STUDY OF A TRAPPED ION SOURCE

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Abstract

In this paper the design and the main features of a Trapped Ion Source (TIS) is shown. In practice, TIS can be seen as a modified version of an Electron Beam Ion Trap (EBIT) or of an Electron Beam Ion Source (EBIS). One can foresee that TIS could overcome some drawbacks of the EBIT and EBIS making it a more flexible device. Special interest will be addressed to the construction of the electron beam transport channel with its focusing quadrupoles of new type.

1 INTRODUCTION

TIS is a new type of source capable, in principle, of producing very highly charged ions and, at the same time, it is a radio frequency quadrupoles linear trap suitable to study the interaction of the trapped ions (or charged microparticles) with electrons, high energy particles or laser beams. In practice, it is a modified version of an Electron Beam Ion Trap (EBIT) recently developed in some laboratories mainly to study X and UV rays spectroscopy for "hydrogenic" and "helium-like" ions. Furthermore the ability of producing very highly charged ions in a small laboratory apparatus at a small fraction of the cost of producing them at a large accelerator represents a great opportunity. In fact new EBIT are being built in several laboratories around the world, and the initial operation of two of them has recently been reported [1]. Among the goal of TIS, other than the production of highly charged particle, it can be foreseen the production and trapping of radioactive isotopes, ion cooling studies, analysis of macromolecules. Further, the usig of TIS as "dust targets" in high energy accelerators can be useful. The status report of the project with a detailed discussion on the “optics” for the electron beam needed to ionize the wanted atoms will be mainly presented.

2 TIS DESIGN

TIS design has already presented in ref. [2], but here, for clarity sake, its main features will be illustrated again. In fig.1 a cutaway drawing of the ion source mechanical design and its operation scheme is shown. From the fig.1b) it can be seen the electron gun that generates the electron beam needed to ionize the atoms. Since an electron gun designed and built for another experiment is intended to use for TIS experiment a couple of iris are been used to match the electron beam emittance to the acceptance of the TIS transport channel. The transport channel that drives the electron beam until to the collector is made of two 90 degree bending magnets (BM) and several quadrupole doublets of new design as will be shown in more details in the following. The main new feature of TIS, with respect to an EBIT (or EBIS), is the adding of radial ion confinement of the rf quadrupoles to the potential well of the eb space charge when it is on. When the eb is off (the eb will be pulsed) only the desired ions will remain trapped.

In the longitudinal direction the containment is obtained by two repelling electrodes placed at the edges of the quadrupole electrodes. These electrodes can be pulsed to pull-out the trapped ions for external use (e.g. acceleration).

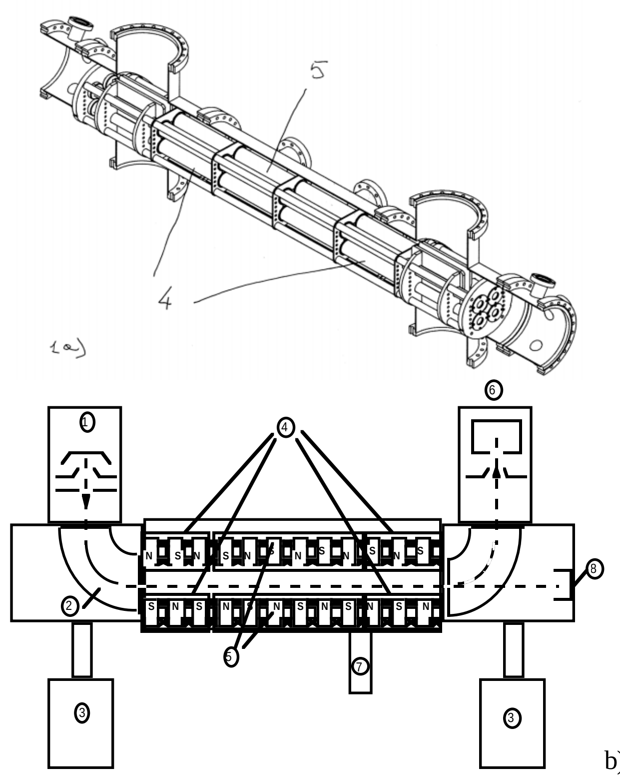


Fig.1a) cutaway view of the TIS mechanical design; 1b) Operation scheme of TIS: 1) electron gun, 2) bending magnet, 3) vacuum pump, 4) static potential electrodes U_0 for longitudinal ion trapping, 5) rf quadrupole electrodes with inside the focusing magnetic quadrupoles, 6) electron collector, 7) gas-inlet, 8) ion collector.

In its normal operation, the electron beam pulse is injected transversally (see fig 1b) in the trap and then bent in the axial direction. Transversally too, in the center of the trap, vapor or powder can be injected, by a valve gas jet, that it is ionized and confined by the rf quadrupole field.

3 ELECTRON BEAM TRANSPORT

The most delicate point in the TIS construction is the eb transport line. The electron will be generated by an electron gun with a Pierce design originally built for an electron cooler experiment (ECOOL) and then modified for our needs. To get a pulsed electron beam the first electrode will be connected to a Bloomlein type pulser. The modified design of the electron gun with the two iris needed to match the emittance is shown in fig.2. In that figure are shown also some of electron trajectories. The density electron current obtained in the simulations is about 100 mA/cm^2 with a perveance of 0.14 µP. The couple of iris have a radius of 1.8 mm and are placed at a distance of 120 mm to give at gun exit an emittance of about 30 mm x mr. The gun cathode is placed at high voltage and the transport channel with the trap region at ground to make more easy the operation.

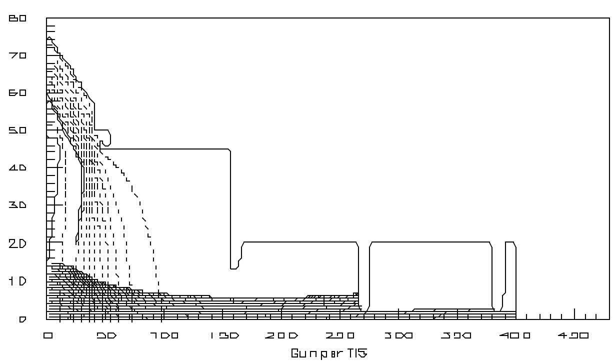


Fig.2 Computer simulations of the electron gun design with electron trajectories. The electrode potentials are: V_1=10.kV, V_2=30 kV; the output density current J=100 mA/cm^2; the emittance ε=30 mm mr.

To save power the electron beam will be recovered trough a collector, the same of the ECOOL experiment.

From the exit of the gun the eb will be transported up to the collector trough two 90° bending magnets and a new kind of magnetic quadrupoles (see below) inserted inside the rf quadrupole electrodes. The eb envelope in the horizontal and vertical plane along a 1.3 m long transport channel is shown in the computer simulations of fig.3. It presents a sufficient symmetry with respect to the center of the channel allowing, in this way, a good eb quality at the collector entrance which is placed at a symmetric position with the electron gun (see fig. 1).

The polar expansions of the two 90° bending magnets can be seen from fig1a). They are inside the vacuum tank in the region of the crosses where the electron gun and the electron collector will be connected to the tank. The dipole polar expansions will be powered by external coils.

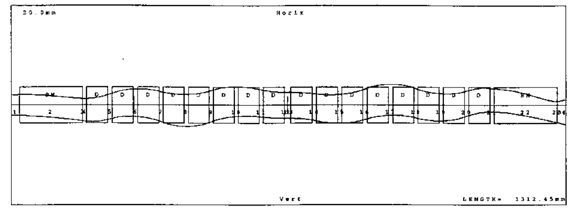
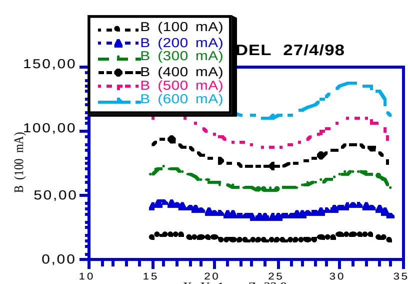


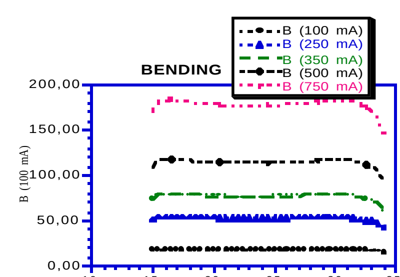
Fig.3 Electron beam envelope through the transport line, from the gun exit to the collector entrance.

This solution has been chosen because in those regions there are the glass tube containing the wires that will power the focusing quadrupoles. Because of mechanical mounting problems, only one edge angle focusing of 10°, has been used for both the bending magnets .

Magnetic field measurements given by these kind of dipoles have been carried out as shown in fig.3. Precisely, in fig.3a) the field measurements of the original dipole, as shown in fig.1a), can be seen. In this case saturation effects occur in the central region for the highest fields. Notice that the field needed to bend an eb of 30 keV is about 60 Gauss. In this region the saturation effect is not negligible. This problem has been solved (see fig. 3b)by adding iron to the polar expansions.



A)



B)

Fig.3 Magnetic filed measurements: a) without the adding of iron b) with the adding of iron.

The iron pieces have been placed between the glass tubes that are on the back of the polar expansions.

A schematic picture of the new type of magnetic quadrupoles poles that will be utilized for the eb focusing is shown in fig.4.

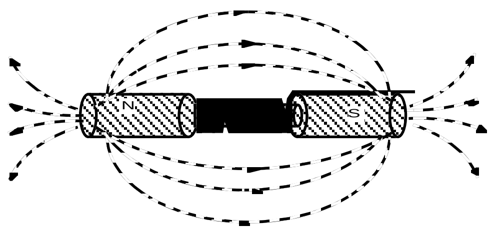


Fig.4 Longitudinal view of the quadrupole doublet single pole utilized for the electron focusing in the trap.

They present a very simple mechanical construction. In fact the poles of this kind of quadrupoles will be built by turning four iron bars, alternating a section of larger to one of smaller diameter. Around the smaller ones are wound the excitation coils with alternating polarity from coil to coil. From fig.4 it can be also seen that this kind of design does not allow the use of a single quadrupole. In fact the magnetic flux lines for each quadrupole pole must be closed, then they go out from the north pole and come back to the south pole.

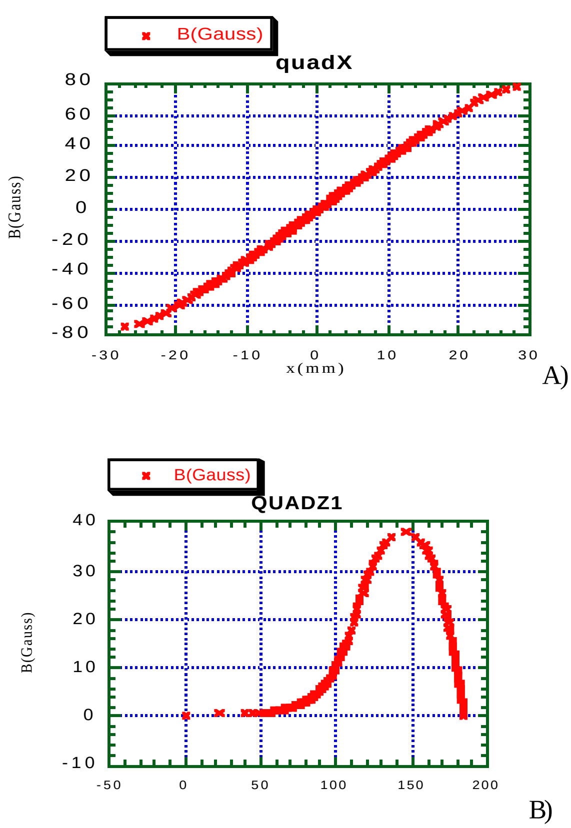


Fig.5 Magnetic field measurements for the quadrupole of the doublet prototype: a) B *vs* x (horizontal position), b)B *vs* z (longitudinal position). The field measured along the vertical position y is the same as in a).

For this reason the beam focusing between the two bending has been accomplished only by quadrupole doublets. A prototype of these new kind of quadrupole doublet has been built and magnetic field measurements have been carried out to test the quality of the magnetic quadrupolar field. In fact, as mentioned in ref.[1], the ratio of the distance from the axis to the cylinder radius of the rf electrodes, which will have inside the magnetic quadrupoles (see fig.1), has been optimized for the rf quadrupole field. In fig.'s 5 are shown the prototype magnetic field measurements for transverse and longitudinal planes. From these figures it can be seen that, in the transverse planes (fig.5a), the linearity of the magnetic field is quite good in the range of 15 mm around the axis. For the longitudinal field (fig.5b)we can observe large fringing fields due to the large gap of these quadrupoles. This means that the effective lengths of the quadrupoles are almost two times greater than the real lengths.

3 STATUS OF THE PROJECT AND CONCLUSION

The mechanical design and the computer simulations of the device has been concluded. The electron gun test has been carried out at low voltage and, by measuring the electron current with a Faraday cup, a perveance of about 0.2 μP has been found. The vacuum chamber has also been tested and the cylinder shaped electrodes for the rf quadrupole field are already available.

The construction and the test of all the quadrupole doublets needed for the eb focusing have been done. The 90° bending magnets are also been constructed and tested. Steering coils with Beam Position Monitor (BPM) will be placed behind the first and at the entrance of the second bending magnet. The system to excite the quadrupole doublet coils inside the rf cylindrical electrodes is also ready. In conclusion, we are ready in the next weeks to test the transport of the eb up to the collector. The next step will be, we think for the end of the year, the ion productions and their trapping.

REFERENCES

[1] R. E. Marrs, P. Beiersdorfer, D. Schneider, Phisics Today, October (1994) 27

[2] G. Brautti et al., to be published on PAC 97 proceedings.