Project "OAE" at GANIL a project for increasing the heavy ion energies

J. Fermé

GANIL

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GANIL, BP 5027, 14021 CAEN CEDEX, FRANCE

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GANIL is composed of three cyclotrons connected in series, with a stripper located between the last two stages (Fig.1). The general parameters have been chosen to fit the characteristics of the PIG ion source. With the advent of ECR sources, which can produce efficiently ions of higher charge state, an optimization of the system has been considered which will result in an increase of the energy range of medium and heavy ions. A few modifications of the machine are necessary and should be carefully prepared so as to minimize the duration of the shut-down planned at the beginning of 1989. Moreover, a systematic study of the axial injection of the first cyclotron has been undertaken in order to improve the intensity of the injected beam with respect to space charge.

Introduction

GANIL has been designed to accelerate beams of heavy ions produced by a PIG source in an energy range extending from 95 MeV per nucleon for Carbon to 8 MeV per nucleon for Uranium. The main parameters were frozen in 1975 on these bases. By that time new types of sources were already in development. It was found that no substantial gain in energy could be expected from the use of these sources, which were full of promise for the production of high charge state ions, because no satisfactory compromise could be made in the design of the accelerator.

Moreover, these sources were running with gaseous ions only, a situation unfavorable for a heavy ion accelerator, and the intensities were modest.

It now appears that the ECR sources can compete in intensity with the PIG source for the gaseous ions, and have recently produced beams of "solid" ions, up to Tantalum, although some progress in intensities are still necessary especially for very heavy ions.

As it will be shown, a modification of GANIL is necessary in order to take full profit of the higher charge states available with the ECR source. A new stripping ratio, namely 5, shall be substituted to the present one of 3.5, but other modifications are also necessary. The so-called "project OAE" will result in an augmentation of the energy of medium heavy ions by the factor 2 and very heavy ions by the factor 3.

The energy limits of GANIL

The energy of a charged particle accelerated with a cyclotron is given by the non-relativistic formula :

$$W = K(Q/A)^2 \qquad (1)$$

W : energy in MeV per nucleon, Q : number of charges,
A : atomic mass.

The K coefficient is a function of the values of the ejection radius and maximum magnetic field. It has been fixed to 380 for both SSC'S.

The energy of the beam produced by the first SSC of GANIL is sufficient to fully strip the light ions up to Argon. For these ions the maximum field level can be reached in the second SSC, and consequently no progress in energy can be expected without unrealistic modifications. But, for ions heavier than Argon, the stripping becomes incomplete, and this phenomenon is particularly important for very heavy ions. As far as the second SSC is concerned and for these ions there exists a potentiality of reaching higher energies, at the condition of being injected at a higher charge state.

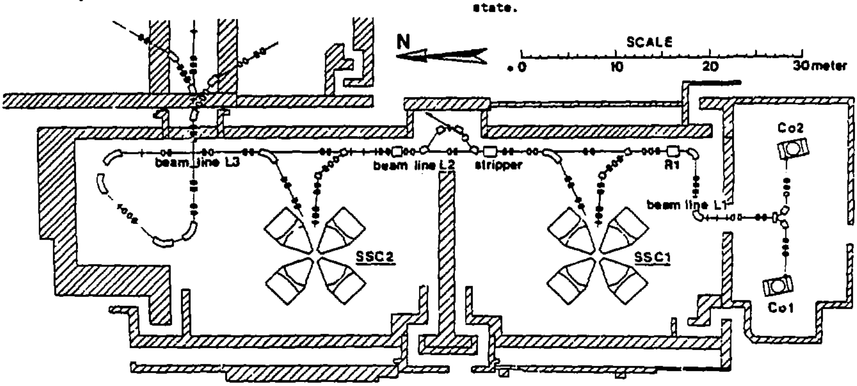


Fig.1 : General lay-out of GANIL accelerator.

Conditions for raising the energy limit of incompletely stripped ions in SSC2

For the moment, let's consider the constraints imposed exclusively by the last stage of acceleration, SSC2.

The augmentation of the energy of incompletely stripped ions depends on two conditions. Firstly, as a consequence of formula (1), the charge state of the ions must be higher. Secondly, the energy of the injected beam should be raised because the cyclotron behaves as an energy amplifier, whose gain is fixed and equal to the square of the ratio of ejection and injection speeds, or radii, in a non-relativistic approximation. More precisely, as far as SSC2 is concerned, the injection of ions of higher and higher ionisation state is possible as long as the charge state q/m can be maintained proportional to the speed v of the ions, so as to keep the value of the magnetic rigidity of the injected beam, mv/q, below the maximum bending power $B\rho$ of injection.

But, as we will see in the next paragraph, the stripping process will be a limiting factor.

Otherwise, there is no limitation due to the frequency range whose upper limit depends only on the maximum energy of light ions.

Constraint imposed by the stripping process

The average charge state $\bar{Q}$ of a stripped ion of atomic number Z can be represented with a good accuracy, by the following empirical formula :

$$\bar{Q} = Z \cdot (1 - \exp(-3.86 \cdot \sqrt{W}/Z^{.447})) \qquad (2)$$

valid for energies W above 1.3 MeV per nucleon[1].

Let's see on an example the limits imposed by the stripping process, in the case of Xenon 132.

Figure 2 shows the value of the average charge state after stripping as a function of the energy (or the speed shown on a linear scale). Two curves of constant rigidity $B\rho = mv/q$ are shown, and they are practically straight lines issued from the origin.

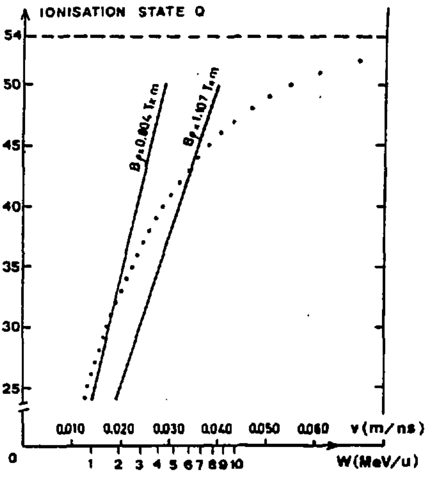


Fig.2. Most abundant charge for Xenon as a function of speed v, or energy W .

In the present state of GANIL, the line $B\rho$ = . 804 represents the maximum bending power of the injection of SSC2 (the actual limit is . 820, but the relativistic effect during acceleration should be taken into account, because the true limiting factor is the maximum bending power at the ejection radius of SSC2). The area located at the right hand side of the line $B\rho$=.804, corresponds to magnetic rigidities superior to the bending power of SSC2 at injection.

Consequently, for a given energy, the most abundant charge will always be available for the charges located on the left hand side of the line $B\rho$=. 804, which can't be trespassed. Charges 31 or 32 are the limits. The access to higher energies is only possible if one remains on the line $B\rho$ = . 804. This means that the corresponding charge will be higher that the most abundant charge.

This possibility is limited to 1 or 2 charges above the most abundant one, owing to rapid diminution of the stripping probability.

For the heaviest ions 2 or 3 charges above may be the practical limit.

How to adapt SSC2 to a higher beam rigidity at injection

On figure 2 the line $B\rho$ = 1.107 represents the new possibilities offered by an augmentation by the factor 1.4 of the rigidity of the injection of SSC2. The reason for this precise choice will be discussed later. But, for the moment, any other choice can be made.

There are two possibilities for increasing the bending power at the injection of CSS2. The most evident one is to increase the maximum magnetic field of SSC2 by the same factor 1.4. This solution seems the most logical, because it has no repercussion on the other parts of the accelerator. But the corresponding transformation of SSC2 appears unrealistic. In fact entirely new magnets with cryogenic coils would have to be designed. Strong constraints on the tuning of the magnetic field would be imposed by the fact that the iron would have to be in various states of saturation, to permit the variable energy operation.

No increase of the maximum energy for light ions could be expected, because the RF frequency is the limiting factor. The beam lines of the experimental area should follow the same augmentation of the maximum bending power.

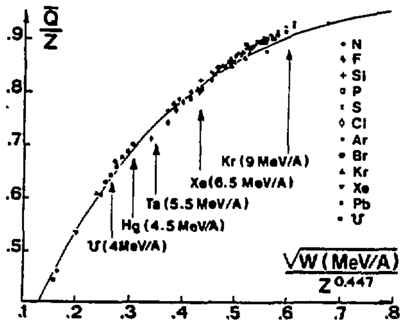


Fig.3. The solid curve is given by formula (2). Experimental data compiled by E. BARON.
The arrows locate the maximum energy at the stripper for different ions in the new configuration .

The other solution consists in an increase of the injection radius of SSC2 by the factor 1.4. But by doing so, the energy gain of SSC2 is reduced by a factor 2. To be valid, this solution implies that the energy of the injected beam be more than doubled. This is the case for the Xenon 132, whose final energy will be multiplied by approximately 3.6/2 = 1.8. In the case of light ions, the final energy will remain the same as before, 95 MeV per nucleon, but their injection energy in SSC2 must be doubled.

Figure 3 shows an experimental confirmation of the formula (2) for various ions.

New injection radius for SSC2

The modification of the injection radius of SSC2 leads to modifications of the upstream part of the accelerator. The choice of the new injection radius must be made considering the importance of the global modification and the influence of the characteristics of the ECR source on the performances.

There is a limited choice for the injection radius, which can be established after recalling the main properties of cyclotrons :

For a single cyclotron :

- The beam pulses are separated by one RF period (characteristic of cyclic accelerators).
- The number of RF periods corresponding to an orbit is an integer (as for the circular machines. The integer is called the RF harmonic number).

For two coupled cyclotrons on the same frequency :

- The speed of ions at the input of the downstream cyclotron is the same as the speed at the output of he upstream cyclotron (conservation of energy).

Consequently the ratio of the harmonic numbers of the upstream and downstream cyclotrons is the same as the ratio of the respective radii of injection and ejection, with or without the presence of a stripper in between. Moreover, if two coupled cyclotrons are designed to operate at the same field level, the optimal stripping ratio (downstream to upstream charge ratio) is identical to the ratio of the harmonic numbers.

Based on the preceding remarks, table 1 gives the exhaustive list of the possible cases, SSC2 being operated on harmonic 2 to preserve the maximum energy

Harmonic number for SSC1	Stripping ratio	Injection radius in SSC2	Energy gain for SSC2	Remarks
7	7/2=3.5	3/3.5= .857m	$(3/0.857)^2$=12.25	Present Configuration
6	6/2=3.0	3/3.0=1.000m	$(3/1.0)^2$ = 9.	- possible
5	5/2=2.5	3/2.5=1.200m	$(3/1.2)^2$ = 6.25	- possible
4	4/2=2.0	3/2.0=1.500m	$(3/1.5)^2$ = 4.	- low gain for SSC2
3	3/2=1.5	3/1.5=2.000m	$(3/2.0)^2$ = 2.25	- same remark
2	2/2=1.0	3/1.0=3.000m	= 1	- SSC1 will perform as SSC2

Table 1. Coupling SSC1 to SSC2

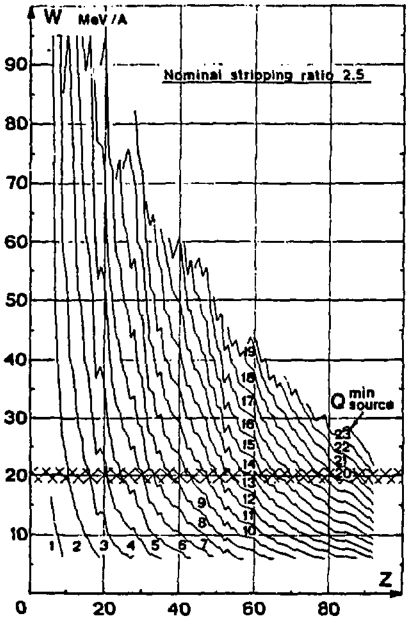


Fig.4. Energies expected at ejection of SSC2 as a function of the charge state at the source. Stripping ratio 2.5.

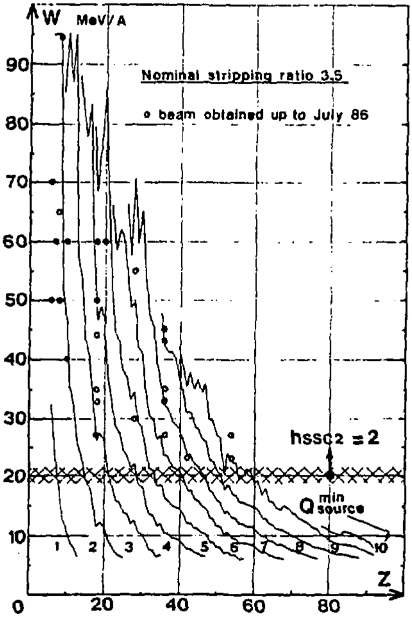


Fig.5. Energies computed (solid lines) and obtained (dots) as a function of the charge state of the PIG or ECR source. Stripping ratio 3.5.

The table must be completed by a remark of fundamental importance : the final energy being given, the charge state q/m at the ion source shall be inversely proportional to the ratio of the harmonic numbers.

Application to the case of ECR sources[2]

The performances of the ECR sources seem adapted to the cases of stripping ratios 3.0 and 2.5.

Figure 4 corresponds to a stripping ratio of 2.5. It shows the energy of the beam accelerated by SSC2 as a function of the ionisation state at the ion source, for the different elements. Each individual curve is limited to the point where the most abundant charge after stripping can no longer be used. The corresponding state of ionisation is 23 for the heaviest ions, 17 for Xenon, 13 for Krypton and 7 for Argon.

Figure 5 displays the same curves in the present case of stripping ratio 3.5. It can be seen that the energy gain in the new configuration is important for atomic numbers higher than 40.

The case corresponding to a stripping ratios of 3.0 yields intermediate results. The stripping ratio of 2.5 seems more favorable, the development of ECR sources being in constant progress.

It should be noted that the PIG source could not be used on the accelerator in the new configuration, with the exception of elements of atomic number smaller than 10.

The modifications of the accelerator

These modifications may contribute also to the choice between the two stripping ratios. The most important items are :

- the injection system in SSC2
- the adaptation of buncher R1 to a new harmonic number of SSC1
- the coupling of the injector to SSC1 in the new configuration.

These items are discussed in the last part of this paper. An important element of choice concerns the injector : with the stripping ratio of 3.0, a new injector should be made. With the stripping ratio 2.5, the magnetic yoke of the injector can be re-used.

Notwithstanding the feasibility of the various other parts of the accelerator, the transformation in the case of stripping ratio 2.5 appears notably more economical.

Beam dynamics and beam intensities

An important remark concerns the operation with the stripping ratio 2.5 : SSC1 can't operate properly on subharmonic 10, which is disadvantaged by a poor gain per turn, and consequently energies below 20 MeV per nucleon won't be available. However, SSC1 on harmonic 5 in stand alone mode may yield beams going from 13.5 MeV per nucleon for light ions, down to 3 for the heaviest ions.

The stripping ratio 3.0 imposes no restriction in the coverage of its own energy range, but the upper limit in energy being considered the most important factor for the forthcoming years, the stripping ratio 2.5 has finally been adopted.

The new beam characteristics have been theoretically investigated and appear to be comparable to the present ones. Some improvement can be expected from the reduction of the transverse emittance in the beam lines where the beam energy will be doubled.

The future beam intensities have been evaluated using the experimental data from the ECR sources[1]

For light and medium heavy ions, the intensities are equivalent. For ions heavier than Xenon, the new intensities appear to be inferior to the old ones by a factor of two for the same final energy, but much higher energies are available. To give an idea of the expected intensities for the heaviest ions, let's consider the case of Tantalum. The ECR source can produce effectively 5 electrical microamperes of charge 22+. Taking into account the beam losses in the injector and in the various parts of the accelerator, including the stripper whose efficiency is 15%, the expected beam intensity will be 40 electrical nanoamperes at 35 MeV per nucleon.

An analysis of the modifications

The modifications of the various parts of the accelerator are examined in the following paragraphs. As will be shown, the work to be done, although not very costly with respect to the resulting advantages, implies an important theoretical and technological effort.

Injector cyclotron C01

SSC1 being used on harmonic 5 instead of 7, the injector shall be modified accordingly. A solution would be to maintain the acceleration on harmonic 4 for the injector. In that case the ejection radius would be multiplied by the factor 1.4, and this means that a completely new injector should be built. But, if the harmonic 3 mode is adopted for the injector, then the extraction radius will be modified by the factor (7/5) * (3/4) = 21/20. This corresponds to a radius increase of only 23 mm. This last solution seems attractive, but necessitates a modification of the accelerating system. The present RF system is composed of two opposite dees connected in phase and driven by a single resonator. These dees will be replaced by a single dee of 180° angle. The number of accelerating gaps being reduced from 4 to 2, the acceleration process will be accomplished in 34 turns instead of 14, even with the use of higher charge states. Single turn extraction can still be expected. But it should be remembered that the injector is a flat pole cyclotron, relying on the radial field gradient for axial focusing. In the new configuration, this would cause an unacceptable shift in phase of the accelerated beam. Consequently new poles will be provided, with spiralled sectors and an isochronous field law. The thickness of the sectors must be limited because the same magnet yoke will be used, and the total magnetic flux should remain within reasonable limits. Another consequence of the introduction of sectors is a further increase of the pole diameter. New main coils will be necessary.

Other modifications concern mainly the vacuum tank and the dee stem.

It shall be noted that with a 180° dee the axial electrical focusing is more dependant on the phase of the particle than in the case of a two-dee system having a convenient angle.

The transformation of injector C01 will also include the construction of an axial injection having better performances than the one installed on injector C02. The main limiting factor is the space charge effect[3] In the new configuration, the injection voltage will stay between 50 and 100 kV. Results obtained from computation show that 20% of the injected beam can be accelerated, for source intensities lower than 200 electrical microamperes.

Beam line L1

The maximum magnetic rigidity of the beam will be the same. Only the buncher R1 is concerned. The electrode provides two gaps separated by a distance of 96 m which corresponds approximatively to a transit time of 3 half periods in the high energy mode. This distance has been initially designed to fit the various modes of operation of the Ganil complex. In the new configuration, the distance between two successive beam pulses will be increased by the factor 7/5 = 1.4. The electrode should be modified accordingly. The distance between the two gaps will be reduced to .51 m which corresponds to a transit time of half a period (Fig.6). The general shape of the buncher will remain the same. The frequency range should not change, and this was confirmed by a tri-dimensional computation made by the laboratory of the cyclotron of Milan.

It can be shown by a non-relativistic formula that the RF voltage of the buncher shall be increased by the square of 1.4. The voltage range will extend from 42 to 91 kV. the present RF amplifier delivers enough power to cover this voltage range, but it will be fitted with an adjustable impedance matching circuit in order to improve the overall efficiency.

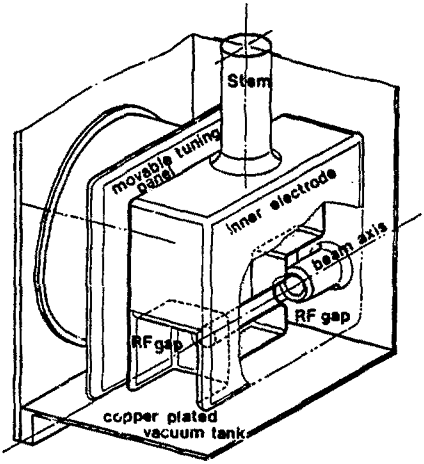


Fig.6. A view of buncher R1 with the modified RF gaps.

SSC1

No physical changes are necessary. The RF harmonic mode will be 5 instead of 7 for the present high energy mode. But at a given RF frequency, and for a given voltage, the number of accelerated orbits will be increased by 25%. This is the result of the combined effect of a higher charge state and a better peak phase angle.

Practically, this corresponds to 92 orbits for medium heavy ions, and 128 for the heaviest ions, the difference being caused by the necessity to lower the voltage at the lowest frequencies in order to avoid the risk of flashes in the tuning panels' gaps. The usual number of orbits is presently 68. To confirm the behaviour of SSC1 in the future configuration, beams have been accelerated and extracted for the two cases cited above. The beam emittance was limited prior to injection to 40π mm.mrad horizontally and vertically, and the beam energy dispersion to $\pm 5.10^{-3}$. The total transparency of SSC1 was 95% in the case of 92 orbits, and 90% for 128 orbits. The beam matching at injection was not optimal and better results should be obtained with more experience.

Beam line L2

There is no change in the part of line preceding the stripper (Fig.1). The magnetic rigidity downstream of the stripper is multiplied, on the average, by the factor 1.4. The two magnetic dipoles in the injection section will have to be replaced. The quadrupoles and their power supplies have a sufficient margin of operation for the new configuration. A small angular displacement of the last part of the beam line will help obtain the correct beam alignment in the injection valley, without imposing too much stress on the horizontal steering magnet located at the entrance of the vacuum tank. For there is also a change of the beam path in the injection valley, where a beam of higher rigidity will be less influenced by the fringe field of the main magnets, the result being an augmentation of the deviation of the steerer magnet.

The stripper itself is the object of particular attention. The Carbon foils must be thicker, from 80 to 300 micrograms per square centimeter. The corresponding average loss of energy is 2 per cent approximately. To compensate this loss, the voltage bias to be applied on the stripper would reach unrealistic values, around 800kV. To maintain the bias in the range of ± 150kV it has been decided to decrease the nominal injection radius in SSC2 to cover all possible cases. Fine adaptation for each beam will be accomplished by a small displacement of the electrostatic septum in SSC2. As in the present situation, the bias will be used only for keeping the energy constant at the entrance of SSC2, during the life time of the stripping foil, by the means of an electronic loop.

Injection system for SSC2

Injection by stripping had been considered at first, but proved to be too difficult to realize and to use reliably. The stripper should be located inside of a sector, with no practical access. The change of a set of foils would necessitate breaking the vacuum of SSC2. Moreover, the external beam path doesn't seem to fit well into the present geometry of the beam line.

A conventional injection system has been adopted, keeping in mind that the new mean injection radius is 1.2 m instead of .857 (Fig.7). The new equipments should be compatible with the existing geometry of the central region. The access panels to the vacuum tank in particular are a limiting factor for the size of these equipments, and the available room in the center can't be increased. Consequently, stronger magnetic fields will be necessary to bend the beam.

The beam dynamics of the injection has been investigated by numerical computation, using a code which makes a continuous integration of the equations of motion, even in the presence of a static or time dependant electrical field. The main magnetic field map is derived from analytical expressions and is in good agreement with the measurements already made on SSC's. The different injection equipments and the dee gaps are also represented by analytical field laws which have been carefully checked for accuracy. In particular, the field law produced between two iron bars located in the magnet gaps has been made to fit as well as possible the physical properties observed on an actual model, even in the region of fringe fields of the main magnet. The code integrates also the equations of the relative motion. The results are presented under the form of a 4 x 4 transfer matrix for the horizontal motion, and by a 2 x 2 matrix for the vertical motion. These matrices are used for the

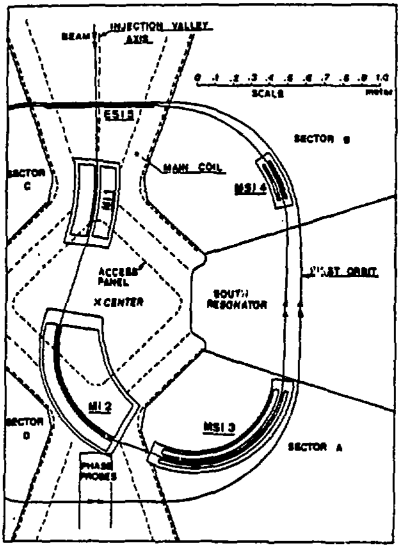
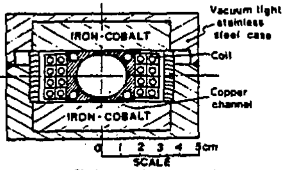


Fig.7. The new injection system will be similar to the present one. Strong fields are needed for magnet M12 and inductive septum MS13.



The gap of the sector magnet is 10cm.

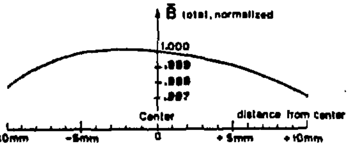


Fig.8. Magnetic septum MS13. Top : cross-section Bottom : magnetic field averaged over the length of the septum. The curve corresponds to an average field of 2.17T on axis. The contribution of iron bars is 6.40T. Beam width is 6mm.

computation of the beam matching, and for an easy verification of the beam enveloppe.

The behaviour of the beam is similar in the present and the future configurations. But the turn spacing downstream of the electrostatic septum is reduced to 5 mm, and precautions have to be taken to avoid beam losses on the septum because the width of the injected beam will be of the same magnitude. The turn separation can be enhanced if some precession is introduced, and the validity of this method has already been established on the accelerator.

A possibility of using harmonic 3 instead of harmonic 2 in the case of the heaviest ions has been considered. The turn spacing at injection will reach 15 mm instead of 6 mm. But the phase acceptance is reduced by 2/3. This suggestion could be verified in the present configuration, but it necessitates some important changes in the RF and phase diagnostics control system which can't be undertaken for the moment.

The magnetic components of the injection system had to be redesigned (see Fig.7). Magnet M12 must be able to reach 2.15 Tesla. A new coil has been studied for this "C" shaped window frame magnet. But the most important work has been done for the magnetic septum MS13. This septum is composed of two thick pieces of an iron-cobalt alloy placed in the gap of sector "A". A coil has been provided for the compensation of the non-linearity of the induction produced by the plates when the inductive field of the sector is varied, (Fig.8).

The maximum field value averaged over the total lenght of MS13 must be 2.18T. As both ends of the septum are located in the fringe field of the sector edges, the field in the middle part of the septum must be much higher than the mean value. Extensive magnetic measurements made on a scale one model of the septum have shown that the necessary peak value of the field of 2.33T can be reached. In the transverse dimensions, the lack of homogeneity amounts to $1.5\ 10^{-4}$ over the total expected width of the beam in that extreme case.

<u>Compensation of field perturbations in SSC2</u>

The most important field perturbations in the acceleration region of SSC2 are the consequence of the magnetic flux of the main magnets derived by M12 and MS13.

<u>Magnet M12.</u> For M12, the level of the field is lowered mostly in the valley located between sectors D and A. In the present state, the magnetic perturbation in the valley is compensated by an adequate shimming of the adjacent pole edges. These shims are not easy of access. However they extend only to the radius of the future first orbits. A new shimming is not thought to be necessary because the new magnet will be almost in the same position, *and is only slightly heavier. In* the future acceleration area, the effect of M12 will be partially compensated by the use of independent current setting of the trimcoils of sector A.

<u>Septum MS13</u>. For MS13, the perturbation is very strong in the vicinity of the iron pieces and extends up to the maximum radius of pole A, where its value is still -25 Gauss at maximum induction. The perturbations are not proportional to the main field, they are relatively more important at high field level. The compensation of the perturbations will be realized in three different ways. In the vicinity of MS13 a small shim made of 2 parallel sheets of iron will maintain the field gradient within the

controllable value of 7 Gauss per cm. For the area comprised between MS13 and the mean radius 2 m the field gradient will be compensated by the trim coils of sector A. These coils are presently connected in series with their homologues in the other 3 sectors. They will have to be separately connected to independent power supplies. Finally, the general field level will be adjusted with the existing special coil which is normally used for small corrections of the general field on each sector.

The magnetic measurements made on sector C of SSC2 during the last yearly shutdown of the accelerator have been of great value. An exact model of the iron pieces of MS13 was installed in this sector, which is free of any equipment. Although sector C has no edge shim on one side like sector A, the measurements could still give a precise information on the field perturbations.

The measurements made previously on the 1/4 scale model of a sector, although rich in information, proved to be insufficiently accurate. The shape of this model is in conformity with the actual magnets, but, probably, the permeability of the iron is not exactly the same.

Septum MS14 : for the magnetic septum MS14, the local perturbations can be compensated with a thin shim. The weight of iron used for this septum is only twenty times smaller than for MS13.

Magnet M11 : magnet M11 is about 5 times lighter than M12 and is located farther than M12 from the acceleration area. It must be noted than M11 and M12 being installed in opposite valleys, the perturbation of M11 combined with part of the perturbation of M12 can be considered as a harmonic 2 perturbation, far less important for the beam dynamics than a harmonic one perturbation.

The physics motivations

After three years of operation, nuclear physics studies performed at GANIL are now in the final stage of the exploratory phase. In the forthcoming years the research activity will undoubtely contribute to reveal the peculiarities and complexity of the various reaction mechanisms observed at these energies.

The progress made with accelerators of increasing energy is a key factor for the evolution of nuclear physics. For a given combination of target and projectile, the relative speed of the two nuclei is the most important parameter of the collision. The development of powerful accelerators has given the possibility to investigate more and more inelastic reaction mechanisms.

GANIL, however, was based on a different conceptual approach. Even before its design, relativistic heavy ion beams were available and it had been shown that, at these energies, the reaction mechanisms are depending on a collision dynamics largely dominated by the nucleon-nucleon interaction whereas below 10 MeV per nucleon the collective phenomena, originating in the nuclear mean field, were preponderant.

The originality of GANIL is its situation, between these two extreme behaviours. The idea relies upon the existence of a transitional regime around 35 MeV per nucleon, the study of which could shed more light on phenomena of great interest. In this transition domain the nuclear matter is out of equilibrium : hence a complex physical aspect has to be investigated.

The method used for the study of this domain has been a global approach to try to find out the limits of the transition as a first step. Does a characteristic relative speed or energy exist ? Are these values depending on the projectile-target combination, are they simultaneously implied in the various collision mechanisms ?

For example, is the transition between the deep inelastic processes and the fragmentation associated to a simultaneous vanishing of the fusion process ?

In order to clarify these questions, nuclear physicists working at GANIL have extensively used the various beams available, owing to the constant progress made in the development of the acceleration of new kinds of ion, and to the flexibility afforded by the energy variation. These two parameters, the variety of ions and energies make GANIL an outstanding tool well adapted to the projected physics program. But, the energy of the beams of ions heavier than Xenon obtained with a PIG source has been found to be not high enough for a thorough study of this part of the physics domain.

"Project OAE" appears to be a natural extension of the present possibilities and gains from the development in the ion source domain. This modification will allow an extension of the GANIL characteristics, mainly in the heavier-ion range, and this will satisfy, almost completely, the needs for the coverage of the transition domain.

Cost and planning

The cost of the modification, not including the installation of axial injection on the injector cyclotron has been estimated to amount to 10 million FF (equivalent to 1.4 million US dollars). The accelerator will be shut down during the first semester of 1989. During this period the new equipments will be installed and final magnetic measurements made on SSC2. The time devoted to these measurements is of three months. The old bench will be reassembled and field maps will be made on the four sectors. Following these measurements and during the final phase of tests for the machine, the data base will be modified for the new parameters, so as to permit resumption of the acceleration of the beam in the best conditions of readiness.

At the same time, a modification of beam line L2 will be made to provide an extra beam line for atomic physics, using the particles of otherwise useless charge state produced at the stripper[5]

Conclusion

The optimization of GANIL to the high charge state ions produced by the ECR sources will be undertaken at the price of a modification of moderate importance.

This modification precludes the further use of PIG sources but recent developments have given satisfactory results for the production of solid heavy ions by ECR sources.

The maximum energies will remain the same for light ions, but will be increased for heavy ions by a factor of approximately two.

The energy range below 20 MeV per nucleon will be only partially covered by the first SSC in stand alone mode.

Beam intensities are expected to be sustantially improved by a new design of the injector cyclotron and its axial injection.

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