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THE PRELIMINARY EXPERIMENT STUDY FOR SOFT X-RAY SELF-SEEDING SYSTEM OF SCLF FACILITY

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Abstract

The preliminary experiment studies for soft x-ray self-seeding system design of SCLF facility have been presented in this paper. Some practical problems and pre-engineering design have been studied for the experimental prepare of soft x-ray self-seeding for the future SCLF facility. The monochromator system designs in this paper include optical structure, optical parameters and mechanical design. The designed optical system has an optical resolution of 1/10000 at the photon energy of 700-1300eV based on the optical simulation. To make the system satisfy the experimental requirements, mechanical install requirements and install precisions are also analysed. Considering the actual varies errors, the errors analyses such as the surface errors of the optical mirror and the machining errors of the VLS grating are also carried out.

INTRODUCTION

The successful lasing of SASE FEL (self-amplified self-emission free electron laser) [1-3] provides a new possibility to generate high-brightness, short wavelength photon source with tuneable wavelength and it makes free electron laser as a credible method to research advanced science such as material, biological and chemical even environment sciences. At the same time, SASE FEL has its intrinsic defects, poor longitudinal coherence, relative spectrum band-width and power jitter, which limit its application. External seeding even harmonic lasering schemes, such as direct seeding, HGHG [4-5] and EEHG [6-8], are proposed to improve the radiation characteristics of SASE FEL. Nevertheless, the radiation photon energy of external seeding schemes is generally less than several hundred eV, it can hardly be used to generate short wavelength soft X-ray even hard X-ray. Self-seeding [9] is proposed to improve the longitudinal coherence of existing FEL. LCLS achieved the first lasing of soft and hard X-ray self-seeding separately in 2014 [10] and 2012 [11].

The self-seeding scheme inserts the monochromator and the magnetic chicane between the long undulator, relative purified spectrum seed is obtained by the monochromator to modulate the electron beam and generate longitudinal coherent radiation. Besides LCLS, other facilities around the world are also trying to carry out self-seeding experiment, for example, hard X-ray self-seeding was demonstrated at SACLA in 2014 [12], European FEL [13] and PAL-FEL [14] facility are also prepared to the hard X-ray self-seeding experiment. In china, there are two X-ray FEL projects, the SXFEL user facility and SCLF facility. The currently under constructing SXFEL user facility will be competed in the next two or three years, the SCLF will also begin to be constructed recently, it's worth to mention that the self-seeding schemes (both soft X-ray and hard X-ray self-seeding) are the basic operation mode of SCLF facility. In my previous works, the self-seeding system design and simulation results for SXFEL user facility have been presented [15]. In this paper, the preliminary experiment studies for soft x-ray self-seeding system design of SCLF facility have been presented to prepare for the Preliminary soft X-ray self-seeding experiment . Some practical problems and pre-engineering design have been studied for the experimental prepare of soft x-ray self-seeding for future SCLF facility.

THE GRATING MONOCHROMATOR PHYSICAL DESIGN

In the design of the SCLF facility, there are three undulator lines and one of them will work on the soft X-ray self-seeding mode (as well as SASE mode) and the electron beam energy is 8GeV. For the limitation of the space, the total length of the monochromator system and chicane should be less than 5m. The layout of self-seeding monochromator system design is displayed in Fig. 1.

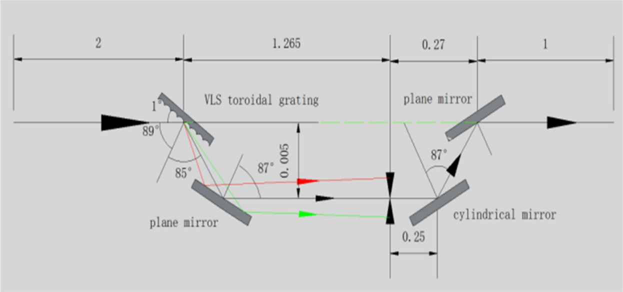

Figure 1: The layout of self-seeding monochromator design.

Based on the actual situation, the grating incidence and diffraction angles are chosen as 89 ° and 85° separately, the object and image distances are 2 and 1.27m. To compensate the geometric-optical aberration and get higher optical resolution, we make the each order optical aberration coefficients as zero and we can get the parameters of the VLS grating monochromator. And the final grating monochromator parameters are presented in the table. 1.

Table 1: Grating Monochromator Parameters of Constant Photonic Energy and Vary Photonic Energy.

Parameter	**Value**	**unit**
Incidence angle	89	degree
Diffraction angle	85	degree
D_0	29389	cm
D_1	417.86	cm^2
D_2	10.092	cm^3
D_3	0.2645	cm^4
$R_m(m)$	116	m
$R_{sag}(cm)$	7.76	cm
$f_{obj}(m)$	2	m
$f_{imag}(m)$	1.27	m
delay(fs)	291~401	fs
M_2 radius	10.67	m
Total length	5	m

The designed monochromator should be works on the photon energy range of 700-1300 eV. In this system design, the incidence angle is constant and we can scan different photon energy by adjusting the angle of the mirror. The Fig. 2 shows the variation of the diffraction angle with the change of the photon energy, it indicates that the variation range of diffraction angle is 83.5°-86°.

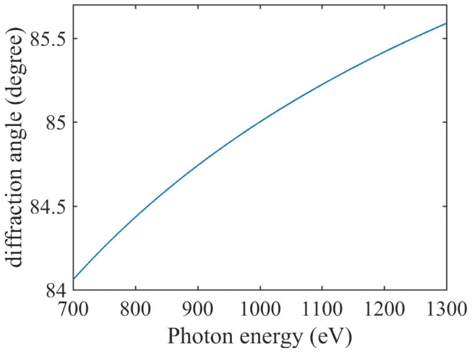

Figure 2: The variation of the diffraction angle with the change of the photon energy.

THE OPTICAL MECHANICAL ADJUSTMENT SYSTEM DESIGN

To prepare for the soft X-ray self-seeding experiment, a mechanical adjustment system is also designed based on the optical design. In this optical design system, four optical elements need to be implemented and adjusted. The optical mechanical adjustment system consist two vacuum chambers: one chamber implements the mechanical system of the grating and the plane mirror, and the other implements the cylindrical mirror and the second plane mirror.

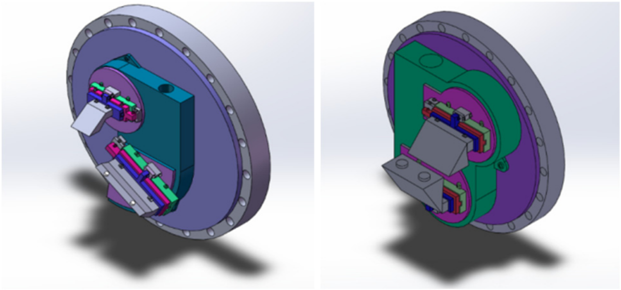

Figure 3: The soft X-ray self-seeding monochromator mechanical design.

In this preliminary system design, both optical elements can be rotated at certain range angles, and these elements can also be adjusted in Horizontal and vertical directions. Moreover, rough and slight adjust structure are both involved in this mechanical adjustment system. The soft X-ray self-seeding monochromator mechanical design and the system integral structure assembly diagram are presented at Fig. 3 and Fig. 4 respectively.

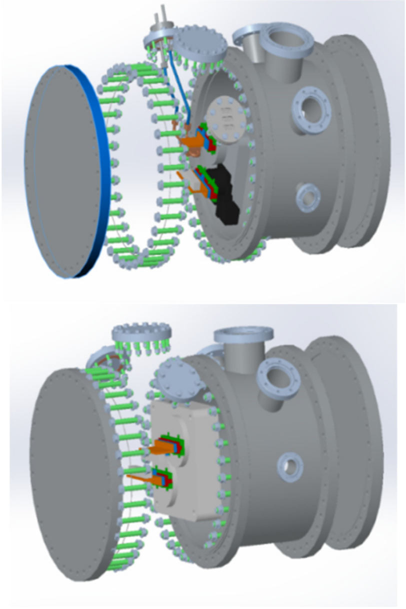

Figure 4: The system integral structure assembly diagram.

THE CHICANE DESIGN

In this self-seeding scheme system, the chicane is mainly used to smear out the electron beam microbunching as well as compensate the optical delay generated by the grating monochromator. In this monochromator system, when we scan different photon energy radiation, the optical time delay can be expressed as:

$$\Delta d = 2 \times 0.05\left(\frac{\pi}{2}+\beta-\alpha\right) = c\Delta t$$

Where α, β are the incidence and diffraction angles separately. In this design, the optical time delay is 200-400 fs corresponding to the photon energy range of 700-1300eV. In this situation, the chicane can make the electron beam synchronize with the light just adjusting the length and angle of the magnetic chicane. In addition, the total length of the chicane should less than 5 m and match the length of the monochromator. The layout of designed magnetic chicane is displayed in the Fig. 5 and the designed parameters are presented in the table. 2.

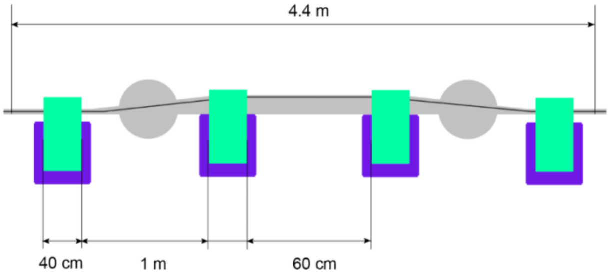

Figure 5: layout of designed magnetic chicane

Table 2: Grating Monochromator Parameters of Constant Photonic Energy and Vary Photonic Energy.

Parameter	Value	unit
Total length	4.4	m
Length of the dipole	400	mm
Distance between dipoles	1000	mm
Length of central space	600	mm
Deflection angle	0.5-0.6	degree
Magnet intensity	0.6-0.7	T
Time delay	200-400	fs
Offset	12.4-14.7	mm

THE OPTICAL MACHINING ERROR AND INSTALLATION ERROR

Considering the actual varies errors, the errors analyses such as the roughness, surface error of the optical mirror and the machining error of the VLS grating are also car-ried out. In this analysis, the machining errors include the radius error, surface machining error, varies orders ma-chining coefficient errors of VLS grating. In the grating substrate machining process, 1% sagittal and meridional radius error are easily to be achieved. Besides, there is also surface error in the mirror machining process. In this analysis we give typical values of surface error, 2mrad in meridional direction, 0.5mrad in sagittal direction. More-over, there are also varies orders machining coefficient errors of VLS grating. In this grating design, VLS grating is meanly used to improve the resolution by eliminate varies orders optical aberrations. Rationally, the resolution of VLS grating will decrease if the varies orders machin-ing coefficient errors of VLS grating are introduced. Gen-erally, the VLS grating machining coefficient errors are less than 1%, and it will have little effect on the grating resolution. We consider all the machining errors together and do the optical simulation with these errors based on the shadow simulation. The optical simulation result without any errors is showed in the Fig. 6 and the opti-cal simulation result considering all the machining errors mentioned above is showed in Fig. 7 (input pho-ton energy is 1000 and 1000.1 eV).

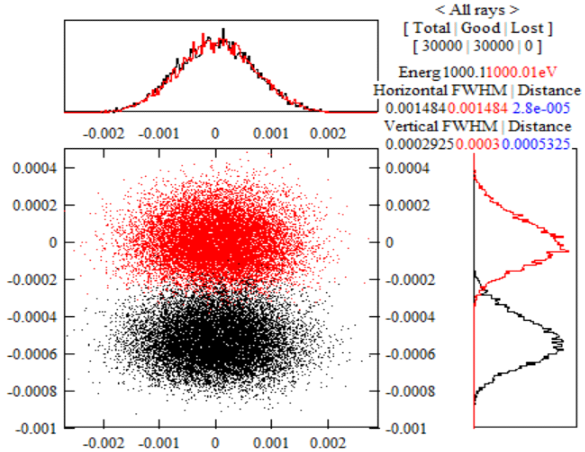

Figure 6: The optical simulation result without any errors.

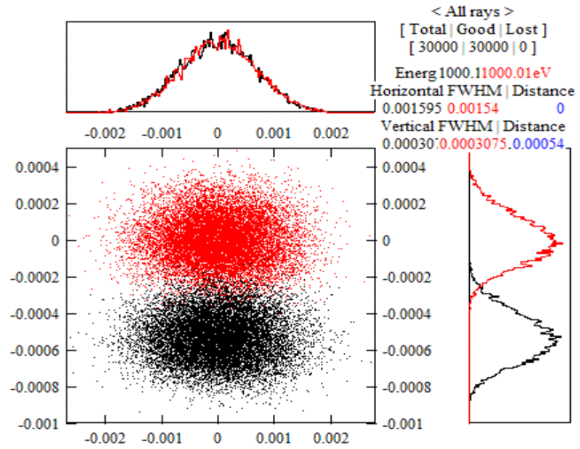

Figure 7: The optical simulation result considering all the machining errors.

In addition, the analyses of installation errors are also carried outed to ensure the enough power resolution (1/10000) of the grating monochromator. Based on the analyses, the optical error mentioned above and instal-lation error analyses are concluded in the table. 3.

Table 3: The Optical Machining Error and Installation Error Analyses.

Parameter	Value	unit
Sagittal radius error	1%	
Meridional radius error	1%	
D_0 error	0.5%	
D_0, D_1, D_2 error	1%	
Grating installation error (horizon)	142.72	μm
Grating installation error (vertical)	2.49	μm
Mirror angle installation error	4.2	μrad
Mirror installation error (horizon)	0.524	mm
Mirror installation error (vertical)	15	μm

CONCLUSION

In this paper, the preliminary experiment studies for soft x-ray self-seeding system design of SCLF facility are given. The grating monochromator physical design is firstly introduced and the system will work on the photon range of 700-1300 eV. And then, a preliminary optical mechanical adjustment system design is furtherly shown, which include mechanical design and the system integral structure assembly diagram. After that, the self-seeding magnetic chicane is also designed based on the optical elements distribution. Finally, the optical machining error requirements and installation error are analysed. In conclusion, preliminary experimental studies including system design and varies engineering requirement are presented in this paper for the experimental prepare of soft x-ray self-seeding for future SCLF facility. Further works will focus on the detail system design and the experimental achievement of the optical system.

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