated on a high voltage platform. A cross section of the PII-ECR ion source is shown in Figure 1 and Table I gives major source parameters. An RF frequency of 10.25 GHz was selected for the Argonne PII-ECR. This choice was a compromise between the best high charge state performance, power requirements, and perceived operational reliability.

ARGONNE POSITIVE ION INJECTOR



ECR ION SOURCE

Fig. 1. A cross sectional view of the Argonne PII-ECR ion source. Overall dimensions are in inches.

The source is completely enclosed by an iron return yoke to minimize the power requirements of the solenoid coils. The coil design parameters listed in Table I allow the necessary magnetic field to be produced with a total coil power of 35 kilowatts. The large inner diameter (ID) of the coils was necessary in order to gain radial access into the second stage for solid material operation. The coil ID affects the axial field shape in such a way as to require a larger axial separation between elements as the ID is increased, if a given mirror ratio is to be maintained. By using iron field shaping plates between the coils surrounding the first stage, it was possible to reduce the overall source size that would otherwise have been required.

The second stage hexapole magnet design is a twelve pole design and is the first source design to employ Nd-Fe-B alloy material. This design allows the diameter of the second stage vacuum chamber to be sufficiently large to allow four radial access ports for use in solid feed material operation. The hexapole field at the chamber is 3.9 kG.

The Argonne PII-ECR ion source has been operating for approximately fifteen months. Since first beam was extracted [4], the source operation has evolved to a point which is comparable to other large ECR ion sources. Figure 2 shows the configuration of the source and charge state analysis system on the platform. During this period the source has been operated with numerous gases and solid materials using a variety of methods.

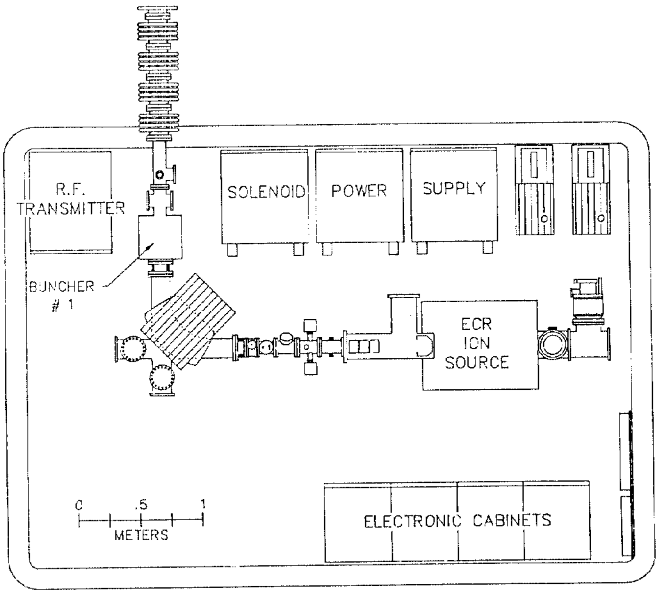


Fig. 2. Plan view of the high voltage platform for the Argonne PII-ECR ion source.

Present Source Performance

The source performance, at present, when delivering beams from gases is presented in Table II. These results were obtained using gas mixing with either oxygen or helium as the support gas. Total RF power never exceeded 850 watts for any operation. The consumption of gas varied from a low of 1.2 mg/hr for krypton to 9 mg/hr for one operating mode with argon.

Solid feed material for source operation has also been initiated. The first solid feed tests were performed with a 2 mm diameter nickel wire fed into the second stage by a manual linear insertion device. Helium support gas was used in these tests. The best performance for this method is shown in Table III. The operation of the source for production runs will require the use of a stepping motor to position the wire on a continuous basis. To maintain source operation the wire feed had to be advanced approximately every five minutes a distance of 0.2 mm. It appears that a stepping motor controlled on time or current as read by the analyzing magnet entrance slits may provide acceptably stable beams. Also a different wire trajectory may reduce the position sensitivity observed in these tests. The nickel consumption measured during these tests was 1.1 mg/hour.

A trial with a 2 mm diameter copper wire has also been conducted. The results of a short test are also given in Table III. The operation of the source was more stable with copper than with nickel but the beam current achieved in this test was significantly less that observed with nickel.

A medium temperature (600 C) oven has been constructed for use with materials with the appropriate volatility. The oven is quite simple and small. It is designed to mount on a water cooled radial second stage port flange which is thermally isolated from the oven by thin-wall stainless steel. The total power consumption for this oven is about 150 watts. The oven must heat the sample material sufficiently to achieve a partial pressure of approximately 10^{-4} to 10^{-3} Torr. The results of a run with a cesium sample material and nitrogen support gas is shown in Table III. A second external oven is now under development. This oven has demonstrated that temperatures in excess of 850 C can be achieved in off-line tests. Source tests with the new oven will begin this spring.

A method using passive heating of a boat containing feed material has been used successfully in tests with calcium (Fig. 3). A simple tantalum tube with calcium metal was suspended on a linear motion feedthrough using a small wire. The 'boat' is then lowered into the second stage plasma where the bombardment of the 'boat' by plasma electrons heat it sufficiently to vaporize the material. The method is simple and easy to use. The coupling of the source parameters such as magnetic field are not too severe and tuning is quite easy. Two different runs of three and four days each have shown this method to be quite reliable.

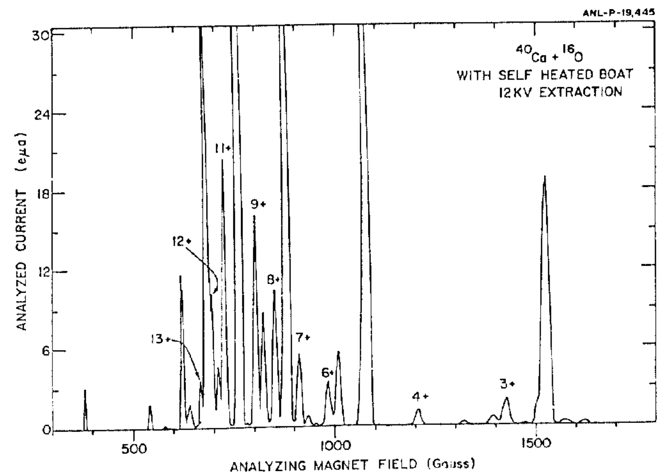


Fig. 3. Charge state distribution spectrum for ^{40}Ca.

High Voltage Platform Performance

The PII-ECR ion source high voltage platform is designed for operating voltages up to 350 kV. This feature is necessary in order to properly match the velocity of heavy ions from the source to the acceptance of resonators in the PII superconducting linac. In addition to the source, the equipment required on the platform are: all power supplies and associated electronics, the RF klystron transmitter, a beam transport and analysis system and a four-harmonic buncher (see Fig. 2) which begins the process of bunching necessary for injection of the beam into the PII linac.

A variety of measurements [5,6] have been made of energy spread from ECR ion sources which indicate that these sources should be able to provide beams which will compete well with the beam quality from electrostatic accelerator systems. The stability of the preacceleration high voltage will be important in determining the overall beam quality of the preaccelerator. While providing beam to the atomic physics program, the voltage stability of the high voltage platform has been measured when biased to 100 kV. The voltage was found to have a four volt, 60 hertz ripple due to capacitative coupling from the high voltage transformers and a slow (few hertz), less than one volt oscillation from the high voltage power supply. The total voltage stability was found to be less than $5x10^{-5}$ from all sources. This value is better than our design goal of $1x10^{-4}$. The largest component of this stability can be removed with active feedback as is presently accomplished on a similar system used on our tandem electrostatic accelerator.

Power requirements for the source and beamline components total approximately 70 kilowatts in normal operation. This is provided by a 350 kV isolation power transformer with a total capacity of 140 kilowatts. The units provided have failed twice while operating at approximately 280 kV. The second failure occurred after nearly one month of continuous operation at voltages between 250 and 320 kV. As a result of our experience, the manufacturer has instituted significant design changes in an effort to correct the problem. The repaired units have been installed and have performed without problems following this repair.

Conclusion

The high charge-state ECR ion source has significantly altered the design of heavy-ion accelerator systems. The ATLAS PII-ECR has demonstrated that these large sources can be reliably operated in difficult environments such as high voltage platforms. This research was supported by the U.S. Department of Energy, Nuclear Physics Division, under contract W-31-109-ENG-38.

References

[1] R. C. Pardo, L. M. Bollinger, and K. W. Shepard, Nucl. Instr. and Meth. B24/25 (1987) 746.

[2] R. C. Pardo, K. W. Shepard, and M. Karls, IEEE Cat #87CH2387-9, (1987) 1228.

[3] K. W. Shepard, Proc. 1986 Lin. Accel. Conf., SLAC-Report-303, (1986) 269.

[4] R. C. Pardo and B. J. Billquist, The Argonne PII-ECR Ion Source Project Status, "International Conference on ECR Ion Sources and Their Applications", NSCL Report #MSUCP-47, 279 (1988).

[5] F. W. Meyer, "Conf. Papers 7th Workshop on ECR Ion Sources," Julich, Jul-Conf-57, (1986) 10.

[6] H. Kohler, M. Frank, B. A. Huber, K. Wiesmann, IBID., 215.

Table I

Parameters of the Argonne PII-ECR Ion Source

	Magnetic Field	
Peak on Axis Field	4.75	kG
Solenoid Magnetic Power	35	kW
Maximum Solenoid Current	500	amps
Typical Solenoid Current	390	amps
Mirror Ratio	1.60	
Length of Second Stage Mirror	47	cm
Hexapole Material	Nd-Fe-B	
Number of Poles	12	
Hexapole field at chamber	3.5	kG
	Dimensions	
Solenoid Inner Diameter	21.6	cm
Solenoid Outer Diameter	64.8	cm
Hexapole Inner Diameter	12.0	cm
Hexapole Length	49.5	cm
Vacuum Chamber Inner Diameter	10.8	cm
Extraction Aperture	6	mm
Puller Aperture	13	mm
First Stage Aperture	1.2	cm

Table II

PII-ECR Ion Source Beam Currents for Gases (electrical micro-amps)

Q	^{16}O	^{20}Ne	^{28}Si	^{40}Ar	^{84}Kr	^{132}Xe
4	-	23				
5	60		15			
6	60	18	15			
7	4	6	15	40		
8	-	5	10	60		
9		0.1	5	30		
10			-	-		
11			0.8	2.5	10	
12				1.5	-	
13					12	
14					-	5
15					8	4
16					-	-
17					4	2.5
18					-	1.5
19					2	-
20					0.8	1.0
21					-	0.4
22					-	-
23					0.2	0.3
24						-
25						0.2
26						0.2

Table III

PII-ECR Ion Source Beam Currents for Solids (electrical micro-amps)

Q	^{40}Ca	^{58}Ni	^{63}Cu	^{133}Cs
7	10	30		12
8	15	30		14
9	30	20		15
10	-	10	2.5	10
11	35	4	3.3	10
12	18	0.5	-	10
13	5		1.2	10
14	2			10
15				10
16				6
17				6
18				5
20				3
21				2
22				1.3
23				0.7
24				.25
25				.15
30				.025