# THE COMPACT ECR SOURCE AND THE AXIAL INJECTION LINE FOR THE MILAN SUPERCONDUCTING CYCLOTRON.

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## ABSTRACT

A 5 GHz compact ECR source has been built and operated at the University of Milan, to be used, together with an axial injection system, as a test source for the Milan Superconducting Cyclotron.
A description of the source and of the axial injection system, together with the results of the source operation is given in this paper.

## INTRODUCTION

The K-800 superconducting cyclotron, in construction at the University of Milan, has been designed as a booster for the 15 MV Tandem of the LNS in Catania.

In this frame an axial injection program with the use of a small ECR source was started in the 86, with the purpose of testing the machine in Milan.[1]
As no effort could be made for an indipendent design, the source which has been built is similar to the LIS source developed at KFA - Julich .[2]

The source is a two stage source operating at 5 GHz, with RF power less than 1 kW, designed for light gaseous elements.

The ECR ion source was first installed in a test stand at the end of 87, where preliminary operation and debugging of the major components took place, during a period of six months. Thereafter, being the cyclotron building completed, the source was transferred in the cyclotron pit together with the axial injection system ( up to the 90° bending unit ); operation of the system resumed in Spring 89.

At the end of 89, the decision was taken, to transfer the Cyclotron at LNS-Catania before the summer of this year, and to test the machine with Tandem injection. Therefore the ECR source and the axial injection program has been temporary set aside.

## THE ECR SOURCE

A schematic view of the source is shown in fig 1.

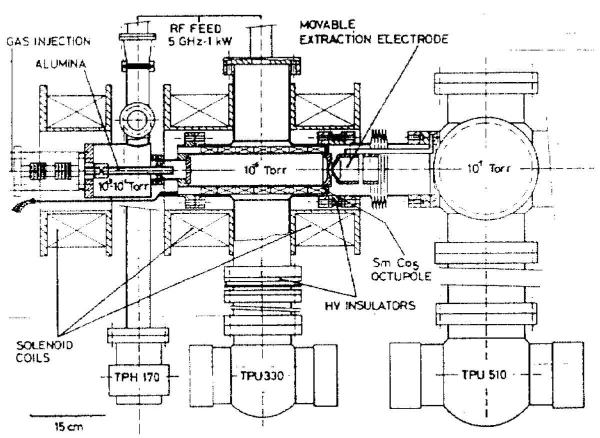


Fig. 1 Schematic view of the ion source

The minimum B configuration is obtained by the superposition of an axial mirror field and a radial octupolar field. The axial field is produced by three identical solenoid coils made of water cooled copper and driven by a common power supply of 150 A. Nominal value of the mirror ratio is 1.6, with a mirror length of 23.5 cm. Small variations of these values can be obtained by changing the position of the coils,which can be easily moved,and by adding iron plates at the end of the coils. The mirror coils are insulated from the cavity and are operated at ground potential.

In the second stage an octupole magnet made with $SmCo_5$ permanent magnets,produces the radial magnetic field. The inner diameter of the octupole is 71 mm. Each pole (14.2 mm wide, 11.6 mm thick) is in a stainless steel water cooled jacket. The octupole is placed inside the second stage vacuum chamber and pumping and RF injection is done trough the voids beetwen magnetic bars.The calculated magnetic field at the center of the second stage is shown in fig.2.

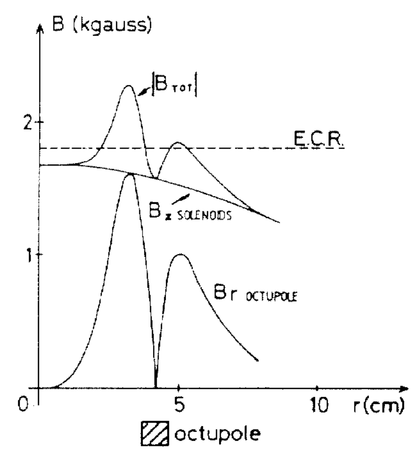


Fig. 2 Magnetic field distribution as a function of the radius at the centre of the II stage

A 1.5 kW klystron ( Varian 888 ) is used to supply the 5 GHz microwave power. The maximum output power of 1.5 kW is splitted into two lines by a fixed power divider and radially fed to first and second stage. The use of the E-H tuner gives flexibility in changing the power in the two stages almost independently. The waveguides near the cavities are high voltage insulated with teflon and mylar sheets and a ceramic window is used for vacuum separation.

Ions extraction is provided by an acel-decel three electrode system: a plasma electrode with a Pierce geometry and an exit hole of 10 mm diameter, a puller with a 12 mm diameter hole, which can be polarized up to 3 kV negative voltage, and a ground electrode.

The source can be moved, with a stroke of 60 mm, with respect to the extraction chamber, thus changing the acceleration gap. The whole source is kept to an high voltage extraction potential and is insulated from the waveguide system, the pumping system, the extraction chamber and solenoids coils. Operating voltage up to 20 kV can be sustained as required from ions injection conditions in the superconducting cyclotron.

## AXIAL INJECTION LINE

A detailed analysis of the axial injection line is reported in ref. 1; here we briefly recall the general outline of the system, which is shown in fig.3.

Downstream the ECR source, the solenoid So refocuses the beam at the extraction slit of the analysing magnet M1. The magnet has wedge angles of 26.5°, 30 cm radius and 6 cm gap; the maximum field is up to 3 kG, which corresponds to almost twice the maximum rigidity of the injected beams, that are in the range of 20-45 kG cm.

The four quadrupoles Q1-Q4, provide the emittance matching in the two transverse plane. A 90° achromatic bending unit brings the beam on the cyclotron axis, and the four solenoids S1-S4 transport the beam up to 3 meters from the median plane. The solenoids S5-S6 keep the beam confined during the motion in the magnetic field of the cyclotron.

All the elements of the line, with the exception of the two solenoids S5-S6 have been constructed. The line has been tested up to the 90° vertical bending unit.

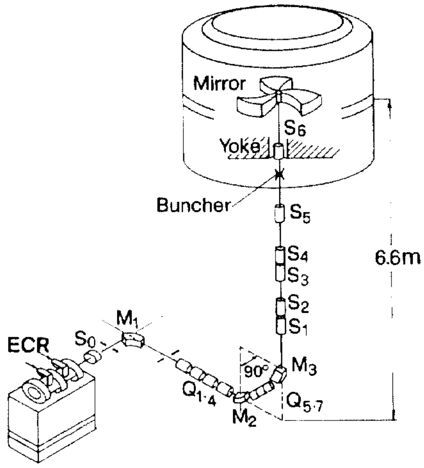


Fig. 3 View of the axial injection system

## ION SOURCE OPERATION

Since summer 89, up to now, the source has been extensively operated. The total ion current drained from the source is usually around 1 mA. The performances of the source in terms of analyzed beam current at the exit of the charge state analyzing magnet,for different kinds of gaseous elements are reported in table 1. These currents represent the best values we have obtained, without the use of gas mixing. The gas is fed only in the first stage and flow rate is not directly measured,but it is controlled by monitoring the pressure in the second stage. Usually the operating pressure in the second stage is a few $10^{-6}$ torr.

Typical Rf power of 200-300 watt are fed in the second stage. No parasitic resonance has been detected in the second stage, although possible as indicated from fig.2; RF power is effectively injected in the first stage even if the coupling port has small dimensions. The extraction voltage for all the data presented is 10 kV. Opening of the analyzing slits is 30 mm and the extraction hole is 10 mm diameter.A reduction of the slit aperture to 10 mm leads to a reduction of the beam transmitted through the analyzed magnet around 25-30%.

Table 1

Ion current (eμA) from the ECR source

| Charge state | p | $H_2$ | He | N | O | Ar |
|---|---|---|---|---|---|---|
| $1^+$ | > 270 | > 260 | 1500 | > 180 | > 200 | > 12 |
| $2^+$ | | | 200 | 160 | 150 | > 64 |
| $3^+$ | | | | 60 | 55 | > 30 |
| $4^+$ | | | | 25 | 30 | 34 |
| $5^+$ | | | | 5 | 8 | 18 |
| $6^+$ | | | | | 1 | 8.5 |
| $7^+$ | | | | | | 2 |
| $8^+$ | | | | | | 0.8 |

Beam currents. Measurements were mostly carried out on nitrogen ions. Argon beams have been produced only for a very short time so the results cannot be assumed as definitive.

The measured output currents are strongly dependent on source parameters ,as magnetic field, RF power and puller to source distance; some typical behaviour of this dependence is shown in fig 4. The behaviour of the output current as a function of RF power shows that in the case of N4+ the dependence is very pronounced and a saturation value is reached at about 300 W; after that there is no increase in the current and the plasma becomes unstable and sharply switches off.The current is also very sensitive to the puller geometry and voltage bias. No optimization has been performed on the design of the extraction system; normal operating values are 3.5 cm source-puller distance and 1 kV bias.

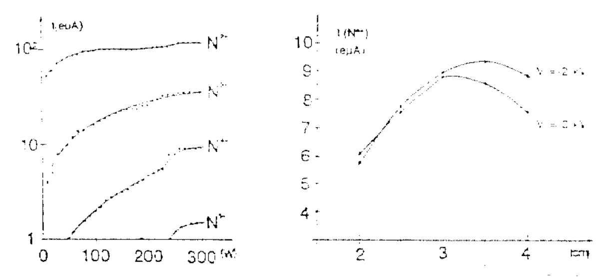


Fig. 4 Dependence of the ion current from microwave power and source to puller distance

With respect to the previous presented charge state distribution values a few comments are in order:

- the operation of the source seems to be satisfactory when producing low charge state light ions. Analyzed beams in excess of hundreds of eμA are easily obtained for charge states 1+,2+,3+ for gaseous elements up to argon. The currents strongly decreases for higher charge states;typically a 25 μA for N4+ is actually our limit.A more conservative value easier to obtain and reproducible is more likely around 15-20 μA. We have various indications that suggest that the limiting factor is in our first stage device.In fact we observe the following phenomena:
- we do not observe any significant variation in the charge state distribution with first stage operation. We have changed the amount of RF power fed to the

first stage,the position and current of the first solenoid coil and we have also completely removed the first stage chamber.In this extreme case the only small effect we have observed is that it is more difficult to start the plasma,especially when we operate with the minimum workable pressure in the second stage.

- the maximum amount of the extracted current is obtained with a relatively high pressure in the second stage, Typically it ranges from 4 to 8 $10^{-6}$ torr; these operating conditions are not favourable for the production of high charge states, due to the high concentration of neutral atoms.
- we have tried to improve the coupling of the RF injected into the second stage by placing an RF screen (copper sheet) around the octupole.The results so far obtained have not shown significant improvement.
- detectable X rays emission from the source is unsignificant, denoting that the high energy electron density is not sufficient for the production of high charge states.We deem that the main responsible for this is the second stage pressure, although some lack of efficient electron confinement cannot be excluded.
- The interpretation of the behaviour of the source with respect to gas mixing is also difficult. Up to now gas mixing has been checked only with nitrogen ions,using helium.What we observe is that we can found a setting of the source parameters where gas mixing seems to be effective, giving an increase of N4+ and N5+ of a factor less than two; however the same values of currents can be obtained with a different setting of the source and of the operating pressure.

Beam quality. Diagnostic of the beam has been performed up to now, by measuring tranverse profile and emittances figures. Data have been taken at the object slit and after the transverse matching unit,in the horizontal part of the beam line. Only transmission measurements have been performed through the 90° vertical bending unit. Profiles are measured by mean of a wire scanner, while the emittance measuring device consists of 16 fixed slits, 0.15 mm wides and 3 mm spaced, followed at a distance of 6 cm by a movable scanner of 0.1 mm radius , for intensity distribution measurements.

Typical beam profiles for N4+ are shown in fig. 5 and they exhibit a gaussian like shape; however we have to point out that this kind of profiles do not corresponds to the maximum obtainable current, where distortions often occur in the beam profile.

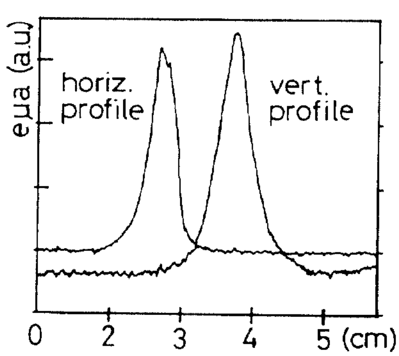


Fig. 5 Horizontal and vertical profiles for a 10 μA, $N^{4+}$ beam, at the image slit

Concerning the emittance, extensive data have been taken for He2+ and N4+. Some example is shown in fig. 6.

Strong variations in the emittance values and also in the shape, which is not always elliptical, are observed, depending on the source parameters that are used. Although the emittance measuring system has uncertainties of the order of 20%, the measured values, of the order of 600 mm mrad, are too high for cyclotron operation; however if we consider the emittances at 60-70 % we get more useful values, near to the cyclotron acceptance.

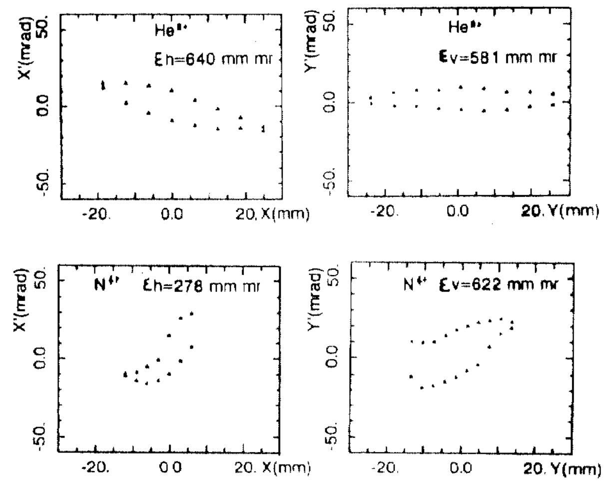


Fig. 6 Horizontal (left) and transverse (right) emittances respectively for a 27 μA $He^{2+}$ (top) and a 10 μA $N^{4+}$ beam (bottom)

## CONCLUSIONS

The operation of the source has shown that while low charge states currents are more than sufficient for cyclotron operation , the same is not true for higher charge states as discussed previously. However the values obtained in intermediate charge states for light ions, as by example N4+ and N5+, are sufficient to provide significative beams for cyclotron testing. This is true also taking into account the need of a reduction in the beam emittances, in order to match the beam to the 300 mm mrad cyclotron acceptance. A careful analysis of the behaviour of the first stage and of the octupole structure has to be done in order to improve at least of a factor three the output currents for the high charge states of the light ions.

Transmission of the beam through the axial injection line ,up to the 90° bending unit has proved to be fairly good, being near to 90%, also for beams having emittances which are almost twice the acceptance of the cyclotron.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] G. Bellomo, Proc. 11th Int. Conf. on Cyclotrons, Tokyo, Japan, 1986, pp. 503-506.

[2] H. Beuscher et al., KFA Julich IKP Annual Report 1984, p. 328.