MODIFICATION OF THE GANIL INJECTORS

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ABSTRACT :

As part of the upgrading project of the GANIL accelerator complex, we have modified the two injector cyclotrons in order to increase their energy, which implies a larger extraction radius and a change of the harmonic mode operation from 4 to 3. The main consequence of this last point is to compel us to use a 180° dee and to double the number of turns (N = 25) which leads to replace the flat poles by spiraled sector poles and to redesign the central and extraction regions with the new isochronous field topology. Beam orbit dynamics computation results are presented.

The first injector is now coupled to the present axial injection beam line (23 kV) with a CAPRICE ECR source. The second cyclotron, nearly identical to the first one, will be connected to the future 100 kV axial injection line (described in this conference). This implies a new inflector and a new central region.

INTRODUCTION

The substitution of the PIG sources by the ECR sources has triggered a necessary modification of the GANIL accelerator complex, in order to take advantage of the energy increase offered by the higher range of charge states.

This modification (1) is possible only by lowering the stripping ratio from 3.5 to 2.5, with the consequence of changing some of the essential parameters of the accelerator and, in particular, an almost complete re-design of the injectors C01 and C02 (2).

At the same time the experience has shown the importance of space charge effects in the axial injection line, and the interest of increasing the injection energy in order to accelerate beams of more than 20 eμA with a good transmission efficiency (3, 4).

Therefore, the injector modification is a two-stage operation :

- One of the injectors was shut down in 1986, modified, and then interchanged with the second injector at the time of the general shut down in december 1988, to be connected to the existing 20 kV injection line. At the same time, a new CAPRICE source (5), identical to the source designed by B. Jacquot in R. Geller's laboratory, replaced MINIMAFIOS on the 20 kV platform.

This phase 1 is now achieved : source, injection and acceleration tests started on March 22d and ended successfully on April 7th with a 3 eμA Xe^{18+} beam, chosen as the tuning beam.

- The other injector, shut down in December 1988, and renamed C01, is now being modified, in a similar manner, except for the central region which is designed with a 100 kV injection voltage and a spiral inflector (6). Its completion is expected for mid-1990.

1. NEW INJECTOR PARAMETERS

The compared characteristics of the "old" (7) and "new" injectors are summarized in Table 1 and a sketch of one of them is presented on Figure 1.

	Previous characteristics	Present characteristics
Number of sectors	Flat poles	3
Minimum and maximum gaps	210 mm	210 - 300 mm
Pole diameter	1200 m	1316 mm
Maximum average magnetic field	1.671 T	1.565 T
Minimum average magnetic field	0.800 T	1.000 T
Number of circular trim coils	6	6
Number of harmonic coils	0	2
Number of dees	2	1
Dee angle	60°	180°
Frequency range	7 - 13.4 MHz	7 - 13.4 MHz
Acceleration harmonic number	4	3
Maximum dee voltage	90 kV	90 kV
Total number of turns	14	25
Internal dee height	49 mm	49 mm
Inflector type	hyperboloïdal	hyperboloïdal
Magnetic radius	3.25 cm	3.64 cm
Inflector electrical gap	20 mm	20 mm
Inflector height	79.6 mm	89.16 mm
Maximum inflector voltage	5 kV	5.2 kV
Maximum injection voltage	20 kV	23.16 kV
Radius of curvature at extraction	0.465 m	0.48825 m
Maximum deflecting electric field	50 kV	50 kV
Radius of curvature of the electrostatic quadrupole	0.672 m	0.735 m
Average steering angle at ejection	1.8 °	5.5°

- **Table 1** -

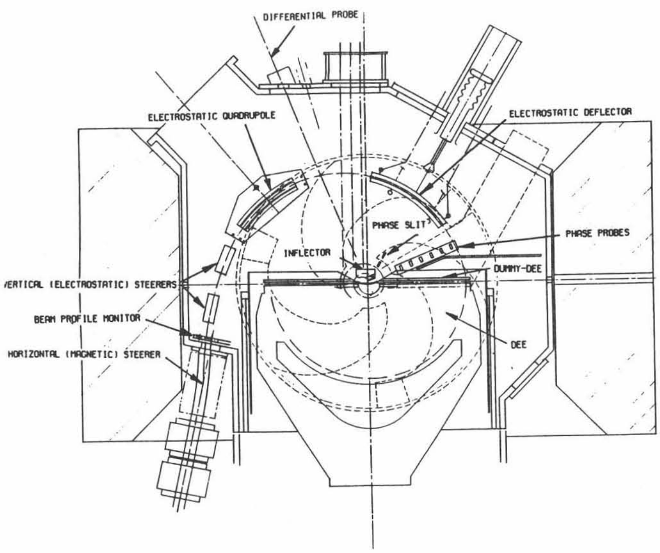

Figure 1 : View of the injector

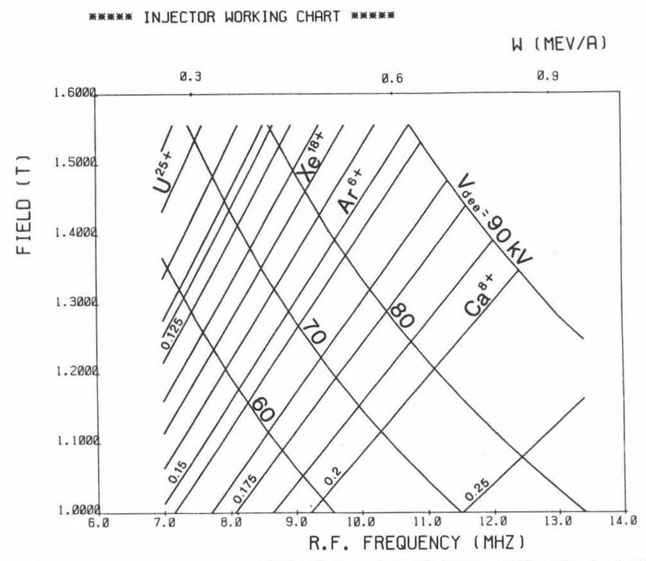

Figure 2 : Injector working chart

The modification consists in :

1.1. Changing the RF harmonic number ho and the extraction radius re , in order to satisfy the condition of compatibility with the first separated sector cyclotron SSC1 :

$$re\ (CO) = ri\ (CSS1).ho\ /h_1$$

Since h_1 becomes 5 instead of 7 for CSS1 with an unchanged injection radius ri, one gets the following changes :

ho = 3 (previously : 4)
re = 0.48825 m (" : 0.46m)

1.2. Changing the accelerating geometry from 60° dees (fitted with ho = 4 and 8) to a single 180° dee ; as a consequence, the number of revolutions is roughly multiplied by 2 (from 14 to 25 turns) and the central geometry, where the first accelerating gaps are radially defined by posts, had to be completely redesigned.

1.3. Changing the magnetic focusing : the old flat pole tip structure, retained for 14 turns, would have led to an unbearable phase slip ; a spiraling sectored structure is needed for isochronism and gives a benefit to the vertical focusing.

1.4. Modifying the extraction radius (as a consequence of 1.2), which imposed an increase of the pole diameter (and consequently a modification of the vacuum chamber) ; the electrostatic extraction devices : deflector and quadrupole had to be remodelled, and the magnetic steerer strengthened.

The new working chart is shown on Figure 2.

2. MAGNETIC STRUCTURE

Although the extraction radius increases only by 2.33 cm, the pole was changed : the minimum gap (210 mm) had to be maintained to allow the liner of the accelerating structure to fit in, which implies a larger average gap with the presence of hills and valleys. The new main coil is narrower but has the same height and about the same number of turns as the previous one.

As for the magnetic focusing, the aim was to reach a vz value of at least 0.1 and even better in order to cope with intensities as high as 100 eμA that will possibly be accelerated in the second injector. Due to the large gap, reaching this minimum value of 0.1 on the first turns was only possible by using a 3 sector-structure (rather than 4), a rather strong spiral angle : tan γ = 0.033.r and 4.5 cm thick sectors.

The following method was used to design the sectors (8) :

- Use of measurements obtained on a 4 sector model already existing at CGR-MEV Company.
- Comparison with the calculations by the Smith's method (9) , which showed that it could be a good approach for 3 sectors.
- Measurements on a 1/3 scale model, which produced results in very good agreement with the previous estimates both in terms of vz and of the average field law B (r), so that the spiral shape did not need to be modified except for its shoe, in the extraction region, which had to be lengthened and widened.
- Finally, measurements on the injector magnet, with adjustment of the central disk thickness in order to obtain the flattest possible field law for the whole range of induction.

Since the beam is not injected on-axis, this disk thickness has three 24 mm diameter holes (of which only one is used for injection) for symmetry reasons.

The 6 pairs of concentric correcting coils remain unmodified and trim the field to be isochronous between 1 and 1.6 Tesla.

Full scale maps were made at 8 different levels. Fourier series expansion exhibited a first harmonic amplitude rising for 1 gauss at 1 Tesla to 8 gauss at 1.6 Tesla in the extraction region ; two pairs of harmonics coils were thus placed in valleys.

3. R.F. SYSTEM

The change from two 60 degree dees to a single 180 degree dee allowing the acceleration up to the .488 m radius, has been a real surgical operation : this radius increase no longer permits the dee to be disconnected from the fork which ends the coaxial line. Therefore the two arms of the fork have been sawed, shortened and welded to the single dee.

The higher capacitance of the new dee leads to a 1.4 kW RF power dissipation. Therefore a very careful thermal design has been done by the RF group to limit the temperature rise of the cooling water to 3 degrees only.

4. EXTRACTION SYSTEM

Due to the wide radial acceptance of the electrostatic deflector (variable from 8 mm to more than 20 mm), this equipment was not modified ; the whole structure was just translated 23 mm outwards to take into account the change in the position of the last turn.

As for the electrostatic quadrupole, both the radius of curvature of the electrodes and their position had to be modified.

The required maximum voltages are about the same as before : 70 kV over a 14 mm average gap width for the deflector and ± 20 kV for the 30 mm bore diameter quadrupole.

The orientation of the spiral angle and the azimuthal position of the shims were optimized in order for the beam to cross the strong radial magnetic field gradient as fast as possible and therefore to minimize its width in the electrostatic quadrupole. A variation of the main magnetic field level over the total range requires a radial displacement of these two elements of only 1 mm.

Following the electrostatic quadrupole, two pairs of electrostatic steering plates are placed to correct for an eventual displacement of the extracted beam with respect to the median plane.

The previous steering magnet located at the exit of the vacuum chamber, that had to correct the radial beam direction by at most 1.5°, was completely redesigned since the new larger extraction radius requires a correction of 5.5° in order to enter correctly the unmoved beam line.

To evaluate possible beam losses, vertical "fingers" are installed at the entrance of the deflector as well as at the entrance and exit of the electrostatic quadrupole.

5. CENTRAL REGION AND INTERNAL BEAM DYNAMICS

Due to the small number of turns, it is still possible to track the particles from injection to extraction in the combined electric and magnetic fields. The aim is to obtain a well-centered beam which has to be matched to the SSC1 and to the intermediate line L1 acceptances, ie :

$40\,\pi$ mmxmrad, $\Delta W/W < \pm 5.10^{-3}$, $\phi < \pm 7°5$

The past experience showed that it would be better to restrict these conditions to obtain a 100% transmission in L1 often limited to 60%. Therefore we have worked to obtain better beam qualities ($\Delta W/W < \pm 4.10^{-3}$, $\phi < \pm 6°$)

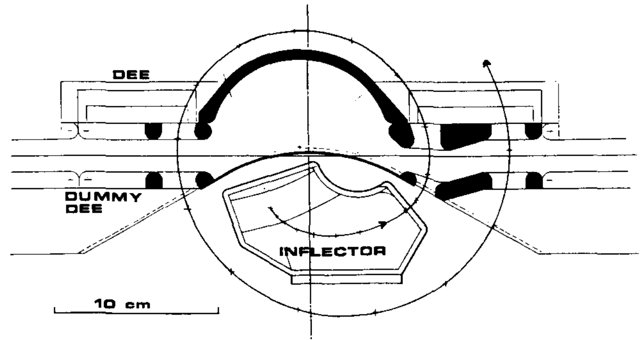

Figure 3 : Central region

The electrostatic configuration, both at the center where the first three gaps have posts and at larger radii, was computed with 2D and 3D codes developped at the laboratory. The central region is sketched on Figure 3. The potential maps are introduced on a cartesian mesh in a ray-tracing program derived from TRIWHEEL ; in fact, the vertical component of the electric field is directly introduced under the form of a series expansion fitting the results of the codes.

The steps of the internal beam dynamic computations have been the following ones :

- Backward trajectory for a first adjustment of the central geometry and matching to the injection energy.
- In the $(x, \dot{x}, \phi)$ phase space, selection of the forward trajectories that have at the same time :
  - . The proper final energy
  - . A small motion of the orbit centers
  - . The best phase history.

Taking into account the ECR emittances and the phase bunching in the axial injection line (Cf.par 6), we limit the phase space $(xo, \dot{x}o, \phi o)$ to : $xo = \pm 1$ mm $\dot{x}o = \pm 200$ mrad, $\phi o = \pm 15°$ corresponding to a set of 315 particles.

As before, we notice a correlation $(\dot{x}o, \phi o)$ equal to 10 mrad/degree and about ± 6 degrees acceptance for each $\dot{x}o$ corresponding to the required energy spread ($\pm 4.10^{-3}$).

On the last turn, if we were be able to select particles having this required $\Delta W/W$, we would obtain the graph plots (ϕ , $\Delta W/W$), $(x, \dot{x})$, $(x, \Delta W/W)$ (Figure 4), showing that in a ± 3.7 mm radial extension, all the beam has the total required specifications with an emittance of $26\,\pi$ mmxmrad.

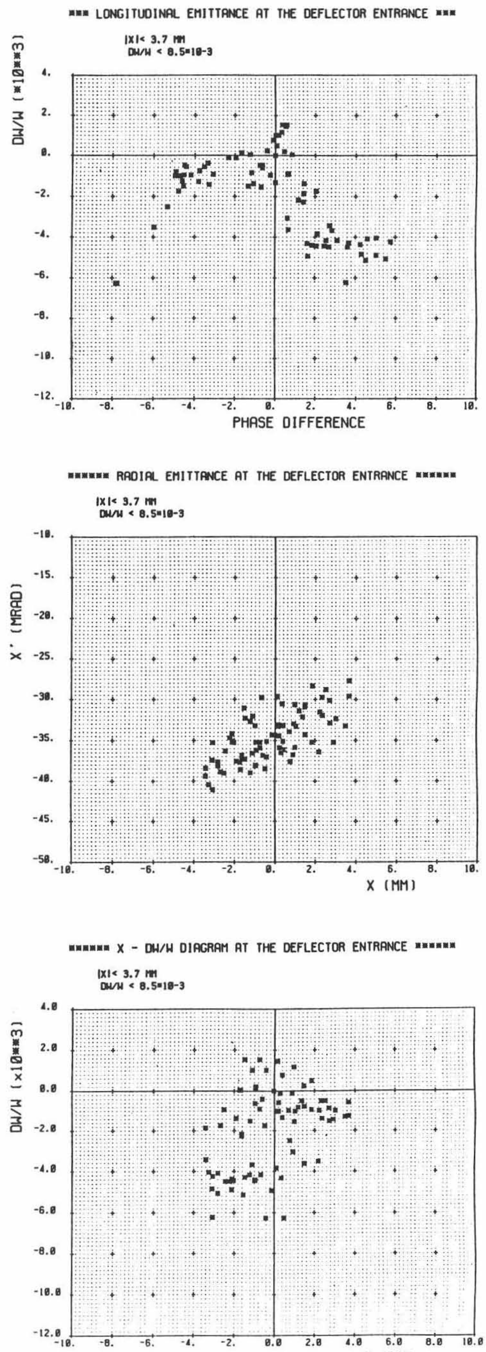

Figure 4 : Graph plots showing the beam qualities on the last turn

If we place now three values of the injected radial emittance 150 π , 115 π , 58 π mmxmrad inside this (xo, xȯ, ϕo) previous phase space, the final values of 26.3 π , 24 π and 21.6 π mmxmrad respectively, are found and the proportion of "good particles" varies from 51% to 56%.

- Concerning the (z, ż, ϕ) phase space, no problem appeared on the motion because of the posts, and a 15 to 20π mmxmrad final emittance was calculated.

6. INJECTION LINE AND ION SOURCE

The very compact (6m - long) axial injection line (10), built in 1985 for the Minimafios source is maintained. The beams required by the users concern mostly heavy ions with rather high charge states (Kr^{13+}, Xe^{18+}, Ta^{22+}, Pb^{23+}) ; therefore, their transmission will not be too much affected by space charge effects.

Since the very beginning, it appeared that the bunching-factor decreased rapidly from 6 to 1 when the source intensity raises from 10 to 100 eμA for a 1.3 keV/A O^{2+} beam.
This effect was partially corrected by reducing the buncher-to-inflector distance from 3.3 to 1.1m : source intensities up to 25 eμA allowed a gain of at least 3, so that yields of 10% (considered as standard values) could be reached.

As for the new injector CO2 which is connected to this existing line, identical yields are expected. However, an improvement was brought by a better use of the injection voltage and a sligth increase of its maximum value (23.3 kV).

As can be seen in Figure 2, the maximum voltage (RF value as well as injection value) is centered on Ar^{6+} at maximum energy, as opposed to the previous working chart (ho = 4), linked to the PIG source, where this maximum voltage was chosen for the maximum magnetic field at the maximum RF frequency ; this past situation dealing in most cases with Ar^{4+} , Kr^{8+} or Xe^{10+}, was concealing the injection voltage in the 10 to 15 kV range. This improvement, along with the longer bunches (ho = 3) allows forseeing the same 10 - 15% transmission efficiency with a bunching factor larger than 3 and with source intensities up to 50 eμA.

The hyperboloidal type inflector is comparable to the one described in (10) ; the vertical injection line is 4 cm off-axis with respect to the pole center, and the orientation of the line with respect to the yoke remains unchanged.

In order to inject comparable intensities of beams with the higher charge states required for the new stripping ratio, the Minimafios source was replaced by a CAPRICE designed by B.JACQUOT ; it is a very stable and reliable source delivering intensities consistent with the values announced by the designer. It was built at GANIL in the second half of 1988 and tested at the end of that year with the following main results :

Ar^{6+}	(support gas : O)	300 eμ A	(50π mmmrad at 15 kV)
Xe^{16+}	(" " ")	45	"
Ta^{22+}	(" " : He)	10	"
Pb^{22+}	(" " : ")	12	"

The metallic ions are produced either by a 2 to 3 mm diameter rod driven to the plasma sheath (for example in the case of tantalum) or by placing the metal in a crucible, if the melting point of the element is lower than its sublimation temperature (case of lead) or if the considered isotope is expensive (CaO to produce ^{48}Ca ions) ; the tungsten crucible is also remotely driven to the plasma sheath.

It is clear that CO2 will not be able to take advantage of the full intensities delivered by CAPRICE : the use of 300 eμA beams will only be possible when the new 100 kV insulated platform will be built and connected to CO1. In addition, the new injection line (6) which has been studied since 1986, taking into account the 6 dimensional phase space including space charge effects and the different couplings between phase planes, will have a better transmission efficiency even for small currents ; however, the number of functions to be contemplated is too large to consider modifying the CO2 injection line in the same manner.

7. FIRST RESULTS

Source, injection, acceleration and extraction tests started on March 22, successively at two magnetic field levels :
1 T with Ar^{7+} and O^{2+} beams
and 1.48 T with Xe^{18+} and O^{2+} beams

The 24 turns of the internal beam were obtained rapidly in the isochronous field given by the trim coils computed values and corroborated by the phase probes (2 degree phase excursion).

A small adjustment of the inflector allowed improving the background between successive turns, and after some tunings on the main parameters, 15 - 17% of the injected current was obtained on the 24th turn and then fully extracted (Figure. 5).

For all these beams, the ECR source current was limited to 20 eμA. The transmission in the axial injection line is 95%, the bunching factor is about 6 ; ≃ 30% of the injected beam are measured on the 2nd turn and 17% after the 14th turn (3.4 eμA).

The beam width is about 3.7 to 4 mm at half-height.

In the vertical plane, the 11 mm high beam on the 2nd turn is affected by a coherent oscillation (4 mm) off the median plane which we have not been able to reduce yet.

After these results, on April 19, the beam (O^{2+} at 1.48T) was ejected and sent into beam line L1 for some preliminary measurements with the low energy spectrometer.

They give the following results nearly all in good agreement with the computations :

- Transmission 95%
- Emittance H 20π mmxmrad
  V 44π mmxmrad
  (due to the oscillation ?)
- Energy spread ± 7.5 10^{-3} total
  ± 2 10^{-3} half-height

Tests will be carried on until June. Already now, it seems that it will be easy to obtain 3 to 6 eμA in L1, and we expect with performances both on the ECR source and in the transmission efficiency (in the axial injection line due to the CAPRICE emittance and in L1, due to the CO2 beam qualities) to be able to improve by a factor of almost 10 for heavier ions currents.

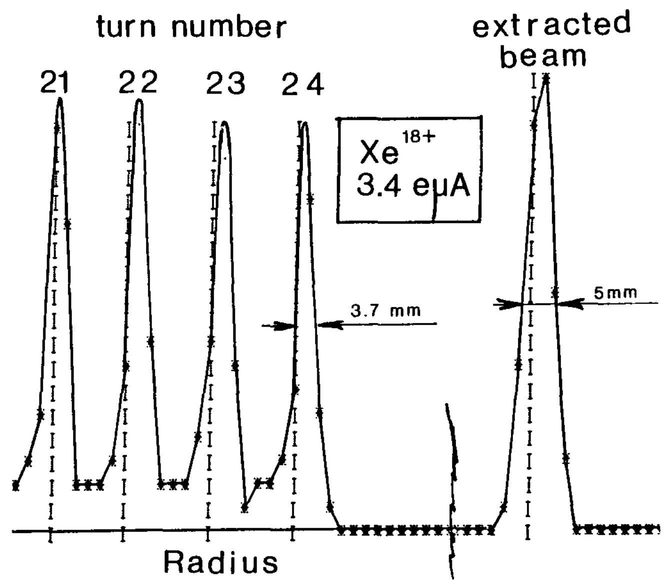

Figure 5 : Experimental results

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