Present Status of Main RF Cavity in UVSOR-II

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As we have reported in the previous activity report[1] we have renewed main RF cavity in UVSOR-II electron storage ring in the last spring. Because of the renewal we have obtained the RF accelerating voltage up to 150kV that is about 3 times higher than the previous cavity voltage (55kV). Table 1 shows basic specifications of previous/present RF cavities. Compared to the previous cavity, basic design of the present cavity has no drastic change, however, unloaded-Q and shunt impedance (Rs) have improved extremely. Because of the performance, the RF accelerating voltage up to 150kV has been obtained by only changing the RF cavity itself: not changing RF transmitter.

Table 1 Specifications of previous/present cavities.

	Previous	Present
Frequency	90.1 MHz	90.1 MHz
Cavity voltage	55 kV	150 kV
Rs	1 MΩ	2.45 MΩ
Unloaded Q	8370	20300
Material	SUS + Cu	Cu (OFHC)
Cells	Re-entrant×1	Re-entrant×1
Inner diameter	1000mm	964mm
Bore radius	50mm	55mm

Until last spring UVSOR-II has been operated in 60nm-rad (achromatic) mode for daily users run, whereas immediate shift of the operating condition from 60nm-rad to 27nm-rad (chromatic) mode has also been strongly requested. In such a low-emittance condition, however, it was difficult to keep sufficient Touschek beam lifetime unless momentum acceptance was improved. Because the acceptance in UVSOR-II is mainly determined by the RF accelerating voltage, it is possible to improve Touschek beam lifetime by increasing the RF voltage. Fig. 1 shows the change in Iτ product on the RF voltage in the chromatic condition. In 750MeV, the product at 100/150kV has improved about twice/three times as much as that in the previous voltage of 55kV. Because of the improvement, the operating condition for users runs has been shifted from 60nm-rad to 27nm-rad mode after the installation of the present RF cavity. At present, typical Iτ product in daily users run (multi bunch, 27nm-rad) is about 1200 mA-Hour that is almost the same as that in previous operating condition (60nm-rad, 55kV). Beam-development study for obtaining much better beam lifetime still continues today.

Because of the improvement of the RF voltage, not only the improvement of the beam lifetime but also decrease in bunch length is expected. Fig. 2 shows experimental results and calculation of natural bunch length in 600/750 MeV under single-bunch operation in UVSOR-II. The natural bunch length has become 63/90 ps in 600/750 MeV when the RF voltage is 150kV; that corresponds to less than 70% in the previous cavity operation (55kV). The compression of the longitudinal bunch size can contribute short pulse SR experiment in single-bunch operation and improvement of laser gain in free electron laser[2].

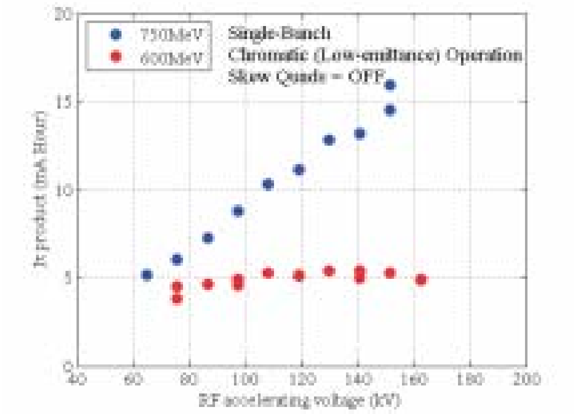

Fig. 1 Change in Iτ product on RF voltage.

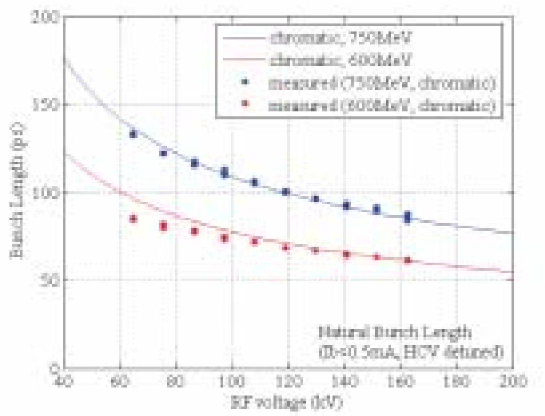

Fig. 2 Natural bunch length in various RF voltages.

[1] A. Mochihashi *et. al.,* UVSOR Act. Rep. 2004 (2005) 35.

[2] M. Hosaka *et. al.,* in this report.

Synchronization System of Mode-Locked Femto-Second Pulse Laser for Beam-Laser Experiment

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In previous activity reports [1,2,3] we have discussed feasibility of generation of ultra-short pulse synchrotron radiation and coherent synchrotron radiation by 'bunch slicing' method with ultra-short laser pulse. In 2005 March, we have installed a mode-locked femto-second pulse laser system whose wavelength is 800nm. With the system we have started to perform beam-laser experiment just after successful installation and tuning of the laser system. Here, we make a brief report of the system, especially for timing system that we have developed; with the timing system we have obtained sufficient synchronization between the laser pulse and the electron beam. Figure 1 shows a schematic diagram of the ultra-short pulse laser system. The laser system is mainly composed of mode-locked titanium-sapphire (Ti:Sa) laser (Coherent, Mira 900-F) that generates laser pulses that synchronize with the RF signal (f_{rf} =90.1MHz) of UVSOR-II and a regenerative amplifier (Coherent, Legend HE) that generates high intense femto-second pulse laser. Typical pulse duration and averaged power from Ti:Sa laser are 130fs and 1W. To make sufficient synchronization between the laser pulse and the electron beam, RF signal that comes from a pick-up coupler of RF accelerating cavity is used for the mode-locking signal. Typical frequency resolution of the cavity length actuator in the mode-locked laser is f_{rf}±100Hz. The seed laser pulses from the Ti:Sa laser are injected into the regenerative amplifier that makes high intense laser pulse whose power is typically 2.5mJ/pulse. The regenerative amplifier is driven by Q-switched pump laser whose averaged power is 30W. The repetition of the Q-switched laser f_Q is based on sub-harmonics of revolution frequency f_{rev} (=f_{rf}/16=5.6MHz), namely, f_Q=f_{rev}/5632=1kHz. Because of the synchronization with the sub-harmonics of the beam revolution, the regenerative amplifier can be driven in sufficient synchronization with the beam revolution despite the repetition rate. To select and fix the electron bunch which the laser pulse cuts, an RF bucket selector that can change the timing of the beam revolution signal with a unit of bunch spacing time is used for making the Q-switching trigger signal. To adjust the timing of the laser pulse within the bunch spacing time precisely, a phase of the RF signal from the RF cavity can be changed with a phase shifter. Typical timing jitter for the Q-switching trigger signal is less than 20ps that is negligible compared to the bunch spacing time of UVSOR-II. The high-intense pulse laser is transported from a laser room to a viewing port that is usually used for extraction port of storage ring free electron laser (SR-FEL) [4] through into pipes in the atmosphere. The laser pulses pass through a long straight section in which a helical/linear undulator is settled, and they interact with the electron beam in the undulator section. Because both spontaneous undulator radiation from the electron bunch and the pulse laser can be observed from another viewing port that is settled in the opposite side of the extraction port of the SR-FEL, the condition of the synchronization between the beam and the laser pulse can be verified easily.

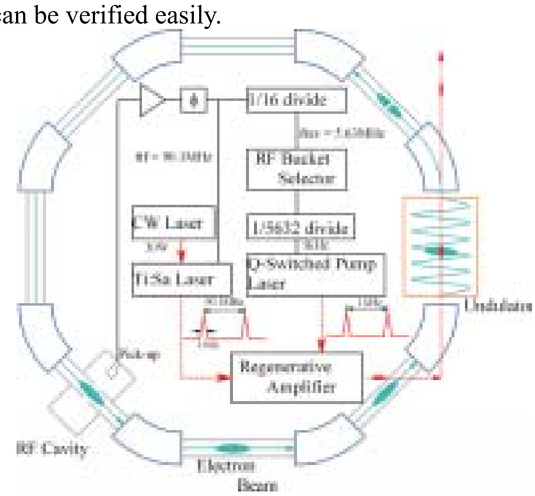

Fig. 1 Schematic diagram of the ultra-short pulse laser system.

Just after the installation of the laser system, we have started beam-laser experiment based on 'bunch slicing' scheme, especially for generation of infra-red coherent synchrotron radiation [5] and coherent harmonic generation experiment [6]. In parallel with the experiments we still continue estimation of basic performance of the pulse laser system; especially for the timing jitter and stability between the laser pulse and the electron bunch that are key issues of the beam-laser experiment.

[1] Y. Takashima *et. al.,* UVSOR Act. Rep. 2001 (2002) 43.

[2] Y. Takashima *et. al.,* UVSOR Act. Rep. 2002 (2003) 56.

[3] Y. Takashima *et. al.,* UVSOR Act. Rep. 2003 (2004) 33.

[4] M. Hosaka *et. al.,* in this report.

[5] M. Katoh *et. al.,* in proc. of European Particle Accelerator Conference 2006 (to be presented).

[6] M. Labat *et. al.,* in proc. of European Particle Accelerator Conference 2006 (to be presented).

Development of an Orbit Feedback System at UVSOR-II

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Abstract

The drift of the electron orbit on a synchrotron light source causes a drift of the light source position, which makes harmful effects on the users experiments. To minimize the effect, we have developed a feedback system correcting automatically the drift of electron orbit by controlling RF frequency. The system is routinely operating now, and the drift of electron orbit is suppressed.

Feedback System

We have developed a feedback system to correct the electron orbit. The following is the principle of the correction. If we make the RF frequency of the storage ring smaller, the electron orbit should extend outward to keep the synchronization with RF acceleration. If we do opposite operation, it should be on the inside. The feedback system corrects the electron orbit by the use of this mechanism.

Fig.1 shows the flow chart of the feedback system. First, the displacements of electron orbit from a standard orbit is obtained by a BPM(Beam Position Monitor) system, which measures the beam position at 24 points in the ring. Second, a program calculates RF frequency " δf_{RF} " which is pertinent to the correction with the use of a formula as follows;

$$\delta f_{RF} = \frac{\alpha \cdot f_{RF}}{\sum^{24} \eta_i} \sum^{24} \delta X_i$$

At the last, the program transfers the value of RF frequency to the master oscillator of the RF system. The program continues doing a set of these actions every 10 seconds. The program has a checking function to prevention of transferring abnormal value of RF frequency calculated by some unexpected reason. We can previously set allowable range of RF frequency and beam current in the system. If the value of RF frequency calculated at second step is out of the range we have set, the transferring should be cancel. The same goes for beam current.

Result and Discussion

Fig.2 shows the orbit drift in the horizontal plane of a day before introduction of the feedback system, and Fig.3 shows that of after introduction. It is clear that the displacement of each point has been closer to the standard orbit. The two lines being distant from standard orbit, the yellow and green line, are exceptions. The BPMs of these lines are installed on a vacuum duct which has some trouble on the water cooling system. It is highly possible that the apparent orbit displacement is caused by the thermal deformation. These two points are removed in the calculation of the RF frequency.

Conclusion

We have developed an orbit feedback system. The system was successfully commissioned. The orbit drift in the horizontal plane has been suppressed at some level.

Future, we aim more accurate correction by using the correction electrical magnets, and we should correct the orbit drift in the vertical plane.

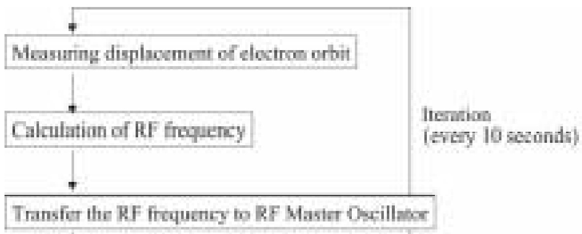

Fig. 1 Block diagram of the feedback system.

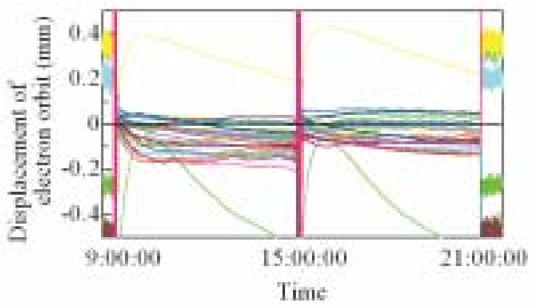

Fig. 2 Displacement of a day before introduction of the feedback system.

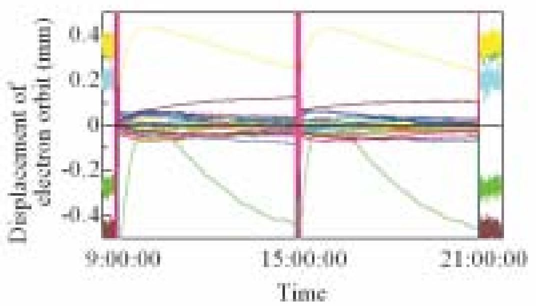

Fig. 3 Displacement of a day after introduction of the feedback system.

Correlation of Terahertz Bursts with Bunch Motion at UVSOR-II

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We have observed intense far-infrared synchrotron radiation at the beam line BL6B of UVSOR-II storage ring operated in single bunch modes.[1] The peak intensity of the bursts is about 10000 times larger than the intensity of synchrotron radiations in the same wavelength region observed in normal multi-bunch modes. The duration and the period of the bursts are about 200 μsec and 10 - 15 msec, respectively. Each burst consists of several quasi-periodic micro-bursts whose periods are about 30 μsec. The period is close to the half of the synchrotron period and the bunch length is changed for the same period of the bursts.

Experiments and Results

We measured the bursts of far-infrared synchrotron radiation at the beam line, BL6B(IR) constructed for using the synchrotron radiation of infrared region.[2] During the experiments, the UVSOR-II storage ring was operated in single bunch mode and the electron beam energy was 600 MeV.

We used a liquid-helium-cooled InSb hot electron bolometer to detect the terahertz radiations. The detector was sensitive to the wavelength region between 0.2 mm and 3 mm. The response of the detector was several microseconds.

Fig. 1 shows typical time structure of individual burst at 201 mA. The each burst contains several peaks which appear quasi-periodically. The period time is about 30 μs. The period of the micro-bursts of about 30 μs is close to the half value of the inverse of the synchrotron frequency of 14.4 kHz. We changed the RF accelerating voltage from 55 to 28 kV and observed the change of the periodic microstructure of the bursts. In this condition, the synchrotron frequency was changed to 10.3 kHz. As shown in the Fig. 2, the period of the micro structure was changed to about 45 μs and is also close to the half value of the inverse of the synchrotron frequency of 10.3 kHz in this condition.

Fig. 3 shows the terahertz bursts and the electron bunch length. The bunch length is derived by the measurement of synchrotron radiation by using a streak camera and the measurement was performed at the same time as the measurement of terahertz bursts. The bunch length is changed periodically and the period is the same as that of the terahertz bursts. There is strong correlation between the generation of the bursts and the bunch motion.

Summary

We observed bursts of far-infrared synchrotron radiation in the wave length region between 0.2 mm and 3.0 mm at BL6B of UVSOR-II. Each bursts contains many peaks whose period is close to the half of the synchrotron period. We measured the bunch length at the same time as the measurement of the bursts and the bunch length is changed in the same period as the generation of the bursts. These may suggest that the bursts are generated by longitudinal density modulations and their evolutions in the bunches.

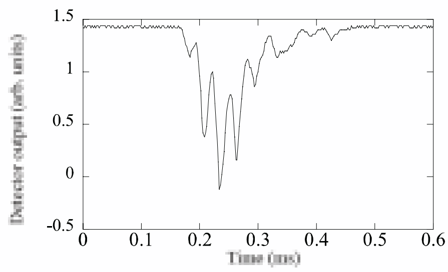

Fig. 1 Time structure of a burst (Ib=201mA).

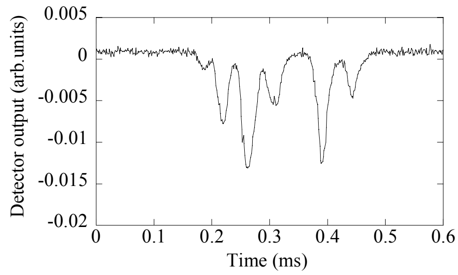

Fig. 2 Time structure of a burst (Ib=197mA,Vrf=28kV).

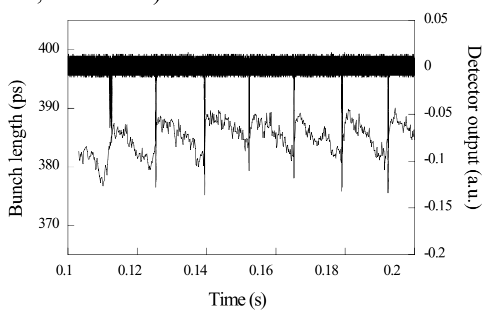

Fig. 3 Terahertz bursts and bunch length (Ib=183mA).

[1] Y. Takashima *et al.,* Jpn. J. Appl. Phys., **44** (2005) L1131.
[2] S. Kimura *et al.,* AIP Conf. Proc. **705** (2004) 416.

BL5U(FEL)

Deep UV Lasing around 215 nm on the UVSOR-II FEL

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On a storage ring free electron laser (FEL), quality of the electron beam is a critical issue for lasing in a short wavelength region. At UVSOR-II, we have continued to improve the performance of the electron beam since 2002. We replaced an accelerating rf cavity in early 2005 and can operate it in higher voltage by factor 3 [1]. Since the FEL gain is proportional to the bunch length, this upgrade is very effective to the FEL. With the electron beam of upgraded performance, we succeeded in lasing around the wavelength of 215 nm that is the shortest wavelength in the UVSOR. In this article, we report on the lasing experiment.

So far the shortest wavelength of the UVSOR-FEL had been 239 nm. In order to meet the recent demand from users, we tried lasing in shorter wavelength region around 215 nm. In the former experiment, multi–layers of HfO_2/SiO_2 were employed as cavity mirrors. The oxide can not be employed for the lasing of 215 nm because the band-gap of HfO_2 is about 5.6 eV (220 nm). Then multi-layers of Al_2O_3/SiO_2 were chosen for the lasing: the band-gap of Al_2O_3 is about 7 eV (180 nm). Since refraction index of Al_2O_3 is smaller than that of HfO_2 , the number of layers of the mirrors should be increased. On the other side, we need high transmission to extract high out-coupled power for users' experiment. Compromising reflectivity and transmission, we chose numbers of layer of 49 for forward mirror and of 37 for backward mirror, from which an FEL power is extracted. The expected round-trip reflectivity of the mirrors is 99.3 % and the transmission of the backward mirror is 0.5 %.

Preparatory to a lasing experiment, we measured the round-trip reflectivity of the mirrors by ring-down method with a low electron beam current. The measured value was round 97.8 %, which was much smaller than expected one. We suppose that a degradation due to synchrotron radiation from the undulator is serious in case of Al_2O_3/SiO_2 mirror. The first lasing experiment was made with an electron energy of 600 MeV, which is ordinal energy for the FEL experiment. Fig. 1 shows a measured FEL spectra using a spectroscope. The measured spectral line width (0.075 nm) is limited by the resolution of the spectroscope. Although the reflectivity of the mirrors is not so high, the lasing continued at the threshold beam current of 11 mA/bunch because of the high FEL gain (Fig. 2). As a next step of the experiment, we increased the electron energy from 600 MeV to 750 MeV. Storing a high beam current in the storage ring, we obtained successful lasing. As seen in Fig.2, the measured threshold current for lasing at 750 MeV is about two time higher than at 600 MeV, however, we obtained much higher power at a beam current of higher than 50 mA/bunch. Moreover, the measured lifetime of the electron beam was about 3 times longer. These characteristics are very favorable for application experiments. Hereafter, we are going to employ the 750 MeV operation for users experiment

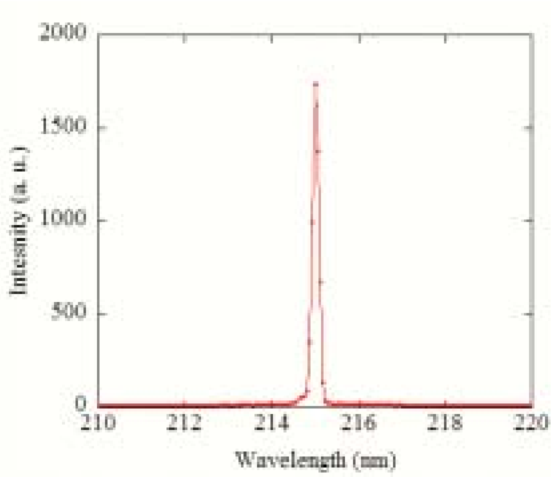

Fig. 1 Measured FEL spectrum at 215 nm.

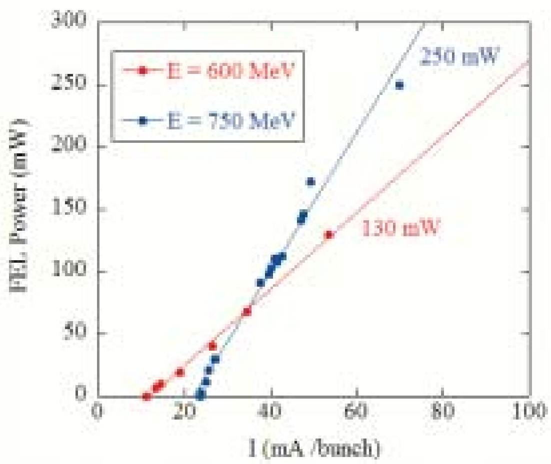

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Fig. 2 Measured FEL out-coupled power around λ = 215 nm at electron energies of 600 MeV and 750 MeV.

[1] A. Mochihashi *et. al.,* in this report.