Accelerators and Beam Physics

New BPM System

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A new beam position monitor system was successfully comissioned at UVSOR storage ring. The new system comprises 16 signal-processing modules, which are commercial products of Bergoz Co. [1]. In these modules, the bunch signals are filtered at the RF frequency (90MHz). The 90MHz signals are down-converted to an intermediate frequency. They are amplified and detected. In the new system, all the electrodes are connected directly to the modules. There are no switches. Typical length of the cables is about 15 m. The lengths of four cables for one BPM head are adjusted with an accuracy of a few cm. The modules output two DC-voltage signals, which are proportional to the beam position in horizontal and vertical. They are AD-converted with 16-bit resolution and a cycle of 1 kHz. The data are averaged over one second to improve the resolution. The data are stored in a PC and sent to the main control system [2]. A schematic drawing of the system is shown in Figure 1.

The standard deviations of the beam position data were measured for various values of beam current, as shown in Figure 2. For the beam current higher than 10 mA, the standard deviations are smaller than a few microns.

New system has revealed orbit drifts in various time scales. In Figure 3, typical orbit drifts in a users run are shown. UVSOR is typically operated for users as follows. After the beam injection, the beam energy was ramped from 600MeV to 750MeV and the orbit was corrected. Then the users experiments start. The data in Figure 3 started also at this moment. There can be seen a rapid drift, especially in horizontal, during the first ten minutes. In vertical, there can be seen a slow drift in time scale of hours. The amplitudes of the drift motions are a few hundreds of microns.

In Figure 4, another example of the orbit movement is shown. These data were taken when the temperature control system of the cooling water was malfunctioned. The temperatures of the cooling water of the magnets and the vacuum chambers were fluctuated with amplitudes of about 2 degree and periods of about 10 minutes. This was caused by periodic on and off of the cooling tower. There can be seen orbit movements in horizontal and vertical synchronized with the temperature changes. The amplitudes are about a few tens of microns.

The beam position monitor system at UVSOR was replaced this year. New system was successfully commissioned. It is providing a set of beam position data every second with a resolution of a few microns. It saves the time for orbit correction significantly. It has revealed the orbit drift at UVSOR in users operations. Their origins will be investigated further with the beam position data. The orbit stabilizing system will be constructed based on the new system in future.

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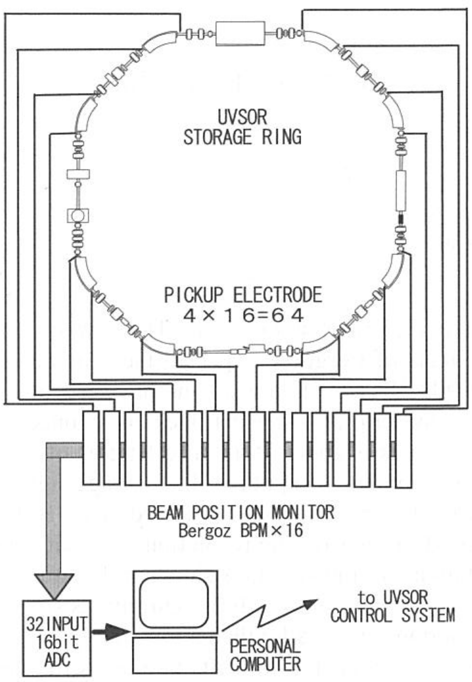

Fig.1 Schematic drawing of new BPM system

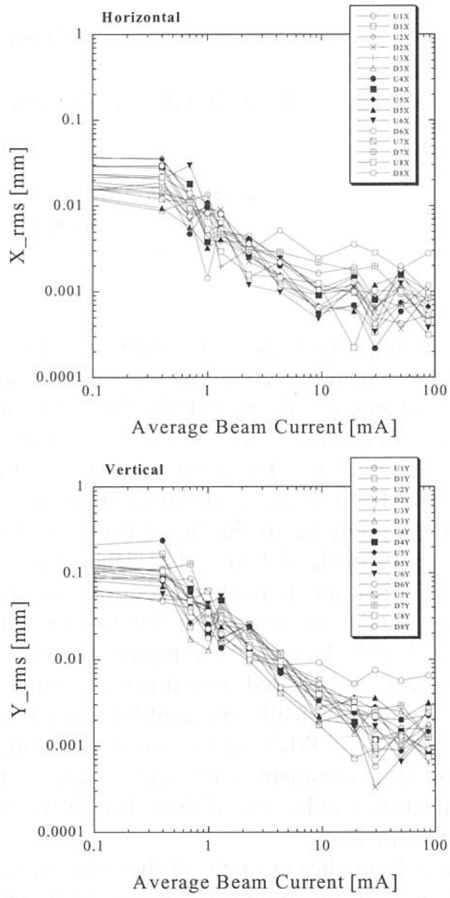

Fig. 2 Standard deviations of beam position data. Those for five samplings are shown against various beam currents. The data from all 16 BPMs are shown. The upper is horizontal and the lower vertical.

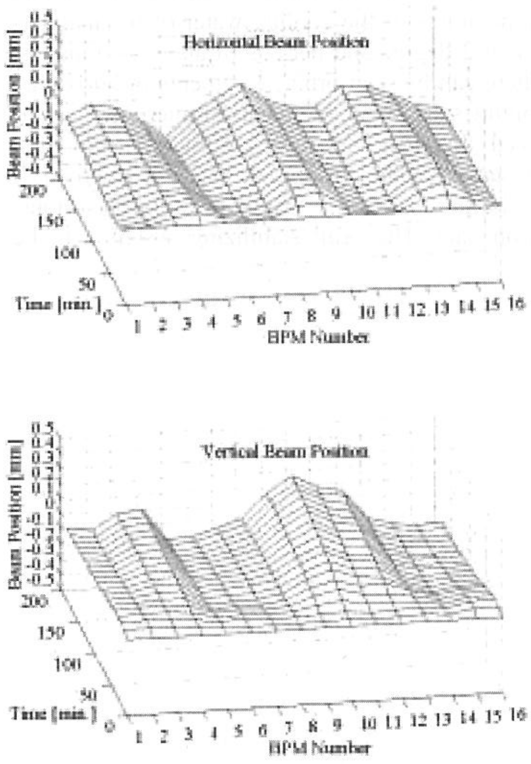

Fig. 3 Typical orbit drift observed during a users operation

The upper is the horizontal data and the lower the vertical data. The data interval is about 10 minutes.

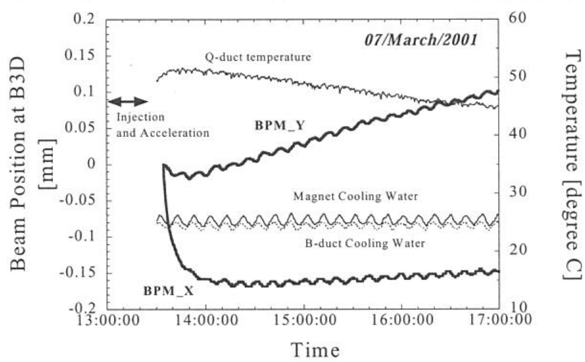

Fig. 4 Orbit movement caused by temperature fluctuations of the cooling waters for magnets and vacuum chambers Beam position at one BPM (B3D) is shown.

DEVELOPMENT OF COMBINED-FUNCTION FOCUSSING MAGNET

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In the upgrade plan of UVSOR that will be started in FY2002, the original magnetic lattice will be modified to reduce the emittance and to increase the number of straight sections for insertion devices. We have completed the lattice design [1].

In the new lattice, the space limitation is very severe. In some of the modern light sources, sextupoles are integrated in the quadrupole magnets, to save the space and reduce the cost [2, 3]. They are successfully operational. We decided to introduce this type of magnet. There are several types of configuration. We have adopted the configuration as shown in Figure 1. The shape of the iron core is same as ordinary quadrupoles. The auxiliary coils on the pole face (sextupole coils) produce both dipole and sextupole fields. Other auxiliary coils on the poles (dipole correction coils) eliminate the dipole field. The main parameters of the magnet are summarized in Table 1.

A prototype was constructed as shown in Figure 2. Field measurements were completed. Some results from the field measurements are shown in Figure 3, 4 and 5. It was proved that the quadrupole and sextupole field required from the lattice could be achieved well below the maximum excitation current. It was also proved that the dipole field could be eliminated by exciting the dipole correction coils, for the typical operational currents of quadrupole and sextupole. However, at around the maximum excitation of quadrupole and sextupole where the iron core is saturated, it was found that the dipole field could not eliminated even with the maximum excitation of the dipole correction coils. In the final design, this point will be improved either by increasing the maximum current of the correction coils or by increasing the thickness of the iron cores.

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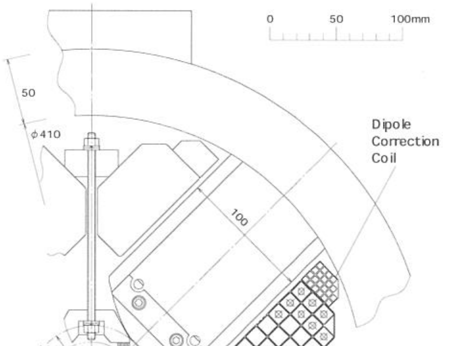

Fig.1 Combined-function (quadrupole/sextupole) magnet (cross-sectional view)

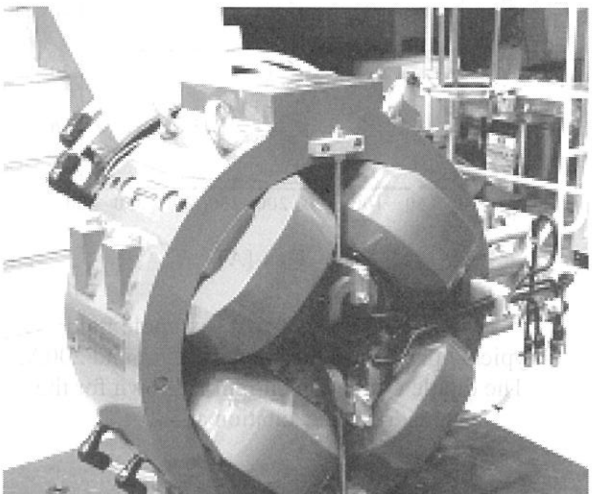

Fig.2 Prototype of the combined function magnet

Table 1. Parameters of combined-function magnet

Core Length	0.2 m
Bore Diameter	94 mm
Quadrupole Coil	625A x 24 turns
Sextupole Coil	400A x 4 turns
Dipole Correction Coil	40A x 21 turns
Maximum Quadrupole Field	15 T/m
Maximum Sextupole Field	35 T/m^2

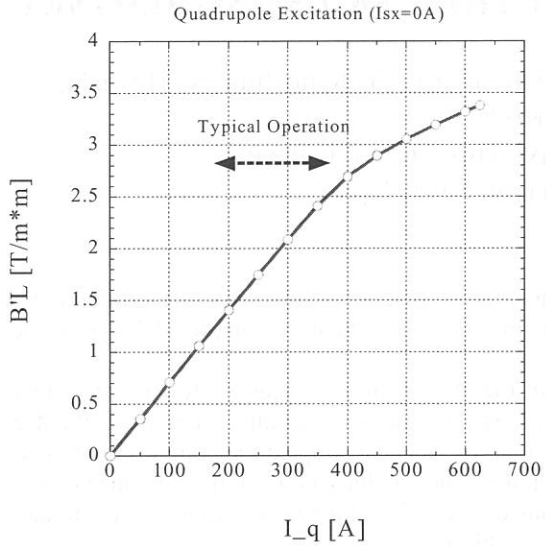

Fig.3 Excitation curve of quadrupole field
Typical operational current will be around 400A.

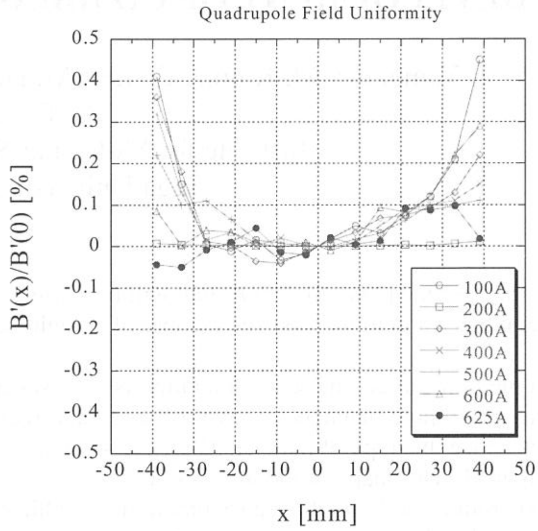

Fig.4 Excitation curve of quadrupole field
Typical operational current will be around 400A. The end shimming is optimised at the maximum excitation current (625 A).

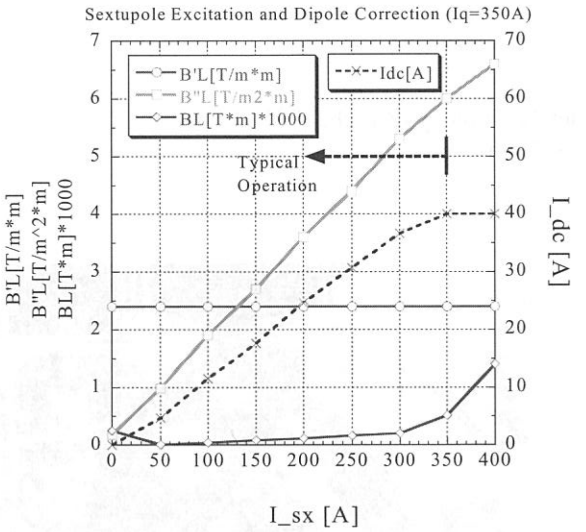

Fig.5 Excitation curve of sextupole field
Typical operational current will be around 200A.
The dipole correction current is shown for the quadrupole excitation at 300A.

Vertical Instability in Multi Bunch Operation in UVSOR

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In the UVSOR electron storage ring a vertical beam instability has been observed in a multi bunch operation, even though it is very weak enough to neglect influence on SR users. To verify the cause of the instability, we have observed betatron oscillation for single/multi bunch condition in the UVSOR storage ring. Firstly, we have observed dependence of a vertical tune on the beam current at the single bunch condition. In the experiment, we analyzed beam signals from a pick-up electrode with a spectrum analyzer and observed the betatron oscillation of the beam. Figure 1 shows the dependence of the vertical tune on the beam current in the single bunch condition. The ordinate of the figure corresponds to the measured tune shifts from the tune of the highest beam current in the experiment. As seen in Fig. 1, the tune tends to decrease linearly as the beam current increases. From the experiment, the current dependence of the vertical tune $\left(\frac{\Delta\nu_y}{\Delta I_b}\right)_{exp.}$ is estimated at (-53.8 $\pm$ 4.03) $\times 10^{-6}$ /mA. Such dependence in the single bunch condition seems to be caused by a wake field that causes head-tail instability[1]. The current dependence of the tune $\left(\frac{\Delta\nu_y}{\Delta I_b}\right)$ due to the wake field is approximately given by[1]:

$$\frac{Z_0^{\|}}{n} \approx \frac{2q\gamma b^3\omega_y}{\epsilon_0 c r_e RC}\left(\frac{\Delta\nu_y}{\Delta I_b}\right), \tag{1}$$

where $\frac{Z_0^{\|}}{n}$ is longitudinal impedance of the storage ring, q an electron charge, γ the Lorentz factor of the beam, b radius of vacuum chamber, ω_y the vertical betatron oscillation frequency, ϵ_0 the dielectric constant of the free space, c the speed of light, r_e the classical electron radius, R the average radius of the storage ring and C the circumference of the ring, respectively. With the experimental value of $\left(\frac{\Delta\nu_y}{\Delta I_b}\right)$ and Eq. (1) we estimated that the longitudinal impedance is 2.46$\pm$0.20 Ω. An analysis of the longitudinal impedance from bunch lengthening in UVSOR[2] has concluded that $\frac{Z_0^{\|}}{n} = 1.6\ \Omega$, that is almost the same value as the analysis from the theory of the head-tail instability.

Secondly, we have observed the dependence of the vertical tune on the beam current in the multi bunch condition in which a series of 12 bunches (a bunch train) followed by a series of 4 empty buckets (a bunch gap) are stored in the ring. Because vertical spontaneous oscillation has been observed in the multi bunch condition we have measured the vertical tune by observing the spontaneous oscillation, not using RF-KO method. In the experiment, the vertical tune was observed above 169.4 mA because the spontaneous oscillation was not able to be observed below the beam current. Figure 2 shows the change in the vertical tunes in the multi bunch condition. The ordinate of the figure corresponds to the measured tune shifts from the tune of the highest beam current in the experiment. To emphasize phenomena in the multi bunch condition, we subtracted the current dependence of the vertical tune in the single bunch condition $\left(\frac{\Delta\nu_y}{\Delta I_b}\right)_{exp.}$ from the multi-bunch experiment. As seen in the figure, the change in the tune due to the change in the beam current still remains after the subtraction, and especially, the tune has step-like changes around the bunch current of 15 and 30 mA. Such a change in the tune in the multi bunch condition could be caused by trapped ion effect[3][4]. According to the classical theory of the ion trapping, an electric field induced by the ions trapped by the electron beam could increase the tune, and the change in the tune is proportional to the ion density. Because a trapping condition of the ions depends not only on configuration of the bunch train but also on a beam size, the condition differs at different positions in the ring under the same configuration of the ring. We calculated a ratio of the total area of regions where the ions are trapped to the area of the whole UVSOR-ring in various configurations of the bunch train. The results are shown in Fig. 3 and 4. These figures show with contour lines the ratio for various configurations of the train. In the calculation[5], ion species of CO^+ and CO^{2+}, which are the main components of the residual gas molecules in the UVSOR-ring, are assumed. As seen in these figures, the ratio has sudden changes at the bunch train length of 12 bunches around the bunch current of 15 mA in CO^+ and 30 mA in CO^{2+}. The bunch current at the sudden changes in the calculation corresponds to the bunch current in which the vertical tune has step-like changes, namely, the tune increases at the bunch current where the ratio also increases and has little change at the bunch current where the ratio also has little change. Therefore, it is

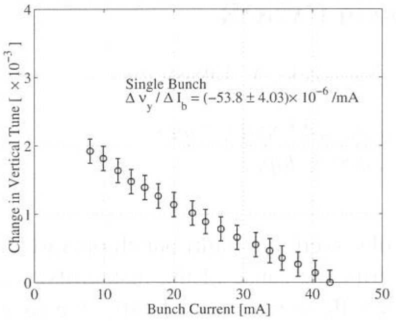

Figure 1: Dependence of the vertical tune on the beam current in the single bunch condition.

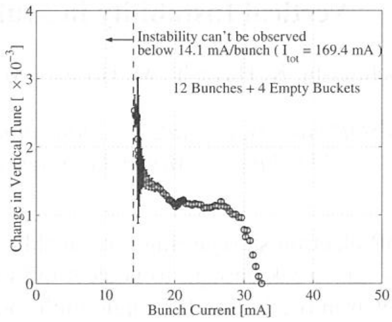

Figure 2: Dependence of the vertical tune on the beam current in the multi bunch condition.

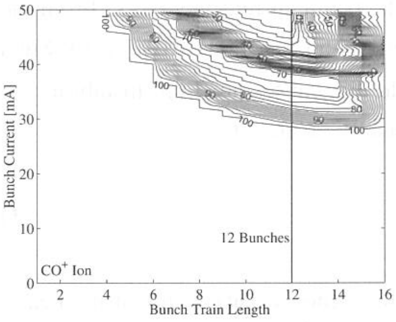

Figure 3: The ratio of the area of the regions where the CO^+ ions are trapped to the area of the whole ring for various bunch train lengths.

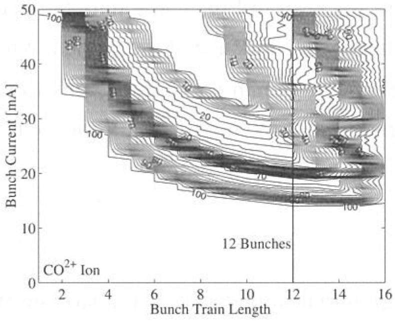

Figure 4: The ratio of the area of the regions where the CO^{2+} ions are trapped to the area of the whole ring for various bunch train lengths.

supposed that the change in the tune observed in the multi bunch condition is caused by the change in the trapping condition of the residual gas ions. To verify the cause of the vertical instability, more detailed experiments for the phenomenon are necessary. Development of a bunch-by-bunch beam diagnostic system and bunch-by-bunch beam diagostics with the system are future plans.

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Feasibility Study of Generation of Ultrashort Pulses of Synchrotron Radiation at UVSOR

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1. Introduction

We have been considering a method for the generation of ultrashort pulses of synchrotron radiation from UVSOR storage ring.

A pulse width of synchrotron radiation is the same as a bunch length of electron beam circulating in a storage ring and is usually several tens to several hundreds picoseconds. In order to obtain ultrashort photon pulses, we have been studying the feasibility of the bunch slicing technique [1,2]. The bunch slice can be achieved by using a femtosecond laser pulse passing together with an electron bunch through in an undulator. We tune the undulator to the wavelength of the laser, so that the energy of electrons overlapped with the laser are modulated by the interaction with the laser field. If the energy modulation is several times lager than the r.m.s. energy spread of the electron beam, the modulated electrons are separated spatially when the electrons pass through a dispersive section as shown in Fig. 1. The sliced electrons emit displaced synchrotron radiations in bending magnets or insertion devices. We can obtain ultrashort photon pulses by using a collimator and optical systems in order to transmit and focus on the radiations emitted from sliced electrons.

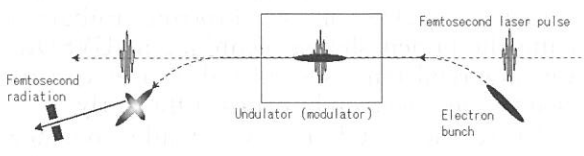

Fig.1. Sketch of bunch slicing technique.

2. Experimental Equipment

Fig. 2 shows an example of experimental setup to generate ultrashort photon pulses. We will use the existing BL5A undulator as an energy modulator in which circulating electrons interact with the laser pulses.

A mode-locked Ti-sapphire laser and an ultrafasst regenerative amplifier is used to make femtosecond laser pulses which should have enough power to make sufficient energy modulation in order to slice the electron bunches. Fig. 3 shows the required peak power of the laser to make the energy modulations. In this calculation, we supposed that the energy of electron beam was 750 MeV, the wave length and the pulse width of the incident laser were 800 nm and 100 fs, respectively. We also supposed the horizontal beam spread of UVSOR storage ring was about 0.5 mm (r.m.s.), and the value of the horizontal dispersion function in the bending magnet was about 0.6 m. If we intend to spread the electron bunch up to 2.5 mm (r.m.s.), 0.4 % of energy modulation is needed and we have to employ 500 MW peak power laser.

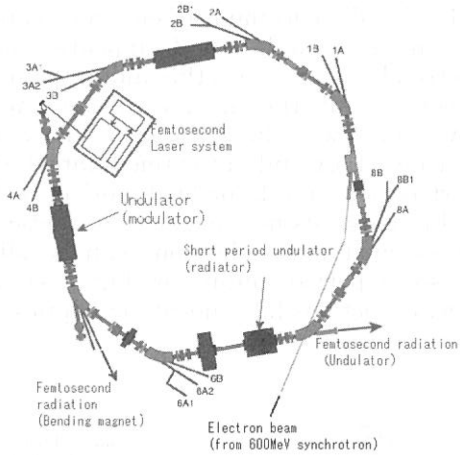

Fig. 2. Layout of experimental equipment.

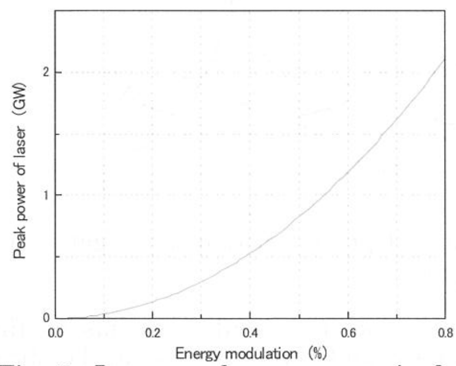

Fig. 3. Laser peak power required for energy modulation.

The intensity of the ultrashort radiation is proportional to the number of sliced electrons. The width of the laser pulse is about 10^{-4} of the bunch length, and in addition, the repetition rate of the laser pulse (1 kHz) is about 10^{-5} of the RF frequency of UVSOR storage ring, so that the averaged intensity of the radiation is 10^{-9} of the intensity of synchrotron radiation from UVSOR storage ring under the normal operation.

In order to improve the intensity of the radiation, we have been considering using the short period undulator as a radiator which will be installed for BL7 of UVSOR storage ring [3,4]. The displacement of electrons caused by the energy modulation disappears when the electron bunch reaches the undulator since the dispersion function is free at the undulator. However, if we adjust the optics between the existing BL5A undulator (modulator) and the short period undulator (radiator) to be locally isochronous using negative-α optics, the energy modulated electrons can be sliced in the short period undulator. Fig. 4 shows the optical functions for a negative-α optics.

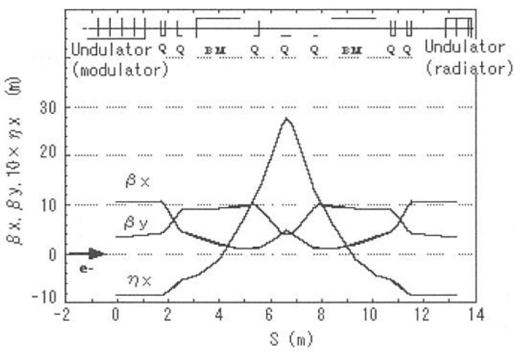

Fig. 4. Optical functions for negative-α optics.

Beam tracking simulations has confirmed that the modulated electrons can be sliced at the short period undulator. The SAD code developed in KEK for accelerator design [5] was used for the simulations. Fig. 5 shows the spatial distribution of electrons at the short period undulator. The electrons of the width of 100 fs in a bunch were modulated their energy up to 0.8 % randomly in the existing BL5A undulator and then traveled to the short period undulator.

3. Intensity of Ultrashort pulse radiation.

We calculated the spectra of ultrashort synchrotron radiation on the following assumptions: the r.m.s. spread of the sliced electrons was five times larger than the natural spread and the radiations emitted from the electrons displaced over three times

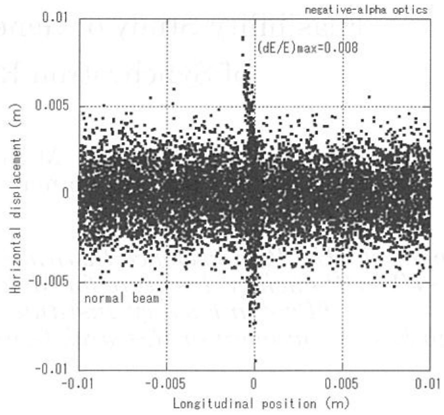

Fig. 5. Spatial distribution of electrons in BL7 short period undulator calculated by using SAD code.

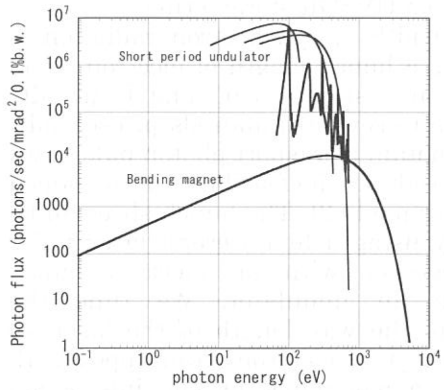

Fig. 6. Photon flux of ultrashort synchrotron radiation from short period undulator and BL5 bending magnet.

of the natural r.m.s. spread were observed. The wavelength and repetition rate of the incident laser were 800 nm and 1 kHz, respectively. Fig. 6 shows the photon fluxes generated in the short period undulator and BL5 bending magnet.

4. Summary

We have been planning to generate ultrashort pulse of synchrotron radiation using the bunch slicing technique at UVSOR. A commercial femtosecond pulse laser can be used to slice electron bunches sufficiently.

For further studying, we should consider methods to improve the peak intensity of the radiation.

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Improvement of out-coupled power of the UVSOR-FEL

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Storage ring free electron lasers (SRFELs) likely have a potentiality for scientific application as a unique light source because of, in addition to variable wavelength, good coherence and temporal feature. Recently an experiment using SRFEL combined with synchrotron radiation (SR) was begun at UVSOR. As the first experiment we have tried to demonstrate the relevance of SRFEL for a pump/probe experiment in the gas phase molecular science that is the double-resonant excitation of Xe [1]. Since the application experiment was planned, efforts to improve the performance of the FEL have been made from the application point of view. We have already developed a feedback system leading to a stable laser [2], with reduced jittering and intensity fluctuations that spoil a quality of the experimental data. Another significant requirement is out-coupled laser power of the FEL. In this report, we present efforts to increase the out-coupled laser power of the UVSOR-FEL and show the latest result.

The out-coupled power of SRFEL at the saturation is approximately given by,

$$P \approx \eta_c J_\varepsilon \sigma_\varepsilon e^{-1/2} P_{SR} \qquad [1]$$

where η_c (= transmittance/cavity loss) is the efficiency of a optical cavity, $J_\varepsilon (\approx 2)$ is the damping partition number of the synchrotron damping, σ_ε is the induced energy spread due to the FEL interaction and P_{SR} is the synchrotron radiation power. Since P_{SR} is proportional to the number of electrons stored in the storage ring, it is crucial to increase the stored electron beam in the storage ring. Therefore we tuned the booster synchrotron and the injection condition and succeeded to store the electron beam of more than 100 mA/bunch. However, Touschek life time of the electron beam is considerably short when the beam current is high. Then we increased the x-y coupling of the electron beam from 2% to 6 % using skew-quadrupole magnets and increased the life time.

In order to maximize the optical cavity efficiency in the region of the wavelength used for the application experiment, we have chosen a multilayer coating of Ta_2O_5/SiO_2 on the fused silica substrates for the cavity mirrors. Since the FEL gain large at a high beam current, numbers of layers were decided to reduce to be 19 and 21 layers for the rear mirror from which the laser is extracted and the front mirror, respectively, to obtain high transmission rate. Measured initial transmission rates at the wavelength of 570 nm were 0.2 % and 0.1 % for the 19-layer and the 21-layer mirrors, respectively. The round-trip loss in the optical cavity was initially measured to be 0.35 %, meanwhile the expected FEL gain is ~ 5 % at a beam current of 100 mA/bunch.

Beside optimizing the basic conditions for the lasing given in Eq [1], we have also developed a new operation of the storage ring: 4-bunch operation. In the ordinary FEL operation, two electron bunches are stored with an equal spacing in the ring, whereas, in the 4-bunch operation, two more bunches are added next to the initial bunches. Then the stored beam current is simply doubled and the extracted power as well. Prior to this operation, we have investigated an effect of the coupled-bunch instability, which would be commonly predicted to be occurred. However, because there is an additional cavity operated at a third-harmonic frequency of the main cavity has been installed on the UVSOR to suppress the coupled-bunch instability in a multi-bunch operation for the user SR machine time, we could find a proper tuning angle for a passive operation of the harmonic cavity to stabilize the 4-bunch operation.

Fig.1 shows the demonstration of the FEL lasing in the visible region around 570 nm. The extracted power exceeds 1 W and is the highest in the SRFELs so far. Using the FEL, the application experiment has been carried out successfully and the relevance of SRFEL for it has been shown [1]. We are planning to extend the high power operation to the UV region.

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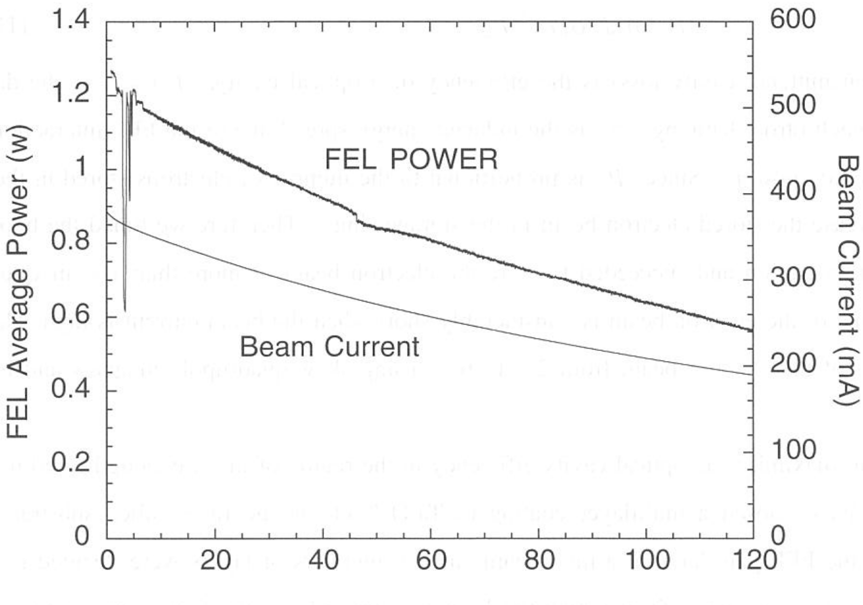

Fig. 1 Demonstration of the FEL lasing in the 4-bunch operation of the UVSOR storage ring. The extracted power exceeds 1 W.

In-Vacuum Undulator for UVSOR BL-7A

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An upgrade plan for the UVSOR[1] mainly aims to realize (1) smaller emittance and (2) more straight sections for insertion devices. The high brilliance beam optics is very suitable for insertion devices with narrow gap such as an in-vacuum undulator because vertical betatron functions for all the straight sections in the ring are very small (~1m). The in-vacuum undulator has been utilized as one of standard types of the insertion devices in SPring-8, and much technical knowledge for the undulators has been stored so far. However, there is no precedent in which this kind of the undulator has been installed in lower energy electron storage ring such as the UVSOR. Going ahead of the upgrade project, we plan to install the undulator and have a performance test in UVSOR BL-7A. Table 1 shows main parameters of the undulator. The minimum gaps of the magnetic poles are 20/10 mm for present/upgraded lattice, respectively. The period length is 36 mm, that results in very wide tunability in VUV and soft X-ray region, as shown in Fig. 1.

For the narrow gap undulators, a wall-current effect, that can cause not only heating of the magnetic poles but also beam instabilities, can't be neglected. We have estimated resistive wall heating on the magnetic poles by the wall-current for the single/multi bunch operation. The results are shown in Fig. 2. In this figure the gap height of 10 mm, that corresponds to the minimum value of the gap, is assumed. According to the calculation, the heating power in the maximum beam current in routine single/multi bunch operation (70/300mA in single/multi bunch operation) is about 0.2 W in the single bunch and 0.3 W in the multi bunch operation, therefore, it is expected that the heating effect is not so serious in our case. We have also estimated growth rates of resistive wall instability induced by the magnetic gap in the undulator. Figure 3 shows the growth rates for both the present and the upgraded lattice of the UVSOR when the beam current is 300 mA. According to the calculation, the growth rates are smaller than the radiation damping time even though in the minimum gap height, therefore, it is also expected that the effect of the resistive wall instability is not so serious in our case, too.

Installation of the in-vacuum undulator has been completed in March 2002. Figure 4 shows a photograph of the undulator just after the installation. After several basic performance test, we plan to investigate performance of the undulator as a light source in detail with the electron beam.

Magnet Type	Pure Permanent (Nb-Fe-B)
Remanent Field	1.17 Tesla
Period Length	36 mm
Number of Period	26
Magnetic Length	936 mm
Overall Length	1.4 m
Minimum Gap	10 mm (Low-β Optics)
	20 mm (Present Optics)
Max. K-parameter	2.27 (Low-β Optics)
	1.15 (Present Optics)
Polarization	Linear (Horizontal)

Table 1: Main parameters of in-vacuum undulator

References

[1] M. Katoh, *et al.*,
UVSOR Activity Report 2000, p. 38.

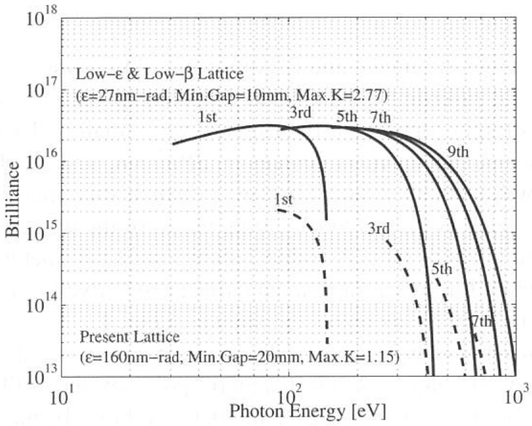

Figure 1: Calculated brilliance for the in-vacuum undulator.

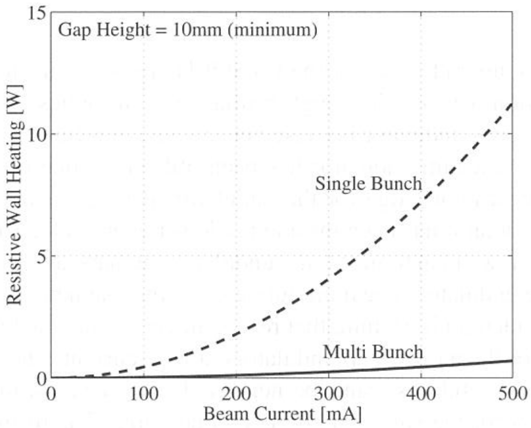

Figure 2: Calculation of the resistive wall heating on the magnetic poles in the in-vacuum undulator.

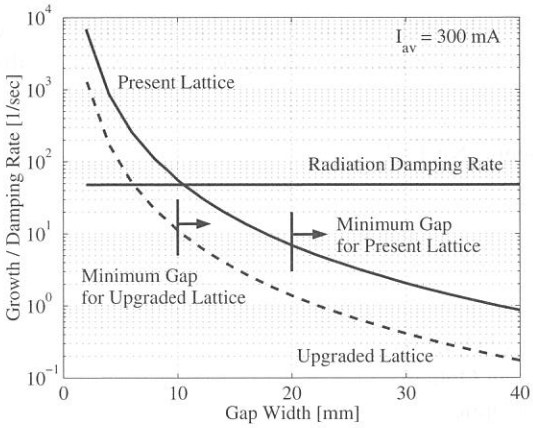

Figure 3: Calculation of the growth rates due to the resistive wall instability by the magnetic poles in the in-vacuum undulator.

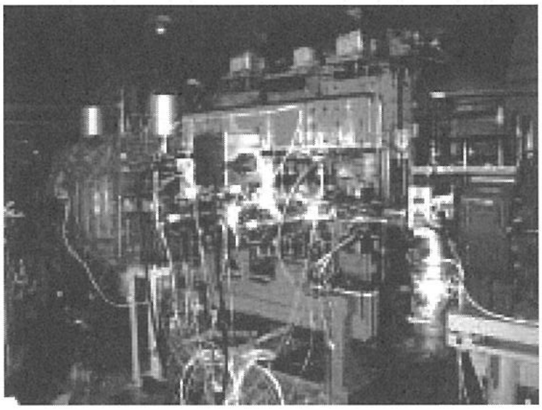

Figure 4: A photograph of the in-vacuum undulator just after the installation.