STUDY ON THE PLANAR UNDULATOR SCHEME WITH FOCUSING PROPERTIES FOR PKU-FEL*

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Abstract

An IR range SASE FEL test facility will be built at Peking University. The project is designed to get the SASE FEL at 7 micron driven by a superconducting accelerator. A hybrid planar Nd-Fe-B undulator is employed and the optimization of the external focus system for the undulator is studied. In the PKU-FEL facility, the electron energy is about 30-40 MeV. The combined function undulator with FODO lattice imposes quite stringent tolerances on the strength of the quads. To solve this problem, the weak natural focusing of the undulator in the vertical plane together with horizontally focusing quads, is proposed to supply the focusing in the facility. The combined function undulator of FOFO lattice and FF lattice in the horizontal plane are studied. Compared with the FODO lattice, the FOFO and FF lattice make the saturation a bit longer and the requirements of the field accuracy for the focusing system are much reduced.

INTRODUCTION

Short-wavelength FELs are primarily directed toward x-ray regime at wavelength down to 1 Å. Such a source of coherent laser-like x-rays would have many applications [1]. SASE mode is one of the best methods to get short wavelength FEL.

Table 1 The main parameters of PKU-FEL

Electron beam	
Energy	20-40MeV
Peak current	200A
RMS emittance	5mm.mrad
RMS energy spread	80keV
Bunch duration	~ 1ps
Undulator	
Period length	27mm
K parameter	1.5
Undulator length	5 m
FEL	
Wavelength	7 μ m
Saturation length	~4.5m
Saturation power	~80MW

PKU-FEL facility is an ideal platform to study the physical and technical issues of single pass SASE FEL and high average power FEL. Peking University Superconducting Accelerator Facility (PKU-SCAF) [2], which comprises a superconducting RF photoinjector and superconducting main linac, will be used to drive FELs. The main coupler and cryostats are designed to work at CW mode. At the first stage, SASE FEL experiment at wavelength of 7 μm will be studied [3]. In this paper, the undulator focusing structure is studied.

THE COMBINED FUNCTION UNDULATOR

Undulator is the most prominent FEL specific component. Given electron beam and undulator parameters, the radiation wavelength is determined by a resonance condition

$$\lambda = \lambda_w (1 + a_w^2) / 2\gamma_0^2$$

where $a_w = K/\sqrt{2}$ for planar undulator, γ_0 is related to the average beam energy. The undulator has to provide a sinusoidal magnetic field so that FEL process can take place, and it also has to keep the beam size small over the whole undulator length. A planar hybrid permanent magnet undulator combined with a superimposed periodic quadrupole lattice structure (Four Magnet Focusing Undulator, 4MFU[4]) is adopted at PKU SASE FEL[5].

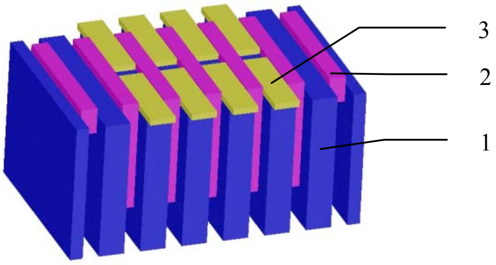

Figure 1: The scheme of combined function undulator, 1: magnets for undulator field; 2: poles; 3: focusing magnet arrays

We optimized the undulator parameters according to the fitting numerical solutions of the coupled Maxwell-Vlasov equations [6]. The electron beam parameters I, ε_n, σ_e are fixed at nominal values given in table 1. The beta function is used the optimized value.

For this undulator used in the IR range FEL, the weak natural focusing in the vertical plane can be used. For example, while the energy of the electron beam is 35MeV, the average beta function in the vertical plane is about

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30cm. In the design of the external focusing structure, the natural focusing in the vertical plane will be included. The FODO, FOFO and FF structure is calculated with GENESIS1.3 in steady state mode in this paper.

FODO scheme

First the focusing magnet arrays were calculated as FODO structure. According to the optimization, the FODO period length is $8\lambda_w$ with focusing field gradient of 17T/m and dispersing field gradient of 14T/m at x direction. With this FODO lattice and natural focusing of the planar undulator, average beta functions of 26cm at both x and y direction are obtained. Figure 2 shows the electron beam rms size along undulator in x and y direction. The average beam sizes are almost equal in the two directions [7]. Figure 3 gives the FEL power along undulator. The undulator field is assumed to be ideal, and the influences of different rms quadrupole offsets to the FEL saturation are also shown in Figure 3.

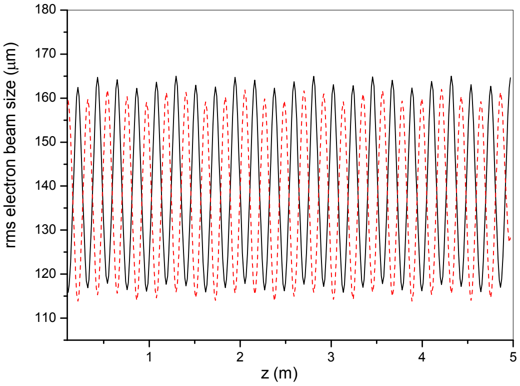

Figure 2: The transverse rms electron beam size with FODO focusing scheme, the solid black line shows the beam size at x direction, the dashed red line shows that at y direction.

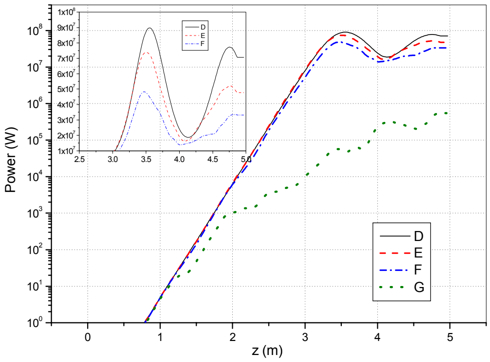

Figure 3: The influences of the rms quadrupole offsets to FEL gain with FODO scheme. The undulator field is assumed to be ideal. The lines marked by D, E, F, G mean that the quadrupole offsets are 0, 30μm, 50μm and 80μm respectively.

FOFO scheme

The FODO lattice in the undulator keeps the transverse beam dimensions within a well specified variation. But the alignment precision of quadrupole is high. Since the natural focusing keeps the beam dimension small in the vertical plane, we put the external focusing quadrupole only in x direction. So the external focusing system is a FOFO structure. The optimized parameters are that the field gradient is 2T/m. The length of the focusing quadrupole is $2\lambda_w$ and the the drift length is $10\lambda_w$. With this structure, the average transverse beam size at x direction is bigger than that of at y direction, as showed in Figure 4. From Figure 5, we can see that the influences of the quadrupole offsets to the FEL saturation power are much decreased, and the saturation length is about 4.2m.

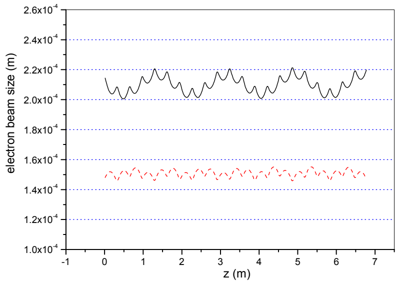

Figure 4: The transverse rms electron beam size with FOFO focusing scheme. The solid black line shows the beam size at x direction, the dashed red line shows that at y direction.

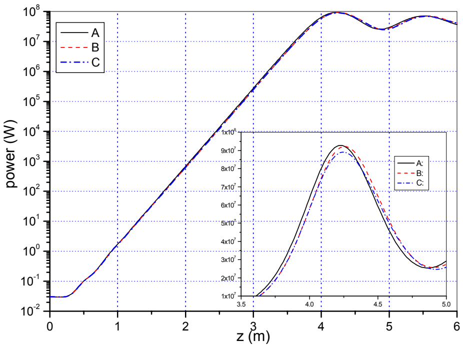

Figure 5: The influences of the rms quadrupole offsets to FEL gain with FOFO focusing scheme. The undulator field is assumed to be ideal. The lines marked with A, B, C mean that the quadrupole offsets are 0, 100μm, 200μm respectively.

To get a round beam size in the transverse section, we can increase the strength of the field gradient of the FOFO structure. When the field gradient is increased to 4.5T/m, the average beam size is nearly round. In this case, the alignment precision of quadrupole is much stricter than that in Figure 5. To make the gain reduction less than 10%, the quadrupole offsets have to be smaller than 70µm.

FF scheme

In fact, the FOFO scheme can be transferred to FF scheme. That is, the focusing magnet arrays are put in the full length of x direction. There is no drift length in external focusing period. According to the optimization, the focusing field gradient is 0.8T/m. The rms transverse beam size is shown in Figure 6. It is nearly round in the transverse section. The FEL power along the undulator is shown in Figure 7, with different quadrupole offsets. To get the gain reduction of FEL power less than 10%, the quadrupole offsets have to be smaller than 150µm.

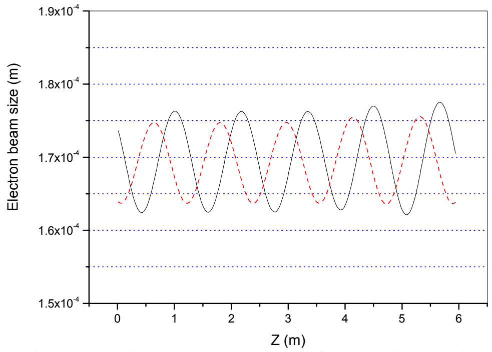

Figure 6: The transverse rms electron beam size with FF focusing scheme, the solid black line shows the beam size at x direction, the dashed red line shows that at y direction.

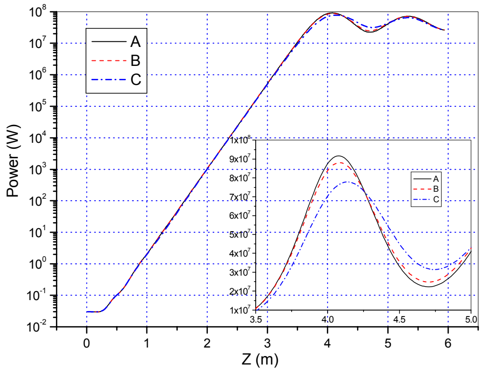

Figure 7: The influences of the rms quadrupole offsets to FEL gain with FF focusing scheme, the undulator field is assumed to be ideal, the lines marked with A, B, C mean that the quadrupole offsets are 0, 100µm, 200µm respectively.

SHORT BUNCH EFFECT

For the IR range FEL, the short bunch effect has much influence at this facility. With the electron beam rms bunch duration of 1ps, the SASE FEL process was simulated in the time-dependent mode using GENESIS 1.3 code. There is only a single temporal spike in the FEL radiation pulse. The radiation FEL pulse has full transverse and longitudinal coherence. The fluctuation of the FEL power and saturation length is large. With the time-dependent mode simulation, the average saturation length of the SASE FEL is about 30cm longer than the result from steady state mode.

SUMMARY

In this paper, the focusing properties of the 4MFU used for IR SASE FEL were investigated. For IR range FEL, the natural focusing in vertical plane and the external focusing quadrupoles in horizontal plane control the electron beam transverse dimensions along the undulator. With the FF focusing scheme, the average beta function is about 38cm. The design and measurement of an undulator model with 10 periods have been finished at BFEL lab. The measurement results agree well with the design values.

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