

STUDY ON FOCUSING PROPERTY OF NEW TYPE WIGGLER AND SASE-FEL EXPERIMENT AT THE ISIR, OSAKA UNIVERSITY

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Abstract

We have developed a new type of wiggler based on the edge-focusing wiggler for free electron laser (FEL) and self-amplified spontaneous emission (SASE) in the infrared region at the Institute of Scientific and Industrial Research (ISIR), Osaka University. The strong focusing (SF) scheme is adopted for the new wiggler in order to keep the beam size small along whole the wiggler. The wiggler consists of four FODO cells for double focusing. A gain length and SASE output power for the strong focusing wiggler were numerically estimated using the 1D FEL model and Genesis code. Measuring the electron beam size in the wiggler at different wiggler gaps performed the experimental study on focusing property of the new type wiggler. We are conducting experiments to generate SASE in the infrared region and to measure its characteristics, using the strong focusing wiggler and a high intensity single bunch electron beam. We have measured the wavelength spectrum of SASE in the wavelength region between 220 and 50 μm using a grating monochromator and a Ge:Ga detector. The second harmonic and the third harmonic peaks of SASE were also observed in the spectrum measurement.

INTRODUCTION

We are conducting experiments of FEL and SASE with a high intensity electron beam in the infrared region at ISIR L-band linear accelerator, Osaka University. While the beam experiment are performing, we have developed a new type wiggler, named the edge-focusing (EF) wiggler, which produces the strong transverse focusing field incorporated with the normal wiggler field [1]. To demonstrate its principle and evaluate the performance, the first model wiggler has been fabricated. It is experimentally confirmed that a field gradient of 1.0 T/m is realized along the beam axis in the EF wiggler. The details of the model wiggler were reported in previous conference [2-3]. The EF scheme has been applied to the wiggler being used for FEL and SASE in the far-infrared region at the ISIR L-band linear accelerator, to make the gain length of SASE shorter by keeping the beam size small along whole the wiggler. Before replacing of the wiggler, the wiggler was a conventional Halbach-type

wiggler and we changed its magnet parts with new ones. We, therefore, hold the wiggler parameters same as before. In order to meet a wide range of the electron beam energy and the wiggler gap, we adopt the strong focusing scheme using the EF wiggler. Focusing and defocusing elements are composed of permanent magnet blocks with the edge angle and they are alternately inserted in magnet arrays of the wiggler. The strong focusing wiggler has been fabricated and the magnetic field has been measured at KEK. In June 2005, the strong focusing wiggler installed to the FEL system at ISIR L-band linear accelerator [4].

After the installation of the strong focusing wiggler, we resumed to conduct the experiment to generate SASE in the far-infrared region. In the beam experiments, a focusing property of the strong focusing wiggler is also studied by measuring the beam sizes using screen monitors in the wiggler at different gaps.

STRONG FOCUSING WIGGLER

In this section, the developed strong focusing wiggler is described shortly. The edge-focusing wiggler is basically a Halbach type wiggler made only of permanent magnet blocks, but their shapes are not rectangular parallelepipeds. The field gradient on the permanent magnet with edge is approximately proportional to the edge angle ϕ and hence the focusing force can be easily adjusted with the edge angle. A polarity of the field gradient can be decided by choosing positive or negative angle of edge against to beam trajectory. In the strong focusing scheme, the electron beam is focused alternatively in the vertical and the horizontal directions to obtain focusing in the both directions using a sequence of focusing and defocusing elements separated by drift spaces, which is called the FODO lattice. Parameters of the FODO lattice were optimized to meet the requirements of our experiment and the parameters of the strong focusing wiggler are listed in Table 1. The permanent magnet used is NdFeB (NEOMAX-38VH, NEOMAX Co.) with $B_r = 1.22$ T and the peak magnetic field of the EF wiggler is 0.39 T at the minimum gap of 30 mm. The number of FODO cells in the wiggler is four and the cell length is 0.48 m. The number of cells is a factor of the number of wiggler periods, 32. Focusing elements are single wiggler periods with the edge angle of $+5^\circ$ and defocusing ones are those with -5° , and they are

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Table 1: Main parameters of the SF wiggler

Block sizes	90x20x15 mm ³
Magnet materials (Coating)	Nd-Fe-B (TiN)
Period length	60 mm
Number of periods	32 periods
Total length	1.938 m
Peak magnetic field	0.39 T (gap 30mm)
Number of FODO cells	4 cells
Length of FODO cell	0.48 m
Edge angle	±5 °
Field gradient	±3.2 T/m

separated by 3 normal wiggler periods. Longitudinally magnetized blocks are added at both ends of the strong focusing wiggler in order to compensate for the horizontal shift of the oscillatory beam orbit due to the fringing magnetic field at the ends. Thus the total length of the SF wiggler is 1.938 m.

In the field measurement, the peak magnetic field was 0.392 T and peak magnitude of field gradient at focusing and defocusing elements was about 3.2 T/m at the wiggler gap of 30 mm. The results of measurements were good agreement with the numerical calculations.

NUMERICAL ESTIMATION

Beam focusing of the strong focusing wiggler

The envelope of beam sizes in horizontal and vertical direction for the strong focusing wiggler and a planar wiggler were calculated with an electron beam of 10 MeV, a normalized emittance of 150π mm mrad in transverse directions and a peak wiggler field of 0.392 T. Figure 1 shows the calculated beam envelopes and the solid line and dashed line show the strong focusing wiggler and the planar wiggler, respectively. In the horizontal direction, the beam envelope of the strong focusing wiggler alternatively changes along the wiggler and the average beam size (σ) in the wiggler much smaller than that of the planar wiggler. On the other hand, the vertical beam sizes for the both type of wigglers are almost same. The FODO lattice of the strong focusing wiggler slightly distorted due to the natural focusing of the wiggler. The average beam size for the strong focusing wiggler (σ_{SF}) and the planar wiggler (σ_{PL}) are 1.41 mm and 1.69 mm respectively, when the average beam size in the wiggler assumed to be $\sqrt{\sigma_{horizontal} \cdot \sigma_{vertical}}$. Transverse charge density of the beam, which is a square of the average beam size, in that of the strong focusing is about 30% higher than that of the planar wiggler. The gain length (L_g) for each wiggler is estimated from the above average beam sizes by 1D FEL model using Eq. 1.

$$L_g = \frac{\lambda_u}{4\sqrt{3}\pi \cdot \rho} \quad (1)$$

where λ_u and ρ are period length of the wiggler and FEL parameter. Here, the bunch charge and the length of the electron beam are assumed to 30 nC and 30 ps (FWHM),

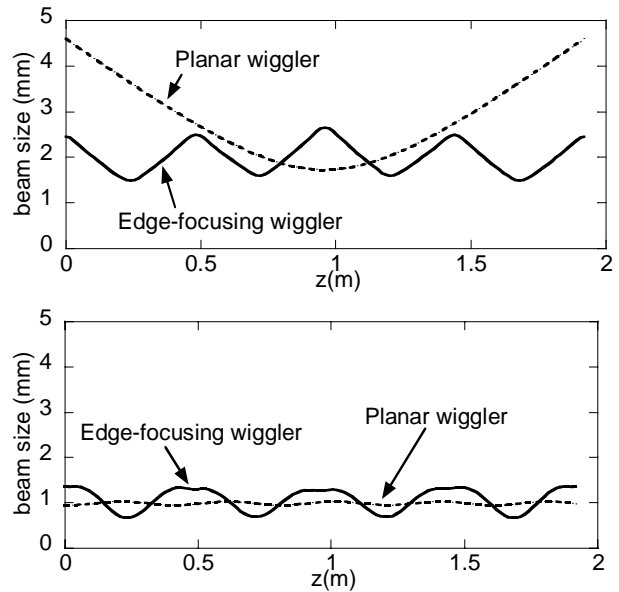


Figure 1: The envelopes of beam size in horizontal (upper) and vertical (down) directions for the strong focusing wiggler and a planar wiggler.

corresponds to the peak current of 1.0 kA. The derived the gain length of the strong focusing wiggler and the planar wiggler are 0.152 m and 0.163 m respectively, therefore the gain length of the strong focusing wiggler is about 7% shorter than that of the planar wiggler. From the difference of the gain length, it can expect 2 times large gain of FEL can be obtained by using the strong focusing wiggler.

SASE output power

SASE output power of the strong focusing wiggler and the planar wiggler are estimated using Genesis code [5]. The beam parameters of electron beam are same in above calculations. Figure 2 shows SASE radiation power along the wigglers. In this figure, the red and the blue lines are SASE radiation power of the strong focusing wiggler and the planar wiggler, respectively. At 10MeV, the beam size is kept small in the strong-focus wiggler and the SASE power of strong focusing wiggler is 5~6 times higher than that of planar wiggler.

BEAM EXPERIMENT

The beam experiment was conducting using the L-band linear accelerator at ISIR, Osaka University. ISIR L-band linac consists of an electron gun, three-stage sub-harmonic buncher (SHB) system, pre-buncher, buncher, 3m-long accelerating structure and the experimental beam lines. The electron beam with peak current of 17 A and a pulse duration of 5 ns was produced with a thermionic gun. The electron beam was injected into the SHB system composed of two 1/12 and one 1/6 SHB cavities for the accelerating frequency of 1.3 GHz to generate a high intensity single bunch beam, and then it was accelerated to 10.3 MeV in the linac. The electron beam was

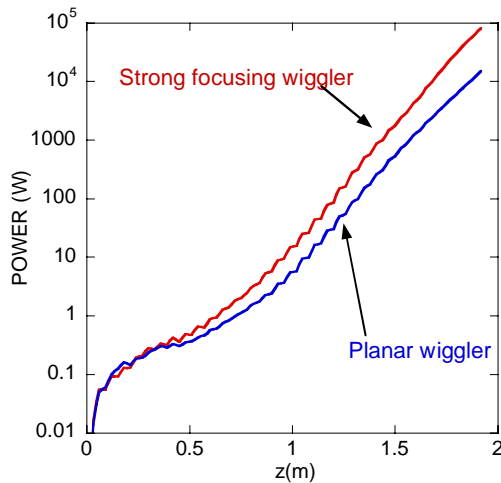


Figure 2: SASE radiation power along the wiggler. (Red line: Strong focusing wiggler, Blue line: Planar wiggler).

transported to the strong focusing wiggler via the achromatic beam transport line as shown in Fig. 3. The peak magnetic field and K-value of the strong focusing wiggler were 0.353 T and 1.4 at the wiggler gap of 32 mm. Twiss parameter and the emittance were measured using a quadrupole scan technique with a 100 μm thickness phosphor screen monitor at the exit of the accelerating structure. The normalized transverse beam emittance was $\sim 170\pi$ mm mrad with a bunch charge of 30 nC and an energy spread of 3.0 % (FWHM). The beam injection condition and an orbit of electron beam were tuned using quadrupole magnets and steering coils at the beam transport line for FEL experiment. The unnecessary energy part of the electron beam was collimated by an energy-slit located at the dispersion section of the transport line and the energy width of the slit was about 2 %. Therefore, the net charge per bunch passing through the wiggler was about 20 nC. The experimental

arrangement is shown schematically in Fig. 3. SASE radiation by the single bunch beam passing through the wiggler was reflected with a mirror (MP1) at downstream, and led to a far-infrared monochromator in the measurement room via an optical transport line. The optical transport line and the monochromator were evacuated together with a rotary vacuum pump. The low vacuum in the optical transport line and the high vacuum in the beam transport line were separated by a 0.2 mm thick, 20 mm in diameter synthetic diamond window, denoted by W1 in Fig. 3. The monochromator is a cross Czerny-Tuner type with a plane reflective grating, whose braze wavelength is 112.5 μm . The monochromator can be used in the wavelength region from 50 to over 240 μm . The wavelength resolution of the monochromator is almost constant over the range and approximately 1.5 μm for a slit width of 6 mm. The monochromatized light was detected with a Ge:Ga photo-conductive detector cooled with liquid-helium.

EXPERIMENTAL RESULT

Beam size measurement in the wiggler

We measured the transverse beam size in the wiggler using three screen monitors, denoted by F3, F4 and F5 in Fig. 3, at different wiggler gap with 10.3 MeV electron beam. In Fig. 4, the solid circles with the solid lines show horizontal beam size and the open circles with the dashed lines show vertical beam size on each screen monitors at different wiggler gap from 30 to 50 mm. The horizontal beam sizes on the all screens slightly change; but they were almost constant at different wiggler gap. The vertical beam size on the F4 and F5 periodically change at different wiggler gap. It seems that the variation of the vertical beam sizes come from the changing of the natural focusing, which is strongly depend on the magnetic field strength of the wiggler. The strength of natural focusing is proportional to the square of the peak magnetic field and

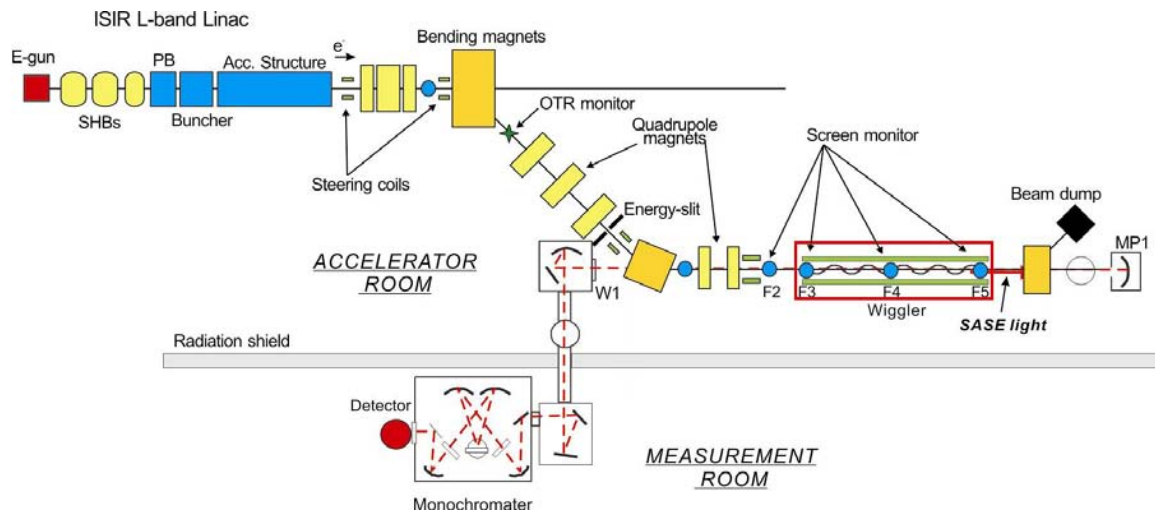


Figure 3: Schematic layout of the ISIR L-band linac and the FEL system. SASE radiation is derived to the grating monochromator and Ge:Ga detector using optical mirrors.

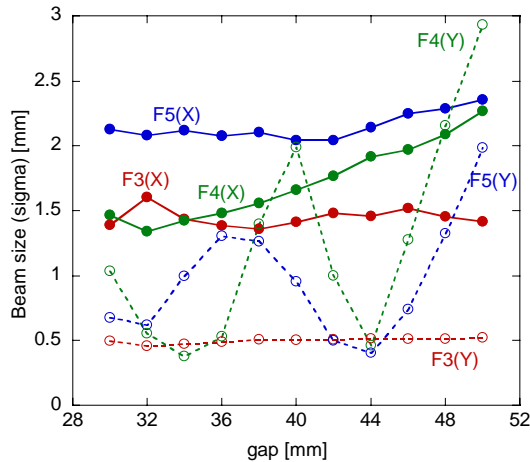


Figure 4: Measured horizontal (X) and vertical (Y) beam size using three screen monitors, denoted by F3, F4 and F5 in Fig. 3.

the strength of the edge focusing is only proportional to the peak magnetic field in the simple model of the wiggler composed of alternating bending magnets with the edge angle. Furthermore, as reported previous FEL conference [4], we have observed the peak field decreases to one-third with wiggler gap from 30 to 50 mm, whereas the field gradient decreases only by 56 % in the magnetic field measurement. The field gradient of the edge-focusing wiggler is kept at different wiggler gap. At this condition of electron beam, the natural focusing is strong and the edge focusing effect cannot be observed clearly. The measurement results were compared with the calculated beam size in the wiggler. In vertical direction, the periodically variation of beam sizes are large different, since the electron beam was injected into wiggler with not matching conditions. We will continue the study on the focusing property of the strong focusing wiggler at different condition of electron beam energy using the beam profile monitors.

Result of SASE spectrum measurement

Figure 5 shows a wavelength spectrum of SASE in the wavelength range from 50 to 240 μm with 1μm step. The closed dots and the error bar show the average values of intensities and a standard deviation, respectively, of five

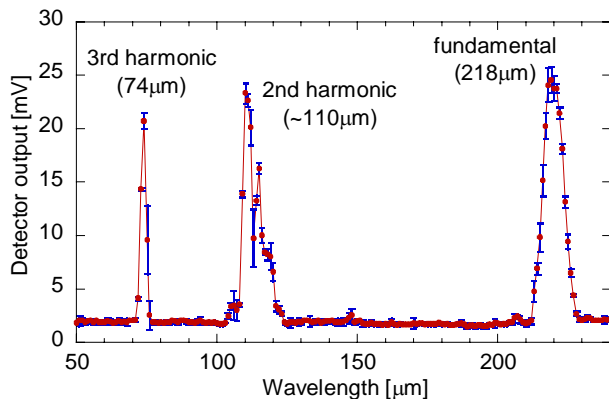


Figure 5: Wavelength spectrum of SASE in the wavelength range from 50 to 220 μm.

highest intensities in thirty successive optical pulses for each wavelength. As reported in Ref. [6], the total sensitivity of the measurement system, including the sensitivity of the detector, the efficiency of the optical transport line, was calibrated over the wavelength range from 50 to 200 μm using a blackbody radiator. We have not measured the sensitivity of the measurement system above 200 μm. In Fig.5, the plotted intensities are, therefore, signal intensities from the detector and the intensities at different wavelengths are not calibrated. Although the second and the third harmonic peaks are comparable in signal intensity to the fundamental one due to the higher sensitivity of the measurement system around 100 μm wavelength, the fundamental peak is actually strongest. The intensity ratios of the second and the third harmonic peak to the fundamental one are roughly estimated from the extrapolation from the previous calibration data to be 1/35 and 1/10, respectively.

The measured spectral width of the fundamental peak was about 1.75 %, which is slightly smaller than those predicted value (1.9 %) by the 1D FEL model (Eq. 2).

$$dw = \sqrt{\frac{9\rho}{2\pi\sqrt{3} \cdot N_w}} \tag{2}$$

We can expect that the FEL parameter (ρ) in the actual experiment is smaller than the predicted one due to that the Twiss parameter of the electron beam are different with matching condition at the entrance of the wiggler and the beam size is larger than optimum one. We will conduct to study on SASE about the spectral width and the angular distribution of the higher-harmonics and the statistically fluctuation of SASE output power.

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