PRELIMINARY DESIGN OF RF CAVITIES FOR THE CYCLOTRON CYCHU-10*

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Abstract

At Huazhong University of Science and Technology (HUST), the design study of a 10 MeV compact cyclotron CYCHU-10 for the application of Positron Emission Tomography (PET) has been developed since 2007.This paper describes the recent status of RF cavities including numerical calculation results of basic parameters, the capacitive trimmer to overcome frequency shift when in operation and the construction and cold test of the 1:1 scale prototype. The inductive coupling loop design and matching simulation with the RF power generator are also presented.

INTRODUCTION

CYCHU-10 is a compact low energy H^- AVF cyclotron for short-life medical isotopes production. Up to present, the central region and magnet design [1] has been completed and magnetic field measurement system is being developed. A typical RF system includes resonant cavities, power amplifiers, transmission lines, low level control circuits and other auxiliary components, such as connectors, directional couplers and measurements modules.

High frequency power from the final vacuum tube tetrode amplifier is delivered to the cavities in vacuum chamber through standard 50 Ohm coaxial transmission lines with length of integer multiples of half wave length. An inductive coupling loop is positioned between the end of the RF power transmission line and the resonant cavities. To achieve high and average voltage distribution along acceleration gaps, the shapes and sizes of Dee plate and stem are carefully designed. Main RF system specifications for the cyclotron CYCHU-10 are listed in Table 1.

Table 1: Main RF Specifications

Parameter	Value/Description
RF Output Power	10 kW
Operation Frequency	98.5~99.5 MHz
Dee Voltage	34 kV
Dee Number	2
Cavity Shape	Coaxial Type
Harmonic Number	4
Frequency Stability	±2e-5

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CAVITY DESIGN AND SIMULATION

A good resonant cavity applied in the field of fixed frequency particle accelerator always has the following characteristics.

- Stable resonance frequency
- Relative higher quality factor (Q value)
- Reasonable distributions of electromagnetic fields and radial Dee voltage

However, there are many other problems to be considered when the system is operated in the real environment. For example, cavity resonance frequency compensation components and high efficiency coupling configurations should be designed and properly located in vacuum chamber.

Cavity Shape

To utilize the valuable space in the vacuum chamber, two Dee plates of triangle types are put above the two opposite valley regions of magnet poles and they are connected electrically in the central region [2]. The single rectangle stem is used to connect the Dee plate with side wall of vacuum chamber, so they form a horizontal half wave length coaxial cavity as a whole, which is shown in Figure 1. The fixed coupling loop is placed at the end of stem where the amplitude of magnetic field is much stronger than that of electric field which will be shown in the next section.

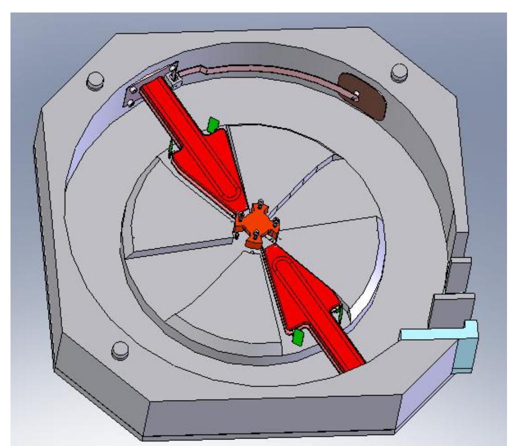

Figure 1: Horizontal $\lambda/2$ coaxial resonance cavity

There are many reasons that can make resonance frequency of the cavity unstable: voltage ripples of power supply, deformation of cavity shape due to power dissipated, ambient temperature variation, magnet gravity and so on. To effectively accelerate the particle in each passage through the acceleration gap, the actual resonance frequency must be maintained stable. The design of a frequency compensation structure is aimed to add a disturber on the cavity resonance frequency. The change in a narrow frequency range compensates the influences of above mentioned factors. The four designed capacitive trimmers at the large radius of Dee plates are also shown in Figure 1.

Numerical Simulations

The cavity shape design and calculation are performed in ANSYS code based on Finite Element Method and the inductive coupling loop is simulated by CST Microwave Studio (MWS) [3] using Finite Integral Technology. To save CPU time and PC memory available, only a 1/2 cavity model is established and the symmetry boundary condition is applied on the median plane. Typical time for the 1/2 cavity simulation is about 20 minutes on the PC with 512 MB memory and Pentium 2.4 GHz processor. The cavity model is meshed with about 80,000 second-order tetrahedron HF119 elements in ANSYS.

After defining electric walls on the vacuum surfaces, setting the analysis type to modal and specifying the frequency range and mode number to be extracted, the solution will start. Adding impedance boundary conditions will allows ANSYS to calculate the cavity's quality factor internally when the macro "QFACT" is issued. The cavity characteristic parameters are obtained or displayed at the general post-processing module [4].

The resonance frequency and unloaded Q factor of the cavity without capacitor trimmer are 99.05 MHz and 7888.8 respectively. The simulation is done in ideal vacuum environment, with dielectric and radiation dissipation excluded in the Q calculations. We can see from Figure 2 and 3 that electric field dominates in the acceleration region and drops to nearly zero dramatically in the stem area, which is contrary to the magnetic field distribution. Note that the values on the figures are only relative, because ANSYS has normalized element results to an arbitrary value in modal analysis.

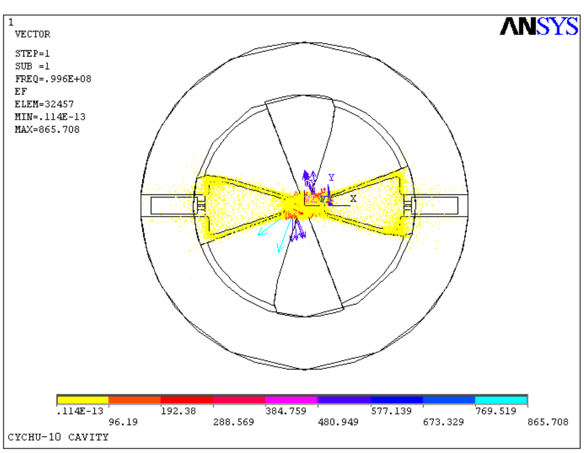

Figure 2: Electric field distribution

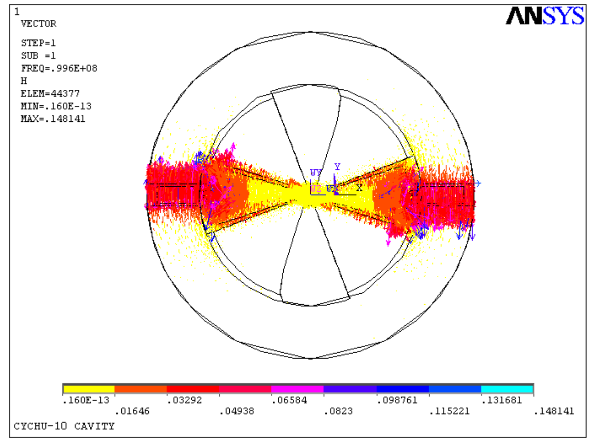

Figure 3: Magnetic field distribution

The capacitive trimmers are located at the junction areas of Dee plates and stems. They can be rotated near or far from the Dee plate and this will increase or decrease the capacitors of resonant circuits. The indicated rotation angle and calculated frequency compensation range are shown in Figure 4 and Figure 5 respectively.

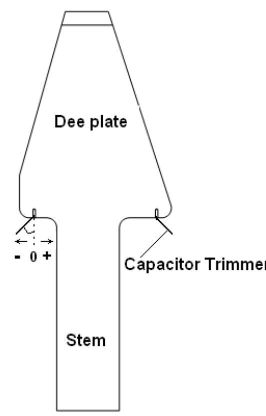

Figure 4: Trimmer

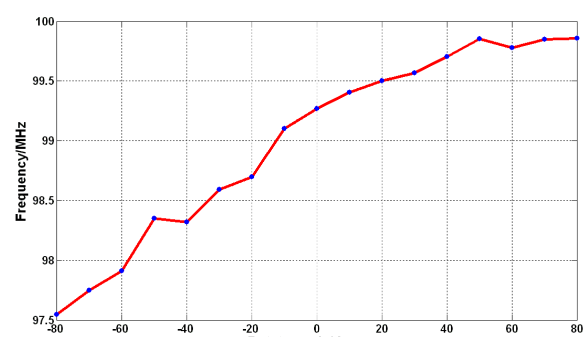

Figure 5: Trimmer compensation frequency range

In fact, the cavity is connected with the standard 50 Ohm coaxial transmission line. The shape and dimension designs of the coupling loop can attain good matching between RF power generator and the cavity. Figure 6 presents the 3D loop model and the reflection coefficient is obtained in transient solver of CST MWS (Figure 7).

The voltage standing wave ratio (VSWR) is 1.26, less than the design value 1.3, which indicates that most power is transmitted into the cavity through the loop.

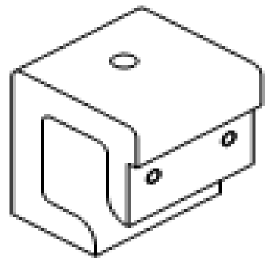

Figure 6: Designed coupling loop

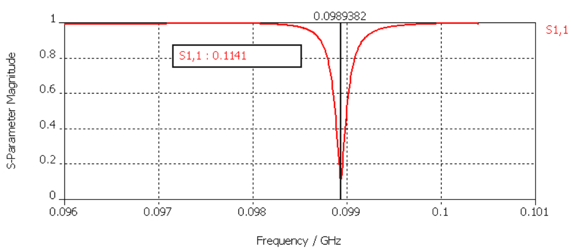

Figure 7: Reflection coefficient S11

CAVITY PROTOTYPE

The previous simulation codes provide an effective and economical way of cavity designs. However, because of the complexity of cyclotron systems, it is necessary to construct a 1:1 scale model to test and validate the simulation results. Only if these results reach good agreements with each other, following work can be done, such as commissioning with RF power generator.

To save cost and weight, the main body of vacuum chamber is made of wood and coved with a shell of 2 mm thickness copper. Some key components, such as central region, coupling loop and capacitor trimmer, are manufactured with copper.

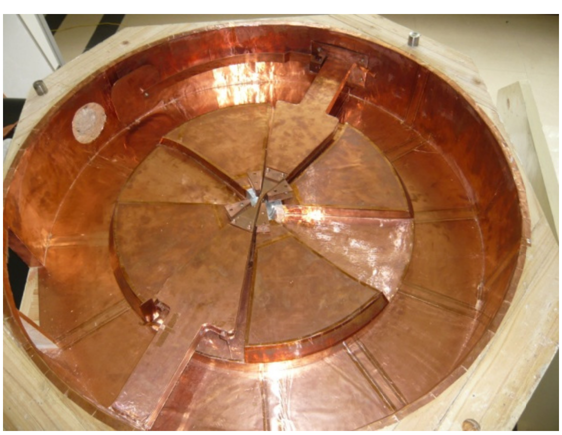

Figure 8: 1:1 scale cavity model

COLD TEST

The resonance frequency is obtained by a microwave signal generator and an oscillograph. Due to symmetry, we test the two halves cavities separately. One is connected to the coupler (No.1), and the other not (No.2).

Table 2: Cold Test Results

Cavity No.	Frequency/MHz
1	97.5
2	99.5

The difference between test value and the simulated one is that the simplification of central region which is sensitive to frequency and some small configurations are ignored in simulation, such as dummy dees, screws, bends and holes on the side wall of vacuum chamber.

Figure 9: Test instrument of cavity model

The coarse surface of copper contributes to very high power loss due to oxidation. Unloaded Q factor is very low (less than 10). Another reason is that the electric connection of central region and magnet is not very good.

CONCLUSION

The preliminary design of RF resonant cavities of a compact cyclotron CYCHU-10 has been finished. The results of test and simulation with commercial electromagnetic codes make good agreements. This work provides solid support for cavity manufacture. Thermal and structural analysis of cavities and tolerance study need future work.

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