DESIGN AND BEAM DYNAMICS STUDY OF A C-BAND DEFLECTING CAVITY FOR BUNCH LENGTH MEASUREMNT *

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Abstract

We design a C-band deflecting cavity at a resonance frequency of 5712MHz. We study the dynamics of the beams in the cavity to ensure that the cavity is suitable to work as a deflector in the future high-precision bunch length measurement of the electron beam. The deflecting cavity supplied by a RF source of 1MW can generate a deflecting voltage of 1.23MV. We obtain a positive correlation between the phases of the electromagnetic fields and the deflections in y-direction.

INTRODUCTION

RF deflecting cavities have many applications in a great quantity of accelerators. They can work for particle separations [1] luminosity upgrade [2] emittance exchange [3] and measurements of bunch length [4]. Recently the ultrafast MeV electron diffraction and imaging facility need to measure electron pulses with the femtoseconds and the sub-Angstrom spatial-temporal resolution. We design a C-band deflecting cavity to measure the width of the electron pulses with high precision.

A deflecting cavity essentially is an RF cavity with a special mode of electromagnetic field. A proof-of-principle RF dipole and crabbing cavity operates in a TE_{11}-like mode [5], and a new compact RF deflecting cavity operates in a TEM-like mode [6]. The cavities provide a transverse kick for a particle when the particle passes through them. The transverse kick may come from electric field, magnetic field, or both of the two kinds of the fields. The TM_{110}-like mode works in the C-band deflecting RF cavity we design. The phase of the microwave in the cavity is time-varying. When a bunch passes through the cavity, its head and tail receive kicks from different directions. We design the deflecting cavity and investigate the beam dynamics for the cavity by using the CST PARTICLE STUDIO.

THE CAVITY DESIGN

CST Model

The model (see Fig. 1) we use consist of four kinds of cylinders (numbered from 1 to 4) respectively representing the beam pipe, two different resonant cavities and the coupling holes. The two end resonant cavities are identical. The table 1 shows the radius and the heights of the cylinders. The length of the beam pipes have little effect in the design of the deflecting cavity. As we have known the TM_{110} mode in the pillbox have a polarization degenerate mode. In the CST model we design the holes to break the degeneracy on account of the cylindrical symmetric structure. In addition the coupling holes also affect the magnitude of the electromagnetic fields in the three resonant cavities. All the radius and heights of the cylinders are the important geometry parameters we utilize to optimize the deflecting cavity.

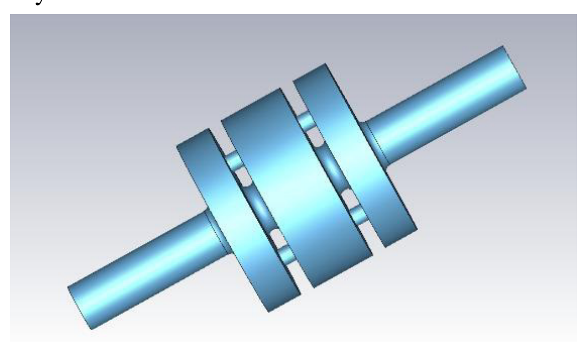

Figure 1: The CST cavity model.

Table 1: Geometrical Parameters

	Radius (mm)	Height (mm)
Cylinder 1	8	33
Cylinder 2	30.50	15.68
Cylinder 3	3	4.75
Cylinder 4	30.78	26.24

Electromagnetic ield

In the deflecting cavity design the y-component of the transverse magnetic field is so small that we can ignore the effect it has on the electrons. According to the Lorentz force, the electrons will receive little force in the x-direction. On the country as is showed in Fig. 2, the x-component of the transverse magnetic field has three large peaks values. The electrons will be kicked by the Lorentz force produced by the x-component of the transverse magnetic field. The phase of the transverse magnetic field is time varying. So the electrons may receive different forces due to the different times at which

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they arrive at the transverse magnetic field. The x-component of the transverse electric field is very small compared with the y-component of that. The y-component of the transverse electric field is showed in Fig. 3. As with the case of the force produced by the transverse magnetic field, the electrons receive force in y-direction and the force in x-direction is zero.

So as we have analysed above both of the transverse magnetic fields and the transverse electric field have no effect on the electrons in the x-direction. The electrons are kicked in y-direction only.

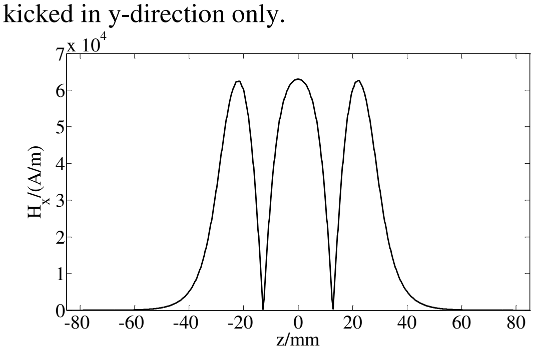

Figure 2: Distribution of the transverse magnetic field.

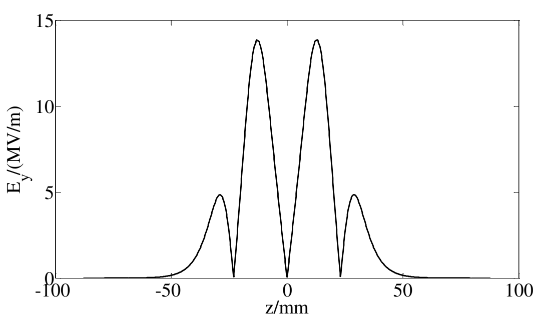

Figure 3: Distribution of transverse electric field.

OUTCOMES

Main arameters

The deflecting cavity consists of three resonant cavities which results in three different modes in the deflecting cavity. We chose the π-like mode as the working mode. The frequency of the π-like mode is quite different from those of others (Table 2). So we suppress the other modes as we set the frequency 5712MHz.

Table 2: Frequencies of the Different Modes

Mode	Frequency (MHz)
π-like mode	5712
π/2-like mode	5751
0-like mode	5841
π-like mode, unwanted polarization	5722

In the future an RF power source of 1MW will supply the deflecting cavity. According to the transverse shunt impedance ($R_{\perp}$) the deflecting cavity will generate a deflecting voltage of 1.23MV.

Table 3: Other Parameters

Parameter	Value
Q_0	9614
$R_{\perp}$	1.52MΩ
$(R/Q)_{\perp}$	158Ω
$V_{Deflection}$	1.23MV
P_{Input}	1MW

Beam ynamics

There are 790 micro particles to track a time. The movement of the beam can represent that of all the micro particles. All the micro particles have the same energy of 2 MeV. The trajectory is showed in Fig. 4. The curves show the evolution of the deflection in y-direction with respect to z. We introduce a reference phase to be a reference of other phases. We take care of the relative value of the phase instead of the real value of that. The reference phase is 167.718 degrees at which the beam centre has no deflection in y-direction. The relative phase are from -2 degrees to 2 degrees and the interval is 1 degree. We can obtain a curve of the trajectory based on a relative phase.

Figure 4 shows the evolution of y with respect to z. At the beginning and end of the curves are straight lines. This is because there are no electromagnetic fields in the forepart and rear part of the deflecting cavity. The curves where z is from -40mm to 40mm are wavelike. The particles are mainly affected in this region where both the electric field and magnetic field are distributed. The influences to the particles are different when we change the value of the relative phases. A large relative phase has a greater effect on the particles. In the region where z is from -40mm to -20mm, these carves are almost coincident. All the relative phases seem to have the similar effect when the electromagnetic fields begin to affect the particles.

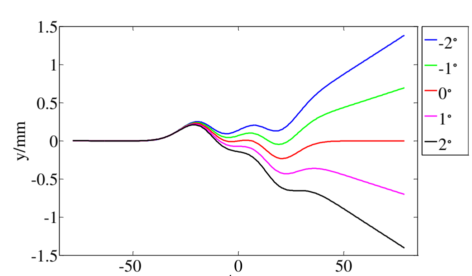

Figure 4: Trajectories of the particles at different relative phases.

According to the trajectories, we can obtain the evolution of y` with respect to z (see Fig. 5). This group of curves are correspond to those in the fig. 4. At the

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beginning and end of the curves are straight lines parallel to the x-axis. The curves where z is from -40mm to 40mm are wavelike because of the wavelike trajectories in this region. The red curve in the Fig. 5 is almost symmetric. We must make sure that the reference particle meet the reference phase when the particles pass through the deflecting cavity.

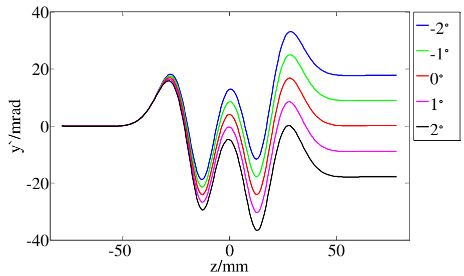

Figure 5: Evolution of y` with respect to z.

The evolution of y and y` at the end of the cavity with respect to the relative phase are almost two straight lines (Fig. 6 and Fig. 7). We can control the deflections and the deflection angles of the beam by changing the relative phases.

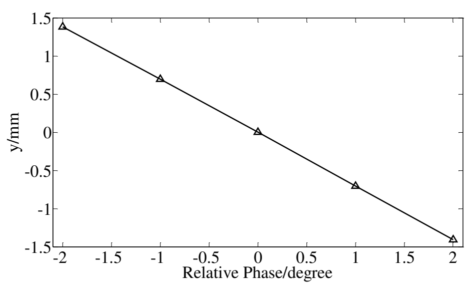

Figure 6: Displacement in y-direction with respect to the relative phases.

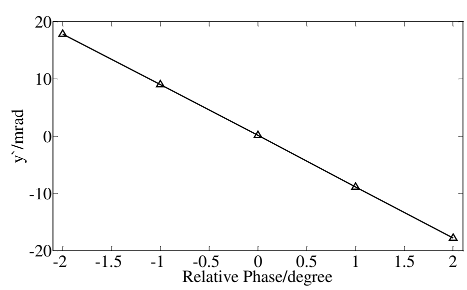

Figure 7: y` with respect to the relative phases.

We eventually study the output energy spectrum at the different relative phases. At the reference phase the energy of the particles at the end of the deflecting cavity change only 1keV at most. The deflecting cavity has little effect on the energy of the particles passing through the deflecting cavity. The energy change of the particles off axis is in proportion to the distance they are apart from the axis (Fig. 8). The ΔE is about 14keV when the relative phase change 1 degree (Fig. 9).

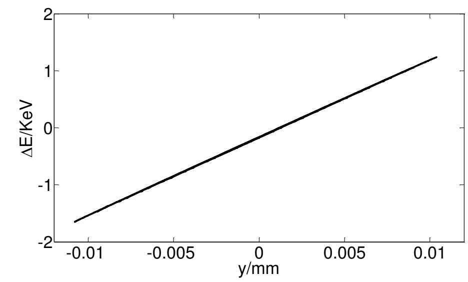

Figure 8: The energy with respect to y at the reference phase.

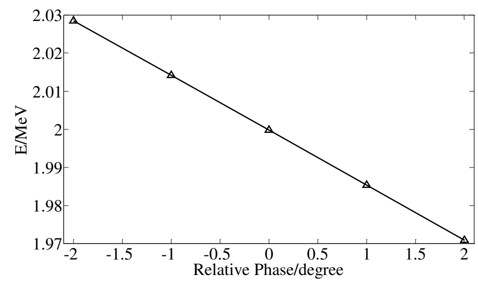

Figure 9: The average energy with respect to relative phases at the exit of the deflecting cavity.

CONCLUSION

We design a C-band deflecting cavity and study the beam dynamics of the deflecting cavity. We give out the main parameters of the deflecting cavity and discuss about the movement of the beam. We give the deflecting voltage of the deflecting cavity and the deflections in y-direction at different relative phases. The deflection in x-direction can be ignored compared with that in y-direction. We eventually study the output energy spectrum at different phases. The energy of the particles change little after getting through the deflecting cavity.

What we have obtained demonstrate that the deflecting cavity is appropriate to work as a deflector which provide deflection in y-direction. The deflecting cavity is able to work well in the width measurement of the electron pulses.

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