BEAM DYNAMICS SIMULATIONS FOR THE CUSTOMS CYCLOTRON

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Abstract

The compact isochronous cyclotron is considered as a source of 1.75 MeV protons for the detection of explosives using gamma ray resonant absorption technique [1]. Given the marginal request for the beam intensity and quality H^- ions were selected for acceleration in the cyclotron aiming at the high efficiency extraction by electrostatic deflector. The tracking calculations were performed by the CBDA code [2]. The electric and magnetic field maps were obtained by the TOSCA/OPERA3D and MERMAID codes [3]. Internal and external injection regimes were tried to select from. The space charge effects of the ions were taken into account in the calculations. The main criteria, imposed in selecting of the operational parameters, were good centering, as high as possible energy gain of the ions in the accelerating gaps, the maximal particles transmission through the machine and the best possible beam quality at the final energy. The overall performance of the facility was optimized by adjusting the corresponding parameters of the cyclotron. Simulation of the interface between the cyclotron and the storage ring was performed in order to provide the required intensity and beam quality for injection to the storage ring.

INTRODUCTION

Requirements to the cyclotron output beam are summarized in Table 1.

Table 1: Required output beam parameters

Parameter	Value
Type of emerging particles	H^-
Average beam current	100 -300 μA
Mean beam energy	1.747 MeV
Energy spread	±30 keV
Beam spot at the target	5x5 mm^2
Divergence at target	±3 mrad
Beam emittance	7.5 π·mm·mrad

The Fig. 1 shows the structure layout, including cyclotron, transport line and storage ring. The transport line contains a duplet of two quadruples - 'F' lens with Grad=-5.6 T/m and 'D' lens with Grad=3.9 T/m and two targets. H^- is ejected from the cyclotron hitting target 1 ($H^- \rightarrow H^0$) and, subsequently, target 2 ($H^0 \rightarrow H^+$).

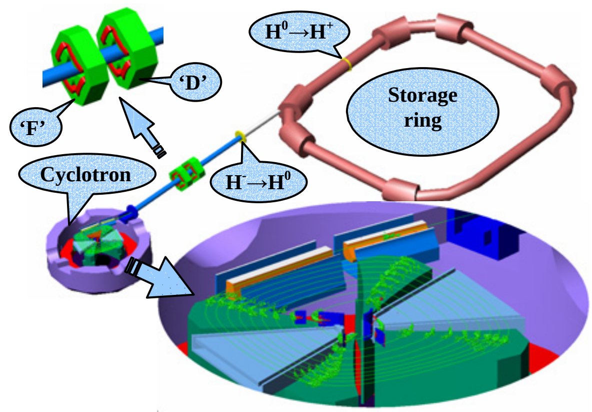

Figure 1: Facility layout.

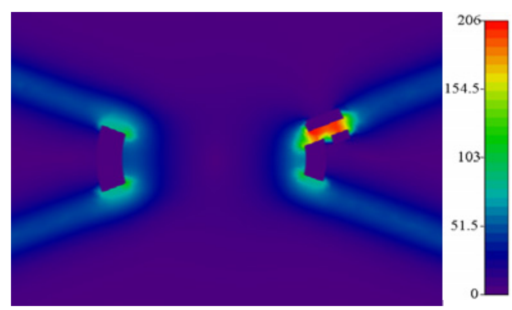

Figure 2: Electric field [volt/m], U_{DEE}= 1 volt.

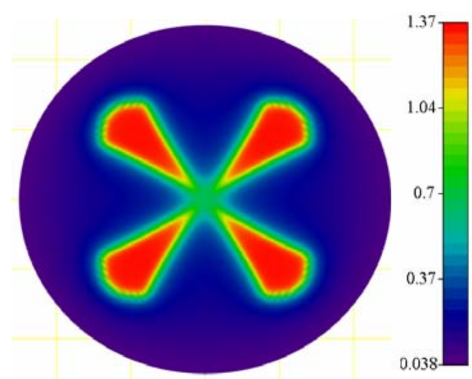

Figure 3: Magnetic field [T].

CYCLOTRON FIELDS

Calculation of the 3D distribution of the magnetic and electric fields for the cyclotron was made with TOSCA and Mermaid code. The maximum voltage on the Dee is 55 kV, ω_{orbit}=9.76 MHz, RF harmonics=4. Fig. 2 illustrates the distribution of the absolute value of electric field in the central region for the median plane.

Fig. 3 presents a distribution of the axial magnetic field component in the median plane.

BEAM ACCELERATION

Fig. 4 and Fig. 5 show the cyclotron structure, namely, acceleration system (Dee), magnet, internal ion source, diaphragm set and extracting system (two electrostatic deflectors (ESD) and permanent magnet (MC)).

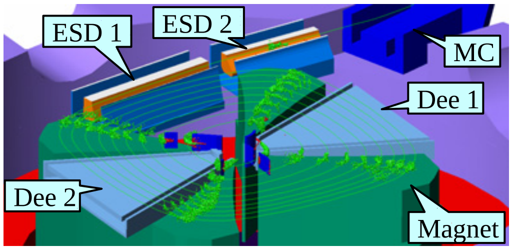

Figure 4: Cyclotron structure.

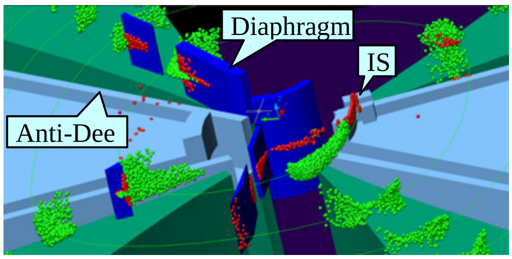

Figure 5: Central region.

The maximum current from the IS for the Dee voltage 55 kV is 2.35mA. The IS body has a rectangular spot with cross section 0.6x4 mm^2. The initial injecting bunch is generated according to $I=A\cdot U^{3/2}$, where A=const, U-voltage on the Dee, I- current. The initial energy of the bunch particles is 0.1 keV and angular size of the bunch is 0 mrad. The extracting system has the following parameters: ESD-1 E=28.6 kV/cm Grad=-3.6 kV/cm^2; ESD-2 E=28.6 kV/cm, Grad=-14.8 kV/cm^2; MC (magnet channel) B=0.45T, Grad=7.5 T/m.

In Fig.4 and Fig.5 accelerated particles are represented by green color, and lost particles on the structure elements - by red color. Particle loss in the central region is about 88%, and in the extracting system - less than 1%. The diaphragm position was selected so that the particles only with RF phases from -8° to 8° are captured into the acceleration. An injected bunch comprises 3000 particles. The space charge effect was estimated by the particle-to-particle (PP) method. In Tables 2-3 the parameters are given of the bunch at the output of the cyclotron with current of 100 μA.

Table 2: The Twiss parameters

Parameters Coordinates	α	β *mm/mrad*	γ *mrad/mm*	ε π·mm·mrad Required	ε π·mm·mrad Obtained
X	-0.9	0.3	7	**7.5**	105
Y	-0.8	0.5	3	**7.5**	76

Table 3: Beam statistics

Parameters Coordinates	Average -position mm	2σ-deviation mm Required	2σ-deviation mm Obtained	Average-angle mrad	2σ-angle mrad Required	2σ-angle mrad Obtained
X	0	2.5	5	0	3	27
Y	0	2.5	6	0		15
Energy	*1.772 MeV*		*49 keV*	-	*30 keV*	-

SPACE CHARGE EFFECT

In this section we consider the space charge impact on the bunch quality and output current. We performed calculations for different injection currents from the IS.

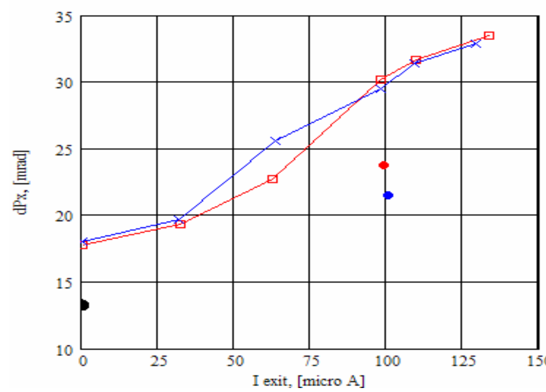

Figure 6: ΔP_r [mrad] .

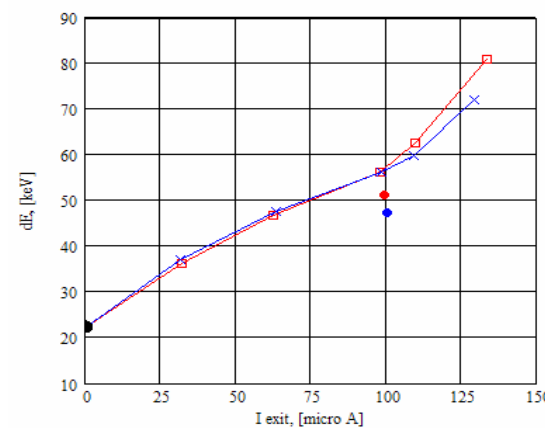

Figure 7: ΔE [keV] .

Fig. 6 and Fig. 7 depict the dependences of angular and energy spreads upon the output current. The red color line stands for case of 1000 particles in the initially injected bunch, blue color line – in case of 2000 particles. Black dots correspond to the case with 10,000 particles (no space charge included), but the red dots (1000 particles) and blue dots (2000 particles) correspond to the calculations with the initial energy of 1 keV (but not of 0.1 keV as in the previous case). Fig.8 and Fig. 9 show the dependences of transverse and axial emmitances on the output current.

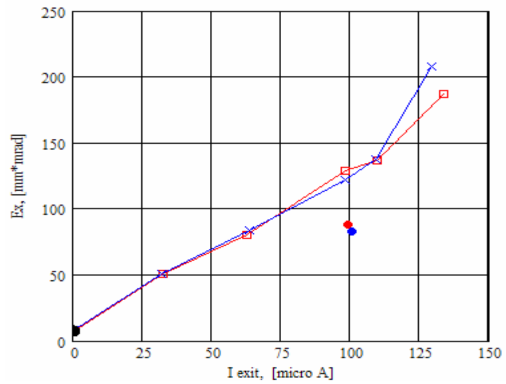

Figure 8: Transverse emmitance.

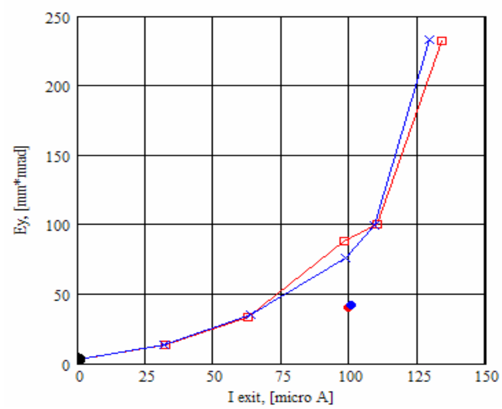

Figure 9: Axial emmitance.

CONCLUSIONS

- The new proposed cyclotron central region configuration permitted a substantial improvement of the final beam quality.
- The present study shows sufficiently larger cyclotron output beam intensity (~272µA - single particle consideration and ~100µA - when space charge effects assumed) as compared with the previous simulations.
- The peculiarities of the present model of the ion source beam made the estimation to be more realistic in comparison with the previous investigations.
- Simulation of the cyclotron–ring transport line has been performed, taking into account the BINP requirements on:
  - Beam quality and intensity
  - Matching to the injection point in the ring
- Dispersion control at the injection point (target N-2) is still to be organized by insertion of the dedicated structure elements in the injection channel.
- Adjustment of the beam transport line parameters should take into account the reference beam intensity emerging from the cyclotron with the space charge effects included in the simulations.
- Transport line elements design is under way.

REFERENCES

[1] V.A.Mashinin et al. Review of the Possibilities of Gamma-Resonance method of HE Detection.

[2] E.E. Perepelkin, S.B. Vorozhtsov, A.S. Vorozhtsov. Dynamical Properties of the Electromagnetic Field of the Customs Cyclotron. RuPAC 2004

[3] A.S.Vorozhtsov, S.B.Vorozhtsov. Magnetic Field Simulation in the Customs Cyclotron. RuPAC 2004.