DESIGN AND SIMULATION OF CAVITY FOR 18 MeV CYCLOTRONS

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Abstract

RF system is the key part of the cyclotron and cavity is the key part of RF systems. The basic parameters of cavity design are the resonant frequency, Dee voltage, RF phase and RF power. Proper operation of the cavity depends on the suitable voltage distribution in accelerating gap, phase stability in the cavity and as well as optimal scattering parameters. In this simulation using CST MWS, different parts of the cavity such as Stem and Dee are optimized to achieve optimum dimensions for the desired resonant frequency, Dee voltage and RF power. Main properties of the designed cavity are resonant frequency at 64.3 MHz, Dee voltage of 45 kV and RF power of 11 kW.

INTRODUCTION

IRANCYC-18 is an 18 MeV compact low energy cyclotron for short life medical isotope production. The RF system is designed to accelerate 150 μA of H− ions to 18 MeV. The RF specifications are shown in Table 1.

Table 1: Main RF Specifications

Parameter	Value
Resonant Frequency	64.3 MHz
Harmonic Number	4
Dee Voltage	45 kV
Resonant Mode	λ/4
Matching Impedance	50 Ω
Material	OFHC copper
Number of Dee	2
Dee angle	44

The RF system is composed of λ/4 delta cavities housed inside the valleys of the magnet, power amplifiers, power switch, directional coupler, transmission lines, coupling and tuning capacitors and low level control circuits. Block diagram of RF system is shown in Fig. 1. RF power has been capacitively coupled into the cavity by rigid coaxial line, also a tuning capacitor is used to adjust the cavity frequency.

DESIGN ITEMS

The Operating frequency of resonant cavity is 64.3 MHz. This cavity works at fourth harmonic [1]. In the design of the cavity, the main parts are Dee, Stem and central region. Angle and width of the Dee and the gap between the Dee and Liner as accelerating region are the points that in the design should be considered. The suitable angle and width of Dee is calculated on the basis of Eq. (1) [2]. Also the distance of the accelerating gap can be calculated on the basis of electric field and required voltage as well as considering the Kilpatrick's criterion.

$$\Delta E_k = V_{dee}.N.q.\sin\left(\frac{h.\alpha}{2}\right) \qquad (1)$$

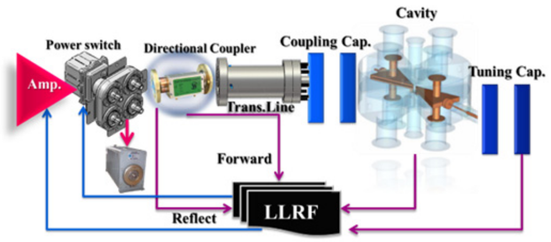

Figure 1: Block diagram of RF system.

Another important part of the cavity is Stem that with regard to the capacitive role of Dee, Stem have an inductive role of cavity circuit. The structure of Stem is like a coaxial line that can play three roles in the design:

1. Inductive's role of Stem can change the resonant frequency [3]
2. Shunt impedance of the cavity structure has direct relation to Stem dimensions and therefore with cavity losses.
3. Displacement of Stem along the accelerating gap can change the voltage distribution along the accelerating gap [4].

CST MWS software has been chosen for design and simulation. CST STUDIO SUITE is a general-purpose electromagnetic simulator based on the Finite Integration Technique (FIT), unlike most numerical methods, FIT discretizes the following integral form of Maxwell's equations rather than the differential one [5]. Geometry designed in this software which has been shown in Fig. 2.

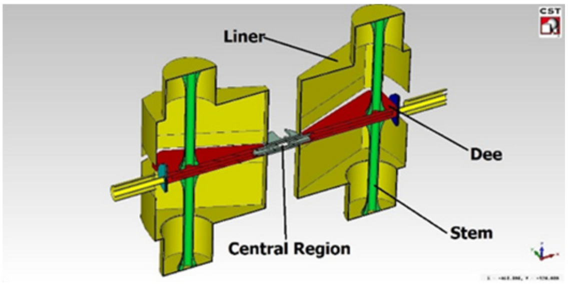

Figure 2: Designed geometry in CST MWS.

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Coupling and Tuning

Power couplers can generally be defined as networks designed to transfer power from an RF power source to a cavity [6]. Possible problems during operation of the cyclotron that may be occur due mismatch, including:

1. The transmitter may not be able to supply enough power to maintain the desired accelerating voltage if the cavity's resonant frequency drifts too far from the driving frequency;
2. The power supply could be damaged by dissipation of excessive power reflected back from the load;
3. Break-down and sparking could occur;
4. The phase and amplitude response of the transmitter may be severely affected by the change in the load

Coupling in RF systems of accelerators will be done in two ways, electric coupling (capacitive) or magnetic coupling (inductive), that in this study, the capacitive one has been chosen.

According to the complicated operating conditions, the resonant frequency of the cavity may be shift with deformation resulting from the unexpected variability of such factors as temperature, gravity, instability of the voltage source, multipacting and so on. Therefore, it is necessary to design a frequency tuning device.

SIMULATION RESULTS

With regard to the capacitive rule of Dee and also equation $C = A/d$ and $f = 1/(2\pi\sqrt{LC})$, Optimum dimensions have been obtained for Dee height and the gap between Dee and Liner that has been shown in Fig. 3.

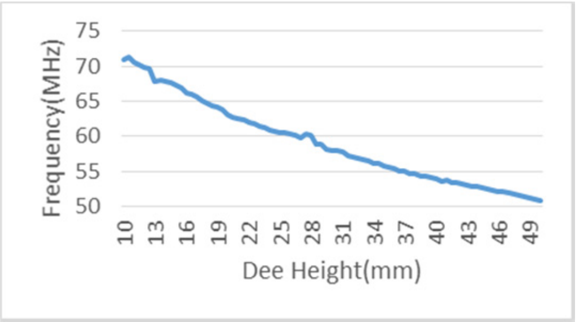


Figure 3: Frequency vs Dee height.

After simulation of different gaps size, finally, with regard to beam dynamic requirements and also Kilpatrick's criterion that at a frequency of 64.3 MHz is 5.22 mm, size of the gap has been chosen to 10 mm. Figure 4 shows the Dee voltage along the accelerating gap.

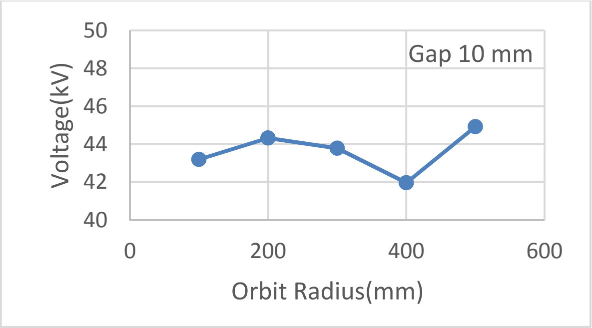


Figure 4: Dee voltage along the accelerating gap.

Process passed in above repeated also for length and radius of Stem and eventually, according to the obtained results, radius of 55 mm and a length of 530 mm were chosen for Stem.

And also, in coupling and tuning section, they have been chosen capacitively too. In the both sections, the purpose was the selection of optimum radius for capacitors. In Fig. 5a, S_{11} has been shown for different radius of coupling capacitors and Fig. 5b has been illustrated the final optimum coupling.

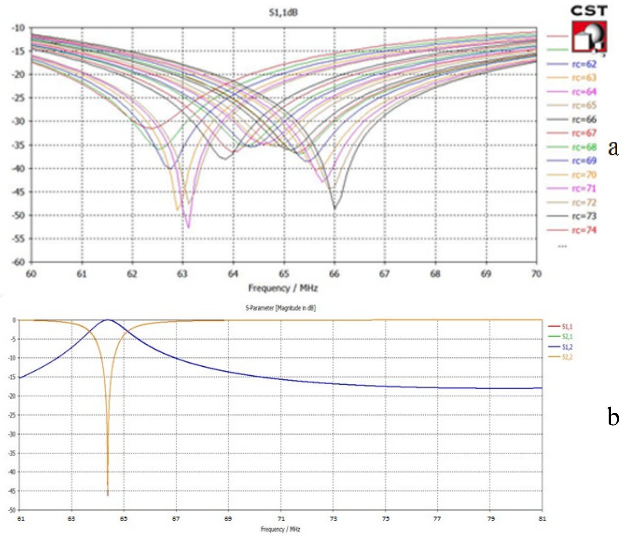


Figure 5: a) Determination of the optimum radius for coupling capacitor, b) Final optimum coupling.

In Fig. 6, plot of frequency vs distance between two plates of capacitors has been given. Accuracy of tuning that will be done with servo motor is $\frac{0.12\ MHz}{0.03\ mm}$.

In Figs. 7a and 7b, the electric and magnetic field has been shown respectively. As it has been indicated, concentration of the electric field is on the accelerating gap and concentrate of magnetic field is on Stem.

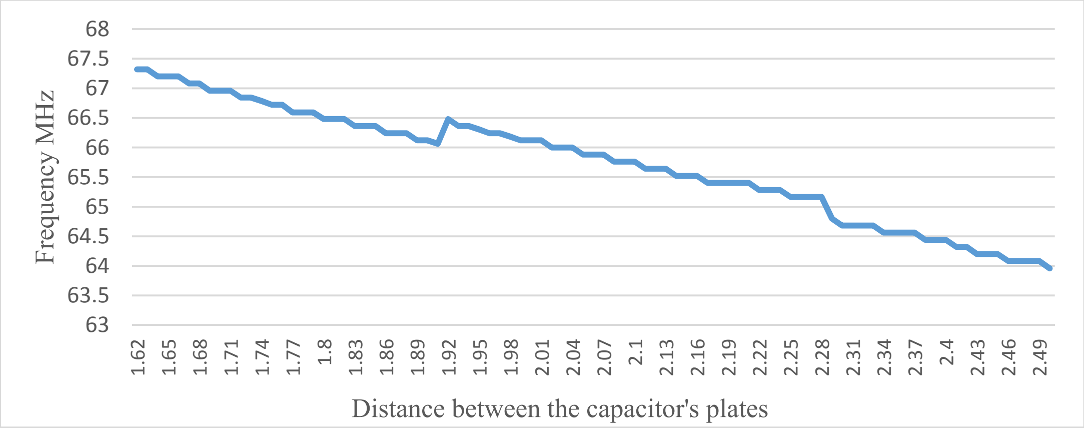
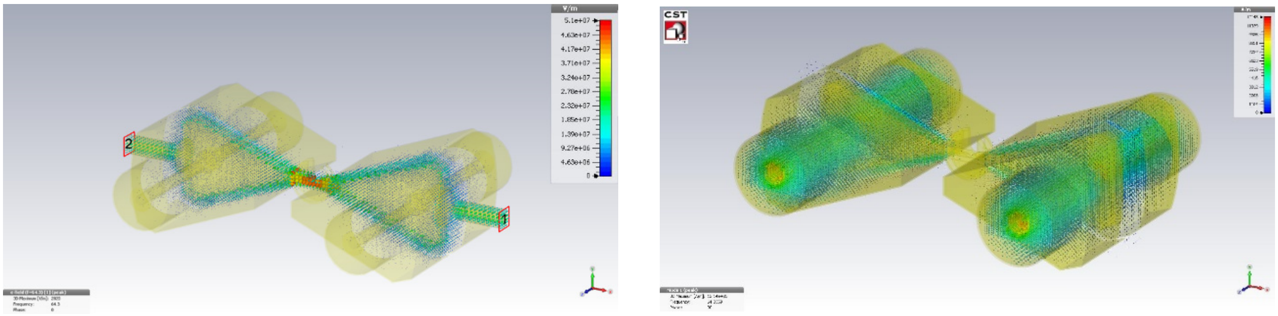


Figure 6: Frequency vs. distance between two plates of capacitors.



a

b

Figure 7: a) Electric field, b) Magnetic field.

CONCLUSION

Design and simulation of cavity for 18 MeV cyclotron in CST MWS has been presented. This design is based on results of magnet calculations and design experience of IRANCYC-10, a 10 MeV compact cyclotron. The simulation results accords to our expected design goals.

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