Injection and Central Region Studies for the VINCY Cyclotron

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Absract

The central region of the VINCY Cyclotron, the main part of the TESLA Accelerator Installation, 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. A tilted spiral inflector with an electric bending radius of 25 mm is used to bend the beams into the median plane of the Cyclotron at the magnetic radius of 16 mm. The requirements were that the beam should be accelerated on a well centered orbit for the harmonic number equal to 1 in the case of H⁻ ions, and to 2 and 4 in the cases of D⁻ and heavy ions. The optical properties of the inflector were studied, and an effort to minimize the inflector fringe field, using the RELAX3D code, for the calculation of the electric potential distribution, was made.

1. INTRODUCTION

VINCY Cyclotron is a compact, four sector isochronous cyclotron [1], designed to accelerate heavy ion beams of very different energies and atomic masses. It is considered that the best quality of machine operation should be acheived for the heavy ion particles which can be produced in large quantities in ECR ion sources and will be extracted by a resonant extraction system. VINCY Cyclotron can provide an almost fixed energy beam of protons. Deuteron and proton beams, which are a potential radiation hazard, will be accelerated as negatively charged particles, so that a 100% efficient extraction by stripping can be employed. In order to achieve a smooth and clean operation, an axial injection system is proposed. Thus, severel ion sources can be independently tested and easily coupled to the cyclotron without interfering with the machine vacuum and injection optics. We inject the beams from the ion sources vertically upwards along the magnet axis toward the centre where an electrostatic spiral inflector [2,3] bends the beams into the median plane. Acceleration then takes place at four dee gap crossings per orbit. The two 30° wide dees operating on 1st, 2nd and 4th harmonics, with the design voltage of 75 KV (peak) are located in the opposite valeys.

2. CENTERING REQUIREMENTS

The radius of the injected orbit for the certain particle is determined by the maximal extraction voltage of the ion source. It is assumed that the maximal extraction voltage of the ECR ion source is 25 kV, and that sets the smallest radius of curvature for the heavy ion ($q/A=0.5$, $B_0=2$ T) to $R_m=16$ mm, and the maximal extraction voltage of a multicusp ion source to 30 kV in the case of protons. Fig. 1 shows the scalling laws for the extraction voltage of the ion sources.

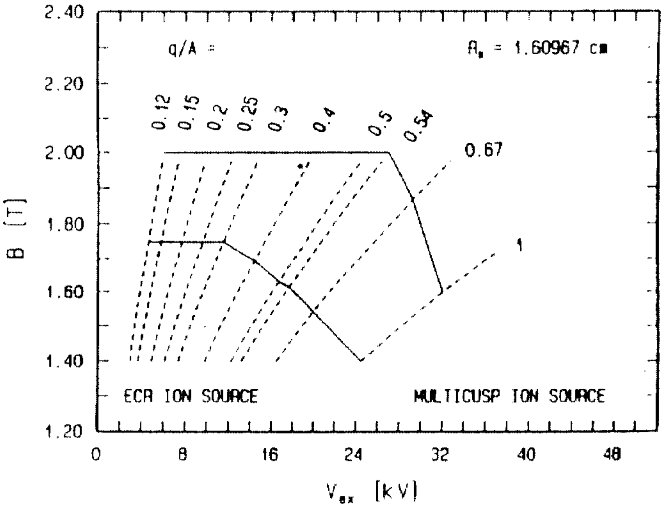

Figure 1. Requested extraction voltage of the ion sources for the operating diagram of the VINCY cyclotron.

When the particle crosses the gaps of the central region it will be accelerated by the potential difference exerienced. Due to particle energy gain at gap crossings the orbit radius increases and the particle which was in phase with the RF field before the gap crossing will experience a phase slip after the gap crossing.

To avoid non synchronous motion due to shifts of the orbit center at the gap crossings the particle should be injected with the certain position of the orbit centre, ρ_c, at the exit of the inflector. This off-centeredness is determined mainly by the geometry of the central region and by the radius gain per gap.

3. CENTRAL REGION

We assumed that the dee configuration, the magnetic fields, the acceleration voltages and the harmonic numbers of the Cyclotron are given. Since we wish to avoid using a field bump, we postulate that the trajectory centers converge towards the center of the machine. The first attempt was always to center the $q/A=0.5$ ion in the central field $B_o=2$ T with the accelerating parameters $h=2$, $V=50$ kV and then protons in the $B_o=15.5$ T for the $h=1$ and $V=65$ kV case, for the large phase acceptances. The next step was balancing of these values. In this procedure we find that $\rho_c=8.8$ mm could satisfy centering requirements for both referent particles as s shown in Fig. 2.

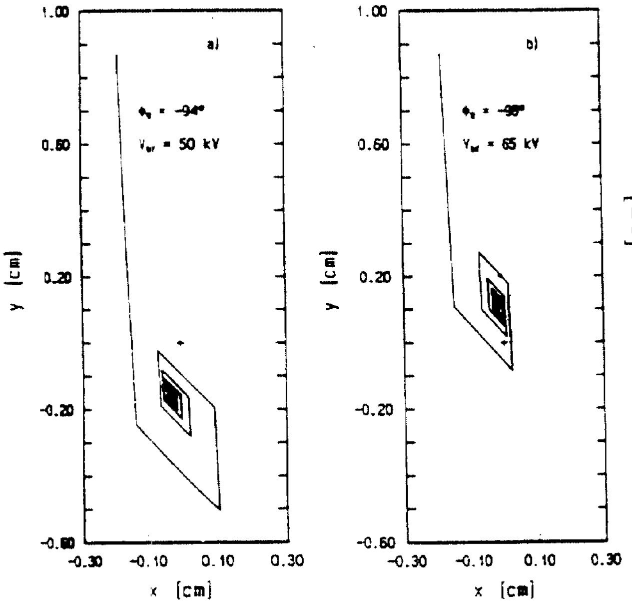

Figure 2. Orbit centers for two referent particles; heavy ions ($q/A=0.5$, $B_o=2$ T, $V=50$ kV, $h=2$) - a) and protons ($B_o=1.55$ T, $V=65$ kV, $h=1$) - b).

The choice of the spiral inflector forced us to work with a fixed orbit geometry, what requires that the ions with different q/A, in the different magnetic fields, follow the same trajectory. This can be acheived with a proper scalling of the dee voltage for all ions with $q/A<0.5$. The proper scalling for the protons requires the dee voltage to be above the design value. On the other hand, a small angular extention of the particle trajectory between the first and second gap crossings allows trajectoris of the heavy ions and protons to overlap on the first orbit but only inside the first dee. This gives the possibility that one inflector-central region combination is sufficient to cover the entire operating region. In designing the central region of our Cyclotron we followed in mean features the central region of the TR-30 [4] cyclotron.

The minimal distance between ground and high voltage in the direction perpendicular to the magnetic field is 10 mm, exept in the injection gap region where it is 7 mm to reduce the transit time. To increase the energy gain on the first two gaps the electric field from the gap is compressed by the pair of posts on the each side of gap. On the subsequent gap crossings the accelerating gap is formed by the parallel edges of the dee gap. The injection scheme is shown in Fig. 3.

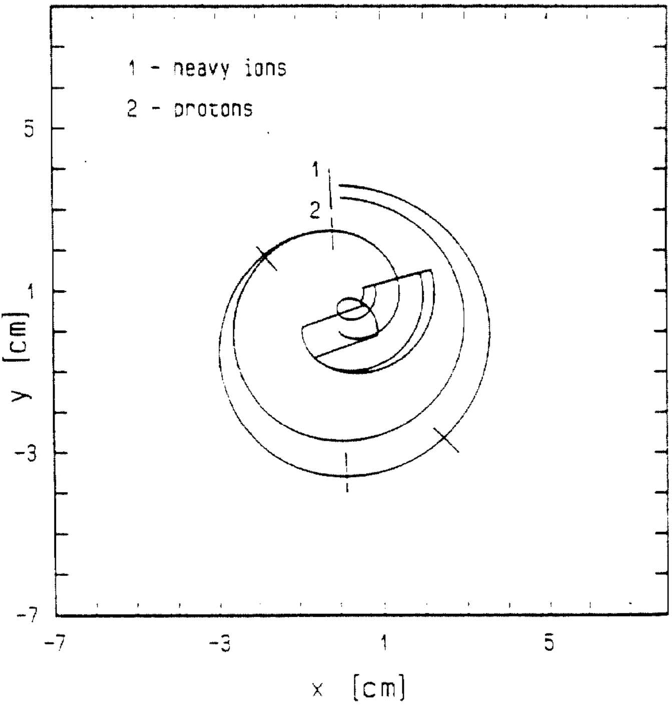

Fig. 3. Principal scheme of central region geometry and reference particle trajectories

4. SPIRAL INFLECTOR

The injection energy, the centering requirements, the inflector size and the angle of rotation around the point of injection have to be matched. The major difficulty in design of the inflector is the space limitation of the first orbit. The main advantage of the spiral inflector compered to the mirror or the hyperbolic inflector is that spiral inflector has two free design parameters. These are the electric radius A and the tilt parameter k′. The inflector parameter K is defined as:

$$K = A/(2\ R_m) + k'/2. \qquad (1)$$

The extension of the inflector in the vertical direction is determined only by parameter A. The size of the inflector in the horizontal plane is determined by parameters A and k′. We have selected K=0.98 (A=25 mm, k′=0.4) with the tapered electrodes, trying to minimize the horizontal cross section of the inflector and to optimize the angle of rotation. The gap in the inflector is 8 mm, the aspect ratio is 2 and the maximal electrode voltage is ± 9.6 kV. The electric field in the inflector is computed from an electric potential map, produced by RELAX3D [5].
The inflector electrode locations in RELAX3D are done with the aid of the subroutine INFLECTOR [6] around the analytic electric field central ray.

4.1 Effects of Fringe Fields

The electric field produced from the electric potential has characteristic fringe field distribution at the ends of the inflector, which increases the effective length of the inflector. Particularly for the case of high electric field in the inflector, fringe fields change the optics of the inflector and push the particles to oscillate around the design line of the inflector. This may be observed by running CASINO [7].

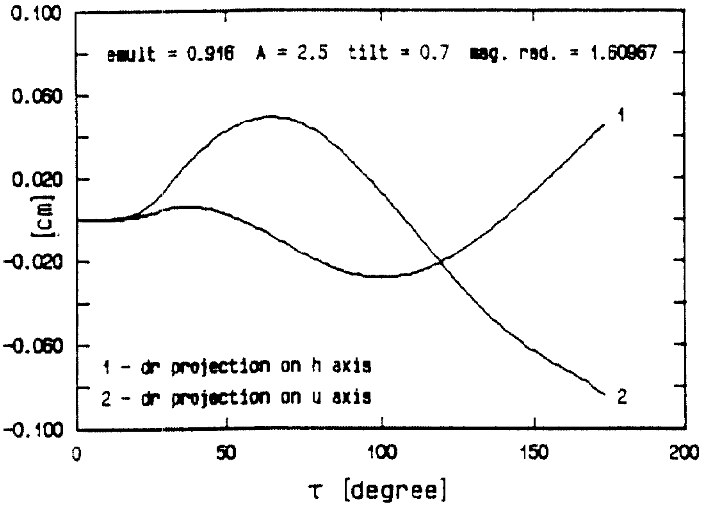

Fig. 4. Deviations of the computed central ion trajectory from the design orbit of the inflector, in the u_r - a), and the h_r direction - b).

The difference between the central ray in the real electric field and the analytic central ray (inflector design line) is shown in Fig. 4 in the rotated coordinate system. We understood these oscillations as the characteristic Δp_u oscillations due to experienced fringe field at the inflector entrace. In order to inflect the orbit properly we usually have to decrease the inflector voltage. In that case the central ray is not in the median plane and we have to introduce a fine adjustment in vertical position of the inflector. We can compensate the entrance fringe field of the inflector cutting a certain piece of the inflector. Which of these technique will be applied depends on the optical properties of the inflector.

5. SUMMARY

Our studies indicate that with two ion sources only one inflector-central region combination will be sufficient to cover the entire operating region of the Cyclotron. It can be shown that in achieving a given orbit centre one can trade off an increase in height of the inflector against the decrease in tilt. To inflect the orbit in the median plane we have to introduce a fine adjustment in the vertical position of the inflector.

6. REFERENCES

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