DEVELOPMENT OF MEDICAL CYCLOTRON IN 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.

1. 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 cyclotron have been already finished by KIRAMS. The expected proton beam current is 2 mA for KIRAMS-5 and 300 A 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.

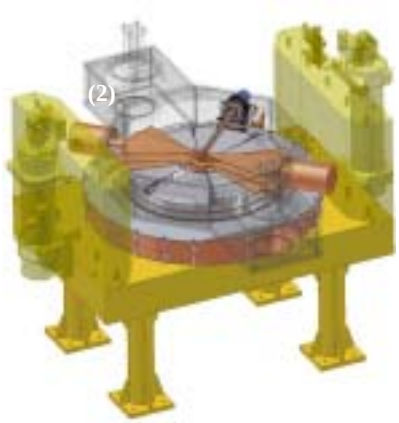
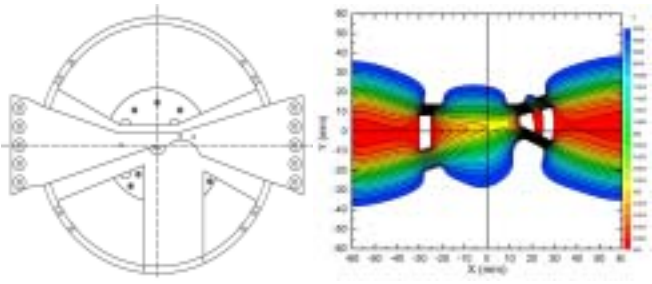


Figure. 1: Overview of KIRAMS-13. (1) Two magnetic poles, (2) A couple of Dees, (3) A PIG type ion source,

2. KIRAMS-13 Technology

Central Region

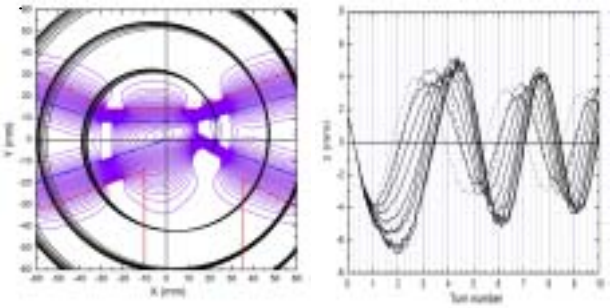
In the case of a static magnetic field and time-varying electric field, the relative positions of the gaps can be centered with the best applying in the theory of horizontal motion of ions. It allows to acquire the higher intensity of external beams. Figure 2(a) shows the drawing of new design of the 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 layer 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.

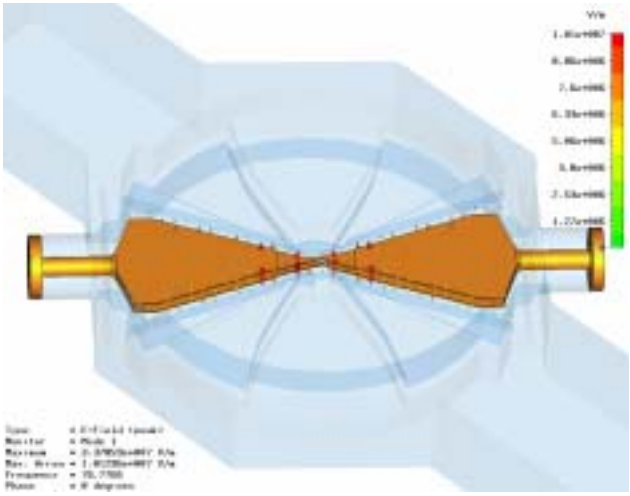


Figure 4: Vector distribution of electric field

Table 2: RF constituent elements

Resonant Frequency	77.3 MHz
Harmonic Number	4th
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

Fig. 5. KIRAMS cyclotron installed at KNU regional cyclotron center

RI PRODUCTION SYSTEM

Development of RI production system [^{18}F]FDG is a widely used radiopharmaceutical for positron emission tomography (PET). KIRAMS [^{18}F]FDG production module has been designed, manufactured and evaluated. The quality of [^{18}F]FDG was proven to be suitable and safe for clinical use. KIRAMS [^{18}F]FDG module has shown high production yield (51±2% in average at EOS) with reproducibility and has been used for routine production with KIRAMS-13 cyclotron(Fig.5).

Fig. 6. [^{18}F]FDG production module installed in hot cell, KIRAMS.

The upgrades for KIRMAS-13 system have been performed since last year. The system for [^{18}O] water titanium target with double grid system has been designed and manufactured to improve the target system for obtaining a high [^{18}F] yield. In addition, to obtain the higher intensity of external beams, new central region of KIRAMS-13 cyclotron has been designed. The RF phase acceptance is more than doubled in the new central region. The magnet design was changed to reduce electric power consumption. The length of a pole gap was shortened by 20 mm and number of coil turns was increased to 16X19. It allowed 67% reduction in electric power consumption of magnet system.

Recently, the needs to develop new cyclotron for radioisotope production and neutron generation are increasing in Korea. The developments of 5 MeV and 30 MeV cyclotron has been started by KIRAMS. The expected proton beam current is 2 mA for 5 MeV cyclotron and 300 A for 30 MeV cyclotron.

In this paper, we report on the improvement of KIRAMS-13 cyclotron, the design of 5 MeV and 30 MeV, and the future plan of KIRAMS.

Double-grid [^{18}O] water target

Fluorine-18 is widely used radio-isotope in positron emission tomography. Material of the target, shape of cavity for [^{18}O] and cooling mechanism have been changed as the research has performed. All different structures of targets were developed to get better performance for good yield and long running time without maintenance at high energy. Materials were chosen to overcome [^{18}F] impurity. Shape of the cavity has been changed to overcome the phase change problem and cooling methods are getting smarter to make the target work in more high energy circumstance. Water-cooled grid support system has better structural strength than double-foil system. The main parts of double-grid target are shown in Figure 3. Material of cavity and foils are titanium. The shape of cavity has two different geometries along beam incident direction. The front volume has a cylinder shape and the back cavity has a fan shape with larger volume to gather ascent vapour bubbles and increase heat transfer area. Total volume of cavity is 1.6 ml. Both open sides of cavity are blocked with 50 μm titanium foils. Two grids of aluminum are placed out side of each foil. Grids were adapted basically to cool foils and prevent their thermal expansion under high pressure. Front water cooled type gird is directly place in the vacuum beam line. This grid has water channel to be cooled. The titanium foil cooling performed by the front grid by only conduction. Rear part cooling mechanism consists of water impinging jet cooling. The functions of rear gird for cooling are increase the turbulence of impinging water jet and increase the cooling surface.

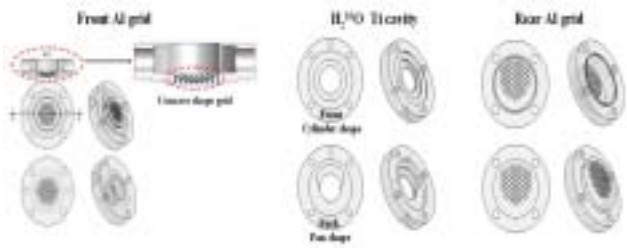


Fig. 7. Aluminum double-grid and titanium cavity structures

In order to evaluate the performance, 13MeV proton had bombard to target with beam current 10 μA, 20 μA, 30μA and 40 μA for one hour. According to the result, the cooling performance of double grid system is excellent. The results of [^{18}F] yield are shown at Figure 7.

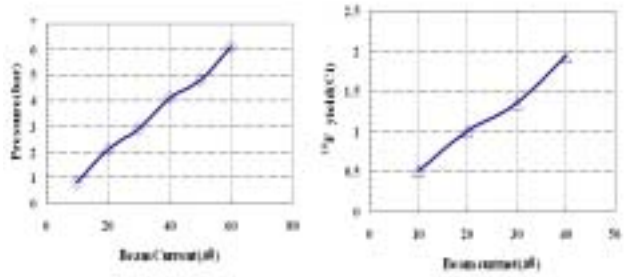


Figure 8. RI production yield depend on beam current

3. Conclusion

In this year, Two KIRAMS-13 cyclotrons was installed Kyungbuk Univ. Hospital in Taegu and Chosun Univ. Hospital in Kwangju. These cyclotrons produce radio isotopes especially FDG with FDG synthesizer. FDG synthesizer will be serve same time with KIRAMS-13, it also designed by KIRAMS. And produce short lived radio isotopes for the regional area in Korea.

All these improvements lead to averaging operation ratio, beam current, and lower costs to produce PET isotopes. KIRAMS-13 cyclotron for regional cyclotron center will be increase a healthy condition of Korean people.

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