PRELIMINARY TESTS FOR THE AXIAL INJECTION OF HEAVY IONS AT THE GRENOBLE CYCLOTRON

M. Lieuvin, J.L. Belmont and M. Bajard

Institut des Sciences Nucléaires, BP 257, 38044 Grenoble Cedex, France.

Abstract

In view of the injection of multicharged heavy ions from an external PIG source, some preliminary experiments have been performed. A guiding system for extracting the beam from the ion source magnet using the method of G. Rallu[1] and a new injection canal with magnetic lenses have been calculated and built. Some experiments have been done to transport heavy ions from the source to the output of the canal. Mean currents of 430 μA N^{2+}, 410 μA N^{3+}, 160 μA N^{4+}, 15 μA N^{5+} have been carried out. The influence of the pressure inside the canal on the transmission and on the charge exchange have been investigated.

1. Introduction

The Grenoble variable energy isochronous cyclotron is a two dee machine which accelerates heavy ions to energies up to 90 n^2/A MeV. Since June 1973 it has an internal heavy ion source and delivers beams of ions from proton to neon[2]. At this date, it was decided to built an external heavy ion source for ions such as Li, B, Na, Al, etc.., the ions being injected axially at the centre of the machine.

For this purpose, it was not possible to use the actual injection canal since because of its small diameter the vacuum is very bad inside. Thus a new injection canal using cylindrical magnetic lenses and with an internal diameter of 36 mm has been studied and built. The source is a hot cathode PIG type with radial extraction and it was also necessary to find a way to extract the ions from the source magnet with simultaneously a good intensity and a reasonable emittance. For this purpose, several methods were tried. The best results were found using an electrostatic deflector in the median plane of the magnet. Finally, beams of heavy ions were injected into the new injection canal to test its transparency and to determine the effects of the pressure on the beam.

2. Problem of the beam extraction from the source magnet

The source magnet is a H shaped type with circular poles of Ø 460 mm and 200 mm gap. The maximum field at the center is 1.1 T. The PIG source is near the center because it is very important to have a good field homogeneity. The source is at a positive high voltage, the extractor is at ground. The high voltage is determined by the injection conditions and is :

$$V = 59.5 \frac{n}{A} \frac{B}{B_{max}} \quad (\text{kV})$$

with B : magnetic field at the centre of the cyclotron

B_{max} : maximum magnetic field at the centre of the cyclotron

typically : 10 kV < V < 25 kV.

The magnetic radius of the trajectories inside the magnet have to satisfy the relation :

$$B_s R_s = B_c R_c$$

B_s : magnetic source field
B_c : magnetic cyclotron field
R_s : magnetic source radius
R_c : magnetic axial inflector radius : 22 mm.

On the other hand we need $B_s \geq .4$ T in order for the source to function correctly. We must therefore have : 33 mm $\leq R_s \leq$ 60 mm. We see that the magnetic radius is small compared to the gap of the source magnet so it will be impossible to extract the ions directly. We choose to use electrostatic deflectors to pull the ions out of the magnet.

3. Choice of the deflector

Three types of deflector were studied for extraction of the ions.
1° Muller inflector[3,4]
2° Belmont-Pabot inflector[4]
3° Pseudo spherical deflector[1].
With the Muller and Belmont-Pabot inflectors, the central trajectory is twisted to be parallel to the magnetic field and with the third deflector the central trajectory remains in the median plane. These three deflectors were tried, the better results being obtained with the third one. It was chosen therefore for the following tests.

4. Study of the pseudo spherical deflector (Fig. 1)

After leaving the source, the ions make a 180° rotation with R_s = 50 mm centered on the magnet axis. Then they enter the deflector and, due to the action of the electric field the curvature is inverted and the radius becomes 146 mm ; after a rotation of 114° the ions leave the deflector and, inversing once more their curvature effect a rotation of 49° in the fringing field. Far from the magnet the ions appears to come from it's centre. The space between the electrodes of the deflector is at each point proportional to the local field. In the vertical plane the deflector has a curvature of 500 mm to focus the ions. A step by step program : TRAJIL was written by G. Rallu[1] which permits calculation of the individual trajectories of ions from the source to the output of the magnetic field. The knowledge of a few carefully chosen trajectories allows us to determine the transfer matrix of the

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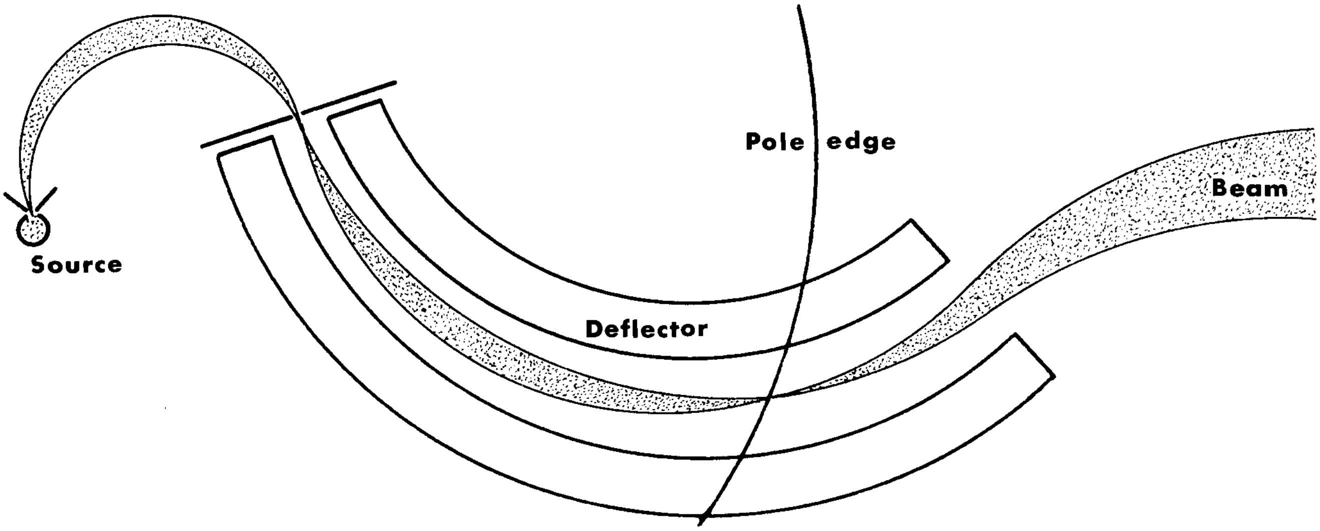

Fig. 1 : Ion extraction from the source magnet

system including second order terms (the first order matrix was not sufficient because the system is not linear and there are large coupling effects between the two planes). With this matrix a transfer program, TRAEMIT, gives us the emittance at the output in the vertical and horizontal plane for a given emittance of the source. See table 1.

Table 1. Output V_s source emittance for an extraction slit of 6 x 10 mm^2

Source emittance mm mrd		Output emittance mm mrd	
h	v	h	v
1200	2000	3100	2700
2400	4000	5650	6400

extraction. One of the cathode is heated by electron bombardment. The extraction slit is 1 x 5 mm^2.

At the output of the source magnet we have successively :

- a pumping unit composed of a liquid nitrogen trapped diffusion pump and a titanium pump.
- a rapid emittancemeter which gives us on an oscilloscope the emittance profile in 20 s.
- a first movable, trapped target.
- the injection canal : 150 cm lenght, 36 mm in diameter.
- a second pumping system with the same pumps as the first.
- a second movable, trapped target.
- a 90° analyzing magnet.

The focalisation in the injection canal is given by four cylindrical magnetic lenses with a focal length adjustable to 30 cm, the admittance is 3500 mm mrd with axial symmetry. The admittance

Table 2. Means currents on the targets and transparency of the canal

Ion	N^{2+}	N^{3+}	N^{4+}	N^{5+}	Ne^{3+}	Ne^{4+}	Ne^{5+}	Ne^{6+}
Mean arc current A	2.2	2.8	4	4	4.7	4.2	4.2	4.2
Arc voltage V	450	500	500	500	450	450	450	450
Extraction voltage kV	10	10	10	10	10	10	10	10
Duty cycle	1	1	.37	.37	1	.37	.37	.37
Mean first target current µA	600	470	190	17	430	140	20	3.5
Mean second target current µA	430	410	160	15.5	300	96	17.5	3
Transparency %	72	87	84	91	70	68	88	86
Horizontal emittance mm mrd	1600	1800	1520	420	1400	2100	400	

5. Experimental setup

See fig. 2. For these first experiments the source was of the same type as the internal one. It is a PIG source with tungsten cathodes and radial

matching between the deflector and the canal is ensured by an electrical quadrupole at the output of the deflector and two electrostatic Einzel lenses. The vacuum at the input of the canal is 1.10^{-6} Torr (due to the gas flow from the source)

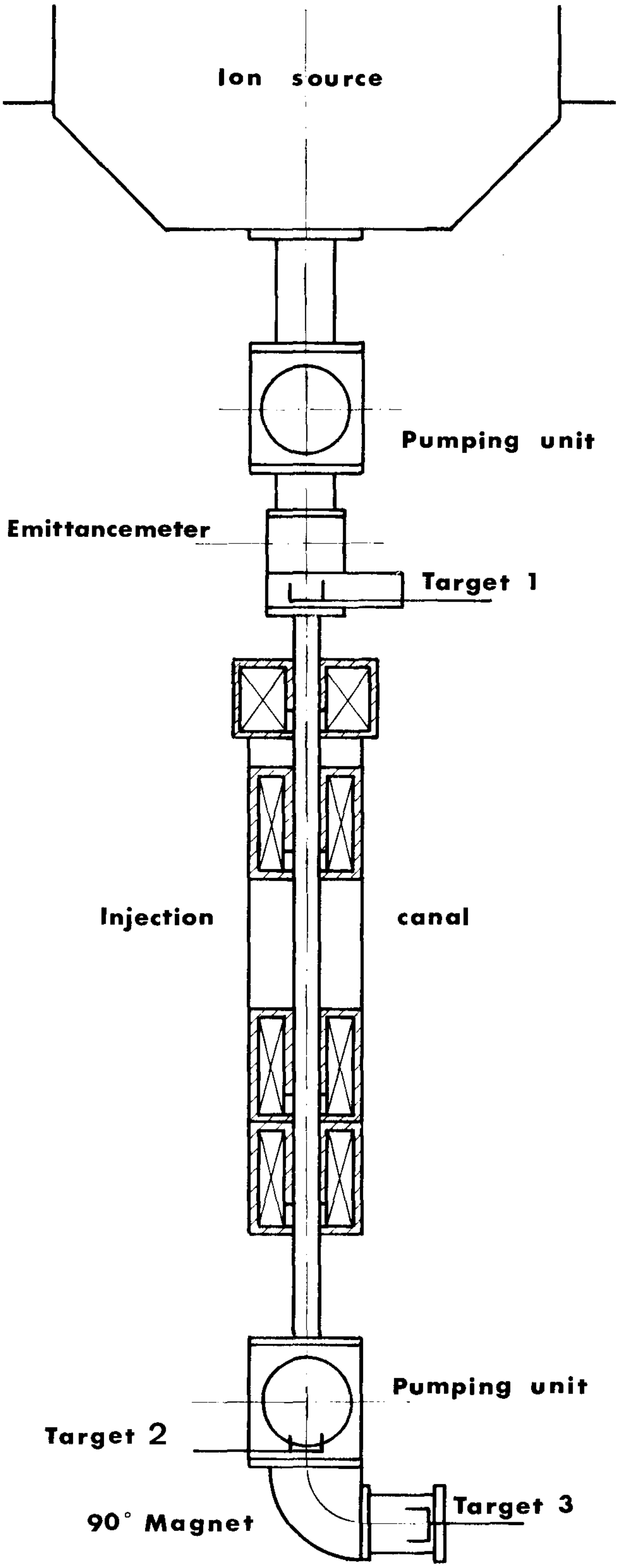

Fig. 2 : Experimental setup

and 1.10^{-7} Torr at the output.

6. Experimental results

Experiments were performed with nitrogen and neon, results are indicated in table 2.

7. Vacuum influence on the transmission

Introducing a controlled air flow at the input and the output of the canal by two leak valves we varied the internal pressure from 10^{-6} Torr to 10^{-4} Torr, the pressure was supposed constant all along the tube after we had verified that the gradient due to the outgassing was of the order of 1 to 2.10^{-7} Torr. Analyzing the ions at the output we were able to determine the transmission of one multicharged ion as a function of the internal pressure. See fig. 3.

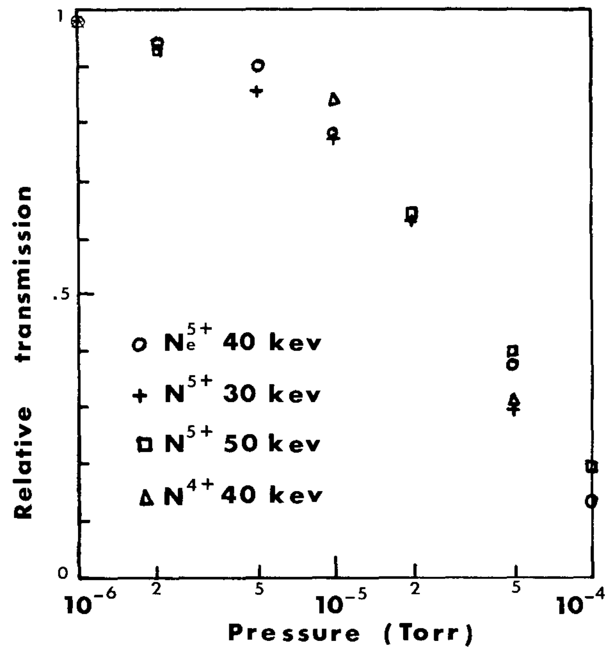

Fig. 3 : Transmission V_s air pressure in the injection canal

Assuming the leak of ions is due to charge exchange processes we were able to determine a global charge exchange cross section for various ions at various energies. See table 3. In these calculations we have taken into account the charge exchange processes which appear between the source magnet and the canal input. The relative precision of these cross sections is of the order of 10 %.

8. Conclusion

From these experiments we can conclude that an external PIG source associated with axial injection will give beams which are competitive with those obtained using an internal source. The vacuum requirements in the injection line will not be prohibitive : 1.10^{-6} Torr permits a good transmission of multicharged ions for a line of 2 or 3 m total length.

An external PIG source will present some important advantages :

a) Possibility of producing ions of all materials.
b) No perturbation of the cyclotron operation, in particular on the RF stability.
c) Amelioration of the extraction and diminution of the beam energy spread due to the better stability of the RF.

Table 3. Total charge exchange cross section ($\times 10^{-15}$ cm^2) for N^{4+}, N^{5+}, Ne^{4+}, Ne^{5+} in air at various energies

Energy keV / Ion	24	30	32	40	50
N^{4+}	1.6			1.9	
N^{5+}		2.1			1.98
Ne^{4+}			3		
Ne^{5+}				2.2	

References

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