LIGHT SOURCE

OVERVIEW OF LIGHT SOURCE

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The light source has been regularly used for the production of synchrotron radiation during 1988. The reliability of the accelerator system has been steadily improved for some years. A rate of unscheduled shutdown time is about 1 %. The operating schedule is unchanged in 1988; machine studies were carried out every monday and user's studies were from Tuesday through Friday. Electron beam was injected into the storage ring twice a day at 9:00 and 13:00 and the beam was dumped at 18:00.

The total operating time of the light source was 46 weeks in 1988. The usual initial current in the multi-bunch mode was 100 mA (120 mA from November) and the beam lifetime was 3-3.5 h at that current. The single-bunch operation was performed at a rate of 1 week in 2 months. The initial current in the single-bunch mode was 10-13 mA and the normal impurity (the electron number in non-assigned bucket/ the total electron number) is less than $0.5 * 10^{-3}$. A total machine time of 3 weeks was allocated to the wiggler users, and the undulator in the straight section S 3 was regularly used through this year.

The beam quality in the light source has been observed and improved continuously. A passive damper for the longitudinal coupled-bunch instability was successfully tried. The bunch lengthening and widening in the single-bunch mode were observed. The longitudinal coupling impedance of the storage ring was estimated from the bunch lengthening measurement. Though the impedance is about twice as large as the designed value, it is not so large compared with existing storage rings. The beam current of the injector synchrotron was considerably improved with vertical steering coils which correct the injection orbit around the inflector and with a sextuple magnet which corrects the chromaticity.

The design parameters with achieved ones are tabulated in Table I.

Table I Main Parameters of UVSOR

	Designed		Achieved	
Linac				
Energy	15	MeV		
Frequency	2.856	GHz		
Synchrotron				
Energy	600	MeV	600	MeV
Current	50	mA	32	mA
Circumference	26.6	m		
Periodicity	6			
Bending Radius	1.8	m		
Tune (Q_H, Q_V)	(2.25,	1.25)		
Harmonic Number	8			
Radio Frequency	90.1	MHz		
Repetition Rate	1-3	Hz	2.5	Hz
Storage Ring				
Energy	600 (max.	MeV 750 MeV)	750	MeV
Critical Wavelength	56.9	A		
Current				
Multi-bunch mode	500	mA	500	mA
Single-bunch mode			71	mA
Lifetime	1 (500	hr mA)	3 (100	hr mA)
Circumference	53.2	m		
Periodicity	4			
Bending Radius	2.2	m		
Bending Field	0.91	T		
Tune (Q_H, Q_V)	(3.25,	2.75)		
Harmonic Number	16			
Radio Frequency	90.1	MHz		
RF Voltage	75	kV		
Radiation Damping Time				
Horizontal	45.4	ms		
Vertical	40.9	ms		
Longitudinal	19.5	ms		
Emittance				
Horizontal	$8\pi \times 10^{-8}$	m.rad*	$<16\pi \times 10^{-8}$	m.rad
Vertical	$8\pi \times 10^{-9}$	m.rad		
Beam Size (at the Center of Bending Section)				
Horizontal ($2\sigma_H$)	0.64	mm*		
Vertical ($2\sigma_V$)	0.46	mm		
Bunch Length (2σ)	0.17	ns	0.4	ns

*10% coupling is assumed.

Suppression of Longitudinal Coupled-Bunch Instability by Decoupling Method

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A longitudinal coupled-bunch instability in the UVSOR electron storage ring for synchrotron radiation research had been observed when routine operation of the ring was started. It was successfully damped with a longitudinal active damping system, which consists of sixteen independent feedback loops; each of them corrects the energy deviation of any one of sixteen bunches individually. However, a fault in the system was found in the regular operation, i.e. the feedback loops have to be finely adjusted according to parameters such as the beam current, the position of the RF cavity tuner and the acceleration voltage. For example, the synchrotron frequency depends on the beam current, because the imaginary part of the cavity impedance at both synchrotron sidebands are different (the Robinson effect). A programmed control of the feedback parameters may offer a solution to this problem. While we were designing the improved feedback system, we also tested a passive damper. Two kinds of passive damping systems have been reported: Landau cavity or harmonic cavity method and a decoupling method. The former makes use of the Landau damping by the synchrotron frequency spread due to the strong nonlinearity which is introduced into the effective acceleration voltage around the stable phase angle. In the latter method, the phase oscillation of individual bunches are decoupled by a spread in their synchrotron frequencies, which is induced externally by modulation of the acceleration voltage. We adopted the latter because the required RF voltage is much smaller than that of the former. Moreover, the wideband acceleration gap for the active damping system was easy to convert into the cavity for the latter. The coupled-bunch instability was damped with this method when the beam current was less than 80mA and the growth rate of the instability is not very fast. The limitation of this method is not in the principle but in the maximum applicable voltage across the acceleration gap.

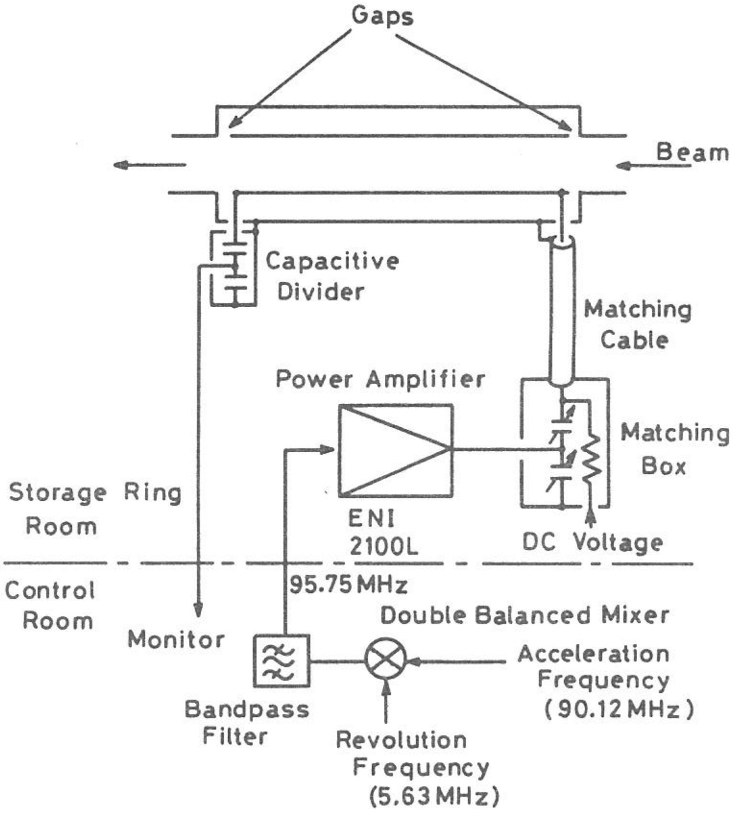

Fig. 1. A block diagram of the longitudinal passive damper.

Bunch Lengthening in Single-Bunch Mode of UVSOR Storage Ring

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The bunch lengthening and widening of the beam in the UVSOR ring were measured in the single-bunch mode. In the measurement certain thresholds were observed and the longitudinal coupling impedance of the ring was obtained with the threshold current.1)

The relation between the bunch lengthening and the longitudinal coupling impedance was theoretically studied2-5) and at low beam current the bunch lengthening due to the distortion of the acceleration potential by the beam pipe is described by

$$\left(\frac{\sigma_s}{\sigma_{s0}}\right)^3-\frac{\sigma_s}{\sigma_{s0}}-\frac{I\alpha e|Z/n|}{\sqrt{2\pi}\nu_{s0}^2 E}\left(\frac{R}{\sigma_{s0}}\right)^3=0 \qquad (1)$$

where σ_s is the standard deviation of the bunch length at the beam current of I, σ_{s0} the natural bunch length, α the momentum compaction factor (0.026 for the UVSOR ring), e the electron charge, |Z/n| the longitudinal coupling impedance, ν_{s0} the undisturbed phase oscillation wave number, E the beam energy and R the mean radius of the ring (16.9 m).2) Above a threshold current the bunch lengthening due to the microwave instability is described by Chao-Gareyte scaling law6)

$$\sigma_s^a \propto \frac{I\alpha}{\nu_{s0}^2 E}. \qquad (2)$$

The synchrotron radiation emitted in a bending section was observed in order to measure the electron bunch length. The beam current dependence of the bunch length at the beam energy of 500, 600 and 750 MeV are shown in Fig. 1. We fitted the bunch length data using eq. (1) at low current and eq. (2) at high current to estimate a and I_{th}. The results are tabulated in Table I. We also measured the horizontal width of the beam to make sure of the change in the energy spread as shown in Fig. 2. The overall resolving power of the measurement is 0.8 in the same unit of the vertical scale in Fig. 2. The data in the case of the electron energy of 600 MeV shows that the width increses above the threshold current.

Table I. Bunch length and longitudinal coupling impedance.

Beam Energy E (MeV)	500		600		750	
Undisturbed Phase Oscillation Wave Number ν_{s0}	3.15×10^{-3}		2.87×10^{-3}		2.55×10^{-3}	
Natural Bunch Length σ_{s0} (ps)	67.2		88.4		124.3	
Estimated from	low current	threshold current	low current	threshold current	low current	threshold current
σ_{s0} (ps)	92.5	124	122.8	143	176.9	
|Z/n| (Ω)	4.4	3.1	4.1	3.2	4.9	

We estimated the longitudinal coupling impedance of the UVSOR ring and it lies between 3.1 and 4.4 Ω. This value is about twice as large as the expected one of 2 Ω.7) The bunch widening is recognized above the threshold current in the case of the electron energy of 600 MeV, and it is consistent with the theory. However, it is difficult to discuss the widening quantitatively because of the insufficient resolution of the system.

The authors wish thank Y. Miyahara for his discussion of beam instabilities in electron storage rings. The assistance of K. Fukui in the use of the photon counting system is also acknowledged.

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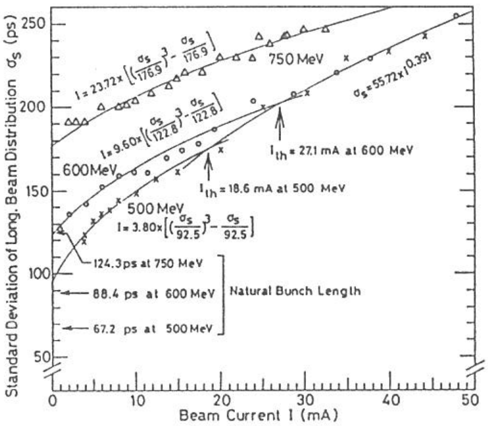

Fig. 1. The current dependence of the bunch length in the single-bunch operation. Triangles, circles and crosses show the measured values at the beam energy of 750, 600 and 500 MeV. Equations in this figure are obtained by fitting the data to eqs. (1) and (2).

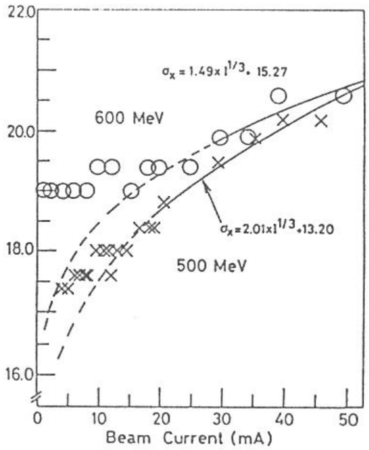

Fig. 2. The current dependence of the bunch width in the single-bunch operation. Circles and crosses show the widths at the beam energy of 600 and 500 MeV, respectively. Solid lines show the fittings above the thresholds (broken lines show the same fittings below the thresholds).

Experimental Study of Free-Electron Laser at UVSOR Ring

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Experimental studies of the Free-Electron Laser (FEL) are being carried out at the UVSOR, which is usually used as a synchrotron light source for the molecular science and its related fields. The wavelength within visible light, especially 488 nm, was chosen for simplicity of the optical system. In order to obtain the one-pass gain of 1 % at the electron beam current of 10 mA per one bunch, an undulator which has the period length of 74 mm, the number of the periods of 29 and the total length of 2.1 m was installed. The electron energy less than 270 MeV was necessary to achieve the wavelength of 488 nm with the undulator, however, the beam lifetime of 5 minutes at the energy was too short to align the optical system and to measure the one-pass gain. Therefore, the number of the periods was changed into 19 by arrangement of the magnet blocks. The beam lifetime increases to 50 minutes at the electron energy of 500 MeV. As the result, an expected one-pass gain is decreased to less than 0.1 %.

To measure the one-pass gain an Ar laser (10 mW) is used. The laser beam is enlarged and made pararrel beam by a laser beam expander (x3). The diameter of the laser beam is less than 2 mmϕ and about 2.5 mmϕ, at the inlet and outlet of the vacuum chamber for the FEL experiment. The size of the electron beam (standard deviation) is about 0.3 mmϕ at the center of the undulator. It is important to align the beams mutually in order to maximize the gain of the FEL. However, it is not esay to overlap these two beams at the undulator completely because these are very thin. An optical alignment system with TV cameras and beam splitters are installed to monitor the overlap as shown in Fig. 1. The profiles of the electron beam and the laser beam at the undulator are observed with the camera #2 with a telephoto lens. The images of these beams on the screens at the outlet of the vacuum chamber and at the point 6 m downstream from the undulator are monitored with the camera #1 and #3 respectively. The alignment of the two beams are tried with the monitoring system.

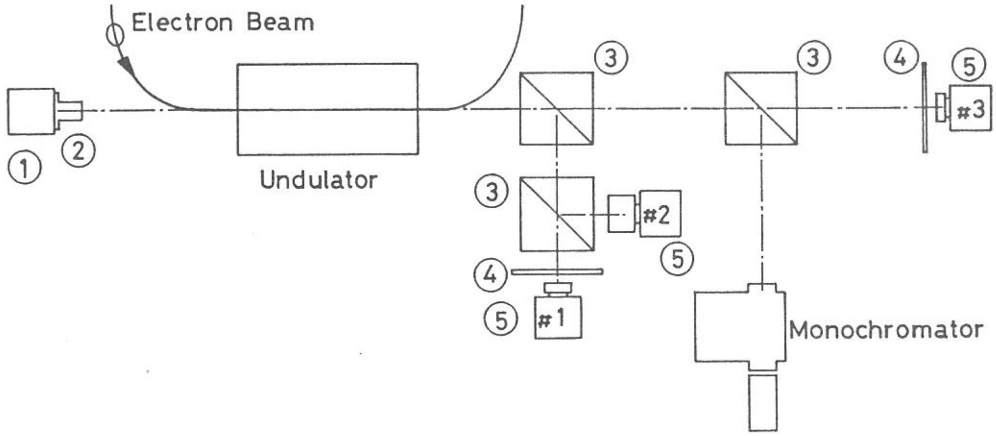

Fig. 1 Optical alignment system. 1) Ar laser, 2) laser beam expander, 3) beam splitter, 4) screen and 5) TV camera.