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A C-BAND DEFLECTING CAVITY DESIGN FOR HIGH-PRECISION BUNCH LENGTH MEASUREMENT*

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Abstract

A standing wave RF deflecting structure has been designed as a tool for high-precision bunch length measurement. This 3-cell deflecting cavity is designed to operate at a frequency of 5.712GHz. In this paper, the RF design and thermal analysis of the deflecting cavity are introduced. We study the electromagnetic field distribution inside the cavity. The coupler design is also discussed. And the beam dynamics simulation is shown.

INTRODUCTION

RF deflecting cavities have been widely used in the characterization of the longitudinal and transverse phase space in ultra-short electron beams [1]. Recently an ultrafast electron source with femtosecond-level is used for diffraction and imaging system [2]. The main parameters of the bunch are given below (Table 1). A C-band deflecting cavity is designed for high-precision measurement of the bunch length.

Table 1: Beam Parameters

Parameters	Value
Electron beam energy (MeV)	2
Transverse beam size (mm)	0.5
Longitudinal beam size(fs)	20

In the second section of the paper, the design of the deflector is discussed including the structure design, electromagnetic field characterization, beam dynamics and the coupler design. Thermal simulation calculated by CST is shown in the third part.

RF DEFLECTOR DESIGN

The required transverse deflecting voltage V_T=1MV can be, achieved by both traveling wave (TW) and standing wave (SW) structures [1]. In our case, we choose a 3-cell SW structure operated at a frequency of 5.712GHz. The 3D-model draw by CST is shown in Figure 1.

Model Design

The main part of the model is composed of several cylinders. The radius of the cell is determined by both the frequency and flatness of the magnet field [3]. The working mode is TM_{110} mode and π-mode. Length of the middle cell is given by [3]:

$$l = \frac{\lambda}{2} = \frac{\pi c}{\omega_0}. \quad (1)$$

where λ and ω_0 are the wavelength and angular frequency of the microwave, c is the speed of light, l is the length of the middle cell which include half of the gap between middle cell and end cell each side. Meanwhile, the length of the end cell is determined by beam dynamics which is discussed later in this paper.

In order to make sure the polarization direction not changed while two cell coupled, two end cells are slotted on the edges which are perpendicular to the direction we put the coupler.

According to the discussion above, the dimensions of the cavity is shown in table 2.

Table 2: Dimensions of the RF Cavity

Dimensions	Value(mm)
Radius of middle cell	30.85
Length of middle cell	21.49
Radius of end cells	30.61
Length of end cells	10.93
Gap between cells	4.76
Radius of beam pipe	8
Radius of slots	3.5

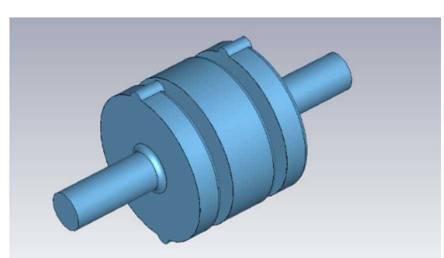

Figure 1: 3D-design of the deflector.

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After the shape is decided, it's easy to get the cavity parameters such as the transverse shunt impedance. And table 3 shows the main parameters of the RF cavity. With 1 MW input power, the deflecting voltage can be 1.19 MV.

Table 3: Cavity Parameters

Parameters	**Value**
Q_0	9003.25
$R_T/Q(M\Omega)$	21.49
$R_T(M\Omega)$	1.42
P(MW)	1
$V_d(MV)$	1.19

The deflecting cavity consists of three cell which results in three different mode: 0-mode, π/2-mode and π-mode. Because of the symmetrical structure, there will also be three degenerate modes existed. The π-mode we need is given in Figure 2. Frequencies of modes near 5.712GHz is shown in Table 4.

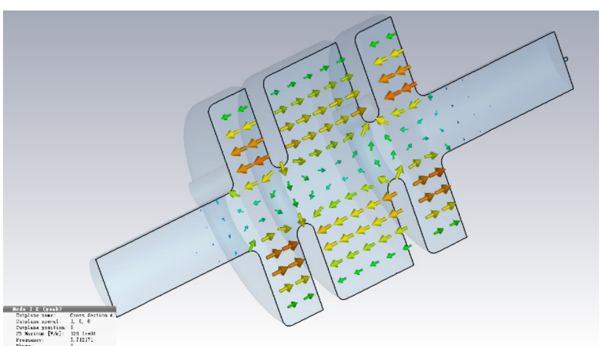

Figure 2: π-mode needed in the RF cavity.

Table 4: Frequencies of Different Modes

Modes	**Frequency(GHz)**
π-mode	5.7121
π/2-mode	5.7518
0-mode	5.8413
Degenerate π-mode	5.6982

Electromagnetic Characterization

The cavity is working in TM_{110} mode and in this mode, the x-component of the electric field is much smaller than the y-component meanwhile the y-component of the magnet field is much smaller than the x-component. As a result, particles crossing the cavity will only kicked in y direction, mainly influenced by the magnet field. The flatness of magnet field has been adjusted to around 0.995.

The normalized E_y and H_x along axis z are shown in Figure 3 and Figure 4 respectively.

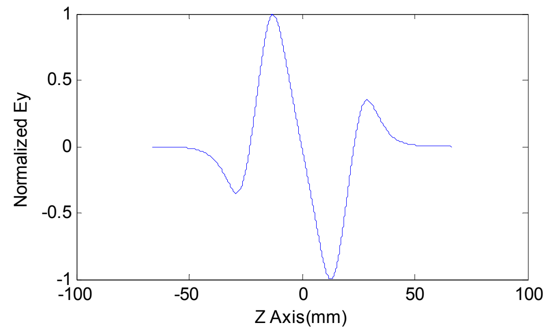

Figure 3: Normalized E_y along z axis.

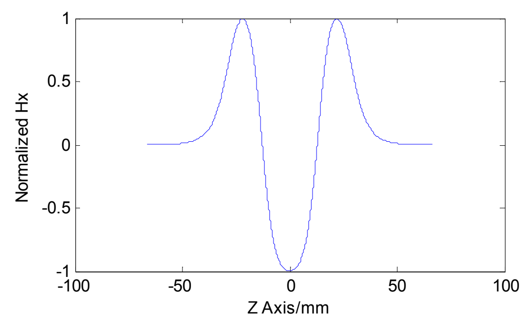

Figure 4: Normalized H_x along z axis.

Beam Dynamics

Figure 5 and Figure 6 gives out the result of beam dynamics simulation. The parameters of the electron source is shown in Table 5.

Table 5: Parameters of Electron Source

Parameters	**Value**
Number of micro particles	1311
Energy(MeV)	2
Current(A)	0.02
Distribution in x-y plane	Round
Transverse beam size (mm)	0.5

The particles at zero-phase have zero deflection and a little vertical offset. The precise value of vertical offset is 0.0575mm. The phase of the electromagnetic field is changed from -4 degree to 4 degree by step of 2 degrees in simulation. The change of phase can be translated into the longitudinal offset of beams as below:

$$\Delta z = \frac{\Delta p}{2\pi}\lambda = \frac{c\Delta p}{2\omega_0}. \quad (2)$$

where Δp means the change of phase, Δz is longitudinal offset.

From Figure 5 and Figure 6, we know that the vertical offset and deflection is proportional to phase shift, which means we can get the bunch length by measuring vertical bunch size after the exit of the cavity.

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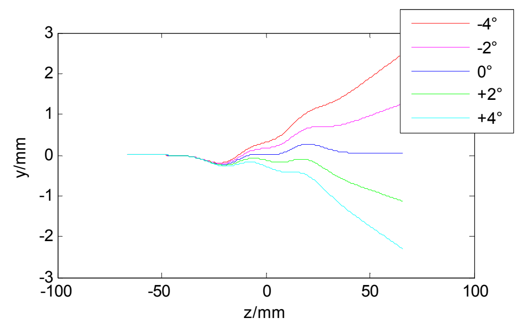

Figure 5: Vertical offset along z axis with different phases.

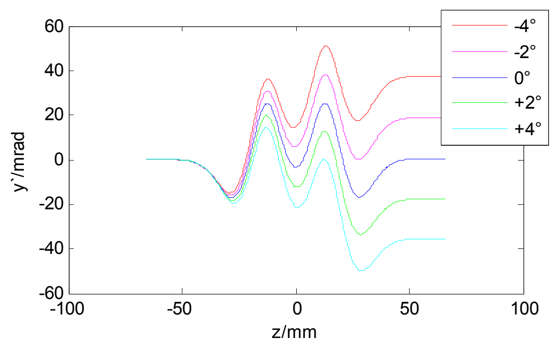

Figure 6: Vertical deflection along z axis with different phases.

Coupler Design

After the optimization of beam dynamics, the power input coupler is added to the structure (Figure 7). A little of adjustment of cells' radius has to be made to make magnet field flatness and resonant frequency the same as before.

The coupler includes a length of oblique waveguide to fit the different type of flange. S parameters are shown in Figure 8. The coupling factor is around 1.07.

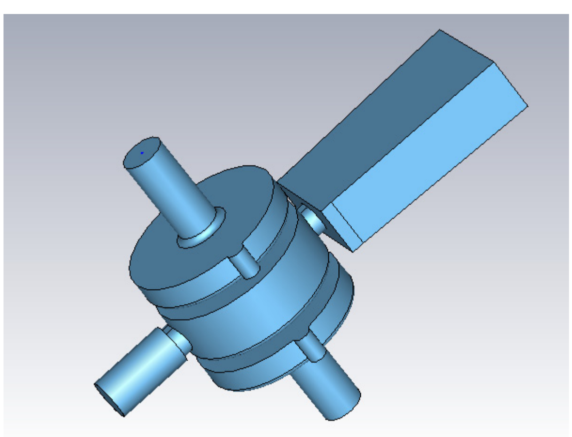

Figure 7: The RF deflector with coupler.

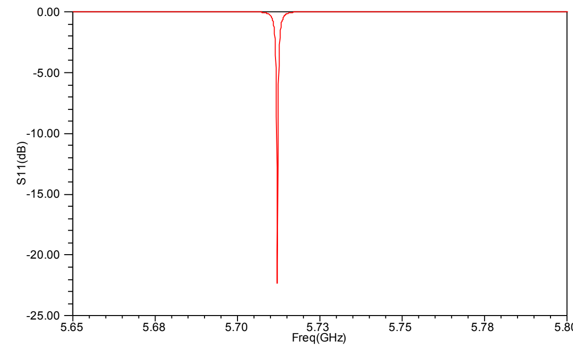

Figure 8: S11 calculated by CST.

THERMAL SIMULATION

Based on the discussion above, we get the final design of the RF cavity as shown in Figure 7. Because of the small size of C-band cavity, heat dissipation becomes a problem we need to concern about. The cooling system added to the structure and the thermal simulation with CST is shown in Figure 9.

The cavity is designed with oxygen-free copper. Two water cooling rings are attached to the end cells at both side and four cooling bars are put on the outer surface of the cavity. All of this cooling system perform well as shown in Figure 9. The maximum temperature rise of the copper surface inside the cavity is around 12.95 degree, which makes sure the deflector work steady.

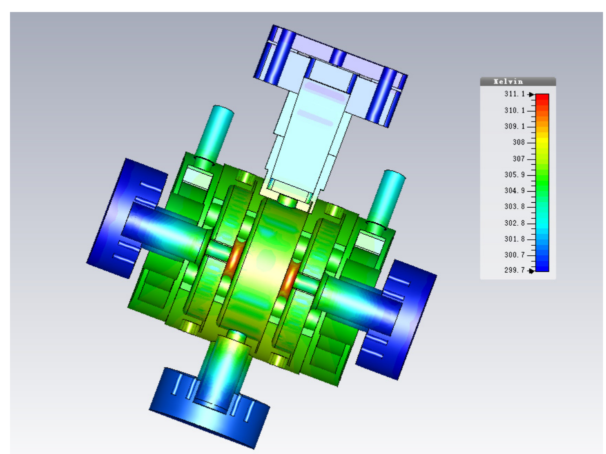

Figure 9: Thermal simulation result of the cavity.

CONCLUSION

We discussed the whole design procedure of the RF deflector made by CST in this paper. The RF deflector proposed is a 3-Cell SW structure working on the π-mode at 5.712GHz and fed by a coupler with β=1.07. The input power is 1MW, with which the deflection voltage is up to 1.19MV. Two end cells are slotted on the edges to shift the resonant frequency of the vertical polarity modes with respect to the working mode. The electromagnet field distribution and simulation of beam dynamics perform

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well. We also discuss the thermal design to make sure the RF cavity work steady. Now, the RF cavity is under fabrication, and beam test going to be made soon.

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