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IMPROVEMENT OF THE KIRAMS-13 CYCLOTRON FOR REGIONAL CYCLOTRON CENTER

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Abstract

Korea Institute of Radiological & Medical Sciences (KIRAMS) has developed PET-dedicated cyclotrons as well as a large ranged of targets and automated chemistry modules. First version of Kirams-13 was developed in 2002 with a mission to PET radioisotopes. And now, KIRAMS cyclotron was adapted for the more than five regional cyclotron center in Korea. For that reason, cyclotron for regional cyclotron center needed to be good performance, reliable, user-friendly and low power consumption. This paper presents the design and successive improvements of cyclotron for regional center.

1. INTRODUCTION

The Production of PET isotopes represents a significant in diagnosis of cancer. The requirements of very short lived isotopes however lead to different approaches. In particular the production of isotopes with long enough half-lives that long distance distribution is practical, and yet sufficiently short that just in time production is required and very short distance are needed. In particular they must be produced at or very near the PET centre. That is reason to increase a baby cyclotron market.

The Korea Institute of Radiological & Medical Sciences, who developed a first version of 13MeV H- cyclotron in 2002. The choice of 13MeV for the energy is expected to allow production of isotopes for Positron Emission Tomography applications.

Regional cyclotron is required good performance, reliable, user-friendly system, easy maintenance and low running cost.

The new version of KIRAMS-13 was design for decrease the electric power consumption less then half of first version. So, Magnet system was almost fully changed. And the other important parts were included. Status of various system and components of Kirams-13 is described in the following section.[1][2]

2. CYCLOTRON SYSTEM

Cyclotron Magnet has a Pole diameter of 96cm and beam would be extracted at 39.6cm radius. The design calls for a four–Sector radial ridge geometry with the magnetic field ranging between 1.99T in the hill and 0.84T in the valley respectively, resulting in a average field of 1.3T. There will be 43.5 degree of dees and fixed operating frequency for RF system will 77.3MHz. Maximum dee voltage is 40kV. The acceleration chamber is evacuated, primarily, with the help of two Diffusion Pumps.

Charactersitic Beams	Ions	Protons, Deuterons
	energy/ current	13MeV / 50mA
Magnet	type	Compact H-type
	# of sectors	4
	pole diameter	0.96 m
	hill/valley gap	4 cm / 12 cm
	n_r / n_z	1.025 / 0.3~0.36
	B_{max} (hill) / B_{max} (valley)	1.99 T / 0.99 T
	Coil current	141.6 A
	power	12 kW
RF	frequency	77.3 MHz
	harmonic #	4
	# of dees	2
	dee angular width	43.5 °
	dee voltage	45 kV
Extraction	Charge Exchange Carbon Foil	
Ion Source	Internal Cold Cathode PIG	

Table 1 General Specifications

2.1 Main Magnet Frames.

The Main Magnet frame which provides return path for the magnetic flux are made from low carbon steel forgings. This H-type structure is made of six major parts i.e. upper and lower pole caps, upper and lower return path and left and right return path wall. There are four pairs of sectors bolted to the upper and lower pole caps and iron are used S10C by POSCO.

New version magnet was using 16 layer and 19 turns coils. It can be possible to reduce the power consumption of magnet. Computer simulation code was using Opera-3d and TOSCA. After the fabrication of magnet system, shimming operation was execution for exact magnet field.

	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)

Table 2 Magent System

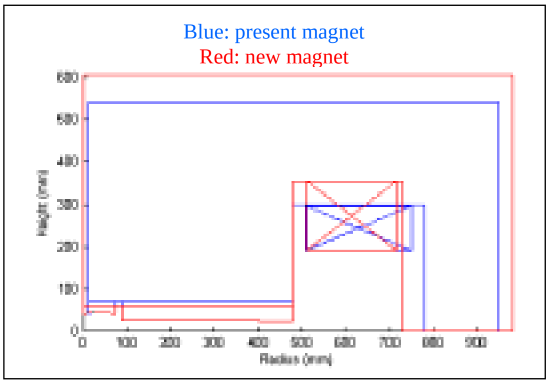

Figure 1 Magnet System Layouts

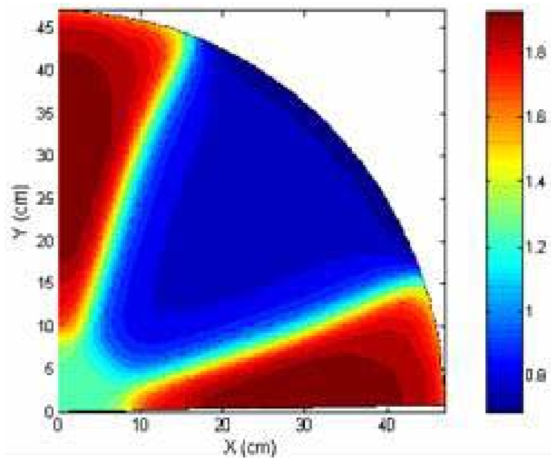

Figure 2 The Measured magnetic field distribution

2.2 Radiofrequency System

Magnet design was changed to reduce electric power consumption. It was shortened the length of a pole gap by 20mm, and reduced 70% of electric power consumption. So, we had to consider RF system design as a result of changing magnet design. But, main RF parameters, such as resonant frequency, RF power, dee structure, cavity structure, and so on, were not changed to reduce cost and time of production. For satisfying these preconditions, we only redesigned liner and center block. In the paper, we describe RF simulation results focused on the change of structures using CST MicroWave Studio(MWS) and the progress being made in production work for regional cyclotron center.

The accelerating system comprise of two dees placed in valleys. Harmonic number of KIRAMS-13 is four. Two λ/2 resonators are attached in chamber horizontally, opposite side, through the magnet pole cap as shown in figure 3 and 4.

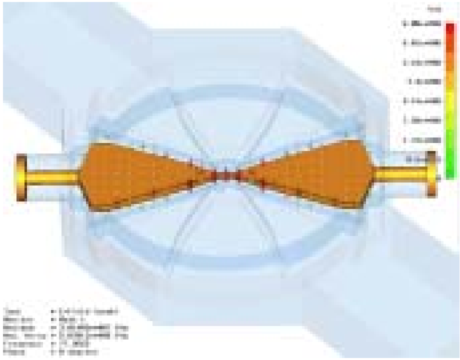

Figure 3 Eelctric field vector distribution

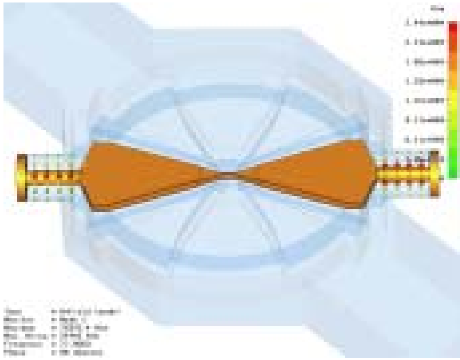

Figure 4 Magnetic field vector distribution

Each resonator consists of cylindrical cavities. These cavities are short circuited transmission and comprises of coaxial inner and outer conductors made of OFHC. Final amplifier can be 20KW and three main amplification stages.

2.3 Ion Source System

H- ions are injected internal PIG type source. Inflector are used at the cyclotron centre for inflection

The electric field distribution in the central region has been numerically calculated from an electric potential map produced by the program RELAX3D. The magnetic field distribution has been measured experimentally. The geometry of the central region has been tested with the computations of orbits carried out by means of the acceleration beam tracking method. The optical properties and acceleration characteristics in the central region were studied by using the information obtained from the beam tracking code and beam traces obtained experimentally.

Type	Cold Cathode PIG	
Cathode	Tantalum	
Cooling	Water Cooling	
Injection	Type	Internal
	Ion	H^-
Slit	Width	0.60 mm
	Height	4.00 mm
Anode	Tungsten / Coper alloy	
Arc	Voltage	0.3 ~ 1 kV
	Current	Max. 2 A
Gas	Type	Hydrogen
	Flow rate	3 ~ 8 sccm

Table 3 Specifications of PIG Ion Source

Figure 5 Ion Source installed in the cyclotron

2.4 Extraction System

As in all circular accelerators, one of the most difficult problems is extracting the beam once it has reached the desired energy. H+ particle accelerator extraction efficiencies in the 75% region are not uncommon. H- particles are accelerated, they can be extracted simply by stripping, using a thin foil to intercept the beam. Kirams-13 employed the H- type system and extract with automatically three-fork change carbon foil system.

First the beam sizes at the several radial positions around the extraction position have been measured to find the position of the largest beam size. Using the generalized equilibrium orbit program of GENSPEO and the position of the largest beam size, we can obtain the energy at the position. In order to configure a beam transport line and study the beam emittances, the beam trajectories after stripping have been calculated with the conventional beam tracking method. From this work the optimized position of the stripping carbon foil and the structure of beam transport line to the target system have been constructed in the KIRAMS-13 cyclotron.

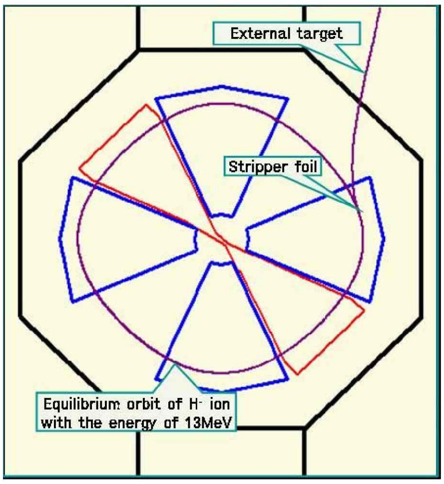

Figure 6 Stripping extraction layout

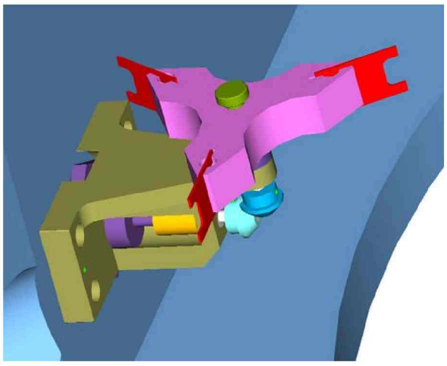

Figure 7 Carbon stripper foil holder

However, the second H- electron is fairly weakly bound(0.755 eV) and so may be lost due to interaction with the background gas. To reduce vacuum stripping, Kirams-13 cyclotron improve the vacuum system.

2.5 Vacuum System

KIRAMS-13 for regional cyclotron center was adapted a two diffusion pump system for reduce vacuum stripping. For this reason KIRAMS-13 was changed a chamber system for the new diffusion pumps. It can be under 5 $*10^{-6}$ torr less than two hour after the nitrogen ventilation.

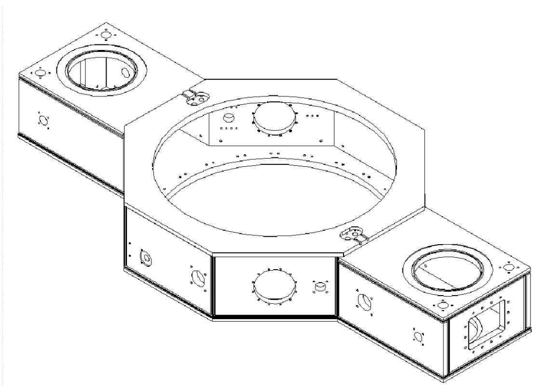

Figure 8 Vacuum Chamber

2.6 Control system

Cyclotron has several independent control devices. For example, cyclotron consists of the magnet power supply as like main power supply of high output, vacuum system, RF system, RF fine tuner, ion source, beam diagnostic device and cooling system. In addition, each device due to being one or several devices includes controller for control them. KIRAMS-13 cyclotron developed the first in Korea at Cyclotron Application Laboratory in KIRAMS. Controllers of KIRAMS-13 automatically communicate with each other in order to maintain the cyclotron to be the best condition. And control system of KIRAMS-13 was designed the distributed control system method in order to fast communication and protective systems. Cyclotron needs the continuous monitoring because of produce RI for several hours. Therefore control system informs operator an analysis about all input and output signal of cyclotron and current situation. And in case of providing cyclotron's trouble, this is organized easily user-friendly control program. Each device basically uses RS-485 in order to use asynchronous communication that hardly error during communication with the main computer. In this work, we will present to improve control system based on LabVIEW program through analyzing the device control of existing cyclotron

This cyclotron and FDG synthesize system are support a user friendly type control system. It provide high-end graphic interface for operator and hard ware interfaces may be add-on cards for PC, PLCs and/or microcontrollers. It can be possible to Auto tuning just a touch in menu of control system.

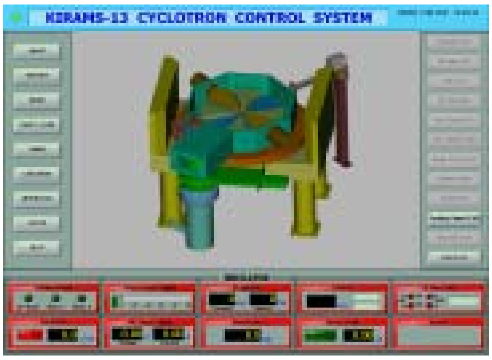

Figure 9 Cyclotron Control System

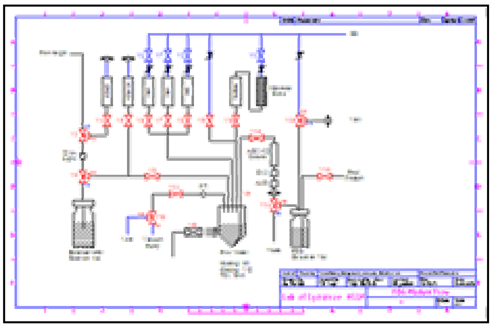

Figure 10 FDG Synthesizer system

2.7 Target system

Target construction and performance are presented and new target model, which is in progress, for better performance to get higher yield production of [18F] will be presented. The satisfied final target design will be provided with KIRAMS-13.

Kirams-13 cyclotron is employed F-18 target with roulette system. It can be possible to connect C-11 target system. F-18 target system using 1.5ml O-18 water and fully automated for the load system. Water targets were constructed to produce high yield of [18F]fluoride from enriched [18O]water. Targets are designed to install on the 13MeV KIRAMS-13 medical cyclotron. The aluminum body, half sphere titanium back targets are characterized a small volume and operate at medium pressure. The double-foil helium windows were installed, which can safely accommodate proton beam to the [18O]water.

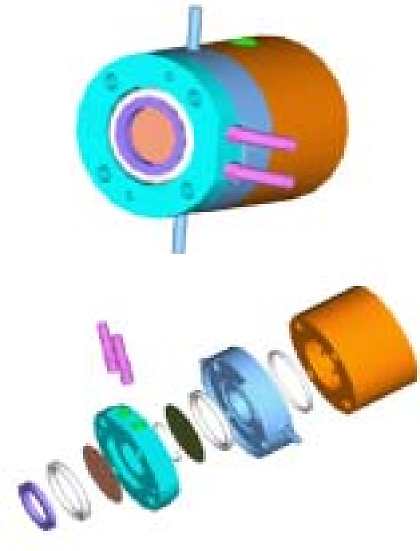

Figure 11 O-18 Water Tagetry System

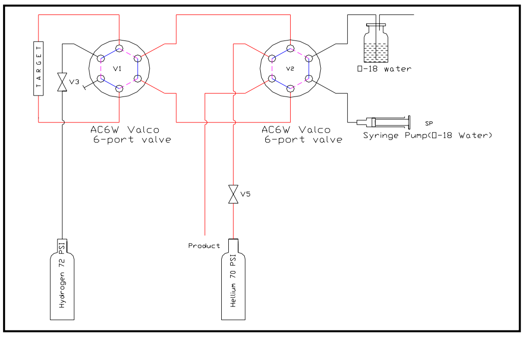

Figure 12 Target Loading System

3. CONCLUSION

In this year, Two KIRAMS-13 cyclotrons will be install Kyungbuk Univ. Hospital in Taegu and chosun Univ. Hospital in Kwangju. This cyclotron will be 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.

4. REFERENCES

[1] M.Yoon, et.al. “Initial Design of a 13 MeV Cyclotron for Positron Emission Tomography,” APAC98 (1998)

[2] Bruce F.Milton. “Commercial compact Cyclotron in the ‘90s,” proceeding of the 14^{th} international Conference(1995)