Measurement of the Orbit Parameters at SOR-RING

Hirofumi KUDO, Kenji SHINOE, Hiroyuki TAKAKI, Tadashi KOSEKI, Haruo OHKUMA and Yukihide KAMIYA
The Institute for Solid State Physics, The University of Tokyo, JAPAN

Abstract

In the 1992 summer shutdown, beam position monitors (BPM's)[1] [2] have been installed in SOR-RING as one of the R&D's for the future plan of a VUV high-brilliant source. They have been also aimed at measuring the closed orbit of the ring and correcting it by beam steerings that have been also installed at the same time as the BPM's. With these systems, we measured the closed orbit distortion (C.O.D.) at the first time since the ring had been constructed. Horizontal and vertical C.O.D.'s were then corrected within 1 mm by exciting the steerings and changing the RF frequency. We also measured the other orbit parameters such as betatron and dispersion functions, chromaticity and RF-cavity parameters. Moreover, it was proved in a recent machine study that SOR-RING is capable of accelerating the electrons up to 450 MeV or more from the present energy of 380 MeV.

I. Operational Status of SOR-RING

A. General

SOR-RING [3] is the oldest among the storage rings that have been constructed as rings dedicated to synchrotron radiation experiments from the start. Its construction was completed in 1974. The ring is located in the site of the Institute for Nuclear Study (INS), the University of Tokyo, but the facility of SOR-RING belongs to the Synchrotron Radiation Laboratory (SRL), the Institute for Solid State Physics (ISSP) of the same university. Electrons with an energy of 308 MeV are injected into SOR-RING at a repetition rate of 1 Hz from ES, Electron Synchrotron of the INS, which is a 21-Hz rapid-cycle machine with a maximum energy of 1.3 GeV and provides the electrons to their own users.

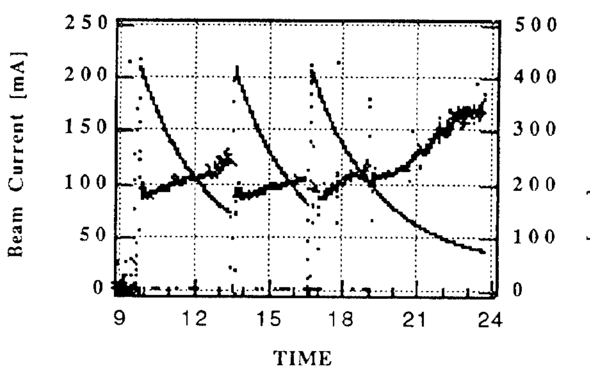

Fig. 1 Typical daily operation of SOR-RING (beam current and lifetime versus time)

Electrons injected into the ring are accelerated up to 380 MeV and then stored until the next injection. The ring is usually operated from morning to night with the beam injection three times per day, and the weekly schedule is from Tuesday to Friday in accordance with the schedule of ES. In 1992, initially stored beam current was around 220 mA and the beam lifetime about 200 minutes at 200 mA (recently the lifetime has been much improved). A typical daily operation of the ring is shown in Fig.1. Total operation time in the 1992 fiscal year was about 2100 hours including injection and machine study.

B. Ring parameters

Figure 2 shows the plan view of SOR-RING. The ring is 17.4 m in circumference and consists of eight bending magnets and four quadrupole triplets. At 380 MeV the beam emittance is about 320 nm·rad and the critical energy of photons from bending magnet is 110 eV. The ring parameters are listed in Table I.

C. Accelerator problems

There are accelerator problems in SOR-RING yet to be solved; (1) ion-trapping that gives rise to growth and fluctuation of the vertical beam size (see Sec. VI), (2) vacuum pressure growth around the RF-cavity, which might be caused by outgassing from the elastic vacuum seal of the cavity or by heating of the upstream glass window due to direct irradiation of synchrotron light and (3) a longitudinal instability caused by a higher-order-mode of the RF-cavity; for multi-bunch mode the threshold currents of longitudinal instability are about 3 mA at 380 MeV and 1 mA at 308 MeV.

Table I. Principal parameters of SOR-RING+

Injection energy	308 MeV
Storage energy	380 MeV
Circumference	17.4 m
Bending radius	1.1 m
Bending field	1.15 T
RF frequency	120.83 MHz (at present)
Harmonic number	7
Revolution frequency	17.3 MHz
Horizontal tune	1.28 (typical)
Vertical tune	1.22 (typical)
Momentum compaction	0.636
Natural emittance	~320 nm·rad
Horizontal beam size	~0.9 mm (at bending magnets)
Vertical beam size	~0.2 ~ 0.3 mm (at bending magnets)
Horizontal damping time	31 msec
Vertical damping time	26 msec
Longitudinal damping time	12 msec
Critical photon energy	110 eV
Energy loss per turn	1.7 keV
Energy spread	3.8×10^{-4}
Bunch length	~10 cm
Synchrotron frequency	110 kHz (typical)
RF Voltage	22 kV (typical)

+The parameters dependent on the beam energy are the values at 380 MeV.

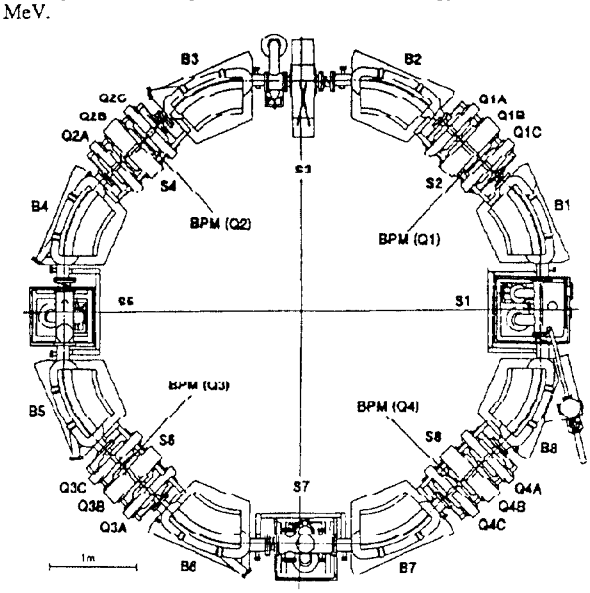

Fig. 2 Schematic of SOR-RING

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II. BPM and Steering Systems

A. General

In last summer shutdown, four vacuum chambers for quadrupoles were replaced by new ones in order to install BPM's and ion-clearing electrodes. The purposes of the BPM system that is one of R&D's for a high-brilliant light source are to test the whole system with a real beam and to measure and correct the C.O.D. of SOR-RING. In addition, an auxiliary coil was wound on every pole of all quadrupole magnets in order to produce steering fields for correcting C.O.D. and to change quadrupole fields for measuring betatron function. Furthermore we replaced manually controlled shunt resistances for changing bending fields with computer-controlled electric loads. As the BPM system is reported elsewhere [2] and [3], we will describe the auxiliary coils here.

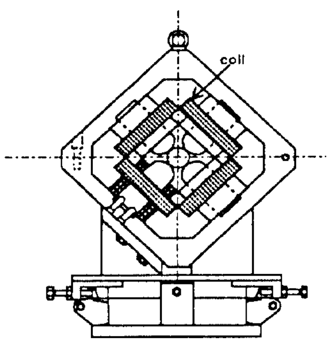

Fig. 3 Auxiliary coils in a quadrupole magnet

B. Auxiliary coils

The coils wound around quadrupoles (Fig. 3) are capable of producing both horizontal and vertical dipole fields by exciting appropriate pairs of coils or of changing the quadrupole strength, though the dipole fields produced by them are not so uniform as in a case of sextupoles. However, beam steering by these coils does work well for SOR-RING. The conductor of coils is 1.8 mm in diameter and the number of turn is 196 per coil. The power supplies (35 V × 5 A) are controlled by the same computer as the BPM system. At present, auxiliary coils of two quadrupoles in a triplet are used for steerings and those of the remaining one for changing its quadruple field.

III. C.O.D. and its Correction

A. Uncorrected C.O.D.

It was found with the BPM system that maximum values of horizontal and vertical C.O.D.'s were about 3 mm and 4 mm at 380 MeV, as shown in Fig. 4 (a). It was also found that RF frequency did not conform to the ring circumference since the average of horizontal C.O.D. along the ring was about 2 mm. At the injection energy, the maximum horizontal C.O.D. is about 9 mm. In SOR-RING, however, it seems that the large orbit distortion at the septum helps the injection.

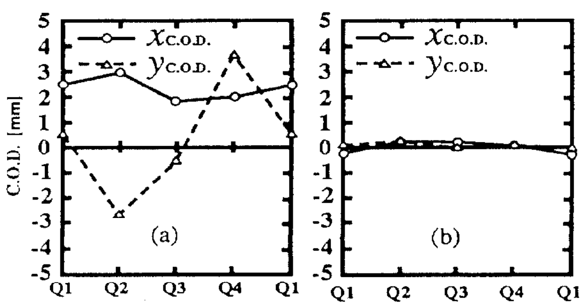

Fig. 4 (a) uncorrected C.O.D. and (b) corrected C.O.D.

B. Correction of C.O.D.

To correct both horizontal and vertical C.O.D.'s, we excited the beam steerings (auxiliary coils). In addition, we changed RF frequency by 100 kHz to correct the horizontal C.O.D. As a result, both horizontal and vertical C.O.D.'s were corrected less than 1 mm as shown in Fig. 4 (b).

IV. $\Delta\beta/\beta$, η and Chromaticity

A. Measured $\Delta\beta/\beta$ and η

Betatron function β at a quadrupole magnet can be obtained by changing its quadrupole strength and measuring the tune shift. Figure 5 (a) shows $\Delta\beta/\beta$, the fractional variation in betatron function. Dispersion function can also be obtained by measuring horizontal C.O.D. at different RF frequencies. The measured η is shown in Fig. 6 (b).

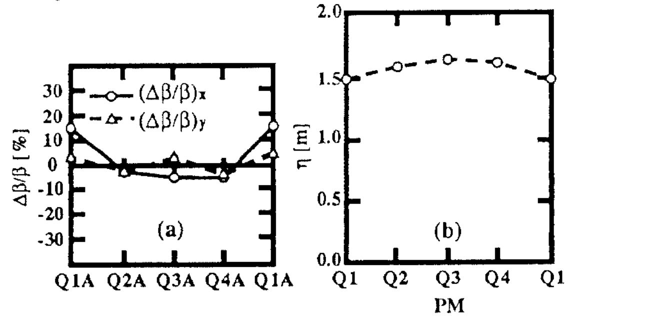

Fig. 5 (a) measured $\Delta\beta/\beta$ and (b) η

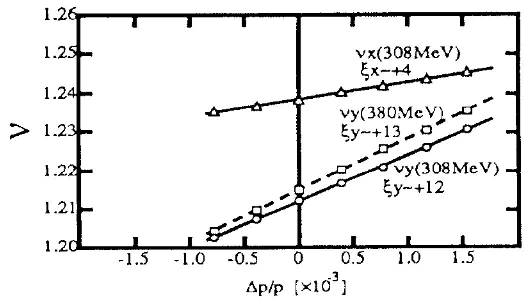

Fig. 6 Measured chromaticity

B. Measured chromaticity ξ

Figure 7 shows the measured chromaticity. At 380 MeV the horizontal chromaticity was not accurately measured. The figure shows that the measured chromaticities in both directions are relatively large in spite of a small ring and even positive, whereas their theoretical values are horizontally -2 and vertically 0.2. This discrepancy has not been settled yet.

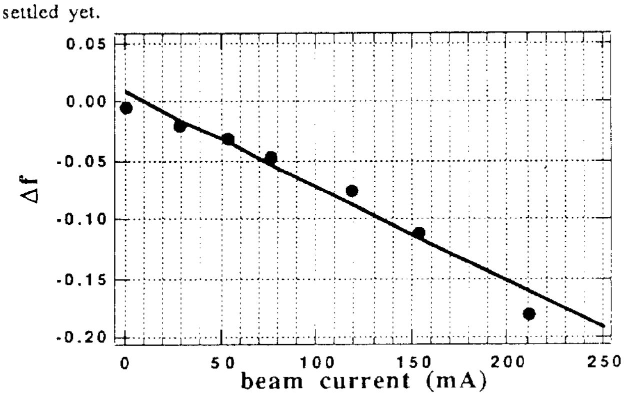

Fig. 7 Measured beam loading
The solid line is the theoretical calculation.

V. RF-Cavity Parameters

A. Measurement of the RF cavity parameters

We newly measured RF power and transmission/reflection coefficients of the RF-cavity. The measured parameters of RF-cavity are listed in Table II. The value of V_a in the table is a theoretical one and the V_c is deduced from V_a and the measured synchrotron frequency. Resonance frequencies and Q-values of the higher-order-modes (HOM's) were also measured and their changes due to the cavity tuners (called flappers) were examined. Since the changes are very complicated, however, the data of HOM's have not been fully analyzed yet.

Table II. Parameters of RF cavity

RF frequency f_{RF}	120.83 MHz
Generator power P_g	5 kW (typical)
Cavity power P_c	0.4 kW (typical)
Cavity voltage V_c	22 kV (typical)
Accelerating voltage V_a	1.68 kV at 380 MeV
Shunt impedance R_s	1.1 MΩ
Unloaded Q-value Q_0	6.4×10^3
Loaded Q-value Q_L	2.9×10^3
Coupling coefficient β	1.22
Tuning range of flappers	500 kHz

B. Beam loading

Beam loading may be expressed by;

$$(V_c t + V_{br}\sin\phi)^2 + (V_c + V_{br}\cos\phi)^2 = V_{gr}^2,$$

where $V_{br} = I_0 R_s/(1+\beta)$, $V_{gr}^2 = 4\beta\cdot P_g\cdot R_s/(1+\beta)^2$, ϕ=synchrotron phase and $t=-2Q_L\cdot\Delta f/f$, f being the resonance frequency of cavity. In a case of SOR-RING where the RF cavity is largely detuned and V_a is relatively small, the Δf is approximated by (the exact expression for the optimum tuning),

$$\Delta f = \frac{-f_{RF}}{2Q_L}\frac{R_s\sin\phi}{V_c(1+\beta)}\Delta I.$$

We can therefore observe an effect of beam loading by measuring Δf in a function of beam current. We first measured the Δf in a function of the position of one flapper at low RF level; the other flapper was fixed. We then measured the flapper position at several beam currents by keeping the cavity voltage constant; the constant cavity voltage would guarantee no frequency shift due to thermal effect. Figure 7 shows the measured result, which well agreed with the theoretical prediction.

VI. Topics in Recent Machine Study

A. Lifetime improvement

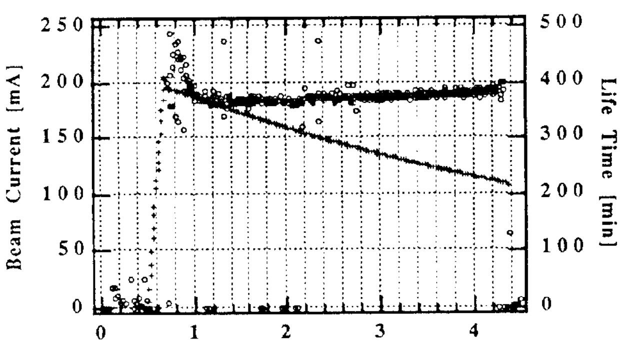

Fig. 8 Improved lifetime

Until recently, the operating point was near a sum resonance and the growth of beam size due to the resonance helped to decrease the Touschek effect at a high current. However, the beam sometimes fluctuated in size, probably due to a combined effect of the sum resonance and the ion trapping. Therefore, we changed the operation point to a new one, near the difference resonance of $\nu_x - \nu_y = 0$. As a result, the beam lifetime was increased by a factor of two at a low current. In addition, about 2-KV DC voltage was applied to ion-clearing electrodes. Then the lifetime was improved even at a high current as shown in Fig. 8.

B. Beam position spectra

In a recent machine study, one of the BPMs was connected to a hybrid circuit that can produce RF signals directly proportional to the beam positions. The RF signals were then fed into the BPM system through PIN diode switches. Almost DC signals from the BPM system were in turn fed into a FFT analyzer to find how the beam positions were fluctuating in a low frequency region. Figure 9 shows the Fourier-analyzed signals of vertical beam position within a frequency span of 50 Hz. Figure 9 (a) is the case where the synchrotron, ES, is operating with a repetition rate of 21.25 Hz, while Figure 9 (b) is the case where ES is turned off. Clearly, almost low-frequency fluctuations have their sources in ES, but presently we are not sure which source causes the fluctuations, magnetic field, AC line noise or mechanical vibration of ES. On the other hand, the frequency spectra around 10 Hz seen in both figures are probably generated from SOR-RING itself; suspicious are air-conditioner, cooling water system, vacuum pumps or cooling fans of RF power supply. With ES operational, the amplitudes of fluctuation were horizontally 3.6 μm and vertically 0.8 μm at 21 Hz.

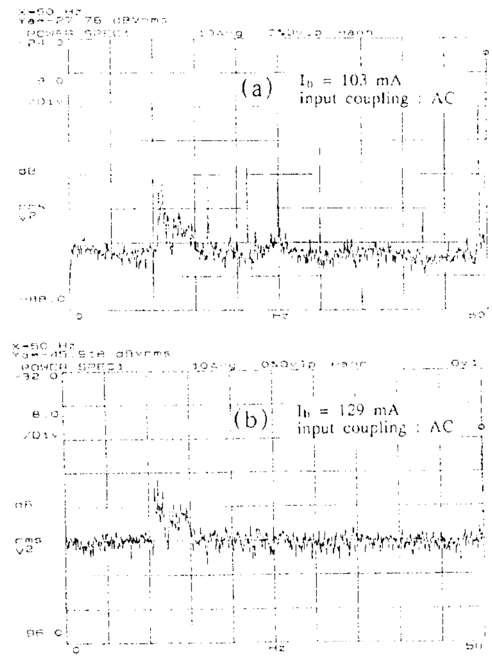

Fig. 9 Frequency spectra of vertical beam position
(a): with ES operational, (b): with ES turned off.

C. To a higher energy

It was proved that SOR-RING has a capability of accelerating the beam up to 450 MeV or more with minor modification; the critical photon energy then becomes about 200 eV. Indeed, a low-current beam of a few tens of mA was successfully accelerated to 450 MeV without any appreciable beam loss. And it is possible to accelerate the beam further, probably up to 470 MeV, since the ring magnets and their power supplies as well as RF power source still have a sufficient capacity. To accelerate a high-current beam as much as in the present user run, however, we need to replace the glass window for a synchrotron light monitor with a new one; the temperature of the window directly irradiated by synchrotron light is more than 100 °C at present.

VII. Acknowledgements

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VIII. References

[1] K. Shinoe et al.: *Design and Calibration of Pickup-Electrodes for Beam Position Monitoring at SOR-RING*, in these proceedings.

[2] K. Shinoe et al.: *Beam Position Monitoring System using PIN Diode Switches*, in these proceedings.

[3] T. Miyahara et al.: *SOR-RING An Electron Storage Ring Dedicated to Spectroscopy*, Part. Accel., Vol. 7, pp. 163-175, 1976.