PRELIMINARY DESIGN OF A NEW CENTRAL REGION FOR THE LNS SUPERCONDUCTING CYCLOTRON

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ABSTRACT

This paper presents the preliminary design of a new central region for the LNS superconducting cyclotron, for the h = 2 mode, and with the use of a spiral inflector. The geometry of the electrodes has been determined by three dimensional calculations, and will be verified later on by electrolytic tank measurements. The results concerning the vertical motion and the radial envelopes are also presented and show that the emittances of a beam injected via a spiral inflector fit the acceptance of the cyclotron.

1. INTRODUCTION

A new central region for the LNS superconducting cyclotron is under study, with a spiral inflector which presents several advantages with respect to the mirror inflector, used in the previous design.[1] The central region design has been optimized for the h = 2 mode, corresponding to the energy range 8 MeV/A to 100 MeV/A,[2] and is foreseen to operate in a constant orbit mode. The present dees are machined down to the radius of 9 cm and must be designed from this radius inwards. All the design calculations were carried out for the ion with Q/A = 0.5, B_0 = 31.3 kgauss, f = 48 MHz, which corresponds to a final energy of 100 MeV/A. This ion corresponds to the highest voltages of the dees and of the ECR source. To get the constant orbit mode for other ions, it will be sufficient to apply a factor proportional to the product $fB\rho$.

2. CHOICE OF THE SPIRAL INFLECTOR

The spiral inflector has been chosen for the many advantages it presents when compared to the others (electrostatic mirror and hyperboloidal inflector):

- the electrostatic mirror deteriorates too much the incident beam properties;
- the hyperboloidal inflector does not enable an injection on the axis of the machine, which is very inconvenient for a superconducting cyclotron, and has only one variable parameter, the magnetic curvature;
- the spiral inflector occupies little space and has two variable parameters (magnetic curvature and "slant" angle). Its drawback is nevertheless a difficult machining.

For the design of the central region, the initial conditions, that is the conditions at the exit of the inflector, are the theoretical ones, obtained from the fundamental equations:[3]

$$\text{position:}\quad \begin{aligned} x &= 2K\lambda \sin(K\pi) - \lambda \\ y &= -2K\lambda \cos(K\pi) \\ z &= 0 \end{aligned} \tag{1}$$

$$\text{velocity:}\quad \begin{aligned} V_x &= V_o \sin\theta\cos(2K\theta) \\ V_y &= V_o \sin\theta\sin(2K\theta) \\ V_z &= -\, V_o \cos\theta \end{aligned} \tag{2}$$

with the usual definitions of K and λ.

The condition at the exit of the inflector is that $V_z = 0$ (corresponds to $\theta=\pi/2$) and from the study made in Milan[4]:

K = 1.1, A = 20.24 mm, V electrodes = $\pm$5 kV

V_{inj} (source voltage) = 20 kV for Q/A = 0.5

which produces the following conditions:

r = 1.41 cm, p_r = 330 mrad, E_o = 0.01 MeV/A.

The radial space occupied by the inflector and its shielding has been chosen equal to the MSU's one.[5]

3. ELECTRIC FIELD AND ORBIT CALCULATIONS

The electric field calculations have been made with RELAX3D.[6] A cubic mesh, 1 mm size, covering a region of 160x160 mm in the X and Y horizontal directions and 17 mm in the Z vertical direction has been used. Starting from spiraled dees down to the radius of 1 cm, several geometries have been tried, and tested with the central orbit calculation made with the dynamics program CYCLONE 3D.[7] The geometry retained is presented in

Fig. 1:

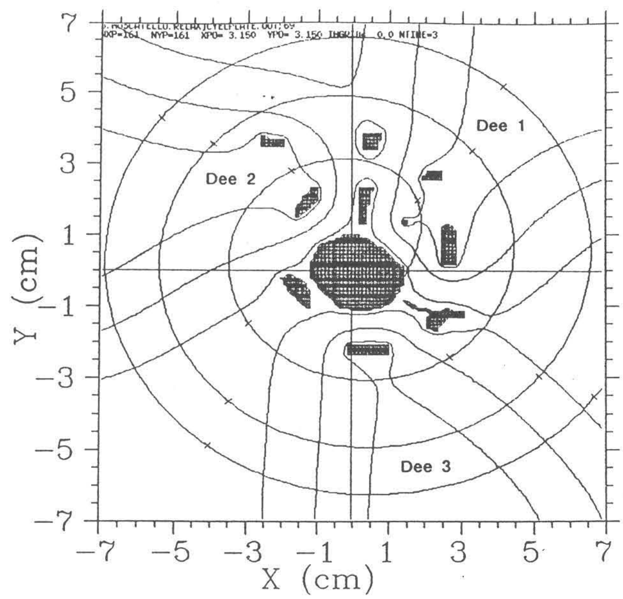

Fig. 1. Central region geometry and central orbit

All the electrodes on the dees and on the dummy-dees cross the median plane. The grounded electrodes should be sufficient to obtain low couplings between the dees.The electric gaps are all equal to 10 mm minimum,in order to have an electric field always smaller than 100 kV/cm.

A calculation of the central orbit was made with an injection voltage of 15 kV instead of 20 kV, and the off-centering is of the order of 2 mm, an acceptable value when the source is operated at a lower voltage.

The starting phase of the beam is in advance of 40° on the RF phase, to compensate the delay taken in the first half turn.

4. RADIAL AND VERTICAL MOTIONS

4.1. Radial motion

The radial phase space study has been made for an emittance $\varepsilon = 100\pi$mm·mrad,greater than the emittance transmitted by a spiral inflector. Figure 2 presents the trajectory of this beam, where it appears that the minimum clearance of the whole beam is of 1 mm.

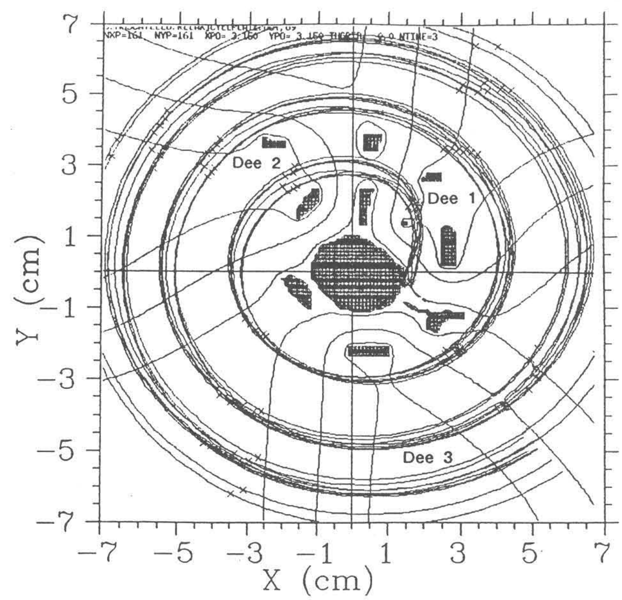

Fig. 2. Trajectory of a beam with a radial emittance of 100π mm·mrad

The beam is represented by 8 particles of a radial ellipse obtained from the eigen-ellipse and then traced back to the centre of the cyclotron, and 2 particles distant ±20° RF from the central particle(Fig.3).

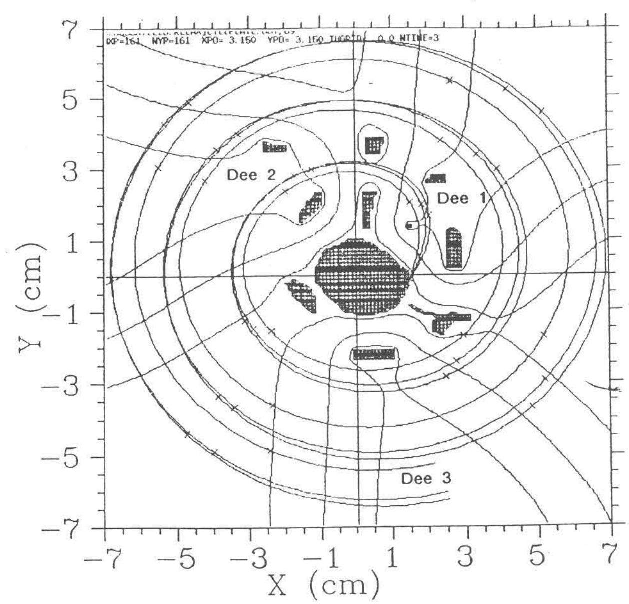

Fig. 3. Trajectory of the central particle and 2 particles distant of $\Delta\phi = \pm 20°$ RF.

The evolution of the beam in the radial phase space during the first turns is presented in Fig. 4.

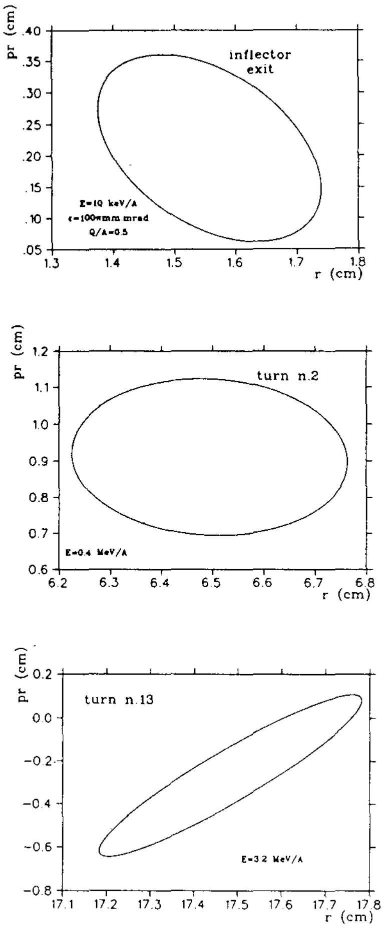

Fig. 4. Evolution in the radial phase space

4.2. Vertical motion

The vertical motion has been studied for an emittance $\epsilon = 100\pi$mm·mrad, and a total height of the beam equal to 4 mm at the exit of the inflector. To get a sufficient vertical focusing during the first turn, some vertical reductions have been added at the locations indicated in Fig.5 (horizontal hatched areas). In these places the vertical gap is of 14 mm instead of the nominal 25 mm. The vertical focusing is rather sensitive to the starting phase.

These radial and vertical emittances accepted by the central region do not take into account the correlations which could be added by the structure of the injection line. When the injection line is designed as well as the inflector, more calculations will have to be made to know the real acceptance of the central region.

4.3. Beam centering

The beam centering has to be improved by a few mm, being up to now of the order of 5 mm at the radius r=18 cm, by slightly modifying the shape of the dees near the centre. Indeed such a value cannot be accepted; ν_r being close to 1, this leads to a substantial increase in the radial dimension of the beam. Of course the harmonic 1 coils can be used to re-centre the beam, but must be considered as a fine adjustment tool.

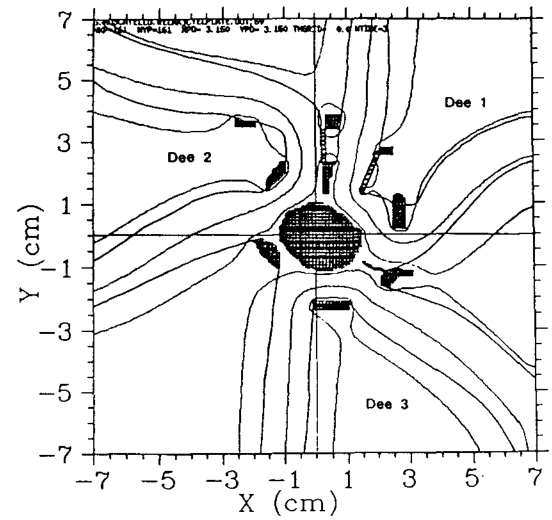

Fig. 5. Central region with the vertical reductions

5. CONCLUSION

This preliminary design shows that the main requirements are reached, although the beam centering must be refined. This work will be followed by a precise calculation of the spiral inflector, with the program RELAX3D, including a fine modelization of the inflector RF shielding, and the construction of a model. Meanwhile, it is intended to build a model of the central region to proceed to electrolytic tank measurements, and to verify that the coupling between the dees at the centre is low enough.

6. REFERENCES

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