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HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS

A Status Report of the KVI-AECR

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Abstract In this paper the first results of the new ECR source at the KVI are presented. The source has been built following the design of Jyväskylä University, which is based on the AECR-U of LBNL. As the commissioning is going on, it seems that the extraction and analysing systems inherited from the old source are the limiting factors for the performance of the new source. Beam currents achieved with the source are at the moment a factor of 3 lower than the AECR source used at the Jyväskylä University. Further modifications to improve the source performance will be discussed.

Key words ECR, beam perveance

1 Introduction

In order to meet the requirements for radioactive beam experiments at the KVI, the existing CAPRICE type ECR source was converted into an LBNL-AECR-U type source[1], following the design used at Jyväskylä University. Design and calculations as well as tests of various subsystems, have been described earlier[2, 3]. In October 2005 the first beams were extracted from the new KVI-AECR and injected into the AGOR cyclotron at KVI. Before presenting the experimental results achieved with the reconstructed source, we will briefly describe the extraction and analysing systems, which have turned out to be the elements limiting further increases in beam intensity.

2 Beam extraction and analysis

The KVI-AECR inherited from the old CAPRICE type ECR source: a puller system, the analysing system and the aperture ladder in the image plane of the analysing system. These systems were not modified during the reconstruction. The analysing system consists of a dipole magnet that is capable of selecting particles with a magnetic rigidity up to 0.154Tm, which is more than the 0.07Tm needed for injection into the AGOR accelerator.

2.1 Extraction systems

The beam is extracted by a single puller system with an entrance aperture of 16mm diameter and a length of 85mm. The puller can be moved over 20mm longitudinally. A ground electrode is located behind the puller with an inner diameter of 29mm and a length of 190mm. A top view of the extraction system is shown in Fig. 1. This ground electrode minimizes the acceptance of the analysing systems to 200π·mm·mrad, which is still larger than of

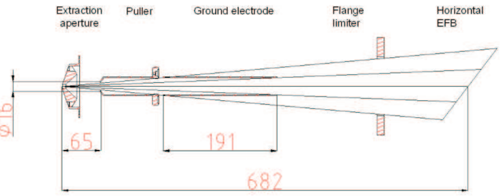

Fig. 1. Top view of the extraction systems of the KVI-AECR.

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140π·mm·mrad, which is used as the design specification of the acceptance of the AGOR injection systems. Horizontally a beam with a width of 120mm could be accepted at the entrance of the magnet. In the vertical plane a beam can be accepted with a width of 60mm at the entrance, limited by the gap of the analysing magnet and the inside dimensions of the vacuum chamber.

2.2 The analysing system

The analysing magnet is an unclamped double focusing magnet with straight, 37° tilted edges, for the vertical focusing. The pole gap is 67mm. The effective pole width is 120mm. The dipole bends the beam over 110 degrees with a bending radius of 400mm. The distance from the extraction aperture to the effective field boundary (EFB) is 682mm and the distance between the image and the EFB is 374mm resulting in a first order magnification of 0.6. The extraction aperture at the exit of the plasma chamber is 10mm in diameter and is imaged to the analysing plane were a Faraday cup with a entrance diameter of 10mm is located. The magnet itself in combination with the extraction aperture does have a horizontal acceptance of 440π·mm·mrad and vertically of 244π·mm·mrad.

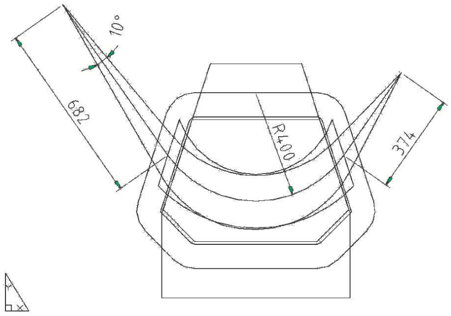

Fig. 2. The M110 analysing magnet.

2.3 Measuring beam intensity

In the image plane an aperture ladder is placed containing a) a Faraday cup with a 10mm aperture, b) a Faraday cup with a 20mm aperture, c) a diaphragm of 2mm diameter and d) a diaphragm of 10mm diameter. The Faraday cups do not have an electron suppression ring. The cups are connected to ground with a resistor of 0.5MΩ. The voltages measured on the Faraday cup are mostly above 20V and due to this, most secondary electrons will not escape from the cup. The Faraday cup with an entrance aperture of 20mm was installed to be able to compare the performance of the KVI-AECR with earlier publications[4] (see Table 2).

3 Experimental results

Since October 2005 beams were developed with the KVI-AECR (see Table 1). Every time a new beam was developed for the AGOR cyclotron the maximum beam current of the specific charge state and the charge state distribution were measured at an extraction voltage of 12kV. Furthermore the beam intensity of the optimised charge state was measured as function of the extraction voltage. From these data we could determine, a) the performance of the source by the maximum intensity, b) how this maximum relates to the whole charge state distribution, c) the intensity as a function of the extraction voltage so as to be able to determine the beam current in relation to the perveance.

3.1 Extracted beams

Since October 2005 only medium charge state beams have been requested for experiments (e.g. $^{20}\mathrm{Ne}^{7+}$, $^{19}\mathrm{F}^{5+}$, $^{12}\mathrm{C}^{4+}$, $^{11}\mathrm{B}^{4+}$, $^{4}\mathrm{He}^{2+}$, $^{16}\mathrm{O}^{6+}$, $^{40}\mathrm{Ar}^{8+}$). The $^{11}\mathrm{B}^{4+}$ beam was made with a BF3 gas, which is a highly reactive gas. The gas system needed for this was flushed with an inert gas to get rid of all the oxygen. At first Ar was used, but this was not a good choice because the production of Ar-ions reduced that of B-ions. Using He to flush the gas system solved this problem. Beams were extracted up to an extraction voltage of 35kV.

3.2 Beam perveance

In Fig. 3. the extracted current of a $^{19}\mathrm{F}^{5+}$ beam is plotted as a function of the extracted voltage. For extraction voltage below 15kV the current-voltage dependence nicely follows the Child-Langmuir law[5] indicating that in this range the beam current is space charge limited. The beam current levels off at extraction voltage higher than 15kV, i.e. in this range the beam is emission limited. By increasing the injected RF power the saturation effect is pushed towards higher extraction voltages, which indicates that the maximum beam intensity is determined by the available ionisation rate. It seems that the plasma cannot produce the high charged ions at the rate needed to maintain a space-charge dominated regime.

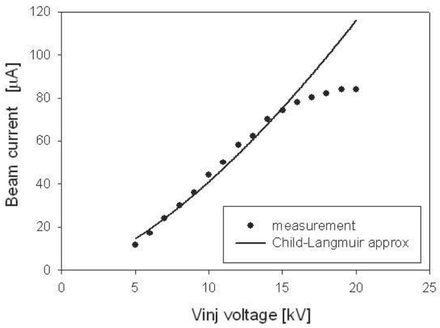

Fig. 3. Measured beam current of a $^{19}F^{+5}$ beam as function of the extraction voltage with a Faraday of 10mm entrance diameter.

3.3 Maximum intensities

The maximum intensities were measured at an extraction voltage of 12kV (see Table 1) with a 10mm aperture before the Faraday cup in the image plane of the analysing magnet. Measurements were accepted if the ripple was less than 10% and the intensity stable for over half hour. No mixing gas was added to the plasma and the bias disk was in operation. The new beams were optimised for one specific charge state, which is marked in bold in the table.

Table 1. Beam currents in μA of beams produced at an extraction voltage of 12kV, with a Faraday cup with 10mm diameter aperture.

	He	B	C	O	F	Ne	Ar
Q \ M	4	6	12	16	19	20	40
1	53	3					
2	50	3					
3		1					
4			18	40	62	28	
5		0.4	9	70	76	58	
6				112	64	70	38
7				33	40	54	48
8						29	84
9							55

In order to compare the performance of our source with the performance of the Jyväskylä group a Faraday cup aperture of 20mm was installed (see Table 2). The values of Jyväskylä were scaled from 10kV to 12kV.

Table 2. Beam currents in μA produced at 12kV extraction voltage, with a Faraday cup with 20mm diameter aperture.

	KVI-AECR		Jyväskylä AECR	
	Oxygen	Argon	Oxygen	Argon
Q \ M	16	40	16	40
4	54			
5	104		375	
6	170		507	
7	50		150	
8		84		372
9		48		239

On the Faraday cup with the 20mm aperture we measure 170μA of O^{6+}, while with the 10mm Faraday cup we find 112μA, which is a 35% difference. Taking in consideration that the size of the image in the analysing plane should be in first order of 6mm and 35% of the beam is measured in between a diameter of 10mm and 20mm than we can conclude that the image is seriously distorted. During the commissioning period no attention has been paid to the position of the extraction aperture with respect to the maximum magnetic field on extraction side. This could be the reason that the emittance of the extracted beam is large and affected by the aberrations of the magnet.

4 Conclusion

At this stage of commissioning of the source we are satisfied with the extra beam current as well as the long-term stable operation of the source during experiments. However, we did not yet reach the beam currents obtained by the Berkeley and Jyväskylä group with this type of an ECR source. Table 2 shows that we are still a factor of 3 below their intensities. In the near future we will start measurements of the 4D-emittance using an emittance meter currently under construction in the framework of the ISIBHI-project. From these measurements and simulations we expect to learn the origin of the current limitations and how to improve the extraction and analysing system.

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