MOP08

Investigation of Minimized Consumption Power about 10 MeV Cyclotron for Acceleration of Negative Hydrogen

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Abstract

SKKUCY-10 cyclotron with 10 MeV particle energy was designed with purpose of production about fluorodeoxyglucose (18FDG). Design strategy was maximization of accelerating voltage in order to secure the turn separation. Magnet had deep valley type, RF cavity had four stems and one RF power coupler. There was internal ion source for compact design of cyclotron. Specification of cyclotron was analysed by simulating particle dynamics for central region and whole system. AVF cyclotron had 83.2 MHz of radio frequency, 1.36 T of average magnetic field, 40 kV of main accelerating voltage. Phase slip between RF and beam was less than 15 degrees, minimum turn separation was over 2 mm. Specifications of both single beam analysis of reference particle and multi-beam analysis of bunch of particles was calculated by using Cyclone v8.4 and CST-Particle studio codes.

10 MeV Cyclotron Structure

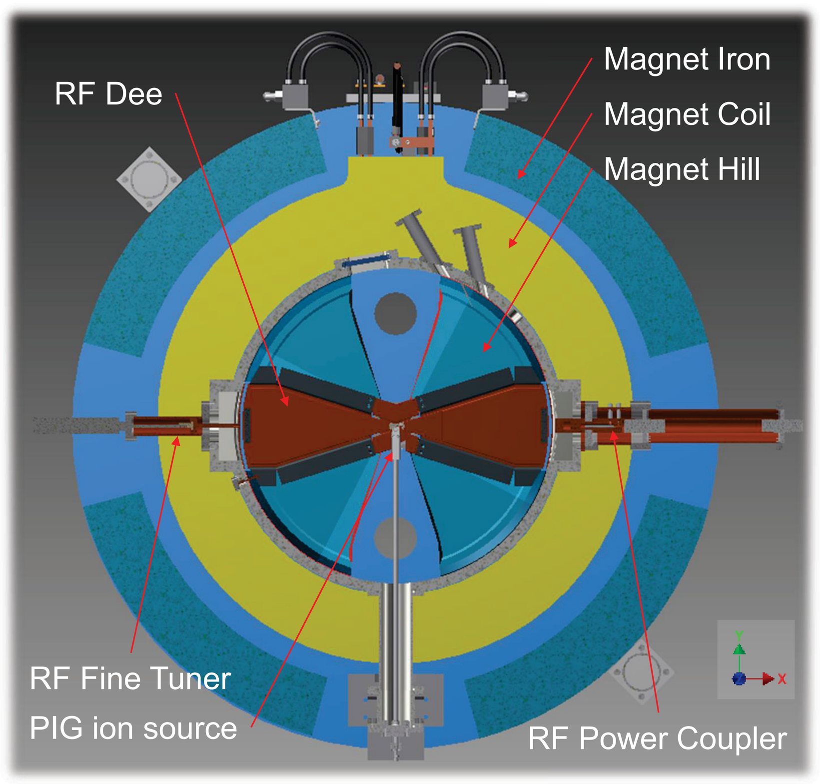

Figure 1. Schematic structure of 10 MeV cyclotron

Table 1. Main specification of 10 MeV cyclotron

Main parameter	Value
Pole Height [mm]	815
Pole Diameter [mm]	1500
Weight [t]	9
Number of Sector	4
Coil Consumption Power [kW]	26
RF [MHz]	83.2
Harmonic	4th
Number of Dee	2
RF Consumption Power [kW]	14
Type of Ion Source	Internal PIG
Ion Source Power [kW]	1.5

- Cyclotron was selected for azimuthal varying field, and deep valley type.
- There were one RF cavity from one RF power, one internal ion source.

Design of Magnetic, Electric field

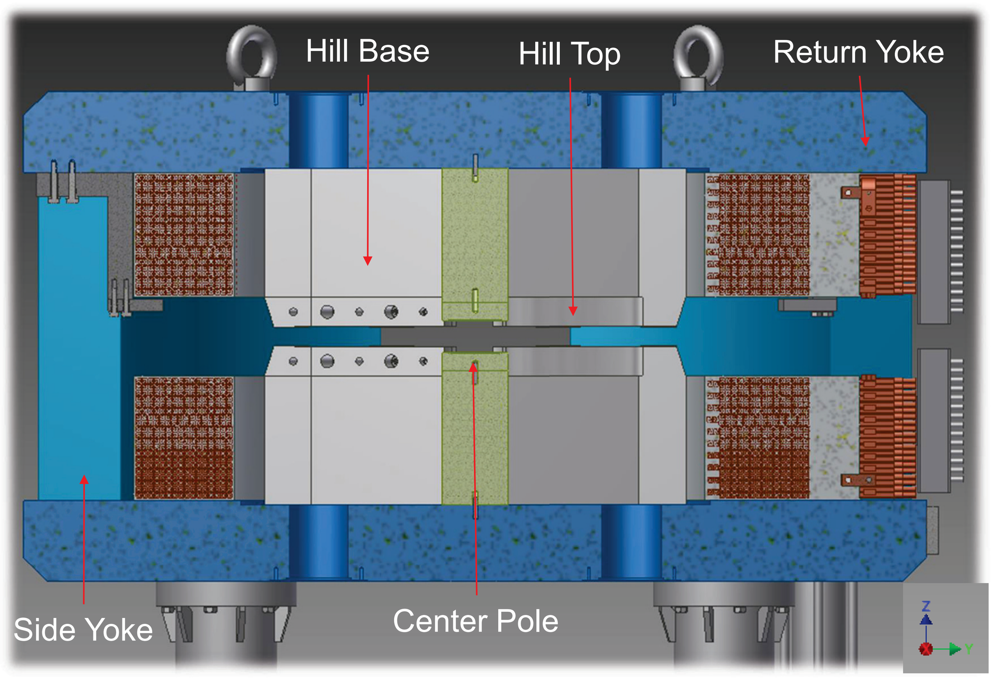

Figure 2. Cross section view for design structure of sector focus magnet

Table 2. Design parameter of cyclotron structures

Design Parameter	Value
Pole Height [mm]	815
Pole Diameter [mm]	1500
Hill Angle [°]	55
Number of Sector	4
Hill / Valley gap [mm]	30 / 560
Coil Cross Section [mm]	195 X 155
Hill Diameter [mm]	730
Liner height [mm]	560
Dee radius [mm]	350
Dee angle [°]	35
Dee-Liner gap [mm]	4-5
Stem radius [mm]	31.8
Stem position from center [mm]	248.2
Dee-Dee gap [mm]	18

- Cyclotron was designed by Inventor code.
- Magnet was consisted of 4 hills, side yokes and 2 center poles and return yokes.
- RF cavity was consisted of 4 RF stems and liners, 1 power coupler and RF tuner.

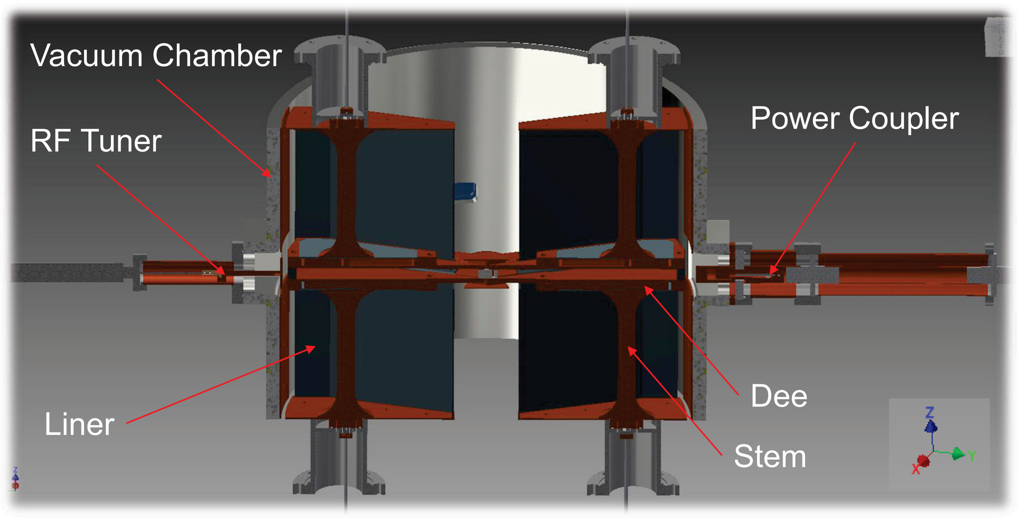

Figure 3. Cross section view for design structure of RF resonator with vacuum chamber

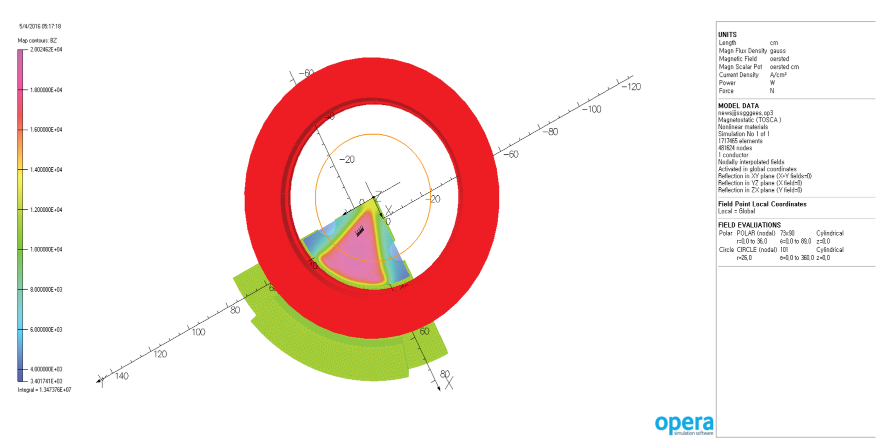

Figure 4. Simulation result of magnetic field on beam plane (z=0) by using TOSCA solver in OPERA3D code (Central average magnetic field 1.36 T)

- For starting the design of magnet, first of all magnetic field was designed to get isochronous magnetic field from isochronous condition.
- Magnetic field was optimized in order to decrease the phase between magnetic field and beam.

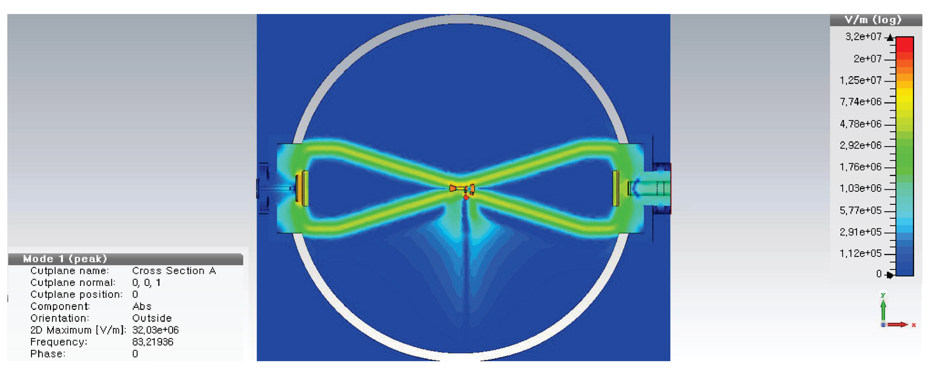

Figure 5. Simulation result of electric field on beam plane (z=0) by using Eigen solver in CST-MWS code (Main dee voltage 40 kV)

- Design goal of RF cavity was minimization of consumption power with keeping the dee voltage to accelerate the particles.
- First the design was considered for electric field with beam acceleration, and then it was done to match RF impedance between RF cavity and power coupler.

Beam specification

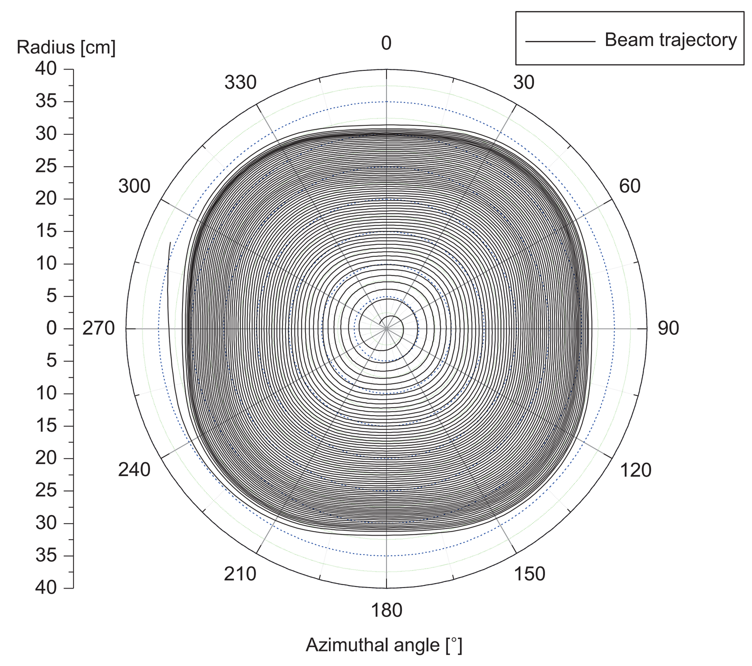

Figure 6. Single beam trajectory from CYCLONE v8.4 code, magnetic field from TOSCA 3D result, electric field from assumption of delta function

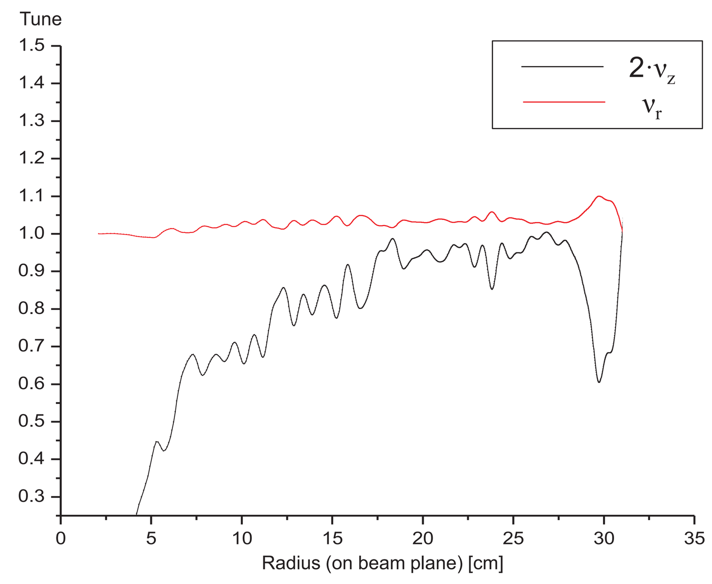

Figure 7. Resonance distribution result from magnetic field from CYCLONE v8.4 code, avoiding dangerous resonance $\nu_r = 2 * \nu_z$ (Walkinshaw resonance)

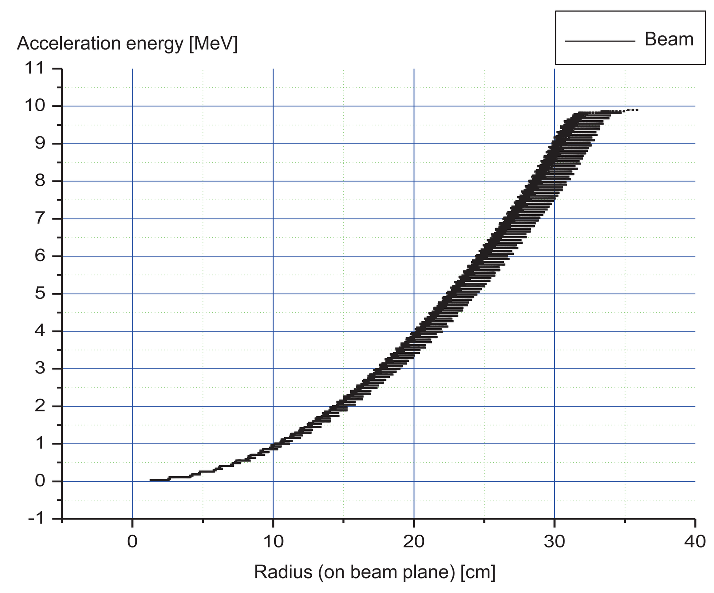

Figure 8. Single beam acceleration energy, Maximum energy 9.8 MeV

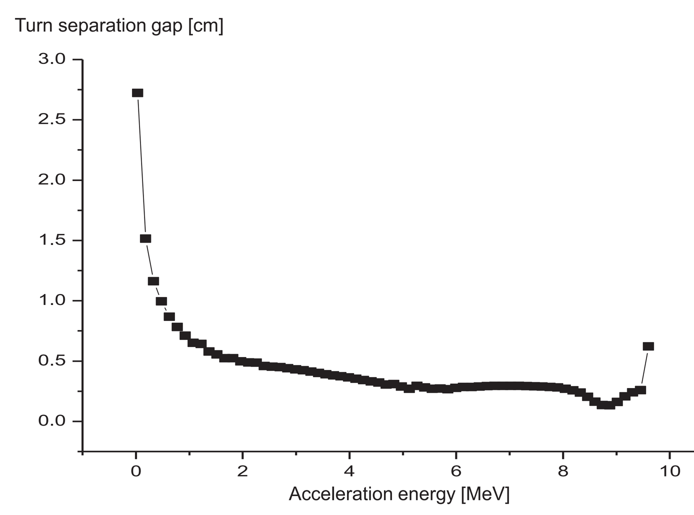

Figure 9. Turn separation distribution according to radius with acceleration energy, minimum turn separation gap is over 2 mm

- Analysis of beam characteristic from 1st turn to final turn was performed by using single particle dynamics.
- Reference particle was checked for acceleration under the designed magnetic, electric field.
- Resonance distribution, energy gain and turn separation were checked by using CYCLONE v8.4 code.

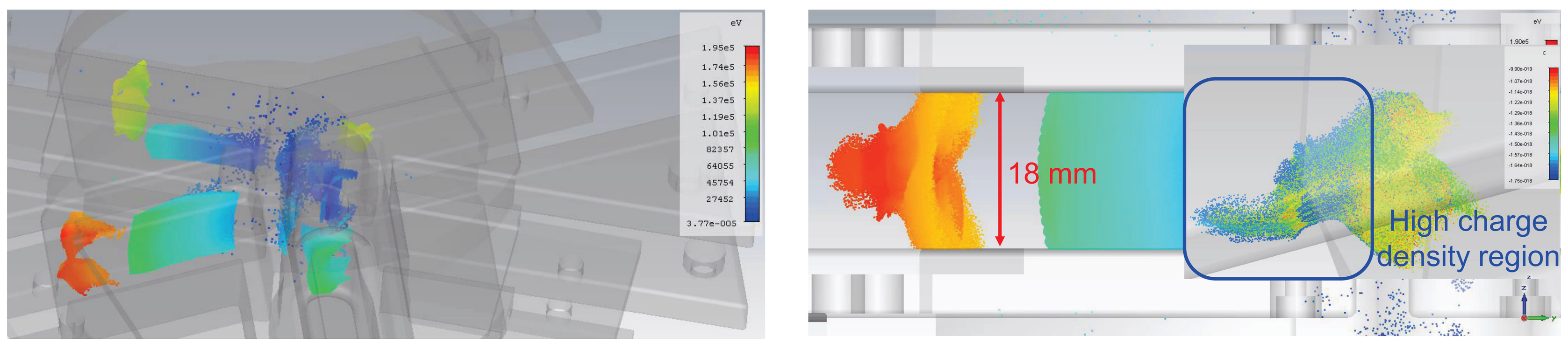

Figure 10. Beam dynamics analysis at central region by using PIC solver in CST-PS, electric and magnetic field were imported Eigen solver in CST-MWS, TOSCA in OPERA3D. (Input beam current is assumed 1 mA at PIG ion source)

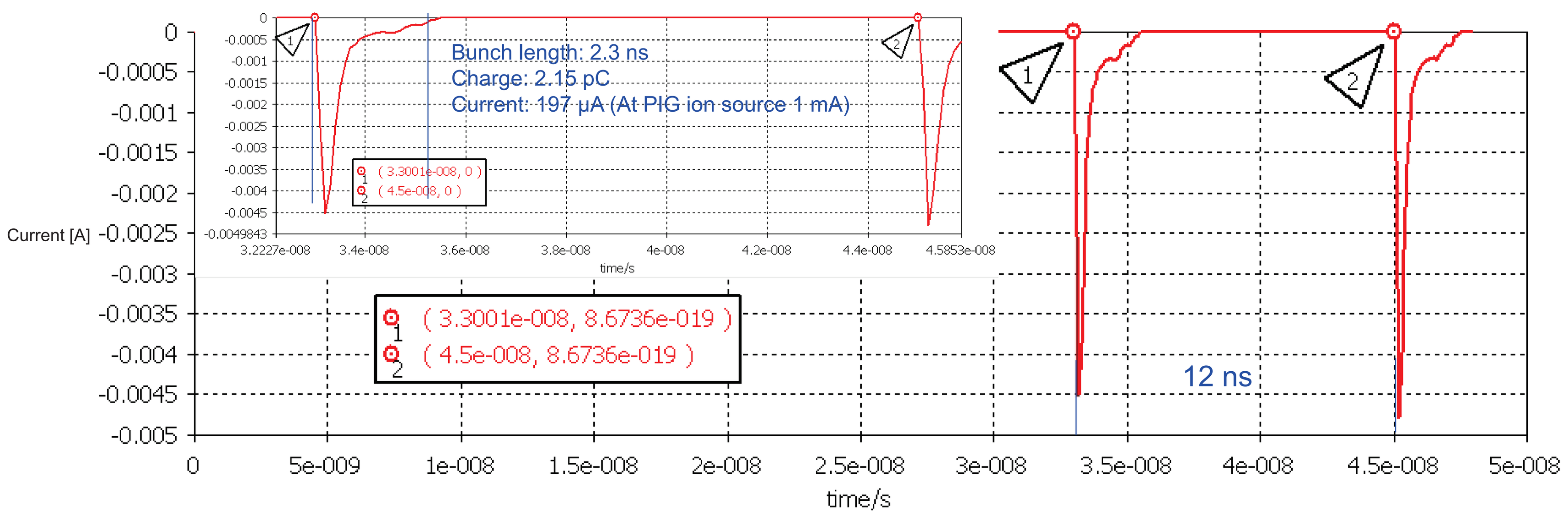

Figure 11. Specification of a bunch after 3rd accelerating gap, Particles in a bunch was projectile at a current monitor, bunching length was 2.3 ns, charge was calculated 2.15 pC, This result was performed with input beam current 1 mA at the ion source.

- Multi particle analysis was performed in order to check beam current and beam loss by using Particle in cell solver in CST-Particle Studio code.
- Electric field was adopted from result of eigen mode solver, magnetic field was imported from result of TOCSA in OPERA3D code.
- One bunch was analyzed after particles were crossed 3rd accelerating gap.

Conclusion

10 MeV cyclotron was designed for increase efficiency of beam current in terms of detail structure of magnet, resonator, and so on. Main specification of cyclotron was selected, 1.5 m pole diameter, 0.8 m pole height, 83.2 MHz radio frequency and 4th harmonics. Total consumption power was about 40 kW for beam power 1 kW (peak energy 9.8 MeV, peak current 90 μA). Magnetic and electric field were designed by using TOSCA in OPERA3D, Eigen mode solver in CST-MWS. These fields were possible to accelerate negative particles it was verified by beam dynamics specifications. Main acceleration was checked from analysis of single beam dynamics by CYCLONE v8.4 code, and low energy part, central region, was analysed as a bunch by using PIC solver in CST-PS. Especially initial beam bunch was analysed after cross to 3rd acceleration gap, peak beam energy 190 keV, charge of a bunch 2.15 pC.

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