ION BEAM DYNAMICS SIMULATIONS FOR THE VINCY CYCLOTRON

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Abstract

The VINCY Cyclotron has to accelerate ions operating with the harmonic number of the RF voltage equal to 1, 2, 3 and 4. Two different central region configurations have been designed in order to satisfy the need for the broad ranges of ion species and energies that are expected to be obtained from the machine. The latest design of the spiral inflector, in the axial injection line, was used in the simulations. We present here only the results of the H^- ion beam dynamics simulations. The ion tracking calculations were performed using the CBDA code. The electric and magnetc field maps were obtained using the TOSCA/OPERA3D and MERMAID codes. The measured magnetic field maps were also used. The main criteria used in the simulations were the good centering, the highest possible energy gain in the accelerating gaps, the maximal transmission through the central and acceleration regions, and the best possible quality of the ion beam at the extraction radius. The overall performance of the machine was optimized by adjusting the corresponding operational parameters.

INTRODUCTION

The VINCY Cyclotron is a medium-sized compact isochronous cyclotron designed to deliver light as well as heavy ions [1]. The main parameters of the H^- ion acceleration mode are given in Table below.

Table 1: H^- ions acceleration regime parameters

Final H^- ion energy , MeV/nucleon	65
Operational frequency, MHz	20.037
Harmonic number	1
Dee voltage, kV	75

The calculations of the ion beam dynamics were performed in the injection, central and acceleration regions, i.e., from the spiral inflector entrance to the stripping foil, used to extract the beams.

INJECTION

The external injection of the H^- ion beam is achieved with a spiral inflector, having in mind its good centring and proper acceleration. A systematic procedure of finding a matched inflector, taking into account the influence of the general magnetic field was applied [2]. The spatial distribution of the electric and magnetc field maps for the beam tracking inside inflector volume were obtained using the well known TOSCA/OPERA3D code. The ion tracking calculations were performed with the CBDA code [3]. The latest design of the spiral inflector, in the axial injection line, was used in the simulations. Parameters of the inflector (Figure 1) are given below:

VINCY inflector parameters:

- A = 25 mm – electric radius.
- R_m = 18.54 mm - magnetic radius.
- k' = –0.19 - tilt parameter.
- B_z= 1.305 T - axial magnetic field.
- d_0 = 8 mm – initial electrode gap.
- V_{inf} = ± 8.96 kV – biasing potential.
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Ion parameters:

- Ion species: H^-
- W_{inj} = 28 keV – injection energy
- Transverse emittance = 60 π.mm.mrad

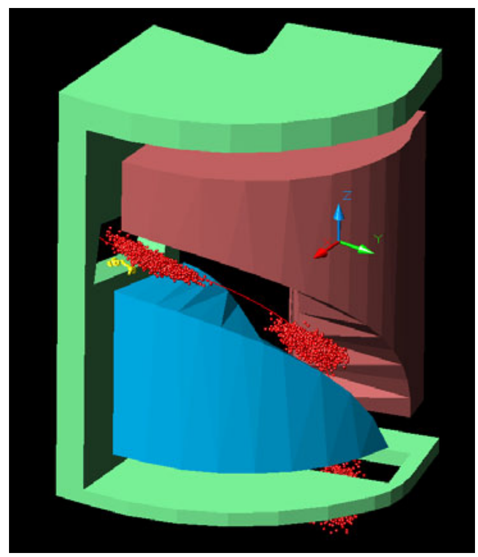

Figure 1: Spiral inflector structure with injected H^- ion bunches shown by red dots.

ACCELERATION

Fields

The midplane cyclotron layout is shown in Figure 2.

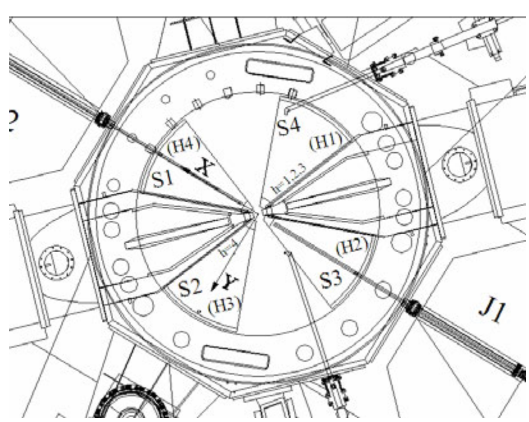

Figure 2: VINCY Cyclotron layout.

The central region configuration (Figure 3) have been designed in order do satisfy the need for broad range of ion species and energies that are expected to be obtained from the machine [4]. The configuration under investigation is characterized by the values of maximal RF voltage and injection voltage of the beam (and consequently - bias potential of the spiral inflector). The final decision on the central region configuration will be adopted after a thorough analysis of the sparking probability for it.

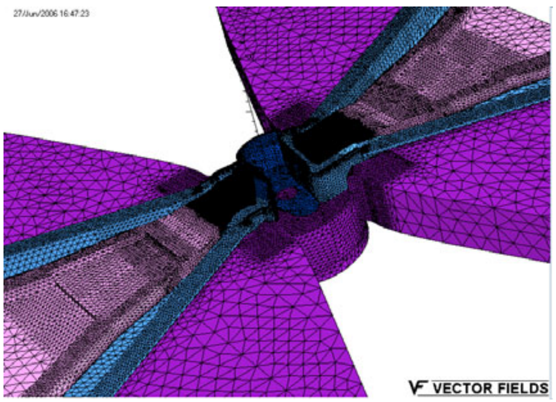

Figure 3: Cyclotron central region configuration.

The spatial distribution of the electric and magnetc field maps for the beam tracking inside inflector volume were obtained using the TOSCA/OPERA3D code. The measured magnetic field maps were also used [5].

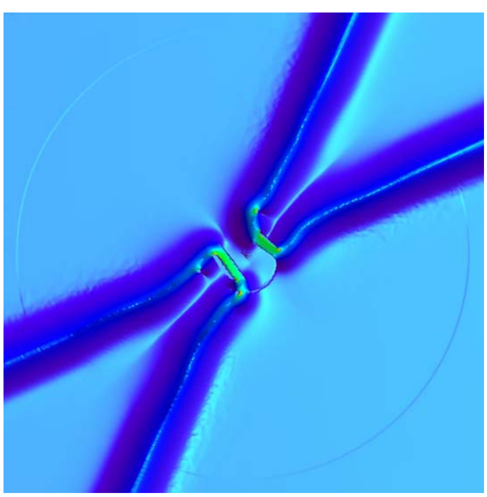

Figure 4: Acceleration field distribution in the central region of the machine.

Ion tracking

The ion tracking calculations were performed with the CBDA code. The main criteria used in the simulations were the good centering, the highest possible energy gain in the accelerating gaps, the maximal transmission through the central and acceleration regions, and the best possible quality of the ion beam at the extraction radius.

In analyzing the beam losses we took into account all the obstacles for the ions (Figure 5) as well as their collisions with the molecules of the residual gas.

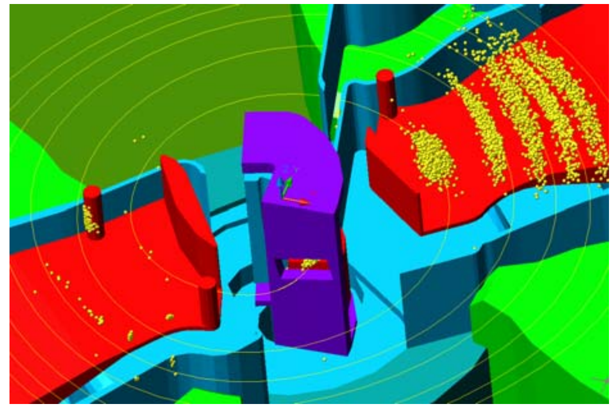

Figure 5: Central region with accelerated and lost on the structure particles (dots).

In the case of H– ions, the effect of their electromagnetic stripping was included too.

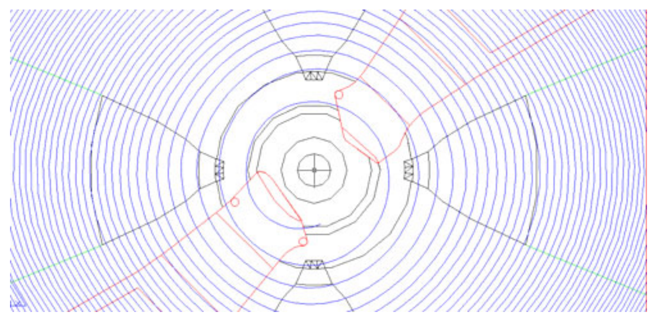

Figure 6: Reference ion orbit in the central region.

A new centring procedure was applied to the reference particle to provide a good quality of the beam. The results are shown in Figure 7 and Figure 8.

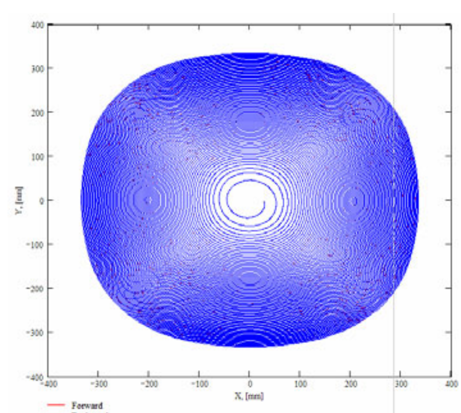

Figure 7: Reference trajectory – forward and backward tracking.

Figure 7 demonstrates good particles orbits centring. The forward and backward trajectories are practically coincident, which is a manifestation of sufficient enough accuracy of the particle motion equations numerical integration with the integration step (~ 10^{-12} sec) selected.

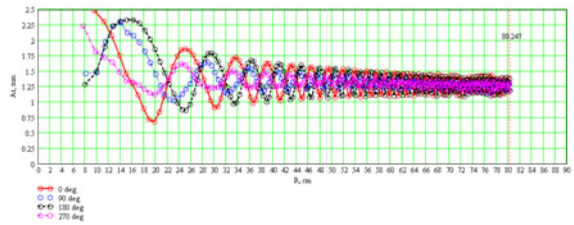

Figure 8: Radial betatron amplitude estimation.

In Figure 8 estimated radial amplitudes are at the level of ~ 1.2 mm near the final radius, which provides a needed high quality of the beam at the extraction.

Concluding one can note that the ion beam centring, phase slip (Figure 9) and energy gain as well as the emitances (Figure 10 and Table 2) and transmission coefficient (~40%) were found to be satisfactory.

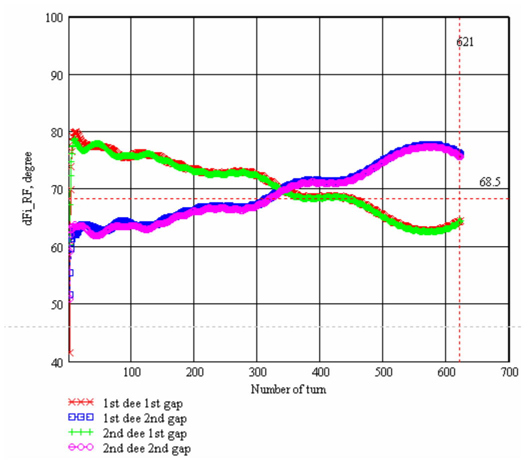

Figure 9: Reference particle RF phase excursion during acceleration.

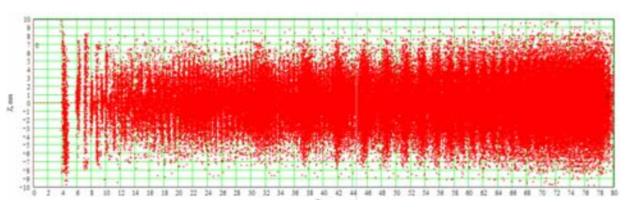

Figure 10: Axial bunch motion.

In Table 2 characteristic beam dimensions (2σ, i.e. 2 standard deviations of the particle distributions) as well as the central point position of the bunch at some intermediate radius (~30 cm) are given.

Table 2 Beam parameters.

Parameters Coordinates	Average-position mm	2σ-deviation mm	Average-angle mrad	2σ-angle mrad
R	301	3.9	16.4	15.4
Z	-0.83	5.3	0.33	2.9
φ_{RF}	-	12.8 °RF	8.3 MeV	0.23 MeV

FUTURE STUDIES

In the future studies the light as well as heavy ions regimes will be considered. The corresponding test ions: H^-, $^2H^+$, $^4He^+$ and $^{40}Ar^{6+}$ are under investigation. This wide range of ion masses and charges to be accelerated is quite demanding with respect to the configuration of the electrodes in the central region of the machine, especially if one wants to avoid the movable parts and keep it as simple as possible.

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