DEVELOPMENT AND STATUS REPORT OF MEDICAL CYCLOTRON AT KIRAMS

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Abstract

This paper is presented on the development and status of medical cyclotron at the Korea Institute of Radiological and Medical Sciences (KIRAMS) at present.

We have developed medical cyclotron which is KIRAMS-13. And the improvement of KIRAMS-13 is presented. Furthermore, the design of new cyclotrons, such as KIRAMS-5 and KIRAMS-30 cyclotron, are presented, and R&D studies for future plan of heavy ion accelerator are discussed.

INTRODUCTION

The medical concern with radiation technology has been growing for the last several years. Early cancer diagnosis through the cyclotron and PET-scanner have been brought to public attention by KIRAM cyclotron in Korea. As a part of Regional Cyclotron Installation Project, KIRAMS-13 cyclotrons and [^{18}F]FDG production modules are being installed at regional cyclotron centers in Korea. The KIRAMS-13 cyclotron is a compact low energy cyclotron developed by KIRAMS in 2002. It produces different short-lived radioisotopes, such as [^{18}F], [^{11}C], [^{13}N] and [^{15}O]. The proton beam was extracted at 30 cm corresponding to the energy of 13 MeV. The two Dees with an angle of 39^{o} operated at the normal frequency of 77.3 MHz. Maximum voltage of the Dees was kept at 40 kV. The improvements for KIRAMS-13 system have been performed since last year. It can be possible to reduce the power consumption of the system. After the fabrication of magnet system, shimming operation was execution for exact magnet field. In addition, to obtain the higher intensity of external beams, new central region of KIRAMS-13 cyclotron has been designed. Recently, the needs to develop new cyclotron for radioisotope production and neutron generation are increasing in Korea. It is also suggested that a 5 MeV cyclotron is used as a neutron generator for Born Neutron Capture Therapy (BNCT). The designs of 5 MeV and 30 MeV cyclotrons have been started by KIRAMS. The expected proton beam current is 2 mA for KIRAMS-5 and 300 μA for KIRAMS-30 cyclotron. Despite the fact the final concept of future medical accelerator has not been decided yet, heavy ion synchrotron is being studied.

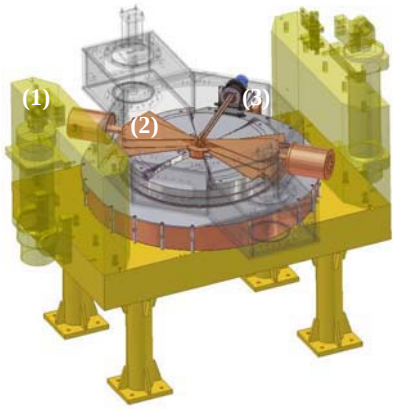
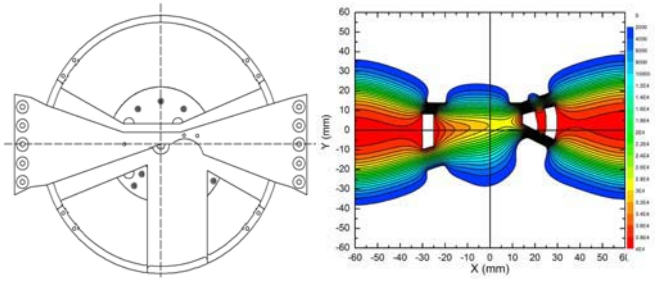


Figure. 1: Overview of KIRAMS-13. (1) Two magnetic poles, (2) A couple of Dees, (3) A PIG type ion source,

IMPOVEMENTS OF KIRAMS-13

New Design of Central Region

In the case of a static magnetic field and time-varying electric field, the relative positions of the gaps can be centered with the best applying in the theory of horizontal motion of ions. It allows to acquire the higher intensity of external beams. Figure 2(a) shows the drawing of new design of the central region, and Figure 4(b) shows the electric potential map which is obtained from RELAX3D program.

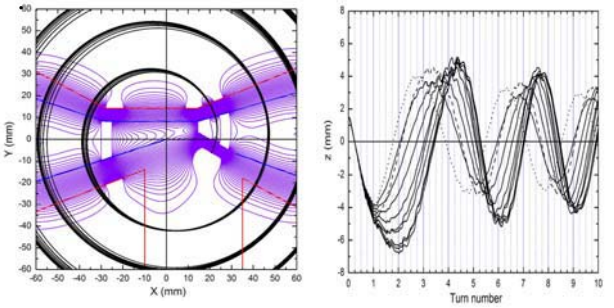


(a) (b)

Figure 2: (a) New design of central region. (b) Electric potential map

Figure 3(a) and 3(b) show the horizontal and vertical trajectories of the ions respectively. The RF phase

acceptance in horizontal and vertical motion is about 55 degrees from 271 to 325. It gives 50 % promotion compared with RF phase acceptance of old central region design.



(a) (b)

Figure 3: (a) Horizontal trajectories of the ions (b) Vertical trajectories of the ions

Magnet improvement

New magnet was used 16 layers and 19 turns coils and hill gap was changed 4 cm. It could be reduced the power consumption of magnet. Opera-3d and TOSCA was used as existed KIRAMS-13 magnet. After the fabrication of magnet system, shimming operation was executed for exact magnet field.

Table 1: Specification of magnet system

	Present magnet	New magnet
Dimension	1.9m×1.2m×1.08m	1.96m×1.3m×1.21m
Weight	14 tons	18 tons
Hill angle	> 30° with radius	> 30° with radius
# of Sectors	4	4
Radial tune	1.022	1.025
Axial tune	0.25 ~ 0.3	0.3 ` 0.36
B_{max}(hill)/B_{max}(valley)	1.92 T / 0.84 T	1.99 T / 0.99 T
Extraction Radius	0.396 m	0.403 m
Pole diameter	0.96 m	0.96 m
Hill / Valley gap	5cm / 14 cm	4 cm / 12 cm
Coil turns	8 layers × 18 turns	16 layers × 19 turns
Excitation current	466 A	135 A
Power	36 kW	12 kW
Material of the yoke	Low carbon steel (S10C)	Low carbon steel (S10C)

RF Simulation & Experimental Results

The RF resonator system is designed with CST MicrowaveStudio(MWS) which is the specialist tool for the fast and accurate 3D EM simulation of high frequency problems. Two 39° dees are located in two valleys. Total length of each dee is 50cm. The distance between the dee and the liner is 3.9cm. Applied voltage is 45kV.

Vector distribution of electric field is shown in Fig. 4. Since electric field is formed vertically to dee edges, it is adequate to accelerate ion beam.

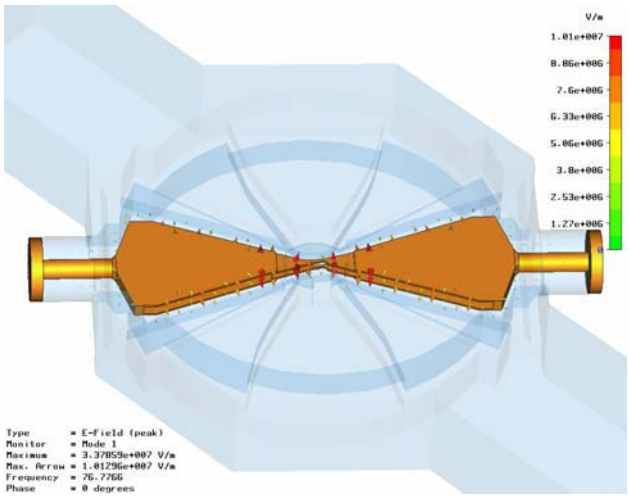


Figure 4: Vector distribution of electric field

Table 2: RF constituent elements

Resonant Frequency	77.3 MHz
Harmonic Number	4^{th}
Dee Voltage	45 kV
Cavity Shape	Coaxial Type
Resonant Mode	λ/2 fundamental mode
Matching Impedance	50Ω
Material	OFHC copper & Diamagnetic material
Cooling Capacity	30 kW
Pole Gap	12cm
Hill Angle	> 30 degree with radius

DESIGN OF NEW CYCLOTRON

KIRAMS-5 cyclotron

The design of low energy and high current cyclotron used as a neutron generator has been started. It is proposed that a 5 MeV cyclotron consists of four sectors of magnet and two Dees of RF system. To guarantee over 1 cm for the turn separation in the last orbit, the constant magnetic field at the magnet center, and Dee voltage were chosen to be 0.8 T and 100 kV, respectively. When the angle of Dee gap center is 43^{o}, the maximum energy gain per turn was given to 399 KeV. Therefore, to reach 5 MeV proton beam, the total 13 number of turn was required. To increase the axial focusing force, the deep valley structure has been employed. The extraction radius was calculated as about 40 cm, and a sector radius was estimated as 45 cm considering the magnetic fringe field at the end of sector. The radial and axial tune, frequency error, integrated phase shift, and average magnetic field

are calculated by using equilibrium orbit program [2]. Figure 5 shows the distribution of average magnetic field versus the radii of equilibrium orbits. Figure 6(a) and 7(b) show the cross-sectional view of the cavities and the Dees in the mid-plane.

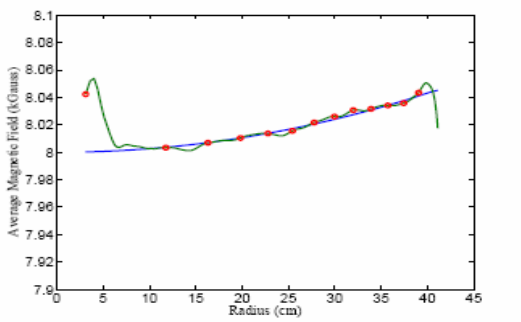
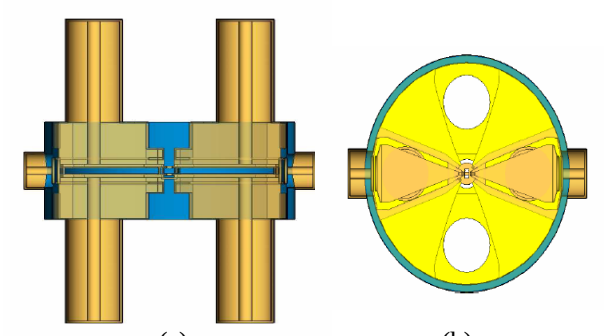


Figure 5. Average magnetic field versus the radius



(a) (b)

Figure 6. (a) Cross-sectional view of the cavities (b) Cross-sectional view of Dees in the mid-plane.

KIRAMS-30 cyclotron

In order to produce gamma emitting radioisotopes by the various (p,xn) reactions, a cyclotron for 30 MeV proton was suggested. Up to now, it was given an outline of specifications of KIRAMS-30 as shown in table 3. The designs of several components, such as magnet, RF, ion source, vacuum chamber and control system are being studied

Table 3: Specification of KIRAMS-30

Extraction Beam Energy	15 ~ 30 MeV
Extraction Beam Current	300 μA
Injection system	
Ion source type	Multi-cusp
Ions	H^- , D^-
Max. output	5 mA
Inflector type	Spiral
Magnet system	
B0 (Tesla)	1.15
Number of sectors	4
Hill gap (cm)	3
Valley gap (cm)	18
Magnet power	10 KW
RF system	
Frequency (MHz)	70
Harmonic number	4
Number of Dees	2
Number of Cavities	4
RF power (KW)	30
Coupling	Capacitive

FUTURE PLAN

In 2003, KIRAMS and the city government of Busan in Korea had agreed to cooperate in the construction of a new hospital for cancer treatment in Busan. The city government of Busan also desired to build a Heavy Ion Therapy Center and cooperate with KIRAMS in the development of heavy ion accelerator.

In 2005, we will start to install KIRAMS-30 at Korea Advanced Radiation Center. With KIRAMS-30, we will produce medical radioisotopes such as Tl-201, I-123, Ga-67.

In spite of the fact that the final concept of future medical accelerator has not been decided yet, heavy ion synchrotron has been studied. R&D study for a future accelerator will be carried out in collaboration with several international laboratories and several companies.

CONCLUSION

The KIRAMS-13 has been modified for lower power consumption of magnet system by decreasing the hill gap and increasing the number of coil turns and also for higher beam current at extraction by increasing RF phase acceptance in the central region.

The design of KIRAMS-5 with the energy of 5 MeV and beam current of 2 mA has been progressing for a neutron generator. The determination of specifications for KIRAMS-30 was performed.

Most subjects of R&D study for a future heavy ion accelerator in Korea will be investigated in international collaboration.

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