RESEARCH ON THE UNDULATOR USED FOR PKU-FEL

H.H. Lu *, J.P. Dai, Y. F. Yang, C.T. Shi, W. Chen, Y.N. Li, J.J. Zhuang
BFEL Laboratory, IHEP CAS, P.O.Box 2732, Beijing, 100080, China

Abstract

A 5m-long combined function undulator used for the Peking University Infrared SASE FEL facility (PKU-FEL) is currently under construction at IHEP, and a 10 period prototype has already been developed. This paper describes the design study of the undulator, which is a hybrid planar magnet structure with extra focusing. The results of magnetic measurements performed on the prototype are also reported and discussed, and it demonstrates that the proposed combined function magnet structure is very promising for the use in the SASE FEL at Peking University.

1. INTRODUCTION

Supported by Major State Basic Research Development Program, a FEL facility to study the physical and technical issues of single pass SASE FEL at IR wave band and high average power FEL is being constructed at Peking University. This facility mainly consists of a superconducting RF photoinjector and superconducting main linac, a bunch compressor and an undulator. The main parameters of the SASE FEL platform are given in Tab.1 [1].

In this paper, we emphasize on the design of undulator, which is a key component of SASE-FEL experiment. The theoretical and numerical simulation of the undulator prototype is described, and the first results of magnetic measurements on the prototype are given.

Table1: Parameters of PKU SASE FEL

Electron Beam	
Energy	~40 MeV
Peak Current	>200 A
RMS Emittance	5 mm.mrad
RMS Energy Spread	80 keV
Bunch Duration	~ 5 ps
Undulator	
Period Length	27mm
K Parameter	1.5
Average β Function	25cm
Undulator Length	5 m
FEL	
Wavelength	4μm
Saturation length	~4 m
Saturation power	~50MW

2. THEORETICAL AND NUMERICAL SIMULATION OF THE PROTOTYPE

From the overall concept of PKU SASE FEL program, we got the main parameters of the undulator such as period length, K value, and average β function. We used the experiential formula [2] as follows to compute the peak field of the structure. We got the value of 0.56T when the gap between the two jaws is 11mm. And the corresponding K value is 1.41. These parameters are fit for the PKU SASE-FEL program.

$$B_0 = 3.44\exp[-5.08\frac{g}{\lambda_w} + 1.54(\frac{g}{\lambda_w})^2] \quad (1)$$

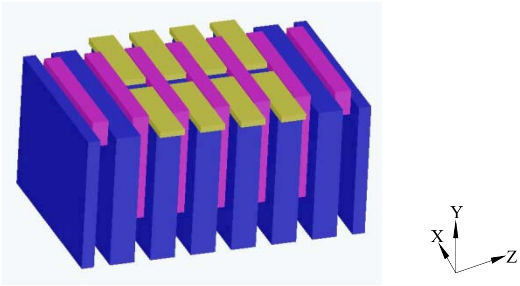
Where $0.07 < \frac{g}{\lambda_w} < 0.7$

$$K = 0.934\lambda_w[cm]B_0[T] \quad (2)$$

*Corresponding author. Tel.:+8610 62563452; Fax:+8610 62563454; e-mail:luhh@ihepa.ac.cn

2.1 The Magnetic Structure Design

A variety of different technologies have been proposed in the past to build insertion devices. We select the planar hybrid magnets structure because it can achieve higher peak fields. The magnet design has been carried out using RADIA code, which is made by ESRF [3]. This code uses the method called Boundary Integral Method with the characteristics of high calculating speed, high accuracy, and perfect field integral function. Fig.1 shows part of the structure used for the simulation.

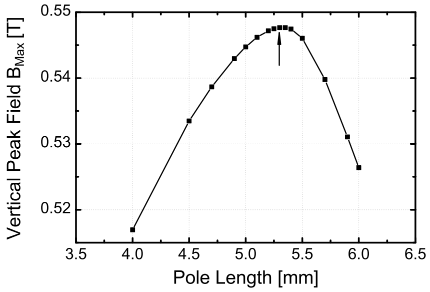


The magnet structure consists of a conventional hybrid structure using NdFeB magnets with a remanent magnetization Mr =1.2T. Poles are made of Vanadium Permendur which has high permeability. With respect to the magnets, the pole tips have an overhang of 2.5mm into the gap region. There is 0.5mm for lowering saturation effects in the poles, and the rest 2mm is the space for the quadrupoles.

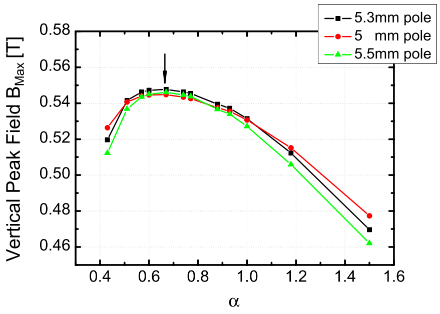
The optimization is an iterative process. Our goal is to get the parameters to match the criteria, such as: the magnets and poles should be of reasonable dimensions to achieve peak field we need, the field roll-off should be less than the Pierce parameter ρ, the electron trajectory less than one fifth of electron bunch radius which is 40 microns in this program, and the field integrals have to be trimmed to zero by means of a special end pole configuration.

The curves in Fig.2 show the final calculation results of determining the geometrical dimensions of magnets and poles.

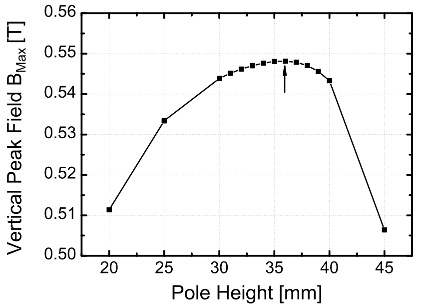
After the calculation, we got the final dimensions: 60mm × 45mm × 8.2mm (width × height × length) for magnets and 43mm×36mm×5.3mm for poles.



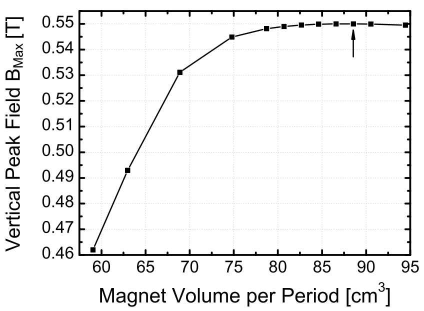
(a) Dependence of the vertical peak field on the pole length for constant period length (27mm) and constant gap (11mm); the arrow marks the design value.



(b) Peak field as function of the ratio of magnet height to magnet width with constant period length and magnet volume corresponding to different pole length; the arrow marks the design value.



(c) Peak field as function of pole height for constant period length, gap and magnet volume; the arrow marks the design value.



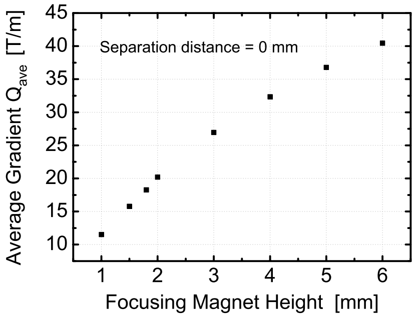
(d) Peak field growth as function of the applied magnet volume for constant period length ,gap and constant transverse magnet proportions; the arrow marks the design value.

Figure 2: Optimization results of hybrid structure.

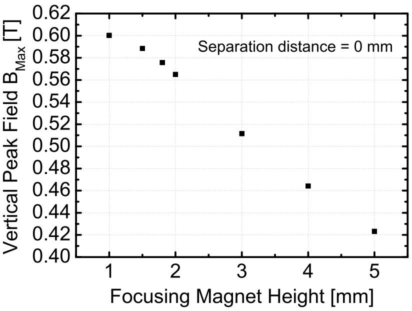
2.2 FODO Lattice Design

Normally, there are two ways to focus the electron beam, one is called superimposed FODO lattice, the other is called separated FODO lattice. For PKU-SASE-FEL program, the optimized average beta function is only 25cm, and the energy of electron beam is 35-40MeV, which is not very high. So, we select superimposed FODO structure to realize the focusing function.

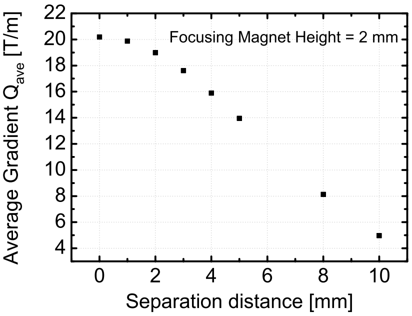
We made a series of calculations using RADIA code and determined the FODO parameters at last. Some simulation results are shown in Fig.3. The whole parameters of 10 periods prototype are shown in Tab.2.



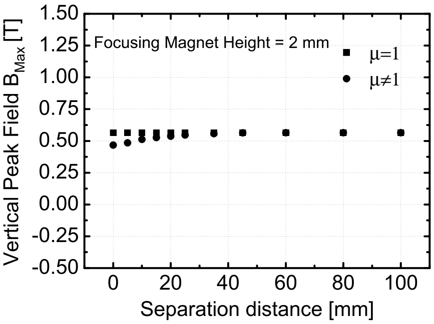
(a) Dependence of the gradient on the height of focusing magnets



(b) Dependence of the peak field in the gap on the height of the focusing magnets



(c) Dependence of the gradient on the separation distance between the focusing magnets



(d) Dependence of the peak field in the gap on the separation distance between the focusing magnets

Figure 3: Optimization results of FODO structure.

2.3 The Prototype with 10 Periods

A 0.283m long prototype structure has been developed, which includes 10 periods and two end-pole structures, shown in Fig.4.

Table 2: Parameters of the undulator prototype

Parameters	Value
Period Length	27mm
Peak Field	0.56T
Average β Function	25cm
Magnetic Gap	11mm
Magnets Dimensions	60mm×45mm×8.2mm
Poles Dimensions	43mm×36mm×5.3mm
Focusing Magnets	30mm×2mm×8.2mm
Gradient	~17T/ m
Quadrupole Length	54mm

Figure 4: The photo of the prototype with 10 periods.

3. THE FIRST RESULTS OF MAGNETIC MEASUREMENTS

We did the primary test. A 3m long measuring bench is used to characterize the magnetic performance of the prototype structure. And we use the Hall probe with 1×0.5mm sensitive area to do the measurement. The whole system provides sufficient mechanical accuracy. The measuring results comparing to the designed parameters are shown in Tab.3. From the table, we can see we got the identical parameters of prototype according to the simulation. At the same time, we showed some graphs of the measurements in Fig.5, so the magnetic performance is clearer.

Table 3: Comparison of parameters between design and measurement (Electron Beam Energy 40MeV)

	Design	Measurement
Peak Field	0.56 T	0.5619 T
Second Integral	5 Tmm^2	4.6 Tmm^2
Beam Offset	36 µm	31.7 µm
Spontaneous Radiation Wavelength	4.39 µm	4.4 µm

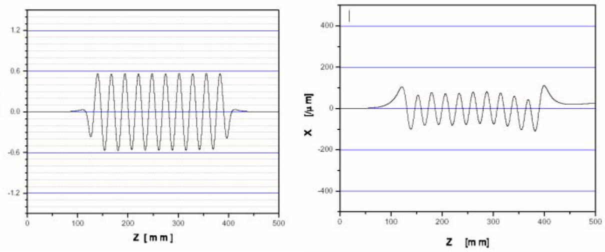


Figure 5: The measurements of prototype.
(a) Peak field distribution on axis (b) Beam offset

4. CONCLUSIONS

The results demonstrate that the proposed combined function magnet structure is very promising for the use in the SASE FEL at Peking University. Future work will include physical and mechanical design with length of 5 meters, the end-pole design to realize the phase matching of different segments, and so on.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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