AXIAL INJECTION OF HEAVY ION BEAMS FROM THE ECR SOURCE AT THE KVI

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Summary

The axial injection system has been installed in 1983 and the first beam was obtained in the last week of that year. This contribution describes the operation and results obtained. Special attention is paid to the points where the system differs from other systems namely the periodic focusing structure and the central region design with bump coils which permits that the axis of the injection line coincides with the cyclotron axis. Internal source operation is still possible allowing for extensive atomic physics experiments with low energy heavy ions from the ECR-source.

Introduction

On January 15, 1983, a drastic reconstruction program was started in order to modify the cyclotron for axial injection. December 27 we extracted for the first time a beam, produced by the ECR-source, from the cyclotron. One of the most delicate operations in that period was the enlargement of the existing axial hole in the cyclotron yoke and upper pole for which we had to install a large boring-machine on top of the cyclotron. Another challenging operation was the installation of new R.F. liners on which the so-called bump coils, the new dummy-dee system and a new ion source- and inflector support are mounted. The central part of the dee has been changed to mount a new puller and to provide space for the inflector. Several slots in the copper lining were made to provide a better vacuum inside the dee. In addition several persistant leaks have been removed resulting in a working pressure of about 10^{-6} mbar.

The design of the axial injection system has been described already in several papers, see e.g. ref. 1. Important points are that the central region has a fixed geometry and that the inflector and internal ion source can be exchanged without any readjustment. A movable phase selecting slit with variable aperture is mounted on the dummy dee. Another important point is that in the beamline magnetic elements are used exclusively. This makes it easy to change from one charge state to another for ions with the same Bρ value, thus low charge state ions can be used as analog beams for the higher ones.

The ECR-source and associated beam lines

The ECR-source of the minimafios type located in the ion source room above the cyclotron vault has been used extensively for many atomic physics experiments. The lay out in fig. 1 shows three experimental stations of which the setup for electron capture spectroscopy (AMOLF, Amsterdam) was installed more than a year ago. Surface physics experiments have been started this month and the Utrecht collision chamber will be connected in May. Table 1 shows results obtained from the ECR-source. For more details see refs. 2 and 3. In these measurements the source was operated in continuous mode, except for argon and the metal ions. Not indicated in the figure are several angle correction magnets and the beam diagnostics. The current is measured on a target following the exit diaphragm (ϕ 9 mm) of the 110° analysing magnet. The diaphragm itself is used as a continuous current monitor. Beamscanners and a viewing target are mounted just before the 90° magnet. The viewing target, a Al_2O_3 disk, is not suitable for several ion species, e.g. O beams. Therefore it is used for current measurements only where the charging helps to prevent secundary emission. This diagnostics will be extended soon with some four position targets.

Alignment of the beam is still difficult due to the presence of magnetic stray fields and the concentrated earth magnetic field. Therefore we restricted ourselves to fixed lens settings roughly corresponding to calculated values.

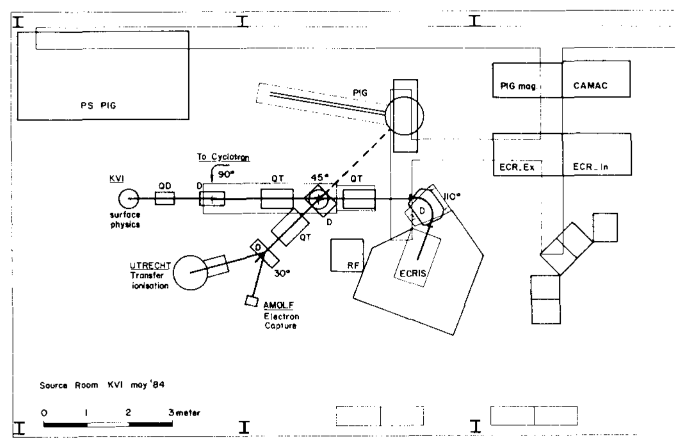

Fig. 1. The ECR-source and low energy beam lines to atomic physics experiments. The 90^0 magnet bends the beam down towards the cyclotron.

Table 1. Max current in μA per charge state q measured behind the 110° magnet.

Ion	^{13}C	N	O	Ne	Ar	$F(O_2)$	$Mg(N_2)$	$Al(O_2)$
extr. volt. (kV)	12	20	20	12	12	20	20	20
q=1	100	140	>80	150	47	>.8		1.5
2	110	120	>80	60	55	.8		
3	30	72	>80	60	38			1
4	16	48	>80*	40	31	.3		
5	2	32	55	40*	40*	.3	2	
6	.22	4	30	25	26			.24
7		.17	32	5	26	.01	.04	
8			.12	1.5	27			.03
9				.05	10			
10					12*			
11					1			
12					.25			
13					.02			

* Impurities included

The vertical line

This part of the system is the connection between the source room and the cyclotron. The total length is about 9 m. About 7 m consists of a periodic focusing structure with permanent magnets. It is described in refs. 4 and 5. Fig. 2 shows the first part of the line just below the 90° magnet. The two cylindrical lenses are intended for proper beam matching to the periodic structure. The acceptance of this structure varies with the Bρ value of the ions. The two pairs of correction magnets have to provide the alignment of the beam. At present there are no further means for alignment downstream. Two sets of beamscanners, located in the coupling blocks, at waist 1 and 2, are used to obtain proper matching. This setup is sufficient to determine both half axes of the emittance in two directions in waist 1 and to monitor the magnification in waist 2, with respect to waist 1, needed to match the beam to the eigenellips of the periodic structure. The horizontal line was designed to give about the same emittance in both transverse directions assuming rotational symmetry at the source and neglecting the angular momentum of the ions. Typical values for the emittance, defined as π times the product of both half axes, in waist 1 are 120 mm.mrad in the direction corresponding to the vertical direction in the horizontal line and 350 mm.mrad in the horizontal direction for 80% of the beam. These values hold for most of the N^{5+}, C^{4+} and Ne^{6+} beams in fig. 8. The horizontal emittance is sometimes much larger. The orientation of the emittance is different in both directions. In the horizontal direction the aspect ratio of the upright emittance ellips in waist 1 is 6 to 8 mrad/mm instead of the design value of 4. There are indications that this has to do with the angular momentum the particles get when they leave the ECR-source.

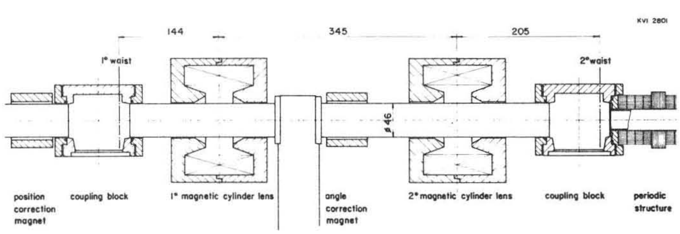

Fig. 2. The first part of the vertical line below the 90° magnet. Two sets of beamscanners are mounted at waist 1 and 2. The beam parameters at waist 1 are determined by the fixed optics of the horizontal line. At waist 2 the parameters have to be matched to the periodic structure and are a function of the Bρ value.

The periodic structure behaves as expected. The period of the trajectory is within a few percent equal to the calculated one, e.g. 2.3 m for Bρ = 2.5 x 10^{-2} Tm (or 40 keV C^{4+}). In this case an emittance of more than 1000 mm.mrad can be transported, with less than 20% loss, while matching and alignment is not critical. Due to the above mentioned large value for the aspect ratio proper matching is not possible at present. The theoretical limit for a well aligned and matched beam would be 1000 mm.mrad. This value is limited by the buncher diameter of 22 mm.

Fig. 3 shows the periodic system in the cyclotron cave. It is divided in sections of about 1 m separated by small coupling blocks. The coupling blocks are used to connect small triode ion getter pumps and two sets of beam scanners at positions S. The first buncher is located just above the iron shielding plates about 2,5 m from the median plane. The basic pressure in the line is 10^{-7} mbar and typically two times larger when in a certain region a few micro-amps are lost on the wall.

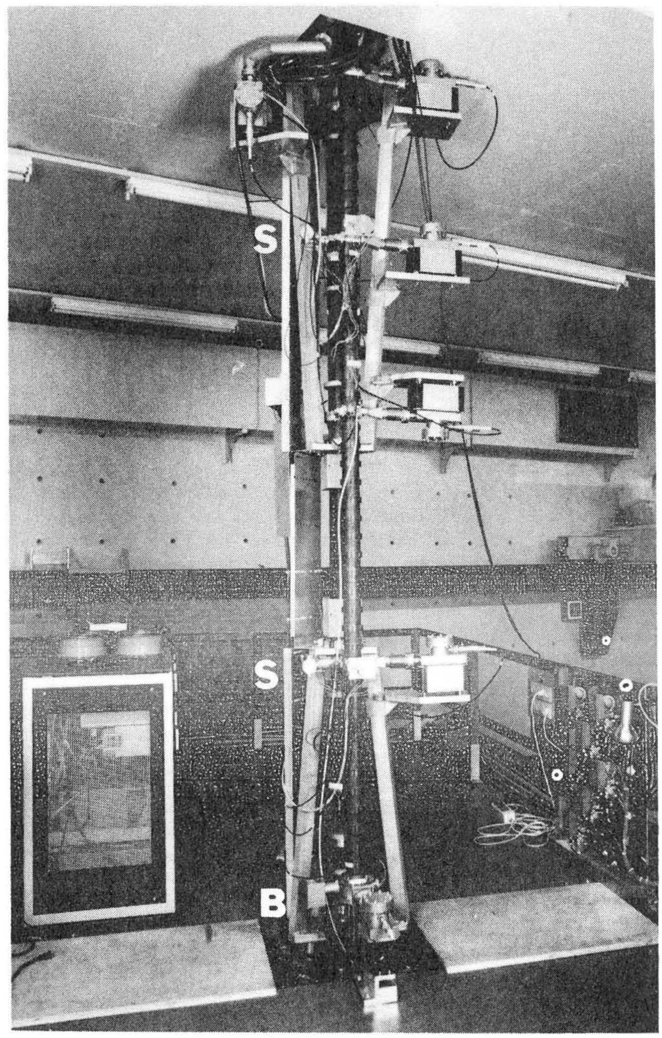

Fig. 3. The periodic structure of the vertical line on top of the cyclotron. Beamscanners are located at position S, the first buncher at B. There are seven small ion getter pumps located along the line. The construction is simple, light weight and easy to dismount, which gives easy acces to the part in the axial hole.

The whole line from buncher to ceiling can be dismounted in half an hour, the coupling blocks can be turned aside and then the part in the axial hole can be lifted out. This part is shown in fig. 4. It contains a second buncher and two cylindrical magnetic lenses. A number of correction coils to compensate for the longitudinal magnetic stray field in the axial hole are not shown in the figure. After the beam has been matched to the entrance of the periodic structure the last lens in the axial hole is the only important parameter to optimize the transmission to accelerated beam. This lens needs 800 A for maximum excitation. A compensation loop is used to compensate for the field disturbance of the current leads. One of the points which clearly influences the beam alignment is the fact that the beam axis does not coincide with the axis of the square part, 200 x 200, of the axial hole. The strong stray field at the entrance and exit of the hole has to be trimmed to become symmetrical with respect to the beam axis.

The buncher will be fed by a symmetrical triangle with a linearity of about ± 0.5% over 150° or more. Up to now we use only the first buncher, which in a typical experiment, curve C^{4+} in fig. 8, bunches 90% of the internal beam within 20° RF phase. This increases the internal beam current by a factor of four and gives a gain of more than 5 in external current, see fig. 8.

The magnetic stability of the structure against external fields has been estimated for a longitudinal field up to 0.15 T. This field was cycled in one direction between zero and maximum. Only after the first cycle a loss of 3 mT in top field was observed.

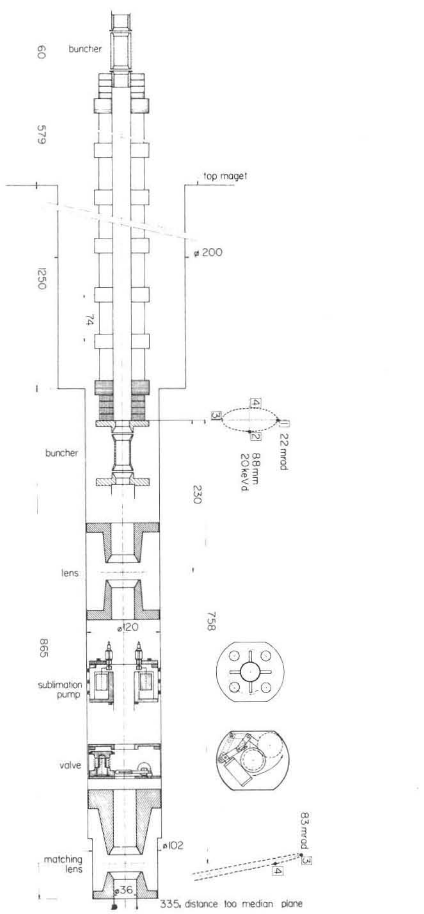

Fig. 4. The last part of the vertical line inside the axial hole. The square hole is inside the yoke and contains the last section of the periodic structure. The axis of this hole is shifted 7 mm with respect to the axis of the circular hole in the pole. Coils to compensate for the focusing action of the stray field are not shown.

The inflector

The hyperboloid inflector consists of a positive electrode opposite to an electrode on ground potential. For this asymmetrical configuration has been chosen in order to minimise the dimensions of the inflector. The electrodes are shielded from the RF by means of a copper housing. Fig. 5 shows the inflector with a part of the support. The inflector is at present equipped with three current measuring devices. The first one is a ring target in front of the entry (A), the second measures the beam current at the entrance, within the housing (B, not visible) and the third (C) can be moved over a distance of 4 cm in the median plane from the exit of the inflector to the first turn. Further outwards movement causes the target to be lifted automatically out of the median plane. This target enables easy adjustment of the inflector voltage and the buncher parameters. The housing of the inflector is watercooled to prevent RF heating. The maximum voltage applied to the electrode and the connection line is 12 kV, which is much more than the maximum voltage needed (i.e. 7 kV for the present choice of the gap width). The transmission from target B to C is roughly 75% when the secundary electron emission at target B is taken into account. This value may be increased when the alignment problems are solved.

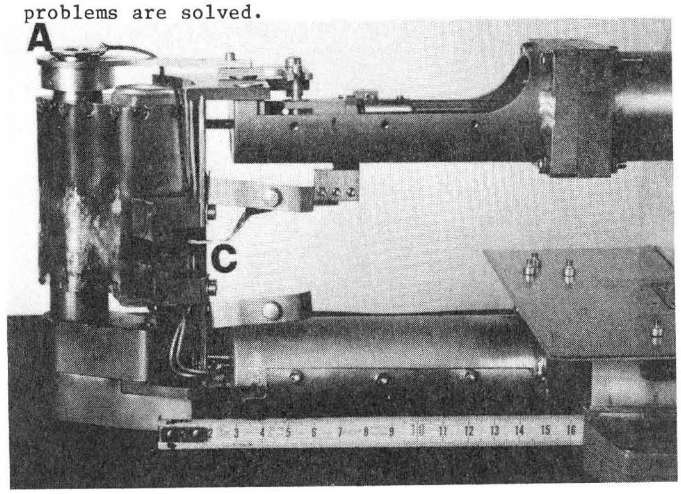

Fig. 5. The inflector support. The inflector is situated inside the copper RF shielding house on the left.

The acceleration of injected beams

The central region has been designed in such a way that the beam is injected along the cyclotron axis with an injection voltage of 20 kV for the highest fields, ref. 1. This has been assumed to be a safe choice. The injected beam is then off centered, which is corrected for by means of two pairs of bump coils, mounted against the RF liners, during the first 10 turns.

In fig. 6 the differential current and the sum current are given as a function of radius. Because of the angle of incidence of the beam on the target useful information from the differential current probe can be obtained only between 60 and 100 cm where the finger thickness is comparable to the turn spacing. Because of several effects which may be regarded as first harmonic field components the beam should be centered as well as possible in that particular region, ref. 6. The small variation in the current density reflects that the beam is reasonably centered in this region. The sum current gives also an impression of the influence of the vacuum condition on the beam current. Routinely the beam current at extraction radius amounts 50-70% of the current at R=40 cm.

Fig. 7 shows the influence of the bump coils. For a current of 675 A the coherent oscillation amplitude is seen to be minimal and the phase of the oscillations changes by about 180° for that value of the bump coil current. The routine extraction efficiency of the beam from the cyclotron with the electrostatic extractor amounts to about 30%. For the C^{4+} beam of fig. 8 this value was 40%, which was obtained by limiting the internal RF phase width of the beam to about 20° by means of the settings of the inner trim coils and the buncher parameters. A new extractor with an active magnetic channel, capable of extracting the maximum energy of the cyclotron has been tested recently. Extraction efficiencies of 50-60% have been obtained for routine operational conditions.

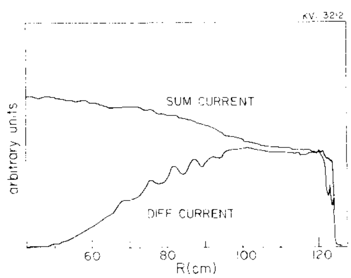

Fig. 6. Plot of differential probe current and total current versus radius measured with the C^{4+} beam.

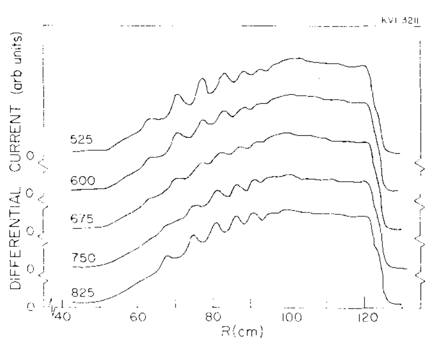

Fig. 7. Plot of differential probe current versus radius measured with the C^{4+} beam at various bump coil excitations. Note the 180° phase change of the coherent oscillations at 675 A.

Conclusions and results

The ECR-source is in use now for more than one year and works very reliably. Table 1 shows the maximum currents the source delivers for different ion species. These currents are measured behind the exit slit of the 110° magnet. It turns out that mixing the gas with some 15% He results in a smooth operation, allowing a reduction of RF power. In one case a considerable beam increase, more than a factor of two for a N^{6+} beam, was observed too. Also the X-ray level around the source, usually far below 2 mrad/hr, is reduced in this way.

Fig. 8 shows the progress made in the development of injected beams. Since the buncher became into operation the transmission from just before the 90° magnet in the source room to extracted beam from the cyclotron is typically 3 to 4%. From preliminary results with the new electro-magnetic extractor an overall transmission of more than 5% is expected and recently realised. Beam development takes, up to now, about one shift. When the correction magnets for beam alignment are ultimately adjusted to obtain maximum transmission their settings do not coincide with those for a well aligned beam. The adjustment of inflector- and cyclotron parameters does not cause special problems and the injection line has ample space to accept misaligned beams.

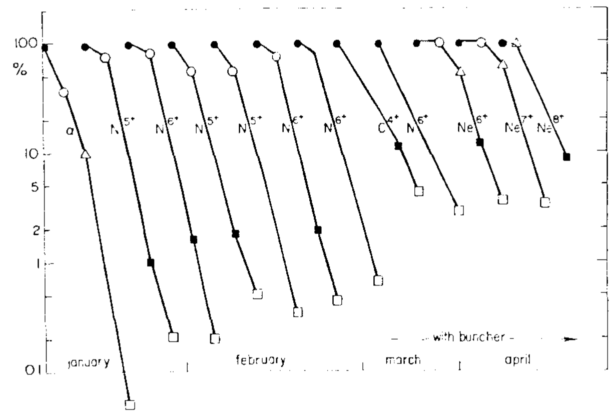

Fig. 8. Transmission from the horizontal beam line in the source area through the vertical line and the cyclotron to extracted beam. In all cases the cyclotron is set for K=120. Measured current just before the 90° bending magnet is taken as 100%. The open circles give the fraction of the beam at the inflector entrance, the triangles at the inflector exit, the closed squares at extraction radius (internal beam) and the open squares the extracted current in the beam line. No correction is applied for secundary emission. Our extraction efficiency is typically 30%.

Especially the parameters for optimal transmission in the vertical line are easy to adjust. The fact that the axis of this line coincides with the axis of the cyclotron is certainly a good choice and beam centring with the bump coils works excellent.

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References

1. W.K. van Asselt, O.C. Dermois, A.G. Drentje, H.W. Schreuder, Proc. 9th Int.Conf.Cycl., Caen (1981), 267-272
2. A.G. Drentje, Physica Scripta T3(1983)45
3. R. Geller and B. Jacquot, Nucl.Instr.Meth. 202(1982)399
4. O.C. Dermois, Nucl.Instr.Meth. 195(1982)435-442
5. O.C. Dermois, Part.Acc., 1983, Vol. 14, 63-73
6. W.K. van Asselt, Internal report

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