NEW DESIGN AND DEVELOPMENT OF 13 MeV PET CYCLOTRON IN KOREA*

J.S.Chai†, J.H. Ha, H. Y. Lee, Y. S. Kim, KCCH, Korea
S. Oh, M. Yoon, Dept. of Physics, POSTECH, Korea

Abstract

Since 1997 design studies have been in progress in a joint collaboration between the Korea Cancer Center Hospital (KCCH) and the Pohang University of Science and Technology (POSTECH) for a 13 MeV PET (Positron Emission Tomography) cyclotron. It will accelerate H^- (negatively charged hydrogen) ions, which, after acceleration, will be stripped of its electrons by a stripping foil and then, on entering the target chamber, interact with the target material to produce positron emitters such as ^{18}F, ^{15}O, ^{13}N and ^{11}C. In this paper we describe the main features of the cyclotron.

1 INTRODUCTION

The era of nuclear medicine started in Korea in the 1960s when the research reactor TRIGA Mark-2 (which was installed at the site of the former Korea Atomic Energy Research Institute in Seoul) began to supply radio-isotopes to KCCH. By the early 1980s however, it was recognized that the species of radio-isotopes that were available from the nuclear reactor were rather restricted and therefore it was felt that an isotope production cyclotron was needed. In 1986 the KCCH's 50 MeV cyclotron, which was built and supplied by Scanditronix, started operation to produce radio-isotopes on site. In the mid-1990s, the benefits of the PET began to be recognized by some of the major hospitals in Korea and, by 1996, two hospitals in Seoul, Korea had installed in-house PET cyclotrons. At KCCH, increasing desire for an uninterrupted, reliable and timely supply of the radio-isotopes to customers and patients has prompted obtaining a dedicated 5-13 MeV cyclotron for PET applications (this energy range contains one of the optimum yield peak for ^{18}F production) and, at the same time, pursuing the purchase of another 30 MeV medical cyclotron for isotope production in the very near future. A decision has been made to obtain an in-house built PET cyclotron this time. This will not only ease the problems associated with maintenance during operation but will also keep the door open for continuous upgrading of the machine in the future. The project is supported by the Ministry of Science and Technology of the government, as a part of the 2nd phase of the mid- and long-term nuclear energy research plan. The cyclotron design study project was approved in 1997, but a formal approval for construction is expected to be given in April 1999. The cyclotron consists of a cyclotron magnet, rf dees and resonators, the vacuum chamber, an ion source, power supplies, an H-beam stripping foil and its holders, internal targets and chambers, and control systems. In the following sections, the design features of the cyclotron magnet, dees and resonators and the ion source will be described.

* This work is supported by Ministry of Science and Technology of Korean government

† Email: jschai@kcchsun.kcch.re.kr

Table I : Main parameters of the 13 MeV PET cyclotron

Parameter	Unit	Value
Maximum energy	MeV	13
Beam species		Negative hydrogen
Number of sectors		4
Ion source		Internal negative PIG
Hill angle	degrees	46.0
Valley angle	degrees	44.0
Maximum average magnetic field	T	1.2
Harmonic number		4
Radio-frequency	MHz	72
Maximum average radius of a beam	cm	43
Maximum orbit distance from the cyclotron center	cm	45
Maximum magnetic field at the hill center	T	1.85
Maximum magnetic field at the valley center	T	0.48
Beam current	μA	$\sim$20

2 CYCLOTRON MAGNET AND CYCLOTRON DESIGN PARAMETERS

The cyclotron magnet consists of poles, pole-tips, return yokes, top and bottom return plates and excitation coils. The magnet has a four-sector radial ridge geometry with a rather large valley-gap to hill-gap ratio. This choice, together with the choice of the fourth harmonic mode of operation for particle acceleration, will provide relatively strong axial focusing while at the same time leaving ample space for placing dees. Table I shows the main design parameters for this 13 MeV PET cyclotron. The hill is constructed from eight pieces of wedge-shaped high quality, low carbon content (0.003 %) steel plates with a wedge angle of 46 degrees. The angular width measured from the center of the cyclotron will, however, be a varying angle from close to zero near the center of the cyclotron to close to 46 degrees near the outer edge of the cyclotron. The side edges of these plates are stepped to provide bolt holes to attach the plates to the poles. The inner surface of these plates are also stepped progressively with radius to provide an appro-

0-7803-5573-3/99/$10.00@1999 IEEE.

priate isochronism throughout the radius. The step heights needed are calculated using TOSCA [1], a commercially available three dimensional magnetic field program. The accuracy of the magnetic field predicted by the program is expected to be in the range of 2%. Fig. 1 is a schematic diagram of the cross sectional view seen from a side. A 16 cm diameter hole in each valley is provided to serve for pumping and rf power connection to the dees. A more detailed description for the magnetic field is presented separately in these conference proceedings and elsewhere [2, 3].

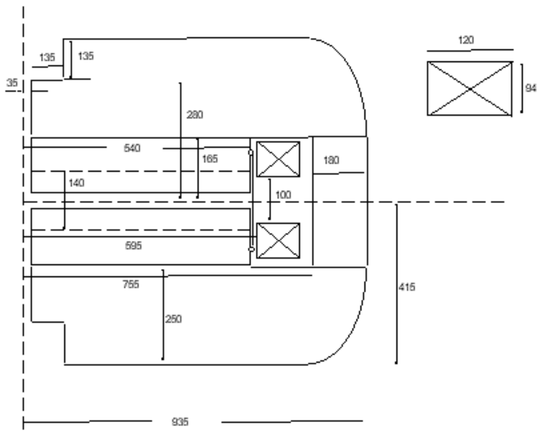

Figure 1: Cross-sectional side view of the cyclotron.

3 DEES AND RESONATORS

The dees we aim to design are supposed to provide an energy gain of 160 keV per H^- ion revolution in the magnetic field of the cyclotron. We decided to accelerate the ions in the fourth harmonic mode of particle revolution frequency, corresponding to 72 MHz. Accordingly a pair of dees with azimuthal width of 43.6°, radial length of 48 cm, vertical height of 3 cm with a vertical gap of 1.25 cm between the dee and the liner, was design studied. The power will be fed to the dee-resonator system by an inductive coupling. For the design studies we used SOPRANO, a commercial software supplied by the Vector Field Company. With the use of this software the rf electric field in the region between the dee electrode and the ground shield liners are investigated. The result showed that, to obtain 40 kV peak-to-ground rf voltage we need 10 kW in rf power. The appropriate dimensions of the rf dee and cavity can be obtained from the effective $\frac{\lambda}{4}$ wave method with zero-impedance at 72 MHz and it turns out to be 124 cm. In the design of the above resonator, due consideration was given for the dee-dee liner distance and the co-axial cavity length. The zero crossing result is shown in Fig. 2.

The adequacy of the chosen dimensions for the dee-resonator system was comfirmed from the voltage-current relation as a function of cavity length. As shown in Fig. 3., the cavity resonates at 72 MHz and maintains almost constant voltage distribution over the entire dee length. A test bench cavity was constructed for further study in the very near future.

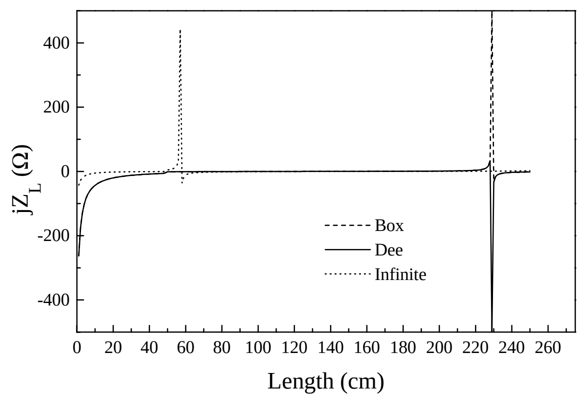

Figure 2: Calculated impedance as a function of cavity length.

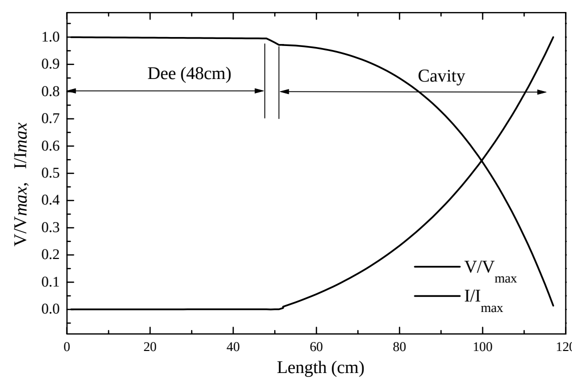

Figure 3: Current and voltage distribution as a function of cavity length.

4 INTERNAL PIG SOURCE

An internal PIG source is located near the center of the cyclotron magnetic field and produces H^- ions. The H^- PIG source is known to release a large amount of hydrogen gas (both atomic and molecular) out into the cyclotron central region. To minimize the gas stripping losses of the accelerated H^- ions, we plan to install two diffusion pumps with 20 cm diameter. A pair of 16 cm vertical holes are provided in each valley of the cyclotron magnet. Fig. 4 shows the schematic diagram of the PIG ion source.

The cathode is envisaged to be made of LaB_6 with tantalum coating. A prototype PIG source was constructed and is now placed in a circular magnet with a field strength of 0.4 Tesla. The source is being tested and studied for further improvements. Computer studies of the beam dynamics from the ion source through several turns will be carried out. At the same time, we are constructing a model of the 13 MeV cyclotron central region to carry out experimental beam dynamics studies for up to 1 MeV acceleration. The model cyclotron has a uniform magnetic field of 1.2 Tesla, a figure which is identical to the field strength at the center of the 13 MeV cyclotron. A pair of dee-tips will be installed inside and 40 kV of rf at 72 MHz will be fed to it. The purpose is to investigate the optimum central region geometry experimentally as well as theoretically.

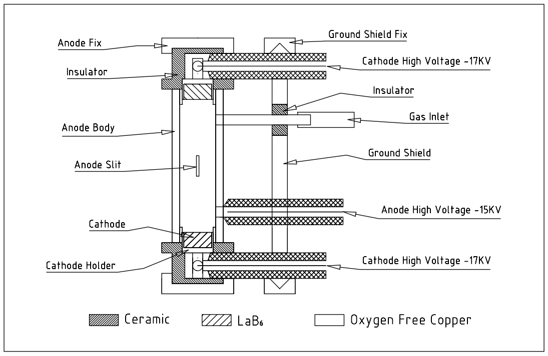

Figure 4: Schematic drawing of the PIG ion source

5 CONCLUSION

Design studies for a 13 MeV PET cyclotron are underway in KCCH and POSTECH. It is aimed at operation in 2002.

6 REFERENCES

[1] Commercial package by Vector Fields Co.

[2] M. Yoon, J.S.Chai, J.W.Kim, W.Y.Yang and S.Oh, Proceedings of the International Cyclotron Conference, Caen, France,1998

[3] S. Oh, W.Y. Yang, M. Yoon, J.S.Chai, J.H. Ha, J.W. Kim, Proceedings of the European Particle Accelerator Conference, Stockholm, Sweden, 1998