DESIGNING A PULSE-RESOLVED PHOTON DIAGNOSTIC SYSTEM FOR SHANGHAI SXFEL

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Abstract

It is presented the design of photon diagnostic system for SXFEL, the X-ray Free Electron Laser facility in Shanghai Synchrotron Radiation Facility. The system mainly includes a diagnostic beamline with two branches and some diagnostic devices. In the direct passing branch, the intensity distribution of the spot is measured. A set of multi-slit plates are applied for measuring the spatial coherence of a single FEL pulse; In the deflecting branch, a high-resolution VLS-PGM monochromator, with a simple manual adjusting system, is set up for detecting spectrum of single FEL pulse. The measuring range of wavelength is 8nm-10nm, might be extend to 3nm. Multi-double-slit system ensures pulse-resolved spatial coherence detecting.

INTRODUCTION

X-ray transmission and diagnostics plays a key role in the SXFEL facility [1][2][3][4]. It is necessary to setup an X-ray photon diagnostic system to characterize and monitor the output laser. Based on the information fed back by the system, the units of the undulators can be adjusted precisely. Furthermore, the applications of FEL are directly depend on the laser characters, such as gain, saturation, coherence, and so on.

Unlike the pulse in the third generation synchrotron radiation, each FEL pulse is quite deferent from each others in nature (ch.2 in Ref.4). Therefore, single pulse diagnostics is significant to FEL facility commissioning and FEL experiments. The system presented below is pulse-resolved in flux measurement, spatial coherence diagnostics, spot imaging and spectrum detecting. The resolution power touches 30Hz.

THE PULSE-RESOLVED SOFT X-RAY PHOTON DIAGNOSTIC SYSTEM

The designed goal of the system is in Table1.

Table 1: Designed goal of the system

Items	Performance
Wavelength	Range: 8-10nm, might extend to 3nm
Energy resolution power	10000@9nm
Spatial coherence length measurement	Range: max to 1mm
Photon Flux measurement	Range: max to 10^{30}ph/s/0.1%BW
Spot shape measurement	Range: max to 5mm Resolution: 14μm
System vacuum	10^{-8}Torr for inert gas; 10^{-10} Torr for others, among which 10^{-12} Torr for Carbon

Two components of the laser output from SXFEL, with wavelength 45nm and 9nm. The system focus on the diagnostics on 9nm lasing, which is close to soft X-ray, and quite different from visible light and hard X-ray.

Therefore, mirrors with glancing incidence are applied; high and ultrahigh vacuum environment is necessary for Photon transmission and mirror cleanness. And the whole system shall be windowless otherwise the photons are easy to be absorbed. Fig. 1 shows the Layout of the system.

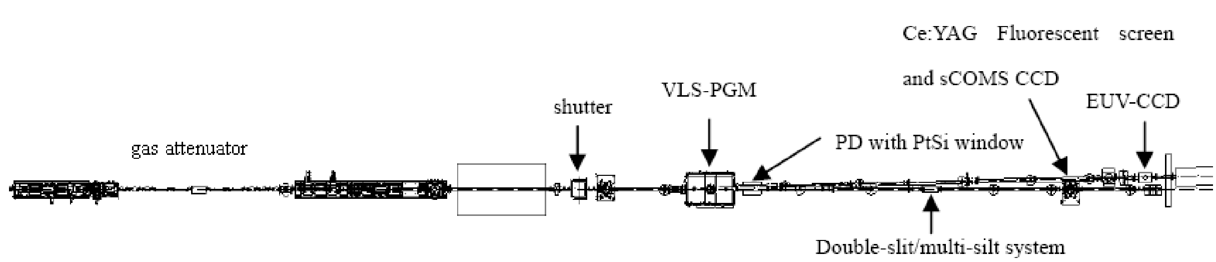

Figure 1: Layout of the photon diagnostic system, including front-end and beamline.

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MAIN INSTRUMENTS FOR X-RAY FEL PULSE DIAGNOSTICS

The system has main diagnostic instruments as follows: 1. beam position sensitive ionization chamber, which can measure the beam position pulse-by pulse with high sensitivity; 2. Photo diode with PtSi window, which has a large dynamic region for flux detecting; 3.A VLS-PGM with EUV-CCD is served as high precise spectrometer to probe single pulse spectrum; 4. Ce:YAG Fluorescent screen and fast optical CCD for spot distribution; 5. multi double-silt system to estimate spatial coherence for a single shot. All above instruments can diagnose a single FEL pulse. In addition, an inert gas chamber as flux attenuator will be put on the front-end to adjust photon flux in a range with 8 orders.

Beam Position Monitor

In the commissioning process of the undulator and accelerator, the intensity and position information of output beam should be monitored real-timely and precisely. The parameters of each undulator unit and the accelerator could be adjusted precisely assisted by this information. Because the FEL pulse to pulse fluctuations could be significant in the laser amplification process and these fluctuations will be reflected in the intensity, time structure and spectrum structure, the beam position detector (BPM) need to be mounted in the front area and beam transmission area to monitor the position and intensity information real-timely.

Currently, the widely used BPM in synchrotron radiation are mainly planar type (photoconductive principle), blade type and wire type (photoemission principle). The blade type is difficult to be tangent with the beam cross-section because the divergence angle and the beam cross-section are small, especially when the position fluctuation of a single FEL pulse is relatively large. Moreover, the blade type BPM is bound to damage the beam filed and it is difficult to guarantee the accuracy if the moving in/out device is added. The laser wavelength of soft X-ray FEL is in the region of deep UV to soft X-ray, in which the scattering cross section of photoelectron is very large. The BPM using diamond films worked in the mode of transmission will absorb most of the X-ray, so the solid planar type BPM is not suitable for SXFEL diagnostics.

The BPMs used in the diagnostic system should be invase and with high-precision, which could measure a single pulse and monitor the pulse position changing. So, the position sensitive gas ionization chamber is selected to be the BPM as a diagnostic device. The gas ionization chamber has the position resolution ability through grooving in the electrode plate. The similar structure has been widely used in synchrotron radiation, such as Spring8 [5], TESLA [6] and FLASH [7]. We will also reference the gas ionization chamber designed by LCLS [8], adding a pair of electrodes perpendicular to the original electrode used to monitor the pulse position in another dimension.

Energy Spectrum Measurement

The energy spectrum of the pulse is recorded by a high-precision spectrometer which mainly includes a varying-including-angle VLS-PGM monochromator and an EUV-CCD (as shown in Fig. 2).

Because the energy spectrum is recorded using the EUV-CCD, the resolution basically depends on the optical components while independent of motion mechanism. Therefore, it is not require high accuracy of motion controlling. In this case, the short sin-bar could be used to reduce the requirement for the machining precision and the volume of the equipment. Especially the linkage accuracy of plane mirror and grating is low, while it is just the technical difficulty for usual varying-including-angle VLS-PGM monochromator. The plane mirror can rotate and translate in beamline direction. Another pre-mirror might be applied to the monochromator to extend the energy range.

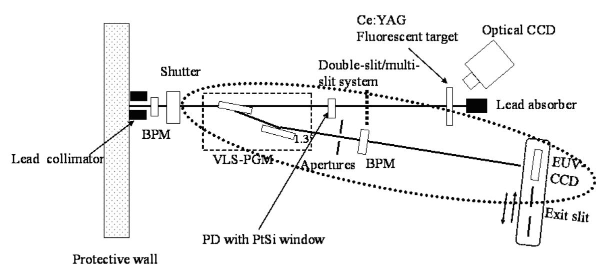

Figure 2: Diagram of diagnostic system.

An advantage of varying-including-angle monochromator is that a wide range of energy spectrum could be recorded without moving the detector. The beam will be switched to an experimental station via an exit silt. Because the position of FEL undulator light source is relatively fixed in the direction of beamline (chronically drift in the millimeter magnitude), the entrance slit is no longer included and CCD is only adjusted slightly along the beamline when recording energy spectrum.

A CCD worked in EUV band is selected as spectrograph because in the case of just reading a narrow area of CCD surface in the dispersion direction, the CCD read rate is over 100 pictures per second, in which case a single pulse of FEL could be distinguished. For example, the DU940 type EUV-CCD produced by Andor company can be used. The detailed parameters of the EUV-CCD are as follows: 2048×512 array, 13.5 micron pixel, up to 943 frames / sec (reading center 20 lines), close to 1ms time resolution. This is sufficient to meet the demand of pulse resolved measurement. Another advantage of using EUV-CCD directly is that the afterglow can be avoided to guarantee the accuracy.

Spatial Coherence Measurements

An apparatus [9] applied successfully to EUV plasma laser was chosen in spatial coherence measurement at

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SXFEL. According to the theorem of Schell law within the Fresnel approximation,

$$I(x) = I_{\psi}(x) * F^{-1}[g(\delta\xi)] \tag{1}$$

where I(x) is the measured diffraction beam field of the diffraction component, I(x) is the theoretical diffraction beam field of the diffraction component, $F^{-1}[g(\delta\xi)]$ is the inverse fourier transform of the complex coherence factor $g(\delta\xi)$. The complex coherence factor $g(\delta\xi)$ could be calculated from Eq. 1 according to convolution theorem when the measured diffraction beam field and the theoretical diffraction beam field of the diffraction component are known,

$$g(\delta\xi) = F[I(x)] / F[I_{\psi}(x)] \tag{2}$$

The module of $g(\delta\xi)$ is the fringe visibility. In our case, the diffraction component is the combination of multi-slit grating, as shown in Fig.3. The combination of multi-slit grating can be made on a foil, which contains a variety of double-slit pairs. There are three parameters in this foil: w is the width of a single slit; p is the intervals of the double slits; L is the intervals of the double-slit pairs. These parameters could be optimized to measure a series of spatial coherence lengths in one shot. A set of fringe visibility of different double-slits could be obtained .Thus the spatial coherence of the pulse could be characterized.

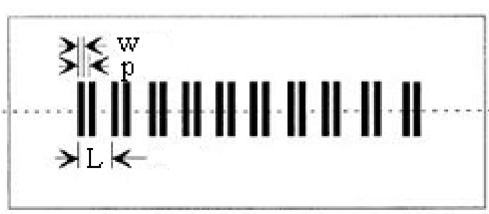

Figure 3: Multi-slit grating for interference.

Spot Size Measurement

The combination of fluorescent screen and CCD detector is selected to observe the spot shape directly, which could achieve single-pulse characterization. This requires rapid response CCD detector, adjustable synchronized with the FEL pulse sequence. In addition, the fluorescent screen materials should be selected suitably to avoid afterglow effect. We choose the sCOM camera to record the single-pulse. This camera can touch 30fps continuous images taken with 2560×2160 resolution, satisfying the requirements of the pulse resolution.

CONCLUSION

X-ray diagnostic system plays a key role in the Shanghai SXFEL facility and the design of photon diagnostic system was shown in the paper. All diagnostic instruments are pulse-resolved, with a frequency to 30Hz.

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