THE GANIL INJECTOR DESIGN

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Introduction

The GANIL injector is a small flat pole tip cyclotron which has to be operated on high harmonic numbers (h = 4 and 8).

Preliminary orbit computations(1) made with a uniform electric field in the gaps for the radial motion and a thin lens approximation for the vertical motion, had shown that the beam qualities required for injecting into SSC 1 could be obtained from such a cyclotron.

In order to get an evaluation of the intensity limitation due to the injector acceptance and of space charge effects, it was decided to modify the CERN model of the SC central region into a fixed-frequency (8 MHz) model of our injector, excluding the extraction system, and to perform a series of measurements on the 5 first revolutions of an N^{3+} beam (h = 4) and an Ar^{3+} (h = 8). At the same time, more accurate computations were made using potential maps obtained with an electrolytic tank.

The results of the measurements, in very good agreement with the calculations, allowed us :

(i) to guarantee, for the injection into SSC1, a beam with a 50 π mm.mrad maximum emittance in both planes, a 15° phase width and a 1 % energy spread, for a 2.10^{13} p.p.s. intensity;

(ii) to establish the possibility of acceleration on harmonic number 8, if the source-to-puller distance were reduced to 3 – 4 mm, which imposes a dee voltage limitation of about 60 kV and thus a larger number of turns, and if "posts" were placed on all the gaps.

The next step, which started in 1977, was the proper study of the injector (magnet, correcting coils, RF system, extraction, ion source, etc...) which is presented here.

Ultimate calculations on central region geometries have still to be performed in order to fit the exact extraction radius which value is imposed by the injection radius of SSC 1, and also to accurately determine the defining slit locations which should be able to reduce the phase width of the bunches down to 6°.

The main injector parameters are presented in table 1. It is to be mentioned that, in order to fit the evolution of the GANIL project (increase of the SSC injection radii and reduction to 3.5 of the stripping ratio), the injector extraction radius had to be increased from 0.375 m to 0.465 m and the extraction system has to be sophisticated as will be explained at paragraph 4.

Table 1. Main characteristics

Frequency range (MHz)	6.5 - 14
Harmonic numbers	4-8 and 1-2 (solo mode)
Extraction radius (m)	0.465 and 0.43 "
Maximum magnetic field (T)	1.671 and 1.9 "
Maximum energy (MeV/nucleon)	0.55 and 3.5 "
Dee angle (degree)	60
Internal dee aperture (mm)	50
Dee-to-ground distance (mm)	45
Maximum dee voltage (kV)	90
RF power (kW)	60
Pole diameter (m)	1.2
Magnetic gap (m)	0.21
Main coil power (kW)	265
Trim coil power (kW)	~50
Number of trim coils	6

1. General design

Figures 1 and 2 show the general configuration of the injector.

The machine was designed for easy access to the central region geometries, in order to permit rapid changes when going from a given harmonic number to another. In view of this, the RF system is a unit which can be disconnected as a whole from the vacuum chamber, and then moved backwards.

As will be explained with more details at paragraph 3, operation with even harmonic numbers (2, 4, 8) will be made with a set of two 60° dees connected at the center, while a single 180° dee will do with h = 1. Also, since in such a small machine, the dees are very small and their shape almost entirely affected by the central region geometries, it appeared that the simplest design was to have one dee for each harmonic mode ; each dee is to be disconnected at the ends of the fork.

As a consequence of this procedure, the required pumping speed has to be high: after each change, a $3 \cdot 10^{-6}$ torr pressure should be obtained within 1 hour.

2. Magnet

The beam energy is in all cases low enough to allow a vertical focusing given only by the radial field gradient of a flat pole tip magnet.

A set of 6 pairs of circular coils is able to correct the field gradient in order to obtain a ν_z value of about 0.1.

Field corrections are reduced with the help of a Rose shim, machined in the pole and calculated with the program POISSON.

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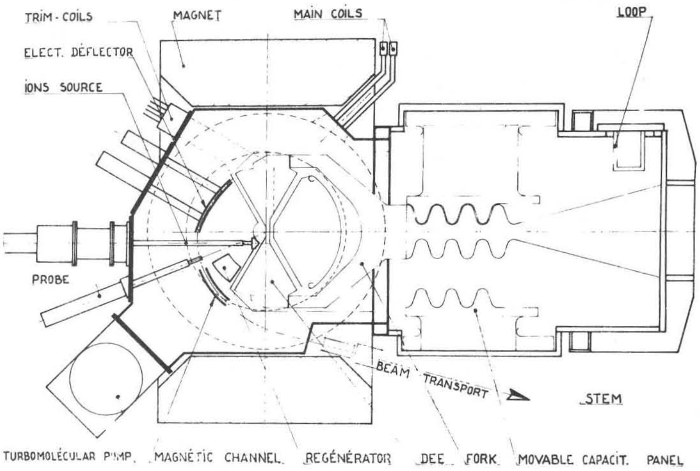

Figure 1. Horizontal section.

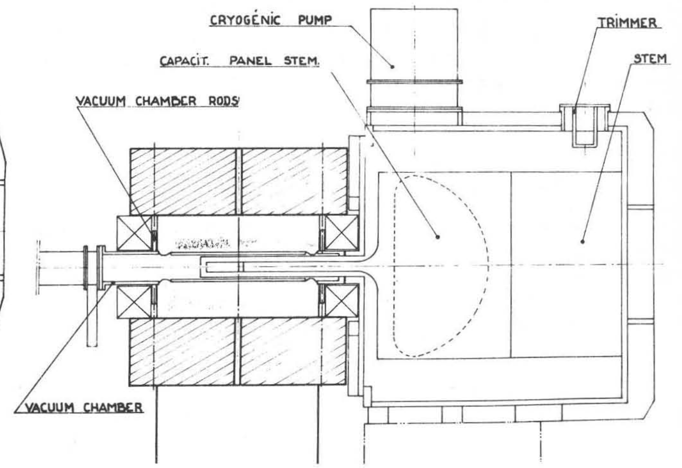

Figure 2. Vertical section.

Figure 3 shows the pole profile and the radial distribution of the coils, along with the field obtained with and without correction.

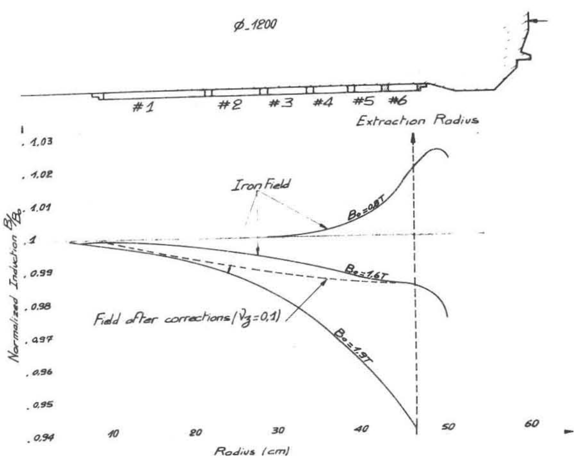

Figure 3. Magnetic field and pole profile.

The trim coils are made of a 7 x 6 mm conductor with a 4 mm diameter hole ; they are placed inside a vacuum-tight box, 1.5 mm thick. Braces between adjacent coils provide the required stiffness of the box. No definite choice concerning brazing (as at Oak Ridge) or soldering has yet been made. The 10 mm high box will be screwed to the pole piece.

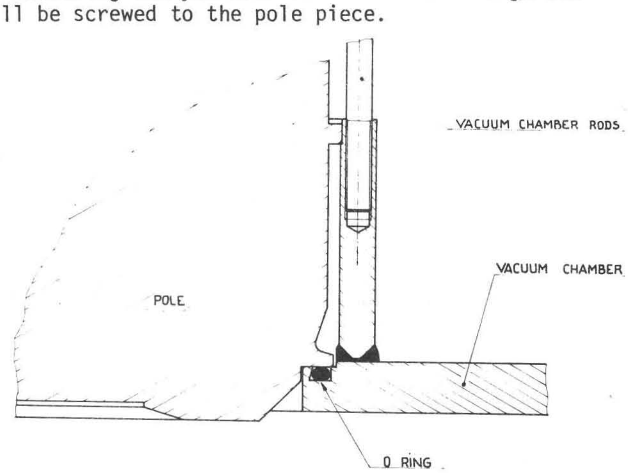

Figure 4. The vacuum chamber hooking system.

The pole piece is machined to receive the vacuum seal of the vacuum chamber : since the coil-to-coil distance was minimized in order to obtain a good magnet efficiency at 1.9 tesla (70 %) and to reduce the field fall-off, no room is available on the pole piece to hold the chamber. The chamber is therefore hooked on the yoke by rods, as shown on figure 4.

3. Resonator

3.1 RF system

In order not to damage the energy spread and phase width of the beam, it was necessary for the extracted beam to escape the dee stem : a twin-line solution, allowing modes 0 and π, could have been a good solution.

On the other hand, since the dee capacitance was low (2 x 60 pF), it is better to cover the whole frequency range with movable panels rather than with a movable short-circuit which would have required a line 6 m long.

Unfortuanately, using both twin-line and movable panels would have required too large a tank and make the beam extraction difficult. Also, the identical displacement of 4 movable panels would have been a serious problem, as would the mechanical structure of the system.

A safer solution was then choosen, consisting of a coaxial line with two 60° dees connected at the center, and only two movable panels ; for operation on harmonic number 1, these dees are replaced by a single 180° dee (this mode will not frequently be used).

The panels (1 m long, 1.4 m high) are located as close as possible to the dees along the line in order to obtain the maximum efficiency. Since their area would be two small to allow the required frequency range to be covered, it was increased thanks to a wavy structure, similar to that of the SSC panels. The shape of the waves (slope 20°, 150 mm deep, radii 35 and 45 mm) increases the area by a factor 1.7.

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The program REGAN used to calculate the main cavities of the SSC was modified to fit this kind of resonator, and measurements were made on a 1/3 scale model.

The computations allowed optimization of the wave structure, the stem length, and the characteristic impedance of the line for the required frequency range. At the lowest frequency (6.4 MHz), the distance between panels was found to be 8 mm ; in that case, the maximum dee voltage will be 45 kV, so there will be no sparking problem between the panels.

The mechanical range of the panels is 20 cm ; the total RF power dissipated in the cavity is 52 kW and the current reaches 7 700 A in the stem foot at 6 MHz.

A special effort was spent to reduce the current density in the panel contacts. The computations have shown the importance of the shape of the stem cross-section on which the contacts are sliding : values may range from 36 A/cm for a classical cylindrical shape, to 26 A/cm for a "hippodrome" shape, and to 22 A/cm for a "kidney-bean" shape. We are studying a finger stock contact which provides both current density and mechanical tolerances.

3.2 Mechanical design

A rapid clamping between the vacuum chamber and the resonator tank is necessary ; in order to get the panels closer to the dees, the flange is brought between the main coils and is clamped by screw-hooks on the two vertical sides only (figure 5). As a consequence, the two horizontal sides would be warped ; calculations were made to get the best choice of the different parameters (gasket, machining, hook size) in order to make the connexion vacuum tight over the whole width. In addition the front door is coffered in the free space between the yoke and the tank.

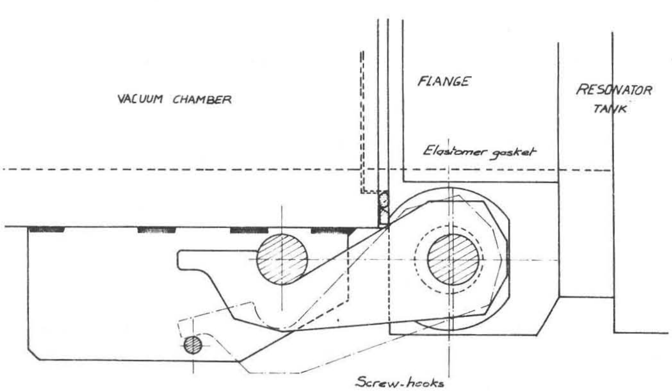

Figure 5. The rapid clamping between the vacuum chamber and the resonator tank.

The stiffness of the tank was also investigated concerning the windows of the movable panels and the rear parts : the sides were filleted in order to reduce the sag due to the pressure difference down to a value of 0.15 mm.

The components of the internal RF line are the following :

1) a stainless steel beam, attached on the rear side of the tank, and covered with both a shell constituting the stem and 2 half-wave capacitance panels;

2) a "fork", attached to the front of the beam, and also covered by shells;

3) a cantilevered "butterfly bow"-dee (60°) or a 180° dee, attached to the fork.

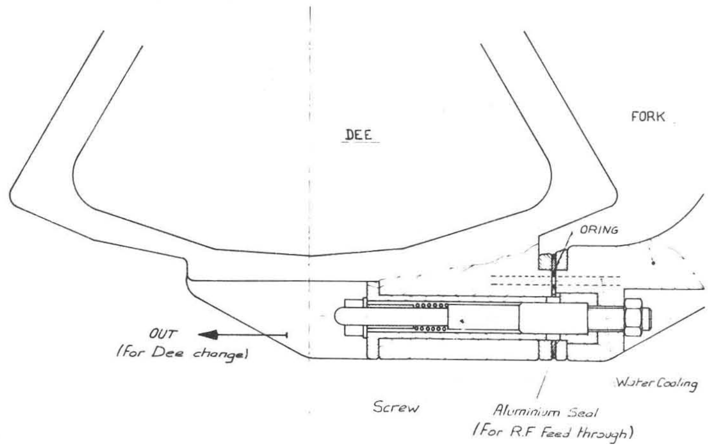

Figure 6. The attachment of the dee on the fork.

In order to minimize the distortion of the copper covers and the thermal expansion of the bearing structure which has to secure the dee positioning, a large number of water-cooling circuits will be installed in the RF system; the dee-to-dummy dee-to-yoke axis is then secured within $\pm$ 0.2. mm.

Since the RF line is attached to the rear side of the tank by 4 legs, limited adjusting possibilities under vacuum are in addition available in the three dimensions ($\pm$ 2 mm).

A trolley allows the RF resonator to move backwards and forwards in an accurately adjusted movement. Apart from the feeder of the coupling loop, no disconnecting is necessary; the water cooling pipes and the control cables stay connected and unwind inside a board.

When the resonator is in the backward position, a change of geometry is made as follows:

a) dismount the dummy dee (source side);
b) disconnect the dee from the fork;
c) dismount the dummy dee (RF side).

Figure 6 shows the attachment of the dee on the fork.

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4. Extraction

Operation of the injector in the "solo" mode (injector + SSC2) brings a sophistication of the extraction system. As a matter of fact, if a classical electrostatic channel with a 40 to 50 kV/cm field followed by a passive magnetic channel to correct the gradient is adequate for ejection of the beam in the normal operation mode, the solo mode requires:

a) a 120 kV/cm electric field to extract 3 MeV/nucleon beams;

b) a regenerator to extract at the nominal extraction radius(46.5 cm) a beam having an energy corresponding to a radius of curvature of 43 cm. It must be recalled that this constraint comes from the facts that :

   i) the ratio between the extraction radius of the injector and the injection radius of SSC 1 or SSC 2 have to be identical to the ratios $\frac{h_o}{h_1}$ or $\frac{h_o}{h_2}$, and

   ii) the injection radii of the SSC's are different (0.814 and 0.857 cm).

Orbit calculations have shown that such an off-centering of the beam could be obtained with an electrostatic regenerator delivering a 57 G/cm gradient (magnetic equivalent) extending over 25° and located 85° after the electrostatic deflector entrance. The regenerator acts over 17 turns and generates a 1.037 amplifying coefficient on the turn separation. The beam-height increase due to the perturbation is less than 25 %.

The electrostatic deflector is of a classical design with two motions for each electrode ; it extends over 55° and the minimum radial aperture can be 8 mm while the maximum applied voltage is 100 kV.

The regenerator is of an electrostatic type (75 kV).

The magnetic channel is made of 3 vertical bars : it delivers a 1:200 G/cm gradient over a 3 cm radial extension. The perturbation generated inside the machine by this channel is corrected by 3 small shims attached to the channel holder and to the ground electrode of the regenerator.

Both elements are movable : the regenerator must be drawn backwards in the normal mode, and the magnetic channel must have a different radial position according to the two modes.

5. Ion source

In order to get four different ion source positions corresponding to the various harmonic modes, the ion source rod will have two motions : backwards - forward, and the rotation of the rod allowing the positioning of the slit in front of the puller. Four different ion source bodies will give the proper angle with respect to the puller. Changing a source to another one, which could happen every eight hours for the heaviest ions, requires only a change of the body. This operation should not take more than thirty minutes.

Figure 7 shows a drawing of the source, with the control of the sputtering system on the side of the chimney.

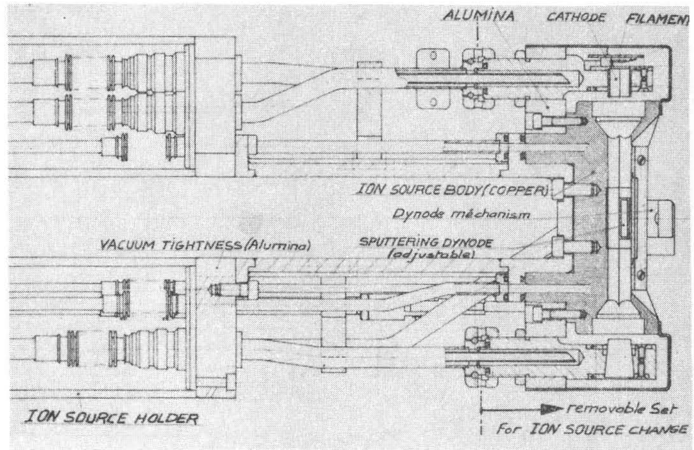

Figure 7. The sputtering ion source.

6. Vacuum

The required pressure for a 90 % transmission coefficient is 5 to 7.10^{-7} torr for the heaviest ions.

Two 6 500 l/s cryogenic pumps located on the resonator tank and a 3 500 l/s turbomolecular pump attached on the vacuum chamber (source side) will provide a pressure of 1 to 2.10^{-7} torr without the ion source in operation.

With an 0.25 cc/min gas flow from the source, the pressure will increase to 10^{-6} torr. Much effort is therefore presently paid on the test stand to reduce this flow. However, the limiting factor of the pressure is the ion source ; consequently, we will keep the classical elastomer gaskets for the injector, since the estimate for going to metallic gaskets show an improvement of the final pressure of only 10 %.

7. Probes and defining slits

The machine equipment will consist of :

. a classical differential probe with 3 fingers for intensity measurements ;

. a phase probe, of the coaxial type, intercepting the beam on the last turn, and going through the deflector window ;

. a system of 3 defining slits on the first and second turns, supported by the resonator ground plates ;

. a fourth slit, located on the last turn before extraction allowing proper cuts in the beam emittance ;

. a diaphragm along the radius attached to the trim coils box to reduce the vertical size of the beam.

8. Present status

The magnet is under construction and will be delivered in January'79. The vacuum chamber and the trim coils are on the verge of being ordered. The manufacturing of the RF cavity will be handed over to the CGR-MeV Company in September '78. The injector beam is expected at the beginning of 1981.

Reference

(1) The Ganil Injector. 7th International Conference on Cyclotrons 132-134.