FEL

Observation of CHG Spectrum at UVSOR-II

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Coherent harmonic generation (CHG) FEL from a relativistic electron beam has an attractive property of producing linearly/circularly polarized short pulse light from UV to VUV region. In the CHG-FEL scheme using an optical klystron (OK), an external laser source is injected inside a first undulator-the modulator-where the energy modulation of electron beam is performed. The conversion into a density modulation occurs in a dispersive section, and coherent emission with strong harmonic content is produced in a second undulator-the radiator. Recently, we have succeeded in observing the CHG-FEL from the U5 optical klystron using a femtosecond Ti:Sa laser [1, 2]. In this report, we describe an experimental spectral analysis of the CHG-FEL as a function of the seeding laser parameter. This study serves not only for the application experiments of the CHG-FEL but also for development of the future seeded free electron lasers.

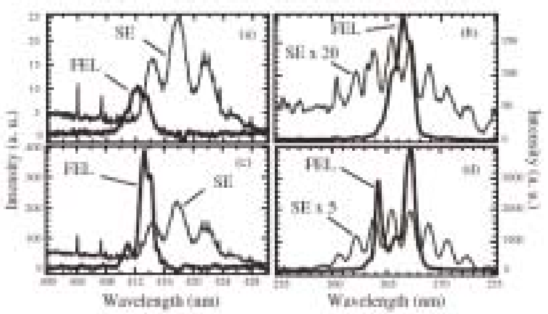

Fig. 1. CHG FEL spectra on the (a) second and (b) third harmonics with smooth focusing configuration and on the (c) second harmonic (sideband at 410.9 nm) and (d) third harmonics (sidebands at 264.2 and 267.2 nm) with the strong focusing configuration. Seeding laser power and pulse duration are 2 W and 1 pic-second-FWHM, respectively. (From ref. [3])

The experiment was performed with the single bunch electron beam at the energy of 600 MeV. The femtosecond Ti:Sa laser at 800 nm with up to 2 W of average power is focused in the middle of the modulator either with a strong focusing of corresponding to a Rayleigh length of $Z_R = 0.15$ m or a smooth focusing corresponding to a Rayleigh length of $Z_R = 1.5$ m. Detail of the experimental setup is given in the separated paper [2]. For spectral analysis, the OK radiation is transported to a spectrometer coupled to a fast intensified CCD camera. The ultrashort exposure time (down to 2 ns) of this system isolates the spectra of coherent light pulses at the laser's 1 kHz repetition rate from the 5.6 MHz incoherent light pulses.

Typical examples of the CHG and the spontaneous spectra are presented in Figs. 1(a) and 1 (b). The CHG-FEL spectral lines around 412 nm and 266 nm, are the second and third harmonics of the laser wavelengths (400 nm and 266.6 nm). The measured spectral width is $\Delta\lambda = 3$ nm ($\Delta\lambda = 1$ nm) on the second (third) coherent harmonics, while spontaneous emission spectral width reaches 10 nm on both harmonics. Additional spectral lines appear on each side of the initial line. In the example presented in Figs. 1(c) and 1(d), when using a strong focusing, one sideband in the shorter wavelength region of the second harmonics at 410.9 nm and two sidebands grow in the case of the third harmonics.

The growth of sidebands in the spectrum is consequence of the synchrotron motion of the trapped electrons in the ponderomotive potential. For an increasing laser power, the electrons experience a larger displacement in phase space, getting deeper in their rotations cycle. For relatively low laser power, (smooth focusing case) the bunching (density modulation) is optimum, and the associated third harmonic spectrum is monochromatic. As increasing laser power (strong focusing case), the debunching (spoiling of the density modulation) starts while sideband appears in the associated spectrum. The PERSEO simulations reproduce the sideband growth in the case of an overbunched beam. Completed simulation results are described in the separated paper [3].

In conclusion, we have shown that the laser-electron interaction has to be finely adjusted to prevent the spectral structure from being spoiled by the growth of sideband.

[1] M. Labat *et al.,* UVSOR Activity Report **33** (2006) 36.
[2] M. Labat *et al.,* Eur. Phys. J. D **44** (2007) 187.
[3] M. Labat *et al.,* Phys. Rev. Lett. **102** (2009) 014801.

Development of Orbit Feedback System at UVSOR-II

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Abstract

At synchrotron light sources, the drift of the orbit of the electrons in the storage ring causes a drift of the light source position, which affects user's experiments.

At UVSOR-II, an RF feedback system [1] has been operating to suppress the orbit drift on the horizontal plane caused by the thermal expansion of the storage ring floor. However, on the vertical plane, there's no system to stabilize the orbit. Here, we have developed a feedback system by using correction magnets. It was successfully demonstrated that the drift of the electron orbit was suppressed.

Feedback System

We have developed a feedback system to correct the electron orbit distortion. The following is the principle of the system. Firstly, the system gets the displacement of electron orbit from a standard orbit from the BPM (Beam Position Monitor) system, which measures the beam positions at 24 points of the ring. Secondly, the system calculates the applicable strength of correction magnet, which minimizes the displacement by minimizing the followings with SVD (Singular Value Decomposition):

$$\boldsymbol{S}=|\boldsymbol{R}\cdot\boldsymbol{q}+\boldsymbol{z}|^2$$

where $\boldsymbol{R}$ is response matrix calculated from the ring lattice data, $\boldsymbol{q}$ is the applicable strength of the correction magnets, and $\boldsymbol{z}$ is the displacement of the electron orbit. At the last, the system transfers the values of correction strength to the PC controlling the magnet power supplies. The system continues to correct electron orbit with a feedback cycle of 10 seconds.

Figure 1 shows the front panel of the system. In this panel, the operator can select/exclude the BPM or correction magnet for correction and can set previously allowable range of BPM data. If the BPM gets false data, the system would calculate abnormal value. To prevent this case, the system would cancel to transfer the values if the BPM data is out of the range previously set.

Result and Discussion

Figure 2 shows the orbit drift on the vertical plane without the feedback, and Fig.3 shows that with the feedback. The system was successfully working for 6 hours without any errors. It was demonstrated that the orbit drift was suppressed within a few tens of microns, and small oscillations (seen in Fig.2) were removed.

Conclusion

We have developed the feedback system. This system was successfully commissioned that orbit suppressed on the vertical plane. The system can be expected to contribute to high precision stabilization at UVSOR-II in the future.

Fig. 1. Front panel of Feedback System.

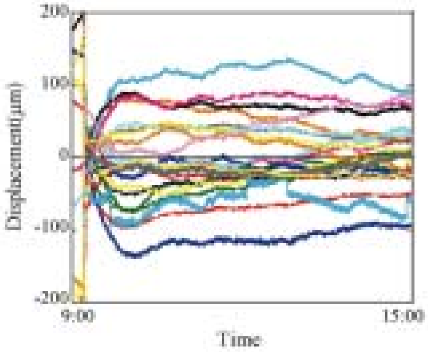

Fig. 2. Displacement of orbit before introduction of the feedback system.

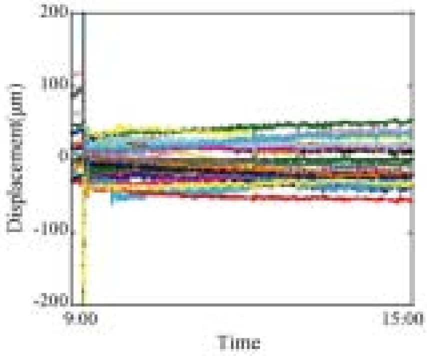

Fig. 3. Displacement of orbit after introduction of the feedback system.

[1] K. Suzumura *et al.*, UVSOR Activity Report **33** (2006) 39.

Development of Superconducting Magnets for Synchrotron Radiation Facility

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Abstract

By using superconducting magnets (SCM), high energy synchrotron light can be radiated. If 5Tesla(T)-SCM is introduced, hard-X ray can be generated by even small circumstance storage ring, such as UVSOR. To apply the SCM scheme for superconducting bends (SCBMs), we designed the pole and coil shapes.

SCBM

The bending angle and peak field are set 12.0 degree and 5 T. The material of the Iron core and coil is of SUY and NbTi, respectively, and the shape of the Iron core is C-type. The coil is cooled by 2 stages 4K-GM cryocooler. At first stage the temperature is cool down to 45K with the cooling power of 40W, at second stage 4.2K with 1.3W. In addition, liquid helium vessel is also set for the accidental case, such as power down of cryocooler. To decrease leak fields, two field cramps are equipped at outside of coil and iron core. The schematic view of the SCBM is shown in Fig.1.

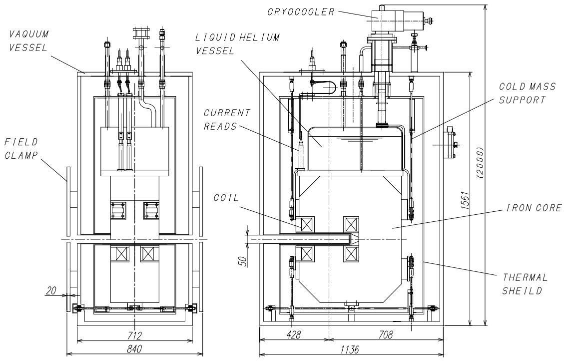

Fig. 1. The schematic view of the SCBM

To study the details of the fields and beam envelops in the SCBM, we have used the add-in program “Radia” [1], which is developed in ESRF. This program enables us to calculate 3D-field distribution with finite elements methods on analytical calculation cord “Mathematica”.

The calculation models of the coil and iron cores are shown in Figs. 2 and 3. In Fig. 3, the red and blue colors indicate the coil and iron core, respectively.

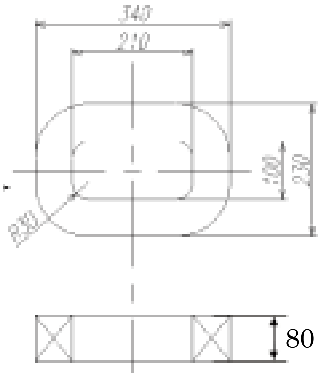

Fig. 2. coil shape

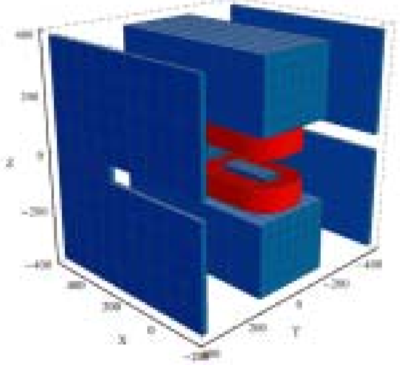

Fig. 3. SCBM simulation model.

Field mapping

We have calculated the field map on the beam orbit plane from the SCBM model, as shown in Fig. 4. In this figure, the requirement field of 5 T is obtained.

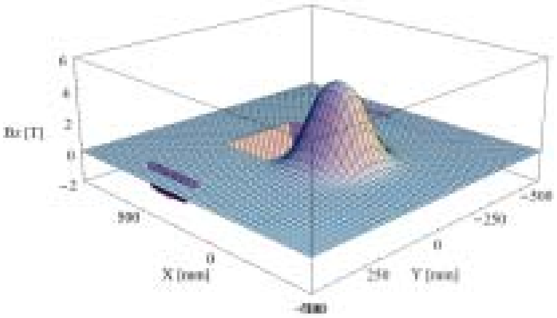

Fig. 4. SCBM field map.

[1] http://www.esrf.eu/

Stabilization of Optical Cavity of UVSOR-II Free Electron Laser

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Introduction

At the UVSOR storage ring, free electron laser (FEL) experiments have been made using a helical optical klystron. We have already succeeded in high power lasing around 1 W in the deep UV region and the shortest wavelength attained so far is 199nm [1]. Recently, application experiments of the FEL in the deep UV region such as photo-electron spectroscopy and irradiation on biological molecules have been carried out. Although a stable FEL is favorable for these applications, we have noticed a rapid power drop with time when the FEL is operated with a high electron beam current (~200 mA). This problem is especially disadvantage for these applications which require higher power FEL.

It was speculated that the power drop was due to distortion of a resonator mirror heated by synchrotron radiation leading to misalignment of the optical cavity. To prevent the power drop, we have developed a feedback system correcting automatically the optical cavity alignment by controlling mirror angle.

Feedback System

Figure 1 shows the outline of the feedback system. First, transmitted FEL power through a cavity mirror is measured by a photodiode, is processed and is send to a personal computer. Then the software on the personal computer decides the direction of a mirror to change. The principle of changing the mirror angle is based on comparison of FEL powers before and after the change of the mirror angle. If the FEL power after changing the mirror angle is higher than one before changing it, the software decides to change the mirror angle to the same direction again. On the other hand, if the FEL power after changing the mirror angle is lower than one before changing, it decides to change to the opposite direction.

Finally, the software transfers the determined value to a stepping motor controller, and the mirror angle is changed adjusting a gimbal by the step motor. This routine action is made every 2 seconds and it controls upstream and downstream cavity mirrors.

Result and Discussion

Figure 2 shows the FEL power variation at 230nm before and after introduction of the feedback system. It is clear that the FEL power has been stable and the rapid FEL power drop has been suppressed. Before introduction of this feedback system, FEL power decreases by a half in about 10 minutes. After the introduction, the FEL power in 10 minutes remains almost unchanged

Conclusion

We have developed a feedback system to stabilize the FEL power by changing mirror angles. The system was successfully commissioned.

As future plan, we aim more accurate correction by controlling RF frequency to synchronize the revolution frequency with the FEL round trip frequency.

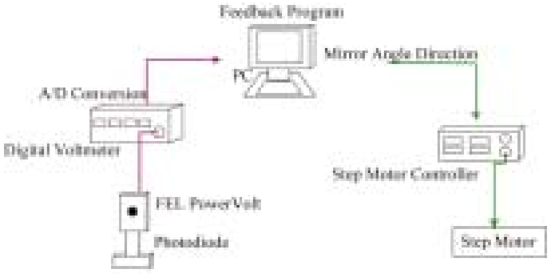

Fig. 1. Block diagram of the feedback system.

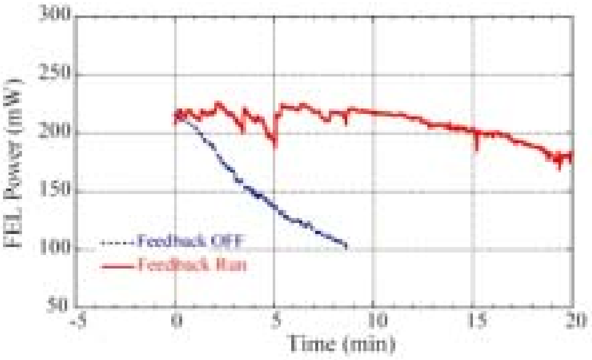

Fig. 2. FEL power variation before and after introduction of the feedback system.

[1] M. Hosaka *et al.*, UVSOR Activity Report **35** (2008) 40.

Top-Up Test Operation at UVSOR

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Introduction

Keeping the beam current constant with intermittent injection (so-called top-up operation) has been realized at several synchrotron radiation facilities. With top-up operation, we can provide not only higher photon flux but also constant flux to beamlines. It is expected that the stability of the light beam also improves, mainly owing to temperature stabilization of the accelerator and beamline components. Thus, top-up operation has been one of the most important plan at UVSOR.

To achieve top-up operation, we had already upgraded the power sources for the booster synchrotron and the beam transport line. With this upgrade, 750MeV (full energy) injection had been enabled. To ensure radiation safety, we had installed a lead shielding wall around the storage ring.

In fiscal 2008, we prepared:

1. An interlock system to ensure the integrated charge (electron number) lower than a specified limit, and a trigger managing module to automatically keep the beam current to a fixed value.
2. Two copper slits in beam transport line.

Soon after obtaining permission of Ministry of Education, Culture, Sports, Science and Technology in October 2008, we began top-up test operation.

Injection Charge Measurement and Automatic Injection System

Injection charge measurement is necessary for radiation safety. With this system (Fig.1), we measure the weekly integration of injected charge (electron number) in top-up mode. If the integration goes over the limit, high voltage for the beam transport magnets will be turned off. Injection module automatically turn on/off the injection trigger to keep the beam current to a fixed value. Electron charge is measured using Integrated Current Transformer (Bergoz Co.).

Fig. 1. Charge integration and automatic injection module (left), Integrating Current Transformer (right).

Slits at Beam Transport Line

Two slits which utilize 60mm thick copper blocks were introduced to the beam transport line (Fig. 2). One purpose is keeping radiation at storage ring low, cutting off the electrons slipping off the central orbit which will be lost in storage ring. Another purpose is protection of magnet poles of in-vacuum type undulators.

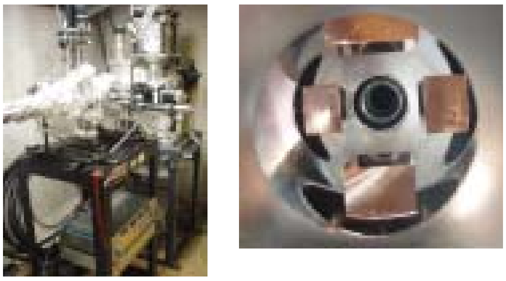

Fig. 2. A slit located at beam transport line.

Status of Top-Up Operation

An example of beam current trend is shown in Fig. 3. Short time fluctuation due to beam loss in every interval is about 1.5mA, which corresponds to 0.5 percent of stored beam. Some dips in the graph are due to decrease of the injection efficiency, which should be settled in future improving the stability of accelerator components.

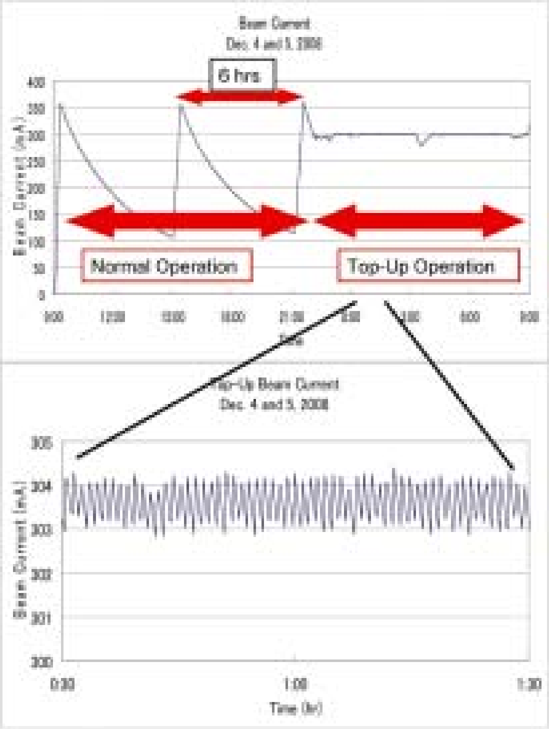

Fig. 3. A beam current trend in top-up test operation. One minute interval, up to 15 seconds injection. The data was taken every 12 second.