PRELIMINARY DESIGN OF A NEW HIGH INTENSITY INJECTION SYSTEM FOR GANIL

Ch. Ricaud, P. Attal, E. Baron, R. Beck, J. Bony, M.P. Bourgarel,
B. Bru, A. Chabert, S. Chel(1), R. Vienet(2).

GANIL, BP 5027, 14021 CAEN Cedex, France

(1) Present address: L'Orme des Merisiers, 91191 Gif-sur-Yvette Cedex, France.
(2) L.N.S. 91191 Gif-sur-Yvette Cedex, France.

ABSTRACT

In order to increase the beam intensities delivered by the GANIL injectors, which are presently limited either by space charge effects (light ions) or by low source currents (heavy ions), we are designing a new high efficiency injection system. A new beam line has been designed for an optimal matching of the beam in the six- dimensional phase space between the ECR ion source installed on a 100 kV platform and the first accelerating gap of injector cyclotron C01. The beam dynamics computation takes into account the spiral inflector associated with a small electrostatic quadrupole located immediately after. The principle and the design of the new injection system, as well as the expected performances, are described in this paper. The completion of this sytem is planned for the end of 1990.

INTRODUCTION

In parallel with the present modification for increasing the energy range (O.A.E.)$^{1)}$, a second improvement of GANIL (O.A.I.) is presently in progress. It was born both from the request for high intensity Ar and Kr beams for exotic experiments, and from the brain-storming about the charge-space effect and the capability to carry the axial injection line efficiency to a better level.

Over the past years, the operation of the accelerator showed clearly that, due to space charge effects, the transmission between the source and the injector outputs $^{2)}$ decreases rapidly from 25 to 3.5 % when the source intensity raises (from 10 to 100 eμA for a 1.3 keV/A O^{2+} beam).If the ion source voltage is raised to 100 kV (maximum value imposed by voltage breakdowns in the inflector) instead of the present 15-20 kV, this efficiency is upgraded to 40%, due to both the velocity increase and the lengthening of the bunches. Thus, an intensity of 100 eμA (our reference beam is 15 keV/A Ar^{6+} for the rest of this paper) can be accelerated in the injector$^{3)}$. On the other hand, the beam line between the source and the cyclotron has not only to transport the beam without losses but must also provide the matching in the six-dimensional phase space into the cyclotron, through the inflector$^{4)}$. Generally, only the betatronic matching is carried out, so that the best efficiency for this type of injection is always bound to the 10-20% range.

Taking into account the total phase space volume makes it possible to handle 300 to 400 eμA beams in the injection line and to accelerate 100 to 150 eμA intensity in the injector.

Finally, in order to take advantage of these improvements for the heaviest ions too, it was decided to increase the ECR source U.H.F. from 10 to 14 GHz and to design this CAPRICE type source with a 2B structure$^{5)}$. This new device will be associated with the second injector, modified like the first one$^{6)}$ which is connected to the 20 kV injection beamline (O.A.E.). A factor of three to five is expected from this operation with respect to the currents obtained with the O.A.E. In the following part we describe the conception and the status of the operation.

1. THE 100 kV EXTRACTION OPTICS

Two possible configurations are presently under study. The first one with a 20 kV extraction utilizes, as the previous injection line, a solenoid to focus the beam (and to moderately select the charges) just before the 100 kV electrode tube. In the second one, the beam is extracted and accelerated up to the final energy with a single 4 electrode tube followed by an Einzel lens.

In both cases a virtual waist is adjusted in the focal plane of the analyzing magnet. Computations taking into account the space charge with the initial conditions that we tried to measure, use a computer code called FOCA, already in existence at SATURNE. This code deals only with axially symmetric beams (with a single charge state) where the space charge force varies linearly with the beam radius, and uses an analytical description of the fields. A more sophisticated code called SOSO$^{7)}$ was recently developped at GANIL. It uses a cartesian coordinate system which allows dealing with irregular density distributions in the phase planes. It is possible to treat a beam composed of several ion species (mass and charge state), which allows in particular to take into account the ions issued from the support gas. Each ion species is represented by a limited number of particles (usually 100) and the lateral dimensions are defined as twice the rms value of the corresponding distribution. External forces can be calculated from any expression (analytical or numerical) of the fields and of their derivatives. As for the space charge forces, they are calculated using the method of the equivalent ellipsoid[2] and are applied through kicks at regular intervals along the line. No solution has been definitely adopted yet.

2. BEAM LINE

The beam extracted from the source has no time structure. On the other hand, the phase acceptance of the cyclotron is about 3.6 % (i.e. ± 6.5° RF). In order to upgrade this yield, the beam line must contain a bunching device.

With the expected energy and intensity levels of the OAI operation (i.e. 100 eμA accepted by the cyclotron), the bunching yield depends on the space charge effect. It is to be noticed that the energy width of the beam is mainly generated by the bunching device, because it is very small (5 to 6 eV per charge state) at the source output. In order to control the situation arising from these facts, it is necessary to know precisely the beam characteristics at the exit of the source.

We have decided to design a beam line having separated optical functions (like the other beam lines of GANIL). The beam line can be divided in two main parts (fig. 1).

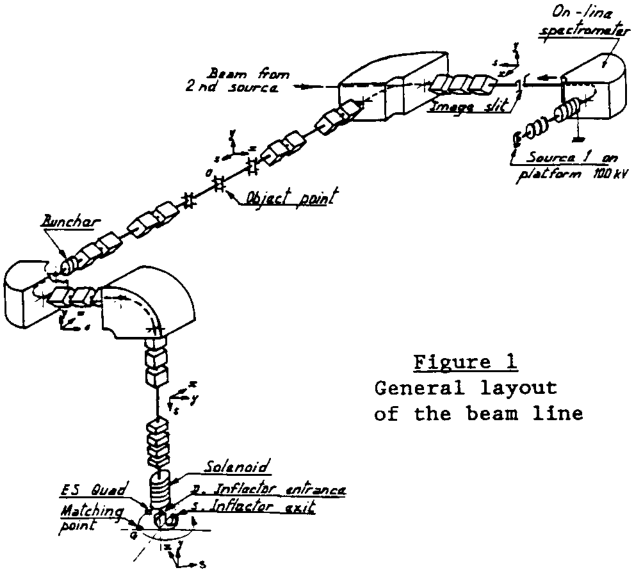


Figure 1
General layout of the beam line

The first part guides the beam from the 100 kV platform, to point 0, which is the object point of the second part. At this point the beam has no time structure and is selected in charge state and in mass (resolution of 1 part in 250 for a 100 π mm·mrad beam emittance). In addition at point 0 the beam is considered not to have coupling between both transverse phase planes. However the longitudinal magnetic stray field[8] in the extraction region of the ECR source generates coupling between both transverse phase planes.

But, besides the classical focusing and bending functions, the beam line structure upstream point 0 contains (study in progress) optical elements to minimize the coupling between the transverse planes. Moreover, whatever the transverse emittances may be at the exit of the source, the beam is matched homothetically at point 0. Thus, the tuning of the second part of the beam line is independent from that of the first part. The drift space surrounding point 0 is equipped by a triple set of profile monitors and adjustable slits, to measure the transverse emittances and, if necessary, to reduce them.

The second part of the beam line extends from object point 0 to the matching point inside the cyclotron. It contains the inflector. Its optical sections and optical functions are presented at this conference[4]. The value of the transverse acceptance is 70 π mm·mrad.

The dipoles and quadrupoles are of a classical type. The skew quadrupole triplet of the horizontal/vertical correlation device is more compact (70 mm bore diameter, 100 mm length and 70 mm drift space) in order to reduce the beam dimensions. A skew quadrupole prototype with field clamps has given quite good results. The solenoid in the yoke hole has a .65 T maximum field. It has an additional winding to adjust the beam rotation. The buncher of double drift harmonic type (DDHB), produces 1.5 to 2 kV efficient voltage on harmonic number 1. About 20 % of this voltage is required on harmonic number 2. In the vertical part of the beam line, near the yoke hole, a space has been saved to insert a rebuncher in the future.

3. THE INFLECTOR

Among the existing inflectors, the spiral type[9,10] was chosen for this project in order to satisfy the following conditions.

At the present energy levels its height fits in the gap of the cyclotron. The energy of the central particle does not change when going through the inflector. Thus, the space charge effect is minimized. Moreover, the spiral inflector has a free parameter which can be used in order to center the horizontal inflector position with respect to the cyclotron.

The following study corresponds to a 120 mm height inflector. This value, corresponding to the theoretical one, must in the final project be reduced by about 10%, but the optical characteristics of the new inflector will be nearly the same.

In our case, the incoming beam is centered on the yoke axis. The inflector parameters are:

Maximum accelerating voltage	100	kV
Injection radius in the cyclotron	74.1	mm
Inflector height	120	mm
Gap width	15	mm
Length of the central trajectory	188.5	mm
Maximum voltage between electrodes	25	kV
Maximum electric field in the gap	16.67	kV/cm
Slant of the inflector edge at exit (with respect to the median plane)	41.4	deg.
Azimuth α_{opt} (with respect to the axis of acceleration)	61.85	deg.

Figure 2 shows the central geometry in the median plane of the cyclotron, the projection OS of the central trajectory in the inflector and the junction with the so-called first orbit in the cyclotron.

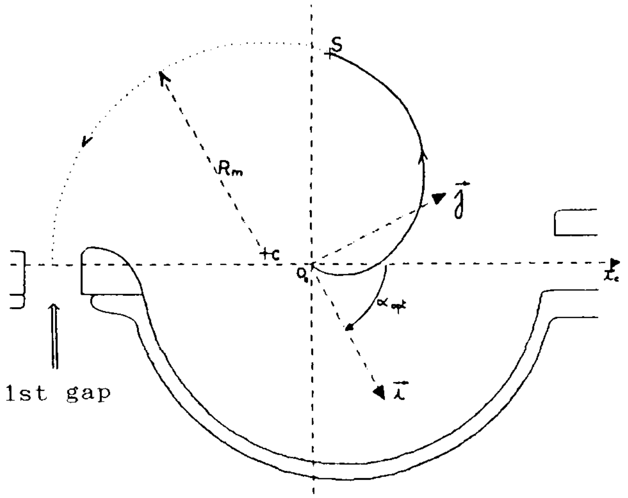


Figure 2

3.1 Field Calculations

We did not succeed in calculating analytically the first order development of the electric field around the central trajectory without adding an arbitrary first order term in view of restoring the maxwellian characteristic of the field. This additional term was chosen in order to simplify the analytical field expression, thus to define the two electrodes. The equipotentionals, especially the electrodes, are rectifiable surfaces.

The potentials of the electrodes defined above are then calculated by a numerical method : a three-dimensional mesh is defined and the potentials on the points are calculated with a finite difference method[11] (algorithm identical to that of the RELAXED 3D code[12]).

Due to the discrete simulation of the electrodes, the field is slightly different from the theoretical one. In order to avoid this difficulty the potential on the mesh points near the electrodes are linearly fitted.

3.2 Beam Dynamics in the Inflector

Due to the electric and magnetic edge effects, the length of the electrodes, as compared to their theoretical value, have to be shortened by about 3 mm, at both ends of the inflector, in order to provide a 90° deflection and to obtain a central trajectory tangent to the median plane of the cyclotron.

The transfer matrix was obtained by calculating six particular trajectories(using the frames given in figure 5a of which initial conditions are defined in the following way : all the coordinates with respect to the central trajectory are equal to zero, except one. Different values of the non zero coordinate have been considered in order to examine the linearity of the transfer matrix terms.

Taking into account the conditions imposed at the matching point in the cyclotron and the acceptance of the inflector, we are led to introduce a) an electrostatic quadrupole between the inflector exit and the first accelerator gap, and b) an electrode-face rotation at the inflector exit. A value of 20° for the latter has been optimized as shown in figures 3 and 4.

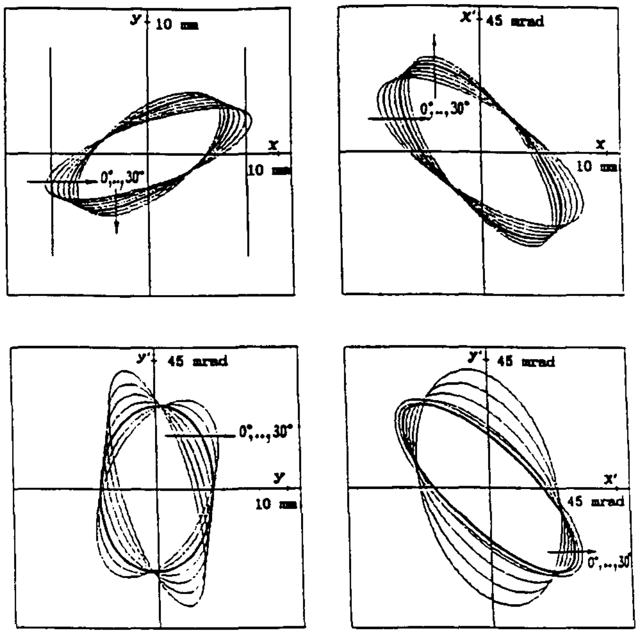
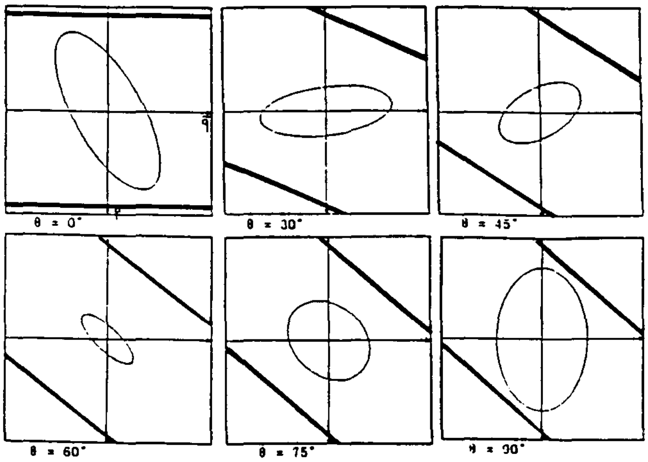


Figure 3

Evolution of the beam matching at the inflector entrance versus the electrode-face rotation value



Thick lines represent the electrodes

Figure 4

Beam cross section inside the inflector

A good agreement was found between the matrix method, and the numerical integration method, using the field map of the inflector. For this purpose, 400 particles have been randomly generated in the six-dimensional beam ellipsoid.

The space charge effect of the beam inside the inflector has been evaluated using the same method as code NAJO[2]: up to 400e μA, the space charge effect is negligible.

3.3 Construction

A prototype was built (fig. 5b). We used the same machining method as L.W. ROOT[12]. This prototype was put in the gap of the cyclotron. At a 1.55 T field level and 2.10^{-6} Torr residual pressure, a potential of +17 and −17 kV could be held.

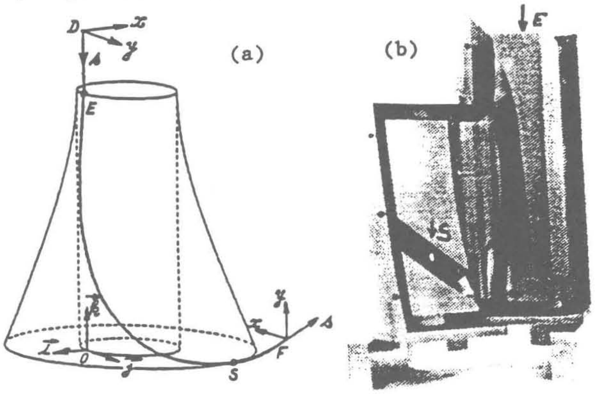


Figure 5

(a) Entrance, exit and fixed frames used in the dynamics. (b) Inflector prototype

4. ELECTROSTATIC QUADRUPOLE

Concerning point a) of paragraph 3.2, preliminary calculations have shown that, in order to focus the 0.6 cm high, vertically divergent beam at the exit of the inflector, a maximum value of 3.4 kV/cm^2 would be required for the electrical gradient if the effective length of the element were 4 cm; a bore radius of 1.5 cm is necessary to handle the 1 cm high beam inside this quadrupole, leading to a maximum voltage of ± 2.3 kV, which is easy to handle, even in a magnetic field. The 4 cm separation between the first and the second turn makes the design feasible, but the large diameter-to-length ratio requires a 3D-calculation (through a code analogous to the one mentioned above) to ensure that end effects would not alter the focusing properties. This 3D potential map is in the process of being included in our ray-tracing computer code devoted to the cyclotron internal beam dynamics.

The ultimate characteristics of the 3 elements: inflector, quadrupole and center geometry are not frozen yet.

5. PLATFORM DESIGN

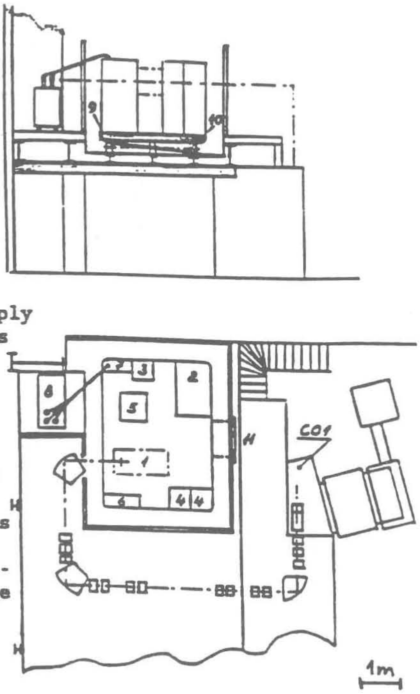
The ECR source will be installed on an insulated platform placed at the same level (3 m) as the floor (at earth potential) supporting the injection beam line (fig.6). This platform, 100 kV insulated with respect to ground, will consist of a metallic tank used as a casing for a reinforced concrete floor. It will be reinforced by nine pairs of insulators borne by the grounded floor.

The common point of each pair of insulators will be electrically and mechanically linked to the others and, in order to evenly distribute the potentials between them, it will be connected to the mid-point of the cooling pipes (2 circuits).

The epoxy-loaded insulators can hold 50 kV electrically and 50 tons mechanically. The 4.2x3x0.2 m high voltage platform weights about 5 tons when empty. The air gap between tank and ground is 0.5 m, and a removable metallic protection surrounds the following equipments:

- the ECR source, extraction, acceleration and focusing devices, including the vacuum system
- the power supplies for the coils of the source
- two electronic cabinets containing the control system and the high voltage supplies
- the UHF emitter.

The total weight of these equipments is 5 tons. A three-phase, 380 kV 150 kVA insulating transformer will provide the required power.



1 ECR source
2 Coils power supply
3 Additional coils power supply
4 Electronics
5 RF generator
6 Water cooling dispenser
7 Power dispenser
8 Transformer
9 Insulating hoses
10 Insulators
11 Door and retractable footbridge

Figure 6

General views of the platform

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