NEW X-BAND DEFLECTING CAVITY DESIGN FOR ULTRA-SHORT BUNCH LENGTH MEASURE OF FEL AT SINAP

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Abstract

For the development of Free Electron Lasers (FEL) at SINAP, ultra-short bunch is the crucial requirement for excellent lasing performance. It's a big challenge for deflecting cavity to measure the length of ultra-short bunch, and higher deflecting gradient is required for higher measurement resolution. X-band travelling wave deflecting structure has features of higher deflecting voltage and compact structure, which is good performance at ultra-short bunch length measurement. In this paper, a new X-band deflecting structure has been designed, operated at HEM11-$2\pi/3$ mode. For suppressing the polarization of deflecting plane of the HEM11 mode, two symmetrical caves are added on the cavity wall to separate two polarized modes. More details of design and simulation results are presented in this paper.

INTRODUCTION

The 840MeV X-ray free electron laser in shanghai institute of apply physics (SINAP) will be built in the Zhangjiang campus where Shanghai Synchrotron Radiation Facility (SSRF) had been completed. It will be designed to be compact coherent X-ray source, and the total length is about 570 meters. The facility will generate electron beams with low emittance and short bunch length, which is about 2.5um and 120um, respectively. For ultra-short electron bunch length measurement, a standard method has been used at LCLS with a new X-band deflecting structure, and the principle of bunch length measurement works as well as stream camera for electrons, however, the deflector is capable of resolving bunch length as short as 10 fs. Deflecting cavity operates in a dipole mode, for suppressing the polarization of deflection plane of the HEM11 mode, with two symmetrical caves added on the cavity wall. In order to diagnose the longitude structure of the bunch, a novel transverse RF deflecting structure is proposed as shown in Fig.1.

DESIGN OF REGULAR CELLS

The simulation of the structure by CST is a dominate method, and it makes that the model can be changed easily without any affection on the structure. The Fig.2 shows the CST simulation single cell model.

The HEM11 mode in an axis-symmetric structure degenerates in twofold. To solve the degeneracy and prevent rotation of the polarization plane or deflection plane, two symmetrical caves are added on the cavity wall for cancelling the degeneracy of the HEM11 mode, then the frequency

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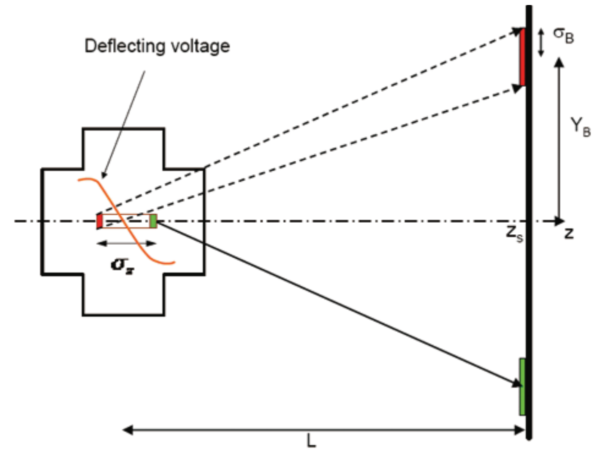

Figure 1: Schematic of an RF deflector.

of the vertical mode increased and the horizontal mode decreased. The phase shift is set to $2\pi/3$, which correspond to the frequency at 11.424GHz and the cell length or the periodic length is 8.7475mm.

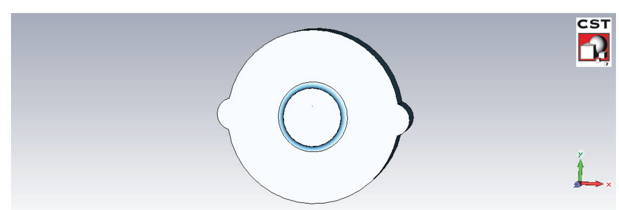

Figure 2: Regular cell of CST model.

The initial RF parameters of the cell is shown in Table 1. To calculate the group velocity Vg and attenuation factor α, the dispersion character of HEM11 mode was considered.

Table 1: RF parameters of the cell

Parameters	Value	Description
a(mm)	5	Iris radius
b(mm)	14.887	Cavity radius
t(mm)	2	Iris thickness
c(mm)	±13.9	Cave center
d(mm)	8.7475	Periodic length
p(mm)	2.8	Cave radius
phase(deg)	120	Phase advance

For accelerating structure, taking single chain of coupled circuit model to account, the approximate expression of dispersion character can be written as:

$$f(\theta) \quad = \quad f_0(1 - \frac{1}{2}k\cos\theta) \tag{1}$$

For deflecting cavity, HEM11 mode could not use the single chain of coupled circuits any more. Taking double chain of coupled circuit model to consideration, expand the field in each cell into a combination of a TM11 and a TE11 mode. The details are presented in Ref[6], then we obtain:

$$\cos(\theta) \quad = \quad \frac{-k_1k_2 - (1-\frac{f_1^2}{f^2})(1-\frac{f_2^2}{f^2})}{(1-\frac{f_1^2}{f^2})k_2 + (1-\frac{f_2^2}{f^2})k_1} \tag{2}$$

where k, f are the couple coefficient and regular frequency, and the index 1 and 2 represent TM11 and TE11 mode respectively. We have calculated the results with double (and single) chain of circuits model, and the double chain of circuits model results are consistent with the dispersion character of HEM11 mode, as shown in Fig.3.

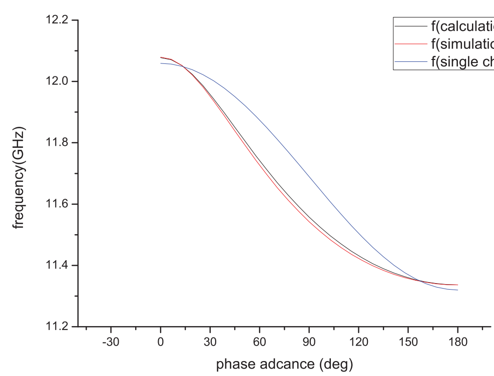

Figure 3: Double chain of circuits model results.

Take advantage of the dispersion expression, we could calculate the group velocity and attenuation factor. The calculation results are shown below. The group velocity is negative, which shows that the structure works at backwave state.

$$Vg = -0.0329c, \quad \alpha = 0.517 \quad 1/m$$

The transverse shut impedance is an important performance to deflecting structure as shut impedance to accelerating structure. The transverse shunt impedance Rs is defined as[7]:

$$Rs = \frac{[\frac{1}{k}(\frac{\partial Ez}{\partial r})]^2}{-\frac{\mathrm{dP}}{\mathrm{dz}}} \tag{3}$$

where z and r is longitudinal and transverse axis respectively, Ez is the electric field amplitude for the dipole mode with angular frequency ω, and P is the RF power as function of z. With the assist of the data from single cell simulation results, transverse shut impedance could be calculated by expression (3),

$$Rs = 50.078 \quad M\Omega/m, \quad \frac{Rs}{Q} = 7.732 \quad k\Omega/m$$

The Table 2 shows the initial scheme of design, by considering the relationship between deflecting voltage and some other parameters[1],

$$eV_T = n\frac{\lambda/c}{2\pi\Delta t}\sqrt{\frac{\varepsilon_N Emc^2}{\beta_d}} \tag{4}$$

where V_T is the transverse deflecting voltage, and E is the electron energy, n is the amplitude in the unit of nominal rms beam size, λ is the RF wavelength, ε_N is the normalized rms vertical emittance and β_d is the vertical beta function at the deflector.

Table 2: Parameters for x-band deflector

Structure type	**Constant impedance**
Operating frequency	11.424GHz
Operating mode	Disk-loaded waveguide $2\pi/3$
Energy	0.84GeV
Bunch length	120um
Resolution	30–20 fs
Input power	<10 MW
Attenuation factor	0.564 1/m
Single cell length d	8.7475mm
Iris thickness t	2mm
Radius of iris a	5mm
Radius of cavity b	14.886mm
Cave radius p	2.8mm
Cave center c	13.9mm
Quality factor Q	6477
Group velocity Vg/c	-0.0329

DESIGN OF COUPLER

For deflecting structure, the RF coupler is an important element. RF coupler is the input port of power and must be matched with the feeding waveguide, so as to feed the input microwave power into the deflecting cavities effectively. The time domain method could be put to use when design and simulation of coupler carry out[3], and the couplers(include input and output couplers) design employ single port feed-in as shown in Fig.4.

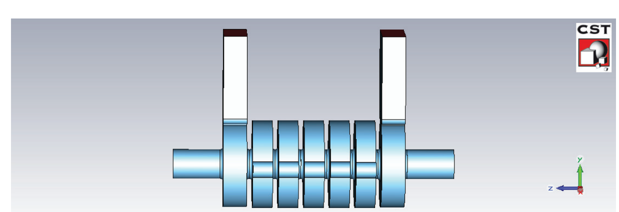

Figure 4: single port coupler model.

The simulation was set with five identical regular cells and two identical (input/output) couplers, the dimensions of the couplers could be changed simultaneously. The results of simulation and calculation are illustrated in Fig.5 to Fig.7.

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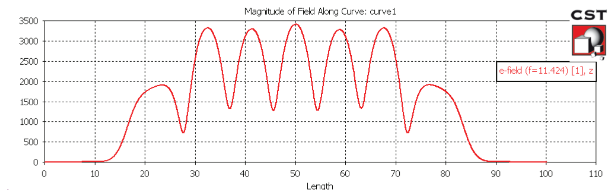

Figure 5: Electric field distribution.

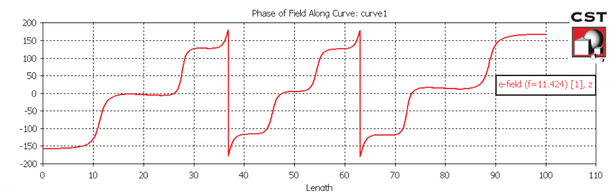

Figure 6: Phase of field distribution.

Considering the electric field along z axis is null, we simulated the off-axis electric field, and the results(Fig.5 and Fig.6) present that the field in the coupler is slightly lower than the cavity, also shows the periodic characteristic of structures. Time domain simulation methods ,the expressions below(5)-(7), could check the couplers match or not.

$$F^{+}(z) = \frac{E_c(z+p)}{E_c(z)} \quad F^{-}(z) = \frac{E_c(z-p)}{E_c(z)} \tag{5}$$

$$\Sigma(z) = F^{+}(z) + F^{-}(z) \quad \Delta(z) = F^{+}(z) - F^{-}(z) \tag{6}$$

$$\cos\phi = \frac{1}{2}\Sigma(z) \quad Re^{2j\Phi} = \frac{2sin\phi + j\Delta(z)}{2sin\phi - j\Delta(z)} \tag{7}$$

where $E_(z)$, $\cos\phi$, R are the distribution of electric field along z, regular cell phase advance and reflection coefficient, respectively.

Figure 7 presents the calculation result, and all results demonstrate that the couplers are matched and the phase advance is 120 deg. It is obvious that the two values $\cos\phi$ and R are indeed constant over the allowed range, and ϕ is corresponding to phase shift $2\pi/3$. It suggests that the regular cells operate at the frequency we wanted. The reflection coefficient R demonstrates that the couplers have satisfied the matching condition.

SUMMARIES

A transverse travelling wave deflecting structure of a disk-loaded waveguide has been designed and optimized for SXFEL at SINAP, with two caves in horizontal orientation to stable the polarization plane. The transverse shunt impedance could up to 50M/m, therefore a 50-cell long deflecting structure fed with an RF power of 8 MV generate a total deflecting voltage of 7 MV, then we can measure the bunch length with a time resolution of 30fs by using

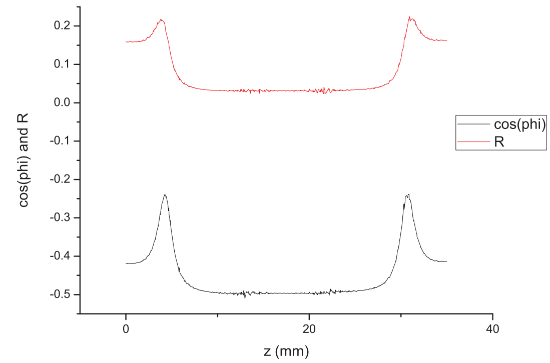

Figure 7: Reflection coefficient and phase advance.

this high gradient deflector. For higher energy or getting higher resolution, improving the fed power could meet the requirement. In the next step, several cells of X-band deflecting cavity will be manufactured and then microwave measurement will be carried out.

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