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Design of EPU oscillator cavity in femtosecond accelerator*

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Abstract We adopt the groove guide as the cavity of the undulator to reduce the diffraction effect. The groove guide has the advantages of lower surface energy loss, larger power capacity, less modes, and larger structure dimension over the traditional method waveguide. The attenuation calculation is given in this paper including the cavity optimization. And the dispersive character indicates that the oscillator can work in different modes with the change of the electron beam energy.

Key words free electron lasers, groove guide, attenuation character, zero slippage condition

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1 Introduction

Free electron lasers are devices that use the relativistic electron beams passing through a transverse periodic magnetic field, i.e. the undulator, in order to generate coherent electromagnetic radiation ranging from millimeter waves to hard X-ray regions. The elliptical polarized undulator (EPU) has been designed and installed in our femtosecond accelerator for the aim to produce the intensive coherent THz radiation.

For traditional oscillator adopting mirrors as feedbacks, the fields are expanded into discrete Gaussian modes. The interaction length L could be expressed as

$$L \doteq 2Z_{\rm R} = 2\pi {w_0}^2/\lambda, \qquad (1)$$

in which $w_0$is the waist size of fundamental mode and λ is the radiation wavelength. Accordingly, in THz region, the interaction length is short enough that the diffraction loss is strong. To confine the radiation, the device of waveguide is in common use. But the side effects are introduced simultaneously such as over-excessive modes, high surface energy loss, and small effective interaction area compared with the field cross section especially in long wave length region. In this paper, we recommend a new proposal applying the groove guide[1, 2] as the semi-open cavity to conduct the transmission of the radiation fields which could overcome those defects.

2 Design of the optical cavity

2.1 Introduction of the groove guide

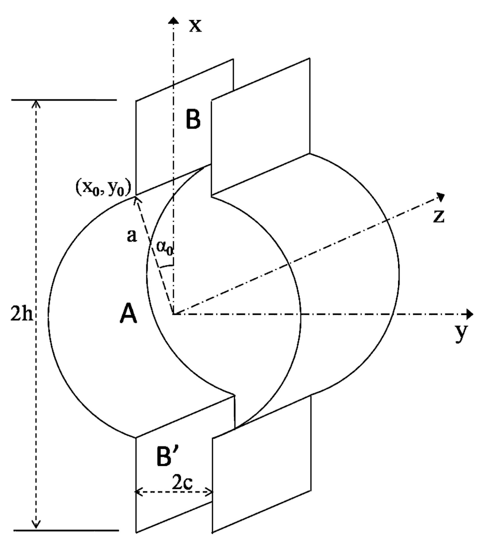

Fig. 1. Schematic of the circular groove guide.

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We adopt circular groove guide, as shown in Fig.1, from which the region A is central groove region with diameter 2a and region B (B') is the evanescent region with the overall wide 2h and the distance of the gap is 2c.

The solutions to the eigen equation represent different modes of the fields in the groove guide. For the fundamental mode $TE^1_{1,1}$ shown in Fig 2, the polarization of electric field is consistent with that of spontaneous emission of FEL and the maximum values of electric field are near the XZ plane, which means that the mode $TE^1_{1,1}$ will interact with the electron beams effectively and amplified efficiently.

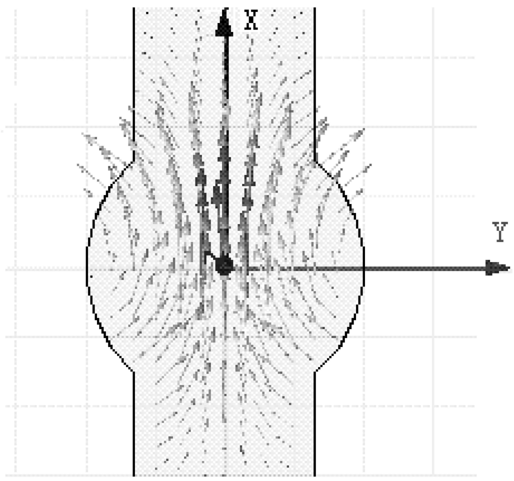

Fig. 2. HFSS simulation shows the distribution of electric field.

Due to the cavity surface absorption of energy, the magnitudes of the fields attenuate with transmission distance. The two following parameters: the attenuation constant and the power capacity play an important role in the design of the cavity, which could be expressed as

$$\alpha = \frac{1}{2}\frac{\oint_l \boldsymbol{S}_A \mathrm{d}l + \oint_l \boldsymbol{S}_B \mathrm{d}l + P_l}{P_A + P_B}(Np/m), \quad (2)$$

$$C_p = \frac{P_A}{P_A + P_B}, \quad (3)$$

where $\boldsymbol{S}_A$ and $\boldsymbol{S}_B$ are the active Poynting vector in two regions, the curve l denotes that the integral actions are conducted along the cross section perimeter of the groove guide, P_A and P_B mean the power stored in the cavity, and P_l is the power leaking through both open sides.

2.2 Calculation of power capacity and attenuation constant

The parameters for our experiments are listed in Table 1.

Table 1. Parameters of electron beam.

beam and EPU parameters	
beam energy MeV (maximum)	24∼30
undulator period cm	10
number of period	5
EPU polarization	Horizontal
magnets strength T	0.59
gap cm	3.6
cavity parameters (to be optimized)	
material	copper etc.
radius of central groove mm	2.5
overall wide mm	10∼50
ratio of c to a	0.1∼0.9

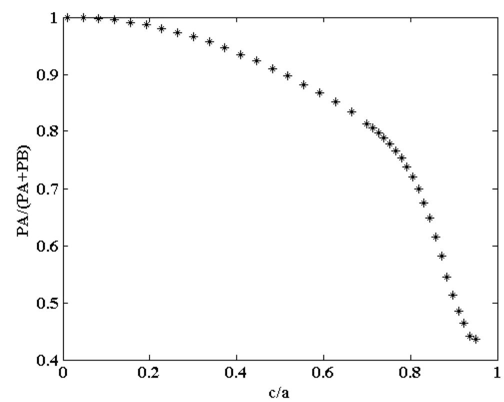

Fig. 3. Calculation of power capacity versus c/a.

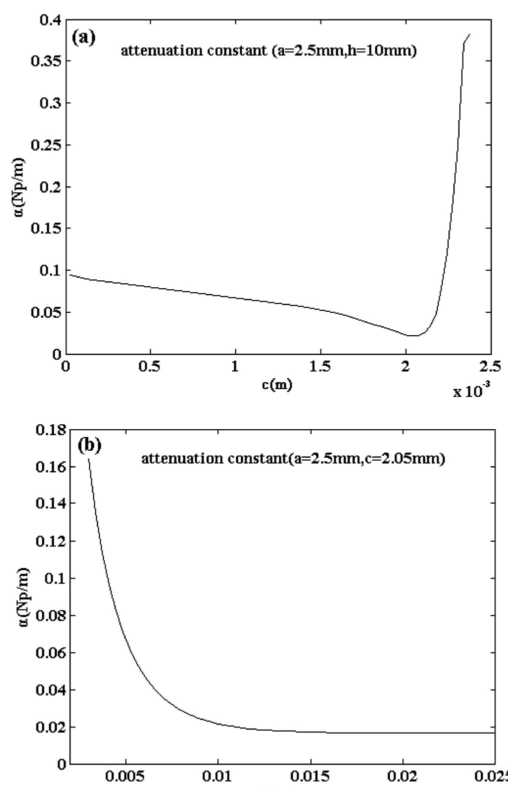

Fig. 4. Calculation of attenuation constant versus (a) c or (b) h.

The calculation of power capacity is shown in Fig 3, from which we can conclude that the power capacity falls with the increase of the ratio of c to a. That is why the slabs used as the FEL cavity have less efficiency to contain the field's energy.

And the calculation of the attenuation constant is shown in Fig 4.

So the dimensions of the groove guide can be decided in order to achieve the minimum value of the attenuation constant. The optimum size for the groove guide is that c=2.05 mm and h=15 mm.

The result of a calculation of the attenuation over a large energy range thus the frequency range is shown in Fig 5, and it presents us the frequency tunablity with the changing of the electron energy.

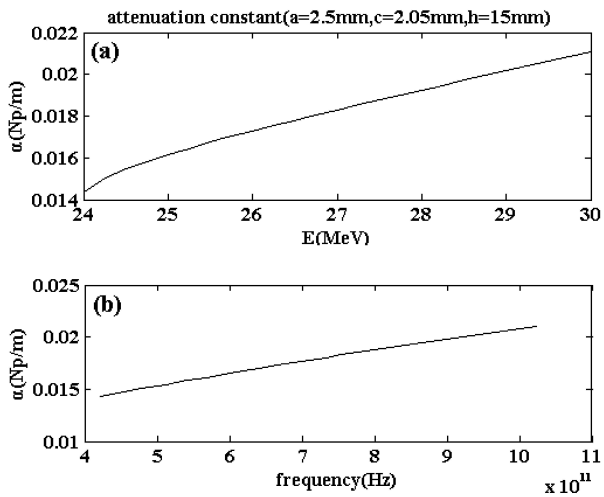

Fig. 5. Calculation of attenuation constant versus (a) E or (b) f.

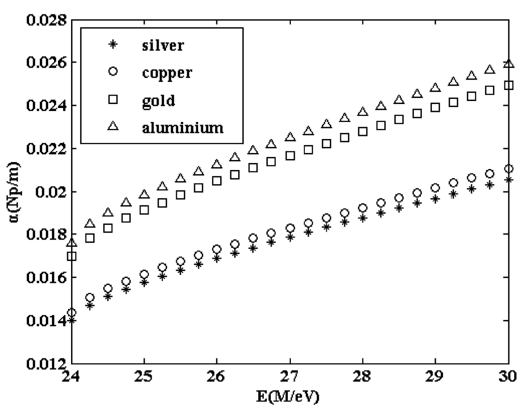

Fig. 6. Calculation of attenuation constant for different materials.

Different materials are adopted as presented in Fig 6, and the results indicate that the silver and copper are the best candidates in the attenuation aspect.

3 Dispersive character of groove guide

The dispersion relation of the groove guide is

$$\omega = \sqrt{c_0^2 k_z^2 + \omega_{co}^2}, \tag{4}$$

where c_0 is the light speed, k_z is the wave number in the longitudinal direction and ω_{co} is the cut-off frequency. For the beam to satisfy the synchronism frequency condition in the undulator, there is relation

$$\omega = k_z v_z + k_w v_z, \tag{5}$$

where v_z is the longitudinal velocity of the electron and $k_w = 2\pi/\lambda$ is the wiggle wave number. As for the electron energy E=25 MeV, the dispersive curve is indicated in Fig. 7, there are backward and forward waves with the group velocity $0.557c_0$ and $0.998c_0$ respectively. And the fast wave is what we need. When E=23.9862, there is a single solution to Eq. (4) and Eq. (5), which means the zero slippage condition[3] is another operation mode.

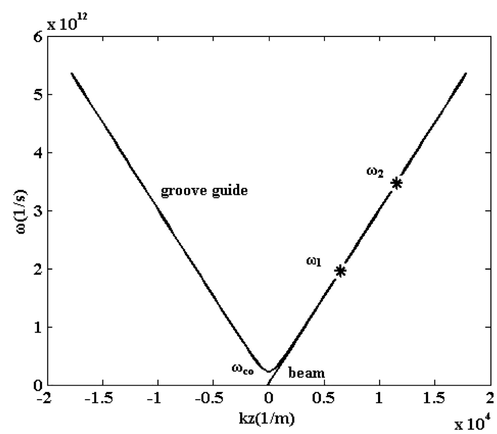

Fig. 7. Dispersive curve for E=25 MeV.

4 Concluding remarks

Groove guide is chosen as the candidate of the cavity to reduce the radiation loss. The design of the guide is given in this paper to reduce the attenuation of the field.

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