TUNER SYSTEM OPTIMIZATION IN 10 MeV CYCLOTRON CAVITY

M. Mohamadian, M. Salehi, H. Afarideh, Energy Engineering and Physics Department, Amirkabir University of Technology, Tehran, Iran
M. Ghergherechi, J. Chai, Electronic and Electrical Engineering Department, Sungkyunkwan University, Republic of Korea

Abstract

Since fixed frequency cavities need fine tuning for the one operating frequency, their design require for the accurate tuning system to reach the best performance and quality factor. In the case of our cyclotron, the fine tuning device, capacitive trimmers, can be done by hydraulically squeezing the outer capacitive tuning disk to the inner disk which is connected to the cavity Dee part. This generates a $\Delta f/f0 = 0.7\%$ (Δf=500 kHz), sufficient to correct pressure changes, thermal effects acting on the cavity and any other supervention.

Computer model of the RF system was developed in the CST and double checked by HFSS. Necessary resonant frequency and increase of the voltage along the gaps were achieved. Optimization of the RF cavity parameters leads us into cavity with quality factor about 15000, and insertion loss about -0.06dB and also reflection power about -57dB, RF power dissipation is about 40 kW.

We have studied some models with different in accelerating gap, dimension of the Dee and Liner, and also optimization of the coupling and tuning capacitors. We analyzed the effect of the tuner and revealed that better diameter and gap space for the tuner is on the 60 and 2mm.

INTRODUCTION

Various small cyclotrons had successfully been developed with compact structure for isotope production from 1990s.[1] The conceptual design of the cyclotron systems is unchanged from that reviewed in the 1978 Conference, but many details have been modified. [2] RF cavity which is included Dee electrodes, couplers ant etc. is one of these parts that has had different structures. Our group has dedicated to the exploration of the cyclotron physics and key technologies with the compact structure for medical purpose recently. The cyclotron developed by our Lab began by referring to 10 MeV medical cyclotrons.

Our cyclotron has room temperature magnets, valley design with four sectors, two Dees in opposite valleys, external ion source and simultaneous beam extraction on opposite lines. The cyclotron is illustrated in Figure 1.

RF SYSTEM

The RF cavity as a resonator is composed of two $\lambda/4$ resonant cavities connected at the center. This option optimizes the resonator power dissipation with minimum Dee voltage off balance between the lower and upper Dee plates. [1]

The RF cavity has been simulated with the general purpose simulation software CST MWS and double checked by HFSS to optimize the resonator characteristics and continues with coupling and tuning optimization.

The coupling of the cavity adopts a fix capacitive method, which allows the simplicity and economy. Cylinder type ceramic is selected as an insulator to separate the vacuum and air. The shape of the inner/outer conductor of the coupling window is designed in a way to have good VSWR and also to prevent excessive multipacting at a certain power level. [3]

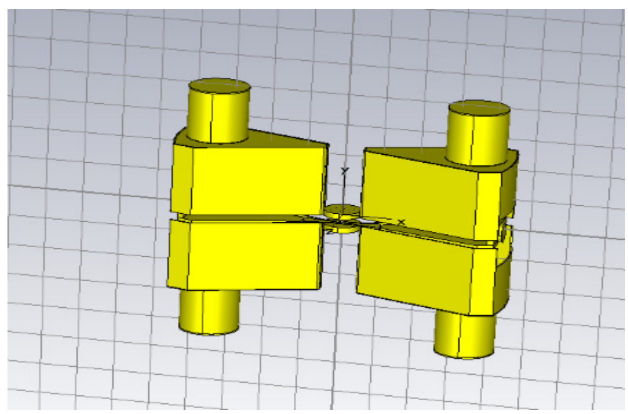

Figure1: RF cavity structure.

CAPACITIVE COUPLERS AND TUNERS

Capacitive coupling is widely used in double gap, coaxial type resonators, because the inner conductor presents an ideal opportunity to couple via a capacitance to the high voltage end (typically the 'Dee structure'); and be independent of geometry changes at the inductive end of the resonator especially if that end is used for frequency tuning. Matching the cavity to a 50 Ω transmission line with a suitable capacity usually presents no special problem; a further advantage can be that a variable capacity (=variable distance of the coupler to the 'Dee') is usually easier to design and operate reliable that a variable area (usually by rotation) inductive coupling loop [4].

SIMULATIONS IN CST MICROWAVE STUDIO AND HFSS

CST STUDIO SUITE is a general-purpose simulator based on the Finite Integration Technique (FIT). This numerical method provides a universal spatial discretization scheme applicable to various electromagnetic problems ranging from static field calculations to high frequency applications in time or frequency domain [5].

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HFSS is an engineering simulation software which mainly relies on the Finite Element Method (FEM). These are general-purpose finite element modeling packages for numerically solving mechanical problems, heat transfer and fluid problems, as well as acoustic and electromagnetic problem [6]. Calculations of the created model were performed by means of Eigen mode JD loss-free solver (Jacobi Division Method) in CST Microwave Studio and Block LANCZOS solver in HFSS.

Voltage value was obtained by integrating the electric field in the median plane of the resonant cavity. To fit the frequency of the cavity to the project value after the first design and reach to a near value for resonant frequency, we had to examine the various coupling parameters. We revealed that variation of the coupler and tuner diameters and the gap between disks changes frequency by about 500 kHz, and the value of the voltage along radius does not change noticeably while fitting by less than 1 MHz.

Simulations show that the frequency of both programs is about, 71.5 MHz, for CST Microwave Studio and 72 MHz, from HFSS.

FITTING OF THE FREQUENCY OF THE CAVITY

We analyzed methods of fitting the frequency of the cavity. In order to decrease the resonant frequency it is possible to change the dimension of the coupler disks and its distance. It was shown earlier that simultaneous variation of the dimension of couplers changes the frequency without changing the voltage behavior along the radius. But there are other consideration and limitation to vary these dimensions.

First of all, we created the model with resonant frequency 71.5 MHz and examined the possibility of decreasing the resonant frequency of this model by modulation of the diameter of the stems, couplers and etc. Figure 2 illustrates the return loss for different stem diameters. The diameter of the couplers was changed from 30 to 130 mm and gap from 1.6 to 2.5. So as a result, the resonant frequency decreased from 71.5 to 70.954 MHz.

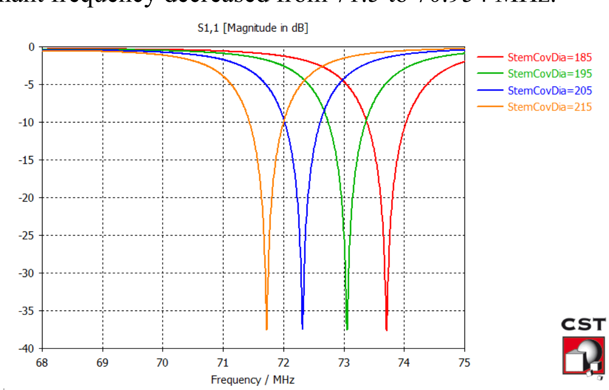

Figure 2: Return loss for different stem diameters.

Beside to reach the desired resonant frequency, the return loss is so significant parameters to consider. So after catching the desired result for resonant frequency, we try to optimize the model to minimum return loss. And, it's also necessary to know the effect of different dimension of the couplers on resonant frequency accurately to tune the system on practice. Therefore, we simulated these variations and analyzed the effects.

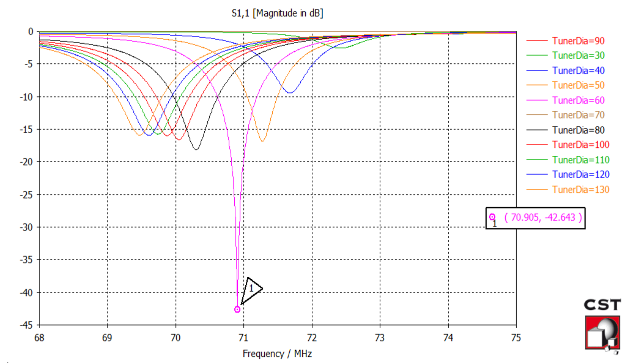

Figure 3: Return loss changes with different tuning parameters.

RESULTS AND CONCLUSIONS

Computer model of the cyclotron RF cavity with 4 stems was developed, simulated and analyzed in CST Microwave Studio and HFSS. The model had the frequency 71 MHz, necessary voltage distribution 40 kV (average). It was shown that the resonant frequency and return loss depends on the diameters and distance of coupler's disks. Figure 3 shows how the return loss changes with different tuning parameters.

Also, Figure 4 show how the return loss changes with different coupler parameters.

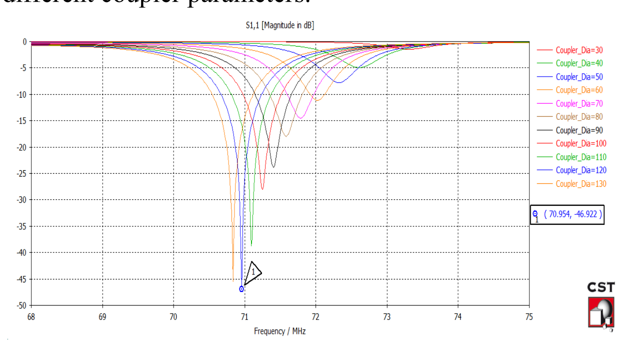

Figure 4: Return loss changes with different coupler parameters.

It was demonstrated that it is possible to change resonant frequency of the cavity and return loss of various diameters and distance of coupler's disks. Finally capacitance tuners at the end of the cavity structure with a diameter of about 60mm and gap distance of about 2mm will provide the necessary frequency tuning with fixed coupling capacitance, at the end of the transmission line with a diameter of about 130mm and gap distance of about 2mm. It should be noted that both tuner and coupler can change the disk's gap for the best tuning of the first installation. And also, tuner disk could have displacement during cyclotron working to fine tuning by hydraulically

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squeezing. Figure 5 show the optimization results on return loss curve.

Table 1: Main Characteristics of the RF System

Frequency	71MHz, 4th harmonic
Dee angle	40º
Dissipated power	15 kW
Dee voltage	40kV
Quality factor	15000

Optimization of the RF cavity parameters leads us into the cavity with quality factor about 15000, RF power dissipation being about 40 kW per cavity. Table 1 illustrates our cyclotron parameters.

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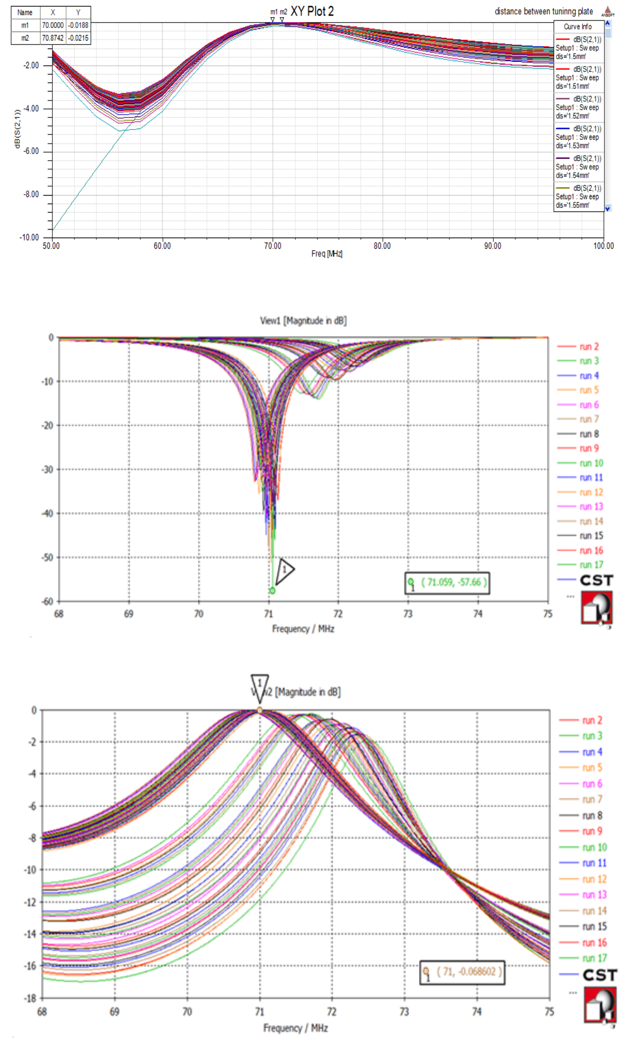

Figure 5: the optimization results on return and insertion loss curve of CST and HFSS simulations.