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Upgrading the GANIL accelerators to higher intensities : the THI project

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Abstract

Presently, secondary beams are produced in our facility by the projectile fragmentation method with the high energy ion beams accelerated by the GANIL cyclotrons. In addition, we plan to generate radioactive atoms in thick targets by the ISOL technique, with a subsequent ionisation in an ECR source and acceleration through an additional, specially dedicated cyclotron (SPIRAL project). In order to ease both the operation of this future machine and the statistics of the present experiments, plans are made to boost the beam intensities by a factor of the order of 15, at least for light ions ranging from C to Ar.

This paper describes the numerous aspects of this upgrading, called the THI (Transport des Hautes Intensités) project, including the thermal and radiation problems raised by the 95 MeV/nucleon, several kW heavy ion beams.

1. INTRODUCTION

The reasons for going to higher intensities are quite obvious and strongly linked to the future radioactive beam facility (SPIRAL) described elsewhere[1, 2].

The first question is : by what amount can we increase these intensities ? Concentrating only on light ions up to Ar, the present situation is the following : until now, the beam power has been limited to a maximum value of 400 watts, mostly to prevent the machine components from thermal or activation effects. This power corresponds to 2×10^{12} pps for C ions or 7×10^{11} pps for Ar ions at 95 MeV/nucleon.

The goal of the THI project is to increase these figures to 2×10^{13} pps for C up to Ne ions, and to about 1×10^{13} pps for Ar ; this can be achieved as follows (see figure 1):

1) the combination of the recently installed 14 GHz ECR source with an injection stage at 100 kV and the modified injector C01[3] already provides higher intensities and a better transmission than injector number 2 (C02 : 10 GHz ECR and 20 kV injection voltage).

2) the overall transmission of the whole machine (cyclotrons and transport lines) must be improved, especially through refined tuning procedures ; this will also bring a benefit for the very heavy ion beams, which are not considered here. A special mention must be made of a rebuncher (R2) to be installed between the two separated sector cyclotrons (SSC1 and SSC2), mostly designed to obtain a ≅ 100% extraction efficiency for SSC2.

The major consequence of this operation is that a series of actions has to be undertaken in order to upgrade the equipment and to protect them against thermal and radiation hazards.

2. THE BASICS OF THE UPGRADING PROGRAM

The most important initial action consisted in checking if the injector can provide the expected intensities within the required emittances. We recently achieved the acceleration of an $_{36}$Ar beam with the following performances:

- a 3.4×10^{13} pps, 60×60 π mm.mrad beam was transmitted through injector C01 with a 64% transmission efficiency
- a pulsed, 1.05×10^{13} equivalent beam with a 30x30 π mm.mrad emittance was accelerated through SSC1 with a transmission efficiency larger than 96%.

Progresses have still to be made in the transmission of transfer line L1 (presently of the order of 65%) ; in the fall of this year, we will try to accelerate through SSC2, in pulsed conditions, the intensity corresponding to the final expected figure of 1×10^{13} pps.

Next, the different topics we have to deal with can be listed as follows :

- the methods of tuning and controlling the beam must be refined and strengthened.
- beam losses must be detected and minimized .
- some activated components of the machine should be safely removable if needed.
- a new buncher is being built between SSC1 and SSC2.
- the stripper foil lifetime has to be improved.

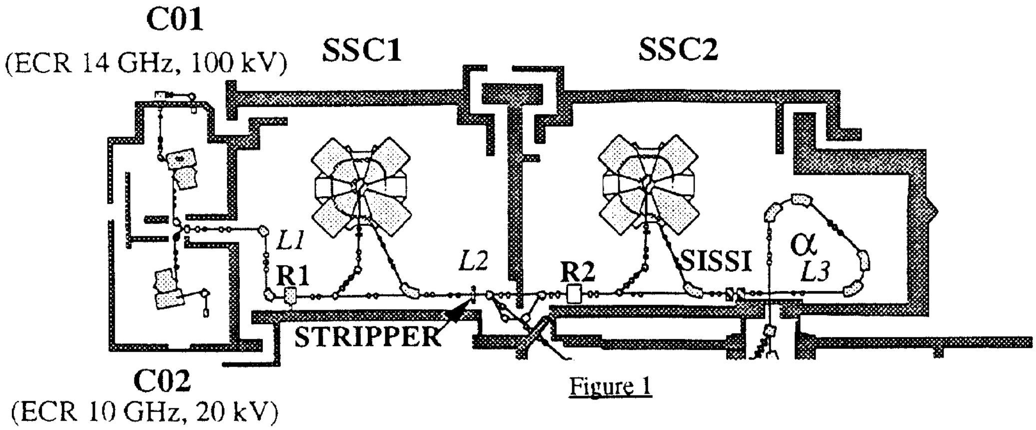

Figure 1

3. BEAM TUNING AND CONTROL : A DIFFERENT PHILOSOPHY

As opposed to the present situation where possible beam losses are considered to be harmless, provided the required output intensity is attained, the attitude must be switched to tuning the accelerators by minimizing these losses. For this purpose, it is planned to install two classes of sensors :

a) sensors for tuning and controlling the beam, which have to be non-interceptive and broad-band in order to accept both weak and high intensities.

- Some are already used in the machine, like ***current transformers*** (instead of Faraday cups) ; however, these elements are not presently sufficiently accurate and stable to allow both precise intensity optimisation and measurements of small beam losses : improvements are still necessary.

- Others will have to progressively replace the multiwire beam profile monitors and the interceptive phase probes. As a matter of fact, the $20\ \mu m$ diameter wires are rapidly destroyed by fusion or sputtering, thus requiring an intensity reduction, sometimes as low as 3×10^{10} p.p.s. ; such low currents make the tuning very uneasy. We plan to use sensors ***based on the ionization of the residual gas*** ; however, these diagnostics, developed at GANIL[4], cannot operate with low energy beams, due to the unavoidable presence of a transverse electric field required for collecting the ionised ions on micro channel plates. Therefore, their use will be restricted to the intermediate energy section L2 between the two SSC's and the high energy section L3 (see figure 1). As for the lower energy section L1, ***spiral scanners*** will be installed.

Through data processing, these sensors will give access to several parameters : beam center of gravity and transverse dimensions, etc..., which can be injected in automatic alignment and focusing processes.

b) dedicated sensors for detection of beam losses

In the course of ***tuning***, it is desirable to have sensors that generate a signal proportional to the loss which can therefore be minimized wherever possible. During the ***high intensity operation***, these same elements should work on a different mode consisting in delivering a fast response if the loss overshoots a given threshold.

We are developing a module with a microprocessor associated to each diagnostic, which will deliver either a signal within a few milliseconds, or the logarithmic value of the detected current, therefore allowing to detect very small intensities.

Inside the two SSCs, these sensors are already existing but just used up to now for the purpose of tuning : they consist of insulated sets of 4-sector electrodes or of diaphragms, located in front of each injection or extraction element ; they collect the fraction of the electrical current which could be lost at each of these places.

As for the beam transfer lines, nothing similar is existing for the present time ; we are investigating the possibility of using ionization chambers, like the model used at PSI, Villigen : these air-filled, simple chambers would be distributed just outside the vacuum chambers, at strategic locations. However, the problem is more complicated than at PSI, because the variety of ion species and energies makes the production of γ rays different in each case.

In addition, a ***supervision of the supplies*** governing any bending of the beam is planned. Two parameters : voltage and current for the current supplies, and two independently measured values of the voltage for the voltage supplies, will be monitored so as to check the constancy of the assigned value within a predetermined tolerance.

Finally, the ***temperature of the cooling water*** of some "sensitive" components like internal injection and extraction dipoles or deflectors, will be supervised.

4. DEALING WITH BEAM LOSSES

The previous paragraph was dealing with what could be called "active" protection : after a correct tuning, any failure is followed by an action on the beam intensity or at least by a warning. In parallel with this, other actions can be undertaken which minimize the consequences of beam losses.

4.1. Preventing thermal accidents.

Due to the short range of heavy ions in metals (about 1.5 mm for ^{36}Ar in Fe at 95 MeV/n), a beam being accidentally stopped by an uncooled element causes a very sharp temperature rise ; in the above example, the density of power deposited in the material may reach several hundreds of kW/cm^3, especially in the Bragg peak.

In the medium and high energy sections of the beam transport system, some dipole vacuum chambers will be internally shielded by carbon or tantalum sheets, in order to prevent the walls from melting and from accumulating too much induced activity.

The cooling of some probes and Faraday cups will be improved, although the use of most of these elements will have to be avoided during the high intensity operation.

There is a very useful radial probe in front of the electrostatic deflector entrance in SSC2, which precisely investigates the last turns and allows optimizing the extraction efficiency : it is not decided yet if this probe has to be modified by making it faster, if not using a thin carbon wire. Finally, the electrostatic deflector of the injector cyclotron has also to be upgraded and adapted to the new situation.

4.2. Radiation and safety problems.

As for the radiation and safety problems, they only concern the high energy section L3 : upstream of the injection into SSC2, the beam energy is at most 13 MeV/nucleon, which does not raise any new radiation or activation problems. For L3 :

- we have now sufficient knowledge about the neutron spectra produced by heavy ion impact to allow a good prediction on where and by how much the concrete shielding should be strengthened.
- however, an important amount of work has to be prepared to safely remove and to replace a few components that could be highly activated (beam stops, defining slits or Faraday cups) , in case their eventual failure would paralyze the accelerator.
- a series of experiments is going on with the aim of accumulating data on activation of various materials (C, Cu, stainless steel, etc...) by the high energy beams and by the secondary particles generated in collisions. Some preliminary results are already available[5].

5. THE ADDITIONAL REBUNCHER

This element is mostly designed to get a 100% transmission efficiency of SSC2. The goal is to reduce the radial dimension Δr of the internal beam at extraction to less than half the turn separation ; writing up the expression of Δr in terms of the energy spread ΔW/W and phase width Δφ at injection, (here R is the average radius at extraction and G is the cyclotron energy gain) :

$$\Delta r^2 \approx \Delta r_{inj}^2 + \frac{R^2}{4}\left[\left(\frac{\Delta W}{W}\right)_{inj}^2 \frac{1}{G^2} + \left(\frac{\Delta\varphi}{2}\right)_{inj}^4\right]$$

clearly shows the advantage of reducing $\Delta\varphi_{inj}$.

Due to the already high ion velocity at extraction of SSC1, 32 kW are required to provide the 240 kV peak voltage, and the frequency must be variable from 27 to 54 MHz (fourth harmonic of the frequency of the cyclotron cavities).

6. THE STRIPPER

A series of measurements made on carbon foil lifetimes led to the conclusion that under a 10^{13} p.p.s. argon beam, a foil, standing still in the beam, would last about 2.5 hours on the average ; then, a smooth operation of the machine becomes difficult, since from one target to the next, the beam has to be slightly tuned again due to the thickening of the carbon layer as the ion bombardment goes on.

Several solutions were envisioned to improve this situation:

- a ***gas (or rather jet) stripper*** must be rejected since the required equilibrium thickness would correspond to about 10^{18} atoms/cm^2, which is probably very difficult to get due to the formation of droplets.

-a stripper ***moving in the beam*** would in principle make a better use of the total area of the foil and therefore would last longer : in the present situation, the beam cross section is about 25 mm^2, as compared to 300 mm^2 for the whole foil. We already checked that, in the course of the sweeping, the lack of homogeneity of each foil does not change the mean instantaneous energy of the beam by any sensible amount.

We still have to demonstrate that, with high intensity beams, no thermal stresses develop in the slowly moving foil which could tear it up . If this test is successful, we will have to give an oscillatory motion to the present stripper, which consists of a mechanism containing 50 foils, polarised at several tenths of kilovolts.

- an additional possible solution is to relax the ideal optical situation, where the angular straggling effect is minimized by getting an upright emittance figure in both transverse planes with as small a beam cross section as possible. Since the future high intensities are mostly related to light ion species for which this effect is not too drastic, it is worth looking for a compromise between the emittance growth due to a larger waist and tolerable losses in the injection system of SSC2.

7. TIME SCHEDULE AND CONCLUSIONS

The whole set of modifications is planned to be finished by the beginning of 1996 ; the THI project must be accomplished without any modification of the yearly schedule of the machine, which means that all installations must take place during the regular maintenance shutdowns.

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