Design of the Central Region for the Axial Injection in the VINCY Cyclotron

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Abstract

This paper describes the design of the central region for h=1, h=2 and h=4 modes of acceleration in the VINCY Cyclotron. The central region is unique and compatible with the three above mentioned harmonic modes of operation. Only one inflector of the spiral type will be used. The central region is designed to operate with two external ion sources: (a) an ECR ion source of the maximum extraction voltage of 25 kV - for heavy ions, and (b) a multicusp ion source of the maximum extraction voltage of 30 kV - for H^- and D^- ions. Heavy ions will be accelerated by the second and fourth harmonics, D^- ions by the second harmonic and H^- ions by the first harmonic of the RF field. The central region is equipped with an axial injection system. The electric field distribution in the four acceleration gaps has been numerically calculatied by the computer code RELAX3D. The geometry of the central region has been tested with the orbit computations carried out by means of the code CYCLONE. The properties of the beam in the spiral inflector were studied by using the code CASINO.

1. INTRODUCTION

VINCY Cyclotron is a compact isochronous cyclotron with four straight sectors [1,2] designed to accelerate a wide range of ions. The magnetic induction at the centre of the machine varies from 1.4 to 2.1 T. Its bending and focusing constants are K_b=145 MeV and K_f=75 MeV, respectively.

The ions coming from the ions sources will be injected in the VINCY Cyclotron vertically upwards along the magnet axis toward the centre where an electrostatic spiral inflector [3,4] bends the beam into the median plane. The acceleration then takes place at four electric gaps per orbit. The two 30° wide dees operating with the maximum voltage of 100 kV are located in the opposite valleys.

In the central region of the VINCY Cyclotron there are four trapezoidal centering coils per pole, one in each valley of its magnet.

The requirements were that the beam should be accelerated for the harmonic number equal to 1 in the case of the H^- ions, to 2 in the case of D^- ions and heavy ions, and to 4 in the case of heavy ions.

2. DESIGN OF THE CENTRAL REGION

Our earlier studies [2] indicate that with two ion sources one combination of the inflector and central region will be sufficient to cover the entire operating range of the VINCY Cyclotron.

The choice of the spiral inflector usually implies a fixed orbit geometry. In the case of the VINCY Cyclotron this can be easily acheived with the proper scaling of the dee voltage for all ions within the h=2 mode of acceleration. The proper scaling for the h=1 mode of acceleration requires the dee voltage to be above the designed value, while the proper scaling for the h=4 mode of acceleration requires the dee voltage to be bellow the designed value. On the other hand, a small angular extension of the particle trajectory between the first and second gaps allows the trajectories to overlap but only inside the first dee.

The small bending radius of the injected particle, R_m=16 mm, determined by the maximal extraction voltage of the ECR ion source for the heavy ion (q/A=0.5, B_0=2 T), and the small energy gain for the first harmonic mode of acceleration strongly affect the design of the central region. Thus, only a very small space is left for the inflector, ground, and inner tips of the dees and anti-dees. Therefore, the special attention has been paid to:

(i) the clearences between the particle and the solid obstacles in the first two turns, and

(ii) the ground to high voltage distances in the horizontal as well as in the vertical directions - to avoid sparking.

After a complex design procedure the shapes of the central region electrodes were specified. A preliminary analysis for different ion trajectories showed that an off-centerdness of ρ_c=8.8 mm at the inflector exit made possible the injection of ions of all specific charges and energies comprised by the operating range of the machine. In the case in which the off-centering of the injected beam is above the tolerable limits, it could be suppresed by the controled perturbation of the magnetic field introduced by the centering coils - in the vicinity of the $\nu_r=1$ resonance in the central region.

Figure 1 shows the horizontal cross section - (a), and the vertical cross section - (b), of the electrodes in the central region of the VINCY Cyclotron together with the tips of the dees and anti-dees of its RF system. Some critical dimensions are also shown.

For this central region we selected a spiral inflector [3,4] with the following parameters. The electric radius of the inflector is 25 mm and the tilt parameter is 0.4. The electric gap is 8 mm and the aspect ratio is 2. Special attention was devoted to the possibility of excanging the inflector through the upper axial channel of the machine without elevating the upper part of its magnet.

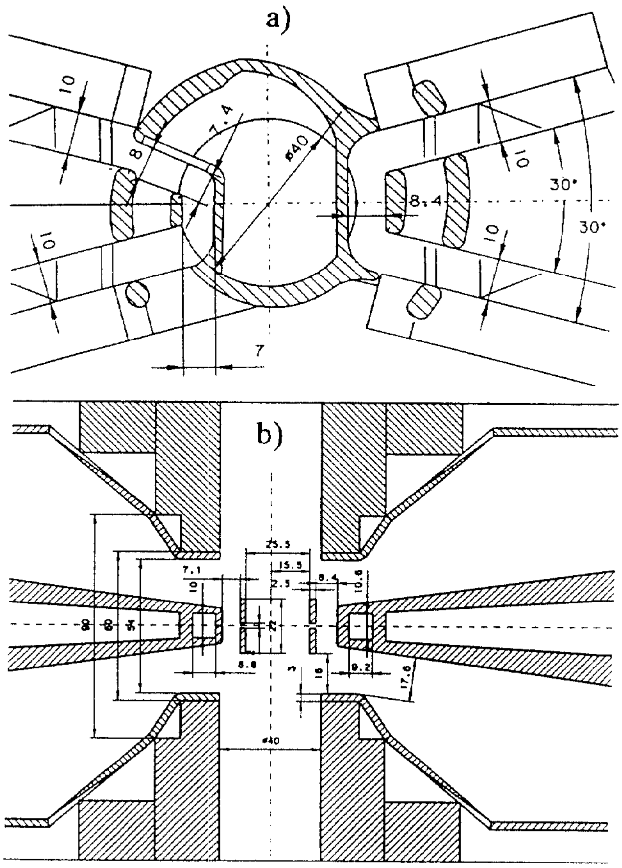

Fig. 1. The horizontal cross section - a, and the vertical cross section - b of the central region of the VINCY Cyclotron.

2. ORBIT STUDIES

To check the design goals of the inflector and central region of the VINCY Cyclotron, and to treat more realistically the inflector and central region we calculated the electric potential maps in them by the code RELAX3D [5]. The boundary conditions of the inflector problem, i.e. the shapes of the surfaces with constant electric potential, are defined via the code INFLECTOR [6]. The shapes of all the electrodes in the central region are specified by a set of codes [7] for introducing the boundary conditions in the code RELAX3D.

The ion trajectories in the inflector electric field, (B=const.), are calculated by the code CASINO [8]. These calculations show that the fringe field of the inflector increases its effective length. In other to inflect the orbit properly ($z=0$ and $p_z=0$) we have to decrease the nominal inflector voltage by 7% and to adjust the vertical position of the inflector (to move the inflector 0.8 mm in the direction opposite to the direction of the ion motion).

For the analysis of the ion trajectories in the central region, which included both the electric and magnetic fields data, we used the code CYCLONE [9]. The parameters of the ions used in these examinations were: $q/A=1$, $B_0=1.465$ T, $h=1$, corresponding to the H^- ion, $q/A=0.5$, $B_0=1.84$ T, $h=2$, corresponding to the referent ion of the machine, and $q/A=0.2$, $B_0=1.84$ T, $h=4$, corresponding to a heavy ion. The results prove that in all of these cases the energy gain corresponding to the central ion trajectory is sufficient to clear all the obstacles successfully. Figure 2 shows these ion trajectories superimposed on the equipotential plot of the electric field in the central region.

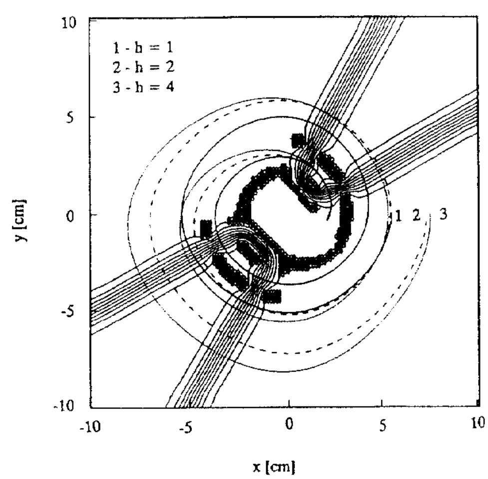

Fig. 2. The central orbits of the three particles in the VINCY Cyclotron which were considered; 1 - h=1, 2 - h=2, and 3 - h=4.

We tested the phase acceptance of the central region of the machine by following the first two turns of the ions. For the very small values of ν_z, what is the case at the injection, the emittance of the beam was reconstructed from its emmitance at the entrance of

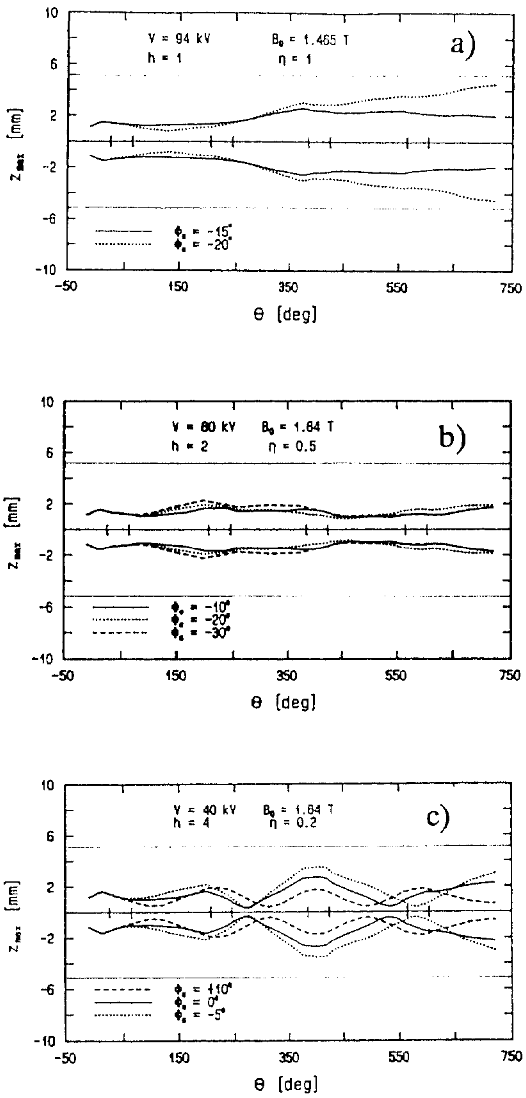

Fig. 3. The maximal vertical desplacement of the beam in the first two turns for the three particles in the VINCY Cyclotron which were considered. The short lines crossing the abscissa show the electric gap positions and the thin lines paralle to the abscissa indicate the minimal vertical aperture of the central region.

the inflector. Eight particles from the circular contour in the (x, p_x) transverse plane which corresponded to the ion source emittance of ε_x=50π mm mrad (at the inflector entrance) were run through the inflector using the code CASINO. The initial (x, p_x) contour changed into a contour in the (z, p_z) transverse plane at the inflector exit. A certain increase of the beam emittance due to the coupling between the two transverse planes was observed.

As the calculations by the code CYCLONE implies, the vertical motion in the central region is linear, and two particles are sufficent to describe the axial phase space. The maximal axial displacement, defined as the beam envelope of the trajectories of eight particles defining the contour at the inflector exit, was checked at each degree in the first two turns. The vertical displacements of the three particles under consideration for severel different starting phases are shown in Figs. 3a, 3b and 3c. Only those starting phases which give the vertical envelopes contained within the smallest vertical aperture of the central region are shown. The calculations showed that the phase dependent effects were much more pronounced in the vertical plane than in the horizontal plane, and that the small vertical clearance of the central region appeared to be a serious limiting factor.

3. CONCLUSIONS

Our orbit studies indicate that with the selected inflector the adequate orbit centering could be acheived for h=1 and h=2 modes of acceleration, and that for h=4 mode of acceleration the off-centering of the beam could be easily suppresed by the centering coils. The vertical focusing in the first two turns is satisfactory, but the larger vertical apertures of the central region are desirable.

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