NEWS DEVELOPMENTS AT SARA

J.L. Belmont, M. Fruneau, P. Martin and the SARA Staff

INSTITUT DES SCIENCES NUCLEAIRES
I.N2.P3. - Université Joseph Fourier
53, Avenue des Martyrs 38026 GRENOBLE Cédex - France

SUMMARY

SARA was one of the first cyclotrons to operate with an ECR ion source. Experience since 1983 showed it would be useful to have two sources situated outside the cyclotron vault to manage continuous operation of the accelerator and development of new ions. A 18 m long injection line for FERROMAFIOS and MINIMAFIOS has been constructed. One of its principal features is a 11 m long electrostatic guide with periodic focusing. Transmission ratios from the source to the internal beam are close to 30 %.

Experiences involving time of flight measurements require short beam bunches ; in order to reduce their duration, a phase selecting system will be installed in the centre of the injector of SARA. A RF voltage at four times the frequency of the dees will vertically deflect early orbits while particles close to the central phase will cross the deflector at zero voltage and will undergo normal acceleration.

I - INJECTION LINE FOR TWO ECR ION SOURCES

INTRODUCTION

The ECR ions source MINIMAFIOS built by R. Geller (1) is operating at SARA since 1983. This source, installed until recently inside the first cyclotron vault, produces ions up to krypton that are accelerated to energies from 2 to 38 MeV/A.

Many reasons induced us to obtain a second source and to install both sources outside the accelerator room :

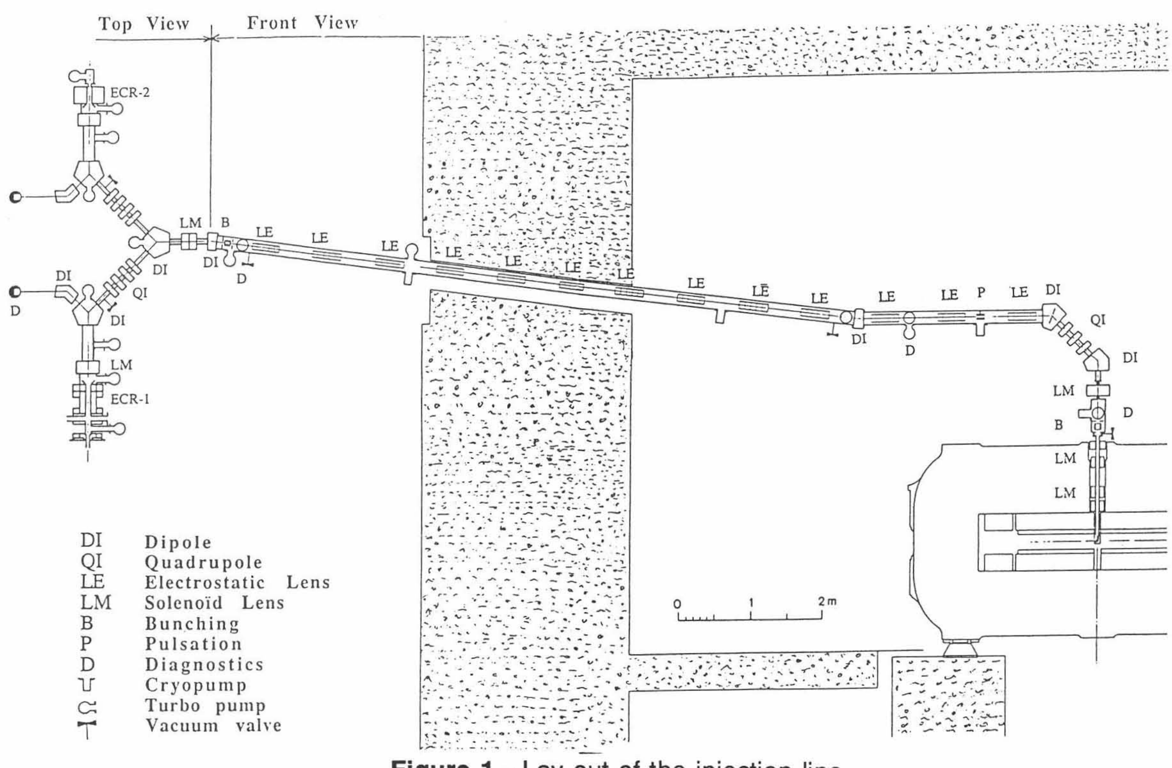

Figure 1 - Lay out of the injection line.

- New sources are under development, giving better yields of heavy ions especially from metals.

- A continuously operating source cannot be easily studied and modified

- Experience with ions from metals or corrosive gases showed the need for cleaning the source or its pumping system to obtain initial yields.

- Pollution due to ions produced precedently is important, and is particularly disturbing if the same q/m have to be accelerated.

So it was decided to install MINIMAFIOS and the new FERROMAFIOS, also built by R. Geller, outside the cyclotron vault. The two sources are located in an existing room. They can be connected either to a short analysing line or to a 18 m injection line, the lay out of which is mostly dictated by the need to use the existing room (Fig. 1 (2)).

DESIGN OF THE LINE

Emittance of the source

Emittances have been measured on MINIMAFIOS several years ago. The area was A = 150 πmm mrad at 14 KV with a plasma electrode hole of 8 mm diameter. These data are consistent with other measurements on the same sources (3), they were adopted for FERROMAFIOS as measurements were not available at the moment of the design of the beam line.

First section

Extraction from the plasma through 6 or 8 mm diameter hole of the sources is done by a conical electrode held at variable voltages to get better extraction conditions irrespective of the acceleration energy. A good vacuum (a few 10^{-7} Torr) is of paramount importance and is insured by 2 turbomolecular pumps (140 l/s speed).

Focusing by a magnetic Glaser lens LM1 is done as close as possible to the source, ions of different q/m are focused in different ways, so that charge space effets are reduced. Two 45° magnets and 4 quadrupole lenses symetrically fed ensure an achromatic and stigmatic transport (4), with a rough q/m selection (1/18) by an analysing diaphragm between the quadrupoles (Fig. 2).

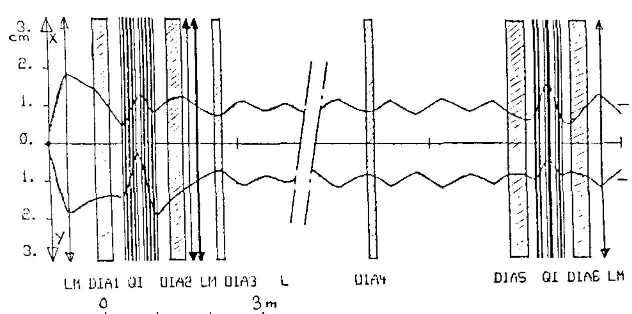

Figure 2 - Calculated beam profiles.

A better q/m selection of 1/50 is obtained on the very short line with the 1st 45° magnet followed by another one.

Two magnetic Glaser lenses LM3/LM4, fed in opposite polarities to prevent beam rotation, adapt the beam emittance to the acceptance of the electrostatic channel which begin just after the vertical 7.6° downward bending.

Electrostatic guide section

This 11 m long section has been designed for a stable periodic focusing ensuring minimum variations of the beam to envelope, a large tolerance of mismatching and poor centering of the incoming beam and a reduced sensivity to mistuning of the elements.

It consists of 13 identical 860 mm long lattices. Each element is composed of 5 cylindrical electrodes between 460 mm drift space (Fig. 3). The central and external cylinders are at ground potential, all active electrodes are at the same negative voltage. At 1.1 time the source voltage, focal length is 0.6 m and there are 2.5 periods of oscillation on the overall length. A vertical upward bending is made before the 3 last elements.

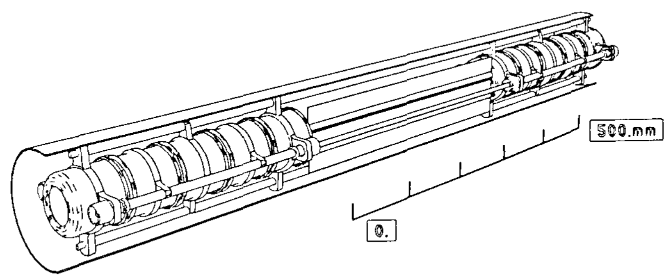

Figure 3 - Two elements of the electrostatic channel.

This solution has been successfully tested in Grenoble on the separator (5), it provides the following advantages : reduced cost, zero power consumption and good pumping speed in the 150 mm diameter tube through the 3 m concrete wall. In fact unforseen difficulties appeared in our case.

Vertical section

Two 45° magnets and 3 quadrupoles in between ensure a quasi stigmatic transport from the electrostatic section to the vertical beam line in the yoke. A Glaser lens LM5 provides a waist at the bunching location and adapts the beam to the admittance of the 4 magnetic lens axial injection channel, ending at the pseudo-cylindrical inflector.

Diagnostics

There are five mobile profile monitors of 16 horizontal and 16 vertical wires. They are used to control good matching at the entrance of the electrostatic channel, the desired periodic focusing and good adaptation to the vertical line.

Pulsation

Two vertical plates 120 mm long and 20 mm apart associated with a movable diaphragm 900 mm downstream are used to deflect the beam and chop it down to the range of microseconds by applying 250 V at the maximum source voltage of 20 KV.

Bunching

The existing first harmonic cylindrical buncher is located at the entrance of the yoke. It introduces a momentum dispersion $\Delta p/p = 10^{-2}$ and provides a gain of 5 in the extracted beam corresponding to ± 60° of RF phase. To increase its efficiency, a pre-bunching will be installed on the beam line in the near future. A short negative pulse (3 ns) up to 100 V at the RF repetition rate will be applied to a gridded cylindrical electrode. The duration of the pulse is short relative to the transit time of the ions in the gaps. These particles, which are beyond the ± 60° mentionned previously, experience the same acceleration or decceleration ($\Delta p/p = 10^{-3}$). After 10 m drift, they join the unaffected particles at the main buncher. The extra gain in intensities is expected to be between 1.5 and 2.

Vacuum

Acceleration voltages of the ions range from 8 to 20 KV, corresponding to energies from 1.3 to 9.7 KeV per nucleus, the lower q/m being 0.15. For these low energies, the charge exchange cross sections are not negligible ; for instance $\sigma = 1.5\ 10^{-15}$ cm^2 for Kr^{15+}, corresponding to beam losses of 6 % per meter at 10^{-6} Torr. Turbomolecular pumps are placed close to the sources where fluxes of gases are important ; cryogenic pumps equip the electrostatic section where the operating pressure in 4.10^{-9} Torr. The maximum pressure on the line is 10^{-8} Torr except for the extraction region and losses are expected to be less than a few percent.

FIRST RESULTS

The winter shutdown has been used to complete the installation of the injection line already connected to Ferramafios and to remove Minimafios from the cyclotron vault to the new location. Continuous operation of SARA resumed with the first one, both sources are available since April.

Emittance measurements

Emittance measurements have been done on Ferromafios after one Glaser lens and one 45° magnet for rough charge separation. They give similar figures to those of Ferromafios when transported back to the plasma hole. However, operating conditions are more critical ; good adjustment of gas flow and confinement coils are necessary to prevent aberrations. The extraction voltage is important and has to be increased up to 8 KV when the source voltage is lower than 10 KV. More curiously, holes are observed on the axis of the emittances for certain settings of the sources !

Beam transport

Measurements on the first section showed that the excitation of the quadrupoles were not the calculated values to obtain a stigmatic beam. The reason is still not clear, various hypothesis have been proposed : asymetric charge space effects, locally bad vacuum, etc... However, the first lens LM1 is very effective to obtain the desired beam shape according to the settings of the source.

Preliminary measurements on the straight part of the electrostatic section showed very large displacement of the beam as the focusing voltage is increased, total disappearance occuring above the nominal value.

A shorter section was tested, calculated values of the focus were consistent with experimental ones either positive or negative, but the steering effect was still present after careful screening of high voltage feedthroughs and interconnections. Considering the large admittance of this type of channel at small focusing voltage, it was decided to run it at half the calculated value and to cope with misalignements by magnetic steerers.

Injection

Injection into the first cyclotron of SARA with both sources is easy and transmissions are good (Fig. 4). Adjustment of the electrostatic channel is facilitated by the beam profilers, the other settings are not critical. For a calcium beam, it was very convenient and time-saving to set the accelerator with an argon beam form ECR2, then switching to ECR1 already tuned on calcium.

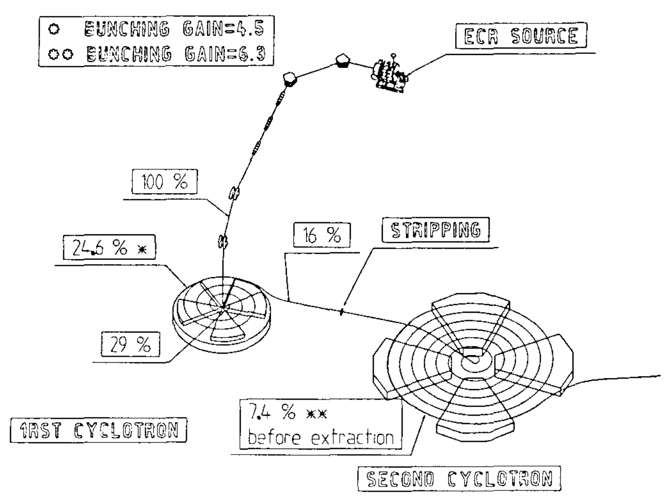

Figure 4 - Transmission ratio for Neon^{6+} at 30 MeV/A.

Pulsation

Due to transit times in the deflecting plates and the energy spread that can appear in the beam, rise and fall times of the axial injection beam are comprised between 100 and 200 ns.

Multiturn extraction of the 1st cyclotron give typical figures of 1 µs rise time and 1.5 µs fall time, the latter can be reduced to 1 µs or less by a slight displacement of the puller electrodes of the first accelerating dee.

II - BURST LENGTH REDUCTION

A very short beam burst length is important for experiments involving time of flight measurements. However, at present beam burst durations are few ns, in some cases, time distributions present one peak and satellites. Studies have been undertaken to shorten these durations by vertically chopping the beam in the early turns of the 1st cyclotron.

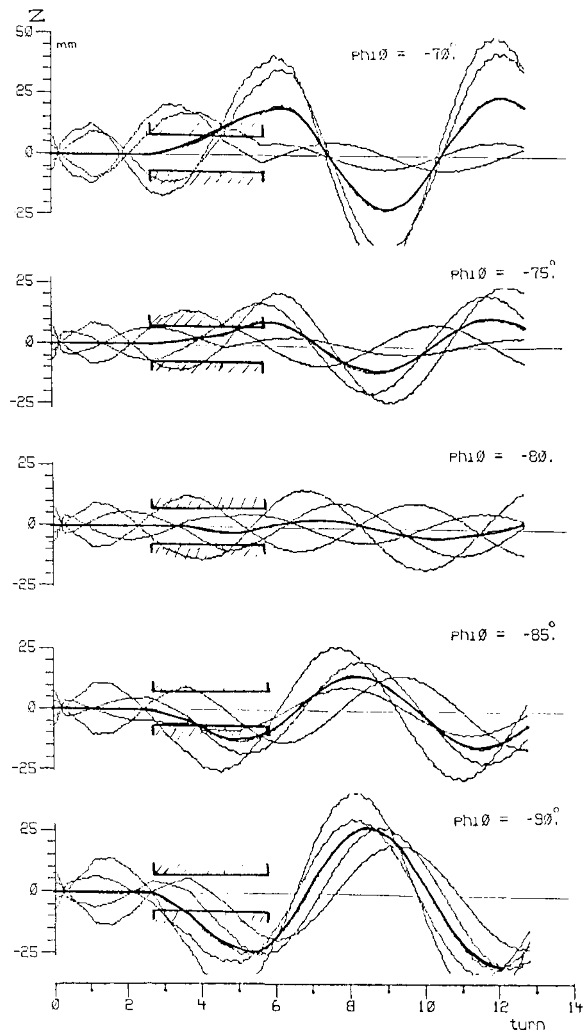

Figure 5 - Vertical deflection by plates for phases of the RF at the start of the particles from Phi_{io} =- 70 to - 90° and 5 vertical trajectories at the entrance of the first accelerating gap. Trajectories starting in the median plane are in bold lines. Example is given for C^{3+}at f = 11.7 MHz, h = 2, RF voltage = 46 KV, deflection voltage is 8 KV peak at f = 11.7 MHz x 4. Relative phase between RF has been chosen for minimum deflexion of particles at the centre of the burst. Horizontal coordinates are turn number.

Phase selection

A few turns after injection, an electrical field between horizontal plates will induce a vertical deflection of the orbits. The plates are fed by a RF voltage at the 4th harmonic and 20 % amplitude of the dee voltage. They also act as a diaphragm intercepting the deflected beam. Their azimuthal extension is 12° and their gap is 12 mm. They cover the 3rd to the 6th turn in the machine. Only a short range of phases, corresponding to the undeflected beam (near to zero voltages on the plates) is accelerated. A better limitation would imply a diaphragm situated at larger radii.

An example of vertical movements is shown on fig (5) for beams starting at different phases of the accelerating RF but roughly in the phase acceptance of the machine. Vertical focusing by the acceleration (phase dependent) and the magnetic field is clearly seen (6). The trajectories shown have been chosen inside the admittance of the axial injection inflector.

Resonator

A full scale model of the chopper was tested before complete design of the phase selection system to be placed in the cyclotron (fig. 6). Deflecting plates may be considered as a 5 pF capacity connected to a 2.5 m long 75 Ω coaxial line connected to a 2 turns inductance and resonnating like a 3λ/4 shortened line. Tuning from 40 to 52 MHz is done by a vacuum capacitor (100 pF to 10 pF). A variable coupler is used to provide the correct impedance on all the frequency range to the 5 KW tetrode TH 547. Peak voltages in excess to 10 KV have been obtained.

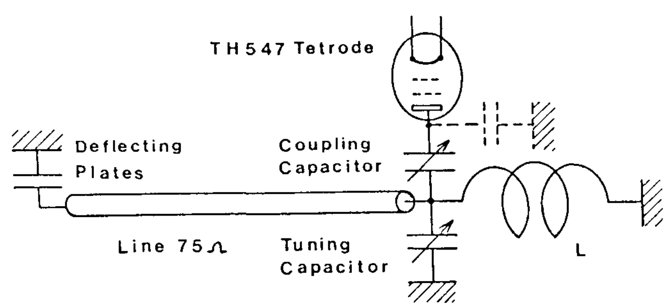

Figure 6 - RF model of the phase selection device.

The final system will consist of two coaxial standard copper pipes. The central one will support the active plate. Insulation is achieved by spacers along the line and an alumina vacuum feedthrough is placed close to the centre. The device is radially inserted into the vacuum chamber, one finger inserted into a hole of the central region ensures precise position. All the system may be axially displaced in order to adjust the plate position.

Acknowledgment

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