

# DESIGN STUDY OF A 83.2 MHZ RF CAVITY FOR THE 9 MEV COMPACT CYCLOTRON\*

SeungWook Shin, Jong Chul Lee, Jong-Seo Chai<sup>#</sup>  
 Sungkyunkwan University (SKKU) Department of Energy Science, Suwon, Korea  
 Byung-No Lee, Korea Atomic Energy Research Institute (KAERI), Daejeon, Korea

## Abstract

A compact cyclotron accelerating  $H^+$  ion for producing a radioactive isotope FDG (FluoroDeoxyGlucose) for PET (Positron Emission Tomography) has been designed at Sungkyunkwan University. The  $H^+$  ion which generated from the PIG (Panning Ion Gauge) ion source will be accelerated at the normal conducting RF cavity which uses 83.2 MHz of resonance frequency and extracted at the carbon foil stripper at the energy of 9 MeV. This cyclotron has to be small to install local hospital while FDG production needs more than 9 MeV of proton beam energy. Chasing two hare at once, deep valley type of magnet has been selected for high energy and compact cyclotron. Due to the small size of valley space where RF cavities will be installed, lots of difficulties have been introduced. Despite of those difficulties at the designing process, we could achieve resonance frequency of 83.2 MHz and Q-factor of 4500 with very compact size of RF cavity.

## INTRODUCTION

Application of cyclotron has been expanded significantly for a past few decades at various field since it was invented by Ernest O. Lawrence in 1932. One of the major application of the cyclotron to the public is to produce radiopharmaceuticals especially FDG for a PET machine [1].

A compact 9 MeV cyclotron has been developed for the FDG production at Sungkyunkwan University [2]. A proton beam is used for the FDG production and this proton beam is extracted by stripping  $H^+$  beam which is produced from PIG ion source located at the centre of the cyclotron. The created  $H^+$  beam is accelerated at the RF cavity which provides electric field activating at the frequency of 83.2 MHz. A main specification of 9 MeV cyclotron is shown at Table 1 while Fig. 1 and Fig. 2 show layout and cross-section view of whole system

## THE RF SYSTEM

To accelerate charged particles, one needs to introduce electric field at the pass of beam path by RF cavity. RF cavity mainly consists of DEE, liner for a RF ground, stem, RF power coupler for feeding high RF power and fine tuner for a fine frequency tuning. RF cavity of cyclotron can be expressed by R-L-C equivalent circuit and those specific values determines RF cavity's characteristics such as resonance frequency, Q-factor, shunt impedance etc.

Table 1 : 9 MeV Cyclotron Main Parameters

Parameters	Values
Beam Energy	9 MeV
Accelerated Ion	$H^+$
Type of Ion source	PIG
Diameter	1.25 meter
Maximum magnetic field	1.9 T
Harmonics	4 <sup>th</sup>
RF Frequency	83.2 MHz, Normal conducting
Accelerating voltage	40 kV
Q-factor	4500

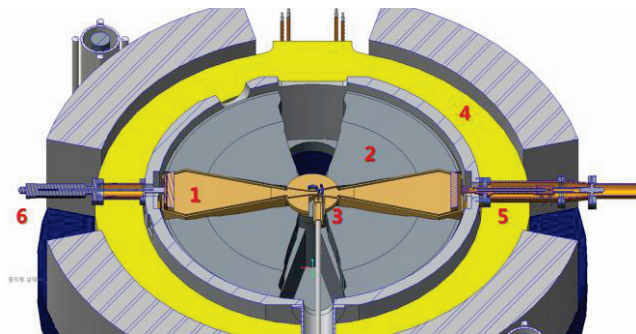


Figure 1: Layout of 9 MeV cyclotron: 1. RF cavity, 2. Magnet, 3. PIG ion source, 4. Magnet coil, 5. RF coupler, 6. fine tuner.

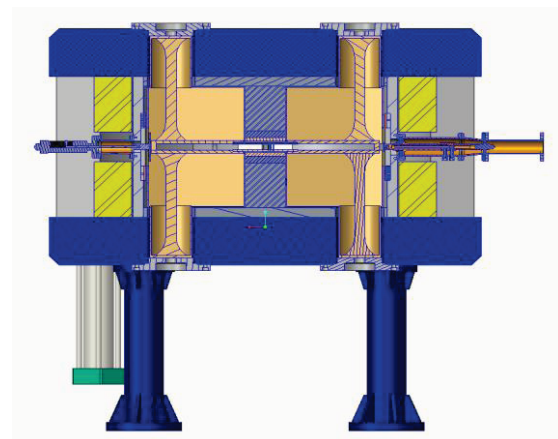


Figure 2: Cross-section view of 9 MeV cyclotron.

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<sup>#</sup>jschai@skku.edu

RF cavity of AVF type cyclotron is installed at the empty space of magnet valley. The magnet valley angle is optimized to maximize phase acceptance of the beam and fixed to 30 degree. Due to the harmonic number of this cyclotron is 4, operating mode of RF cavity was chosen to  $\lambda/2$  mode which is called push-push mode.

RF cavity can be assumed as a lossless transmission line with characteristic impedance  $Z_0$ , capacitance of DEE and inductance of stem; stem as an inner conductor and liner as an outer conductor [3]. Characteristic impedance of coaxial line can be expressed as follow [4]:

$$Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} \frac{1}{2\pi} \ln\left(\frac{b}{a}\right) \quad (1)$$

With characteristic impedance of RF cavity,  $Z_0=50 [\Omega]$  and diameter of liner,  $b = 130 \text{ mm}$ , one can get a diameter of stem  $a = 56.5 \text{ mm}$ . Due to a shape of the RF cavity is much more complex than ideal coaxial line, this value could be a reference value not exact design value.

At the 1950s, W. D. Kilpatrick suggested maximum electric field which can cause electric breakdown and Kilpatrick's results were expressed by following formula by T.J. Boyd [5].

$$f(\text{MHz}) = 1.64 E_k^2 e^{-8.5/E_k} \quad (2)$$

If we think about the time when Kilpatrick has established his experiment, technical level of fabrication of copper cavity and clean vacuum was poor than nowadays. Even though this criterion is not considered today's standard, RF cavity designer used to use as a conservative criterion data by applying bravery factor.

By adapting parameters of 9 MeV cyclotron,  $f = 83.2 \text{ MHz}$ , bravery factor  $b = 1.5$ , one can get  $E_k = 10.68 \text{ MV/m}$ . To accelerate charged particles to 9 MeV, this RF cavity has to provide 40 kV as an effective accelerating voltage. Due to the accelerating gap is much smaller than a RF wave length, transit time factor can be assumed as 1 and DEE gap should be larger than 3.7 mm by following Kilpatrick's criterion.

By adapting those criterion, optimization of RF cavity has been started with those values as an initial condition.

CST MWS (Microwave Studio) which is well-known as a 3D electromagnetic field simulation at high frequency has been used to optimization process [6] and Fig. 3. shows that simulated electromagnetic field distribution and surface current distribution.

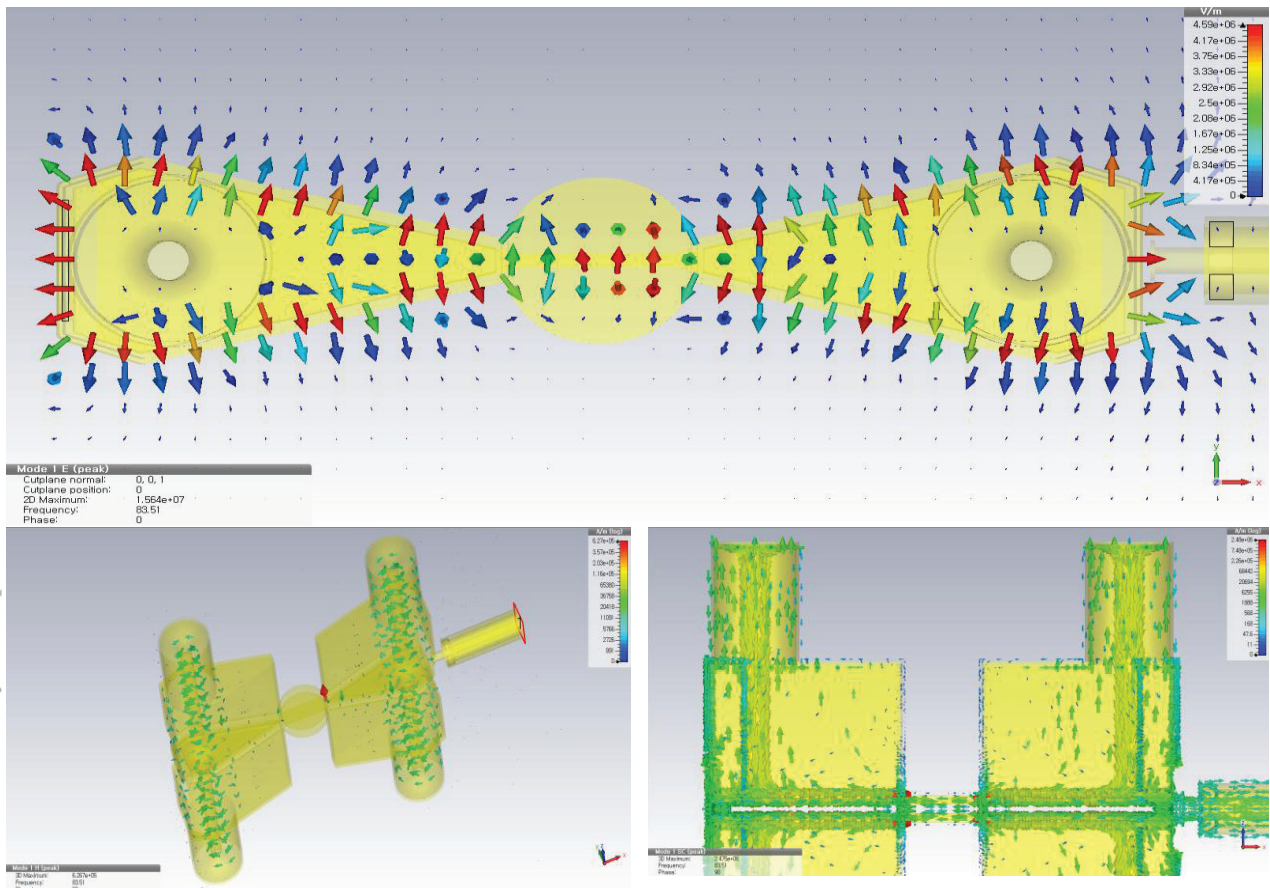


Figure 3: CST Simulation results of RF cavity: Electric field distribution, Magnetic field distribution, Surface current distribution.

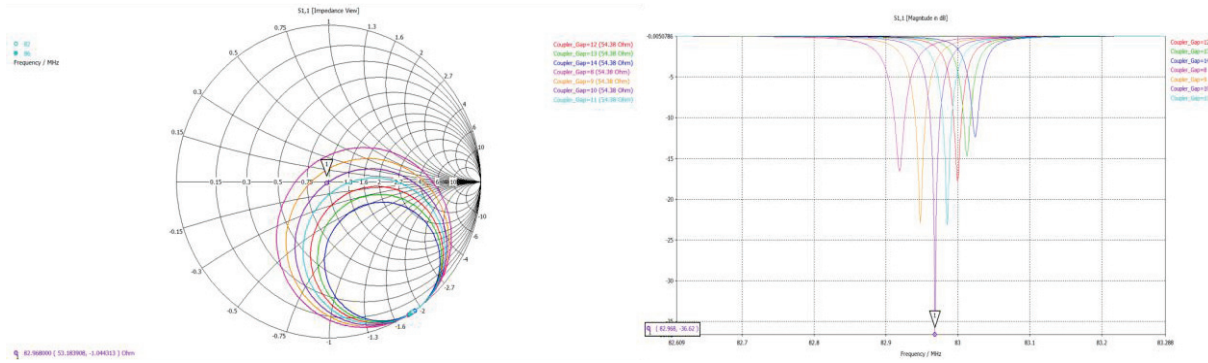


Figure 4: Matched impedance data of RF power coupler simulation: Smith chart and S11 data.

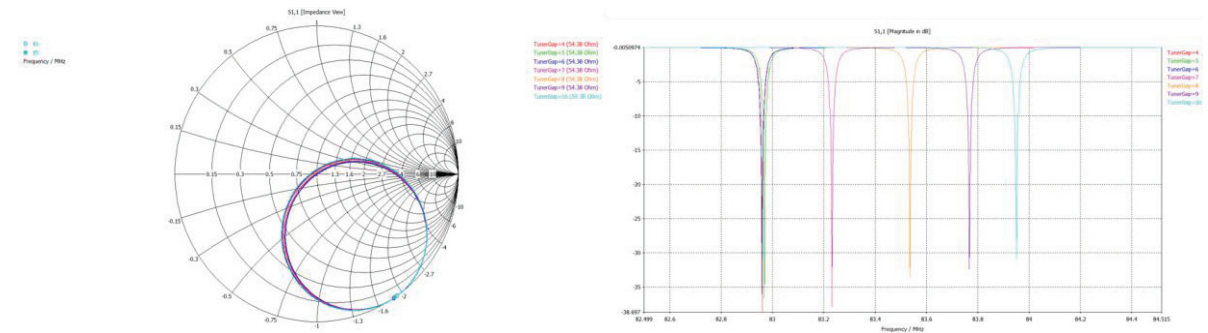


Figure 5: Frequency variation by changing tuner range : smith chart and S11 data.

RF power generated and amplified by RF amplifier is fed into the RF cavity to induce suitable electric field to accelerate charged particles through RF power coupler.

To get an efficient RF power coupler, one needs to consider power loss, power reflection and usable frequency range. Capacitance coaxial RF power coupler has been introduced to 9 MeV cyclotron to meet the condition which includes easy to matching, relatively small size and easy to tune. When an outer part of coaxial coupler is decreased, usable frequency range will be broadened while maximum transportable power decreases. Optimization process has been done to get a less power loss at the operating frequency and to reduce a reflecting power by impedance matching process. Results of impedance matching process are shown at Fig. 4.

None of fabricated product can avoid machining tolerance and assembly tolerance. Those tolerance make imperfectness of RF cavity and should be compensated. Apart from fabrication error, variation of operating temperature, vibration caused by cooling channel and beam loading can make operating frequency differ from resonance frequency. Capacitive fine tuner has been introduced to compensate those cause of frequency changes. Normally, capacitive tuner is used for its simple structure than inductive tuner. Figure 5 shows tuner variation simulation by changing a tuner gap.

## DISCUSSION

Design study of RF cavity for the 9 MeV compact cyclotron for the FDG production has been processed. Due to this design study is limited to RF simulation, additional mechanical and thermal simulation needed. After fabrication of RF cavity, commissioning stage will be progressed.

## ACKNOWLEDGMENT

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