DESIGN AND ANALYSIS OF RF CAVITIES FOR THE CYCLOTRON CYCHU-10*

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Abstract

The design study of a 10MeV compact cyclotron CYCHU-10 has been developed at Huazhong University of Science and Technology (HUST). We developed the basic shapes and dimensions and carried out the simulations for the CYCHU-10 cavities with 3D numerical calculation softwares in this paper. The distributions of electromagnetic field are illustrated by means of the electromagnetic and structural analysis, and the wooden model test is preformed as well. In addition, this paper gives mechanical tolerance effects which deformed due to the limit of mechanical working of cavities under practical conditions. This work helps to evaluate the performances of capacitive frequency trimmer design.

INTRODUCTION

CYCHU-10 is a 10MeV compact low energy H-AVF cyclotron for short life medical isotopes production. After the magnet of it has been already designed, the RF system is being developed now, which is composed of resonant cavities, power amplifiers, transmission lines, low level control circuits and other auxiliary components, such as connectors, directional couplers and measurements modules. The whole Virtual Prototype is given in Figure 1, and the parameters of the main magnet and vacuum chamber for the cyclotron CYCHU-10 are listed in Table 1 as well.

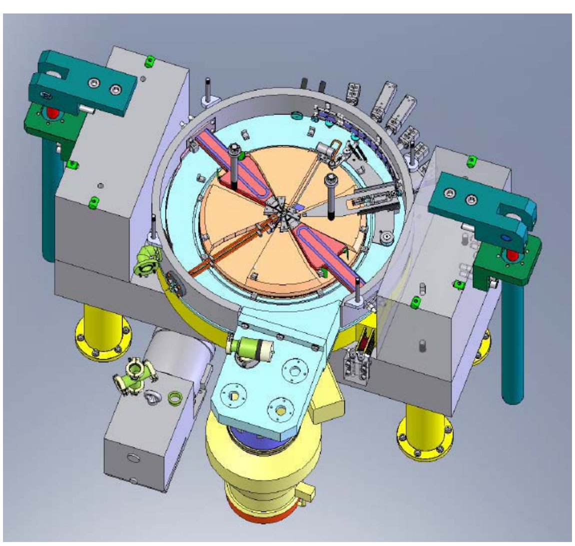

Figure 1: Virtual Prototype of CYCHU-10.

Table 1: Main Parameters of Magnet And Vacuum Chamber

Parameter	Value
Input Energy	20KeV
Output Energy	10MeV
Magnetic Pole Number	4
Magnetic Pole Angle	51°
Particle Cyclotron Frequency	24.8MHz
Harmonic Number	4
Ampere Turns	38570 A.N
Average Magnetic Induction	1.63T
Vacuum Chamber Radius	480mm
Vacuum Chamber Height	184mm
Magnet Radius	325 mm
Valley Depth	32.7 mm

PRELIMINARY DESIGN

To design a useful resonant cavity with perfect characteristics, many problems should be considered, and cavity resonant frequency compensation components and high efficiency coupling configurations should be designed and properly located. The cavity design and calculation are performed in CST Microwave Studio (MWS) [1] using Finite Integral Technology, as Figure 2 shows, and main RF system specifications are given in Table 2, as following.

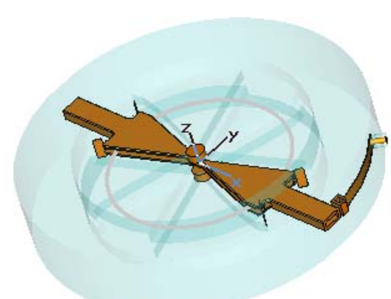

Figure 2: Cavity designed by CST.

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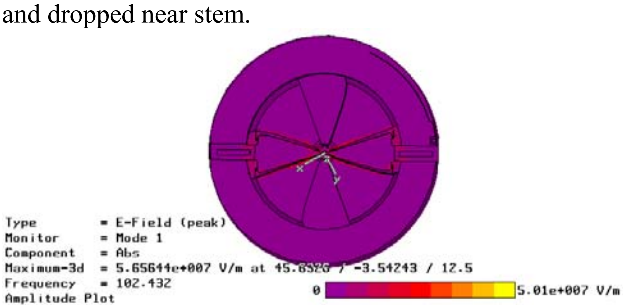
Table 2: Main RF Specifications.

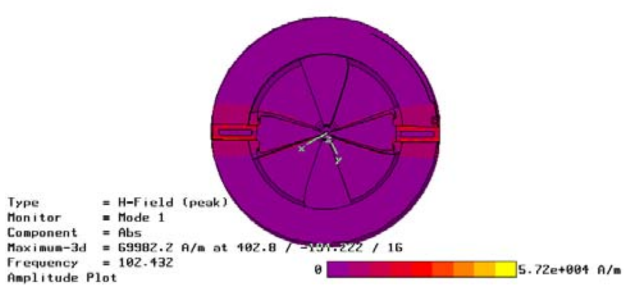
Parameter	Value
RF Output Power	10kW
Operation Frequency	101MHz
Dee Voltage	35kV
Dee Number	2
Harmonic Number	4
Dee Plate Thickness	8mm
Dee Plate Flare Angle	33.7°
Dee Plates Gap	16mm
Stem Width	64mm
Stem Thickness	32mm

In order to improve the calculation precision, it's important to choose proper boundary conditions at first. Using ANSYS[2], we find both PMC and PEC boundary conditions are suitable, the resonance frequencies and unloaded Q factors of the cavity without capacitor trimmer are close to 101MHz and 6440 respectively.

After modelling, choosing PEC boundary condition, meshing and using Eigen-model simulator of CST, We can see from Figure 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. Figure 4 shows the accelerate voltage distribution along the central line of Dee plate, and it's uniform from central field to the largest derivate radius and dropped near stem.



(a)



(b)

Figure 3: (a) Electric field distribution. (b) Magnetic field distribution.

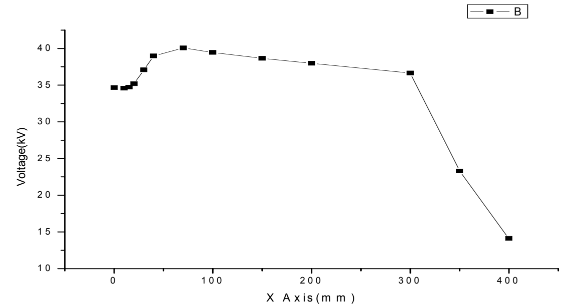


Figure 4: Accelerate voltage distribution

FREQUENCY TRIMMER

In real operated conditions of accelerator, resonant frequency of cavity will shift due to temperature increment, instability of voltage source, and so on. So we need design a frequency tuning device such as sliding short plate and capacitive trimmer [4]. Comparing to the former, trimmer is more suitable for low range tuning like 100.5-101.5MHz.

We locate capacitive trimmers at the junction areas of Dee plates and stems, and change the capacitors of resonant circuits by rotating them along the Dee plate. The structure of trimmer is shown in Figure 5, and the dimensions of it are listed in Table 3. We can see the indicated rotation angle and calculated frequency compensation range in Figure 6, and the resonant frequency almost increases monotonously with rotation angle of trimmer. This result is equal to theory, due to the formula of plate capacitor.

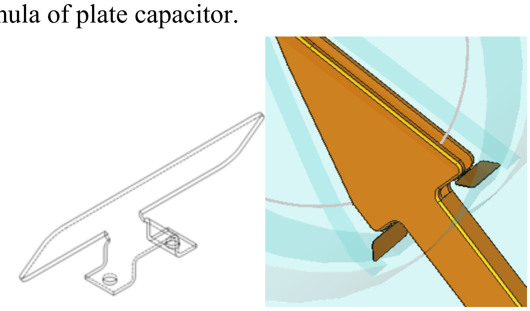


Figure 5: Capacitive trimmer

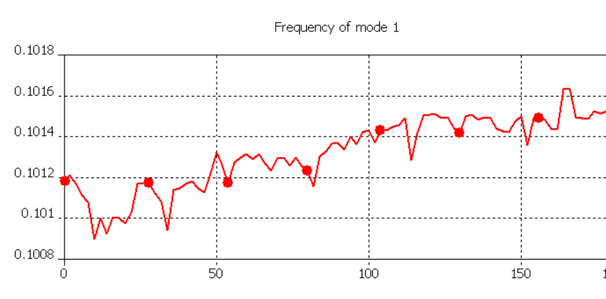


Figure 6: Trimmer compensation frequency range.

Table 3: Dimensions of Trimmer.

Parameter	Value
Length	76mm
Width	25mm
Thickness	1mm
Rotation Angle	180°

WOODEN MODEL TEST

To test the results from previous design and simulation, we can use a 1:1 wooden model, rather than complex real cyclotron. Because of the wooden model can save much cost and more convenient, it's mainly made of wood and covered with copper. Table 4 shows the resonant frequency by testing the model with trimmer and dummy Dees.

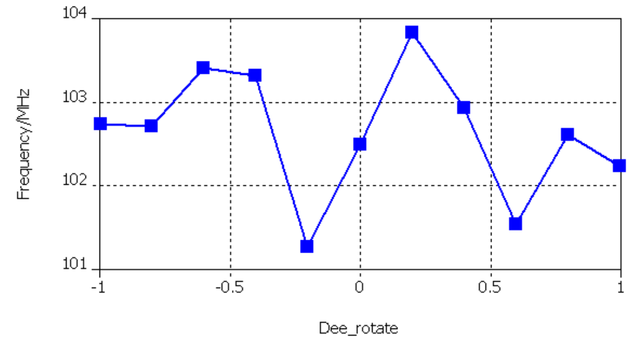
Table 4: Measurement Results

Parameter	Value
f_0	100.4MHz
BW	16MHz
Q	6.3

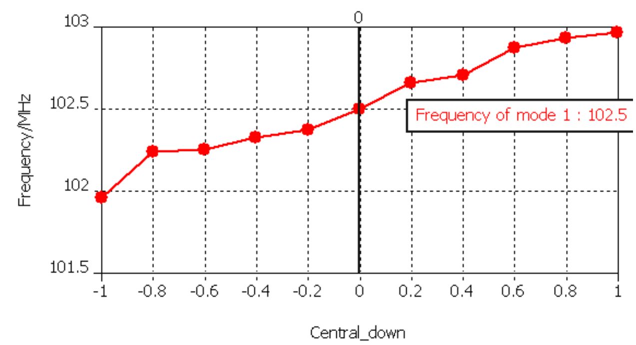
For simplification, some small configurations in central region are ignored in simulation, such as screws and holes. However the central region is very sensitive to frequency, and the coarse surface of copper results in very high power loss, as well as the bad electric connection of central region and magnet, so there're some differences between measurement results and the simulation results, especially the Q value is much less.

EFFECTS OF MECHANICAL TOLERANCE

In order to provide references for mechanical working of cavity, it's necessary to discuss the effects of mechanical tolerance. Analysing by CST, we get a series of effect curves change with some mechanical sizes, such as magnet surface height, Dee plate gap depth, Dee plate rotation angle, etc. Among these, Dee plate rotation angle relative to central axes is the most effective factor, because distributed capacitance of cavity is sensitive to it, shown in Figure 7(a). And Figure 7(b) indicates resonant frequency changes with the distance between the head of magnetic pole and upper surface of magnet.



(a)



(b)

Figure 7: (a) Dee rotation angle effects; (b) Magnetic pole head effects.

CONCLUSIONS

The design and simulation of resonant cavity with capacitive trimmer for CYCHU-10 has been developed. To achieve high and average voltage distribution along acceleration gaps, the shapes and sizes of Dee plate and stem are carefully designed. The wooden model test results are fit to simulated ones, and the effects of mechanical tolerance are discussed which helps to mechanical working of cavity in the future.

REFERENCES

[1] In Su Jung and Dong Hyun An et al, "Design of KIRAMS-13 RF system for regional cyclotron center", Proceedings of the 17th International Conference on Cyclotrons and Their Applications, 2007, p. 353-355.

[2] ANSYS Inc, ANSYS High-frequency electromagnetic analysis guide, ANSYS release 10.0, 2005.

[3] M. Puglisi, Conventional RF Cavity Design, RF Engineering for Particle Accelerators, CERN, 1993: 156~197