Present Status of SOR-RING

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Abstract

SOR-RING [1] is the oldest ring that has been constructed as a ring dedicated to synchrotron radiation experiments from the start. Its construction was completed in 1974. The ring is, however, being improved and its accelerator studies are still active. In the 1992 summer shutdown, beam position monitors (BPM's) [2][3][4] were installed in the ring and the BPM system that used PIN diode switches showed a good performance; the relative accuracy was 0.3 to 0.4 μm. Recently the beam lifetime became by a factor of two longer; it was obtained by changing the betatron tunes and by applying a few kV on the ion-clearing electrodes. In this paper, we will present an operational status of the ring and some of recent machine studies [5].

I. Introduction

SOR-RING is located in the site of the Institute for Nuclear Study (INS), the University of Tokyo, but the facility of the 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. Electrons injected into the ring are accelerated up to 380 MeV and then stored until the next injection. Figure 1 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. The ring parameters are listed in Table I.

In last summer shutdown, four vacuum chambers for quadrupole triplets were replaced by new ones in order to install BPM's. A purpose of the BPM's is to test a BPM system that has been developed for the future plan of a VUV and soft X-ray high-brilliant light source [4], and the other purpose is to measure the C.O.D. of SOR-RING and correct it by beam steerings that have been also installed at the same time as the BPM's. The beam steerings consist of auxiliary coils wound on every pole of all quadrupole magnets, so that a quadrupole can produce both horizontal and vertical dipole fields by exciting appropriate pairs of four coils or change its quadrupole strength to measure betatron function. The conductor of coils is 1.8 mm in diameter and the number of turn 196 per coil. 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. In the summer shutdown we also replaced manually-controlled shunt resistances for changing bending fields with computer-controlled electric loads. With these systems, we measured the closed orbit distortion (C.O.D.) at the first time since the ring had been constructed, and further corrected both horizontal and vertical C.O.D.'s much less than 1 mm by exciting the steerings and changing the RF frequency.

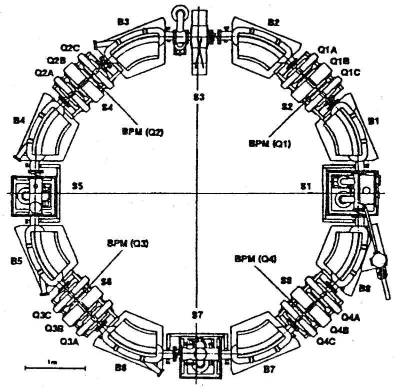

Fig. 1 Schematic of SOR-RING

When new vacuum chambers for triplets were installed, ion-clearing electrodes were also incorporated in them. At present, a few kV DC-voltage is applied on the ion-clearing electrodes in the routine operation of the ring. With the DC voltage applied, the beam lifetime has been improved by a factor of two at a high current. The lifetime at a low current has also been improved by changing the operating point of the ring (see Sec. II). Recently, we measured the fundamental parameters of the ring such as betatron and dispersion functions, chromaticity and RF-cavity parameters. Moreover, it was proved that SOR-RING is capable of increasing its energy up to 450 MeV or more. Some results of machine studies are presented in Sec. III.

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	1.23 (typical)
Vertical tune	1.19 (typical)
Momentum compaction	0.636
Natural emittance	~320 nm·rad
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	3.0×10^{-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.

II. Operational Status

The ring is usually operated from morning to night, sometimes the next morning, with the beam injection three times per day, and the weekly schedule is from Tuesday to Friday in accordance with the schedule of ES. The operation time in a fiscal year is continually increasing as shown in Fig. 2. Total operation time in the 1992 fiscal year was about 2100 hours including injection and machine study. The initial current of stored beam was around 200 mA and the beam lifetime about 200 minutes at 200 mA. Figure 3 (a) shows a typical example of 1992 daily-operation of the ring. Until then, the operating point was near a sum resonance (see Fig. 4) and it seemed that 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.

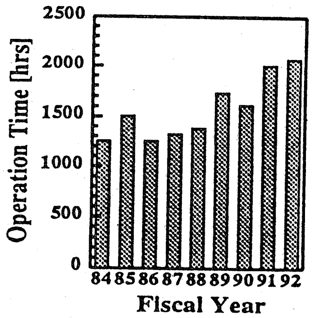

Fig. 2 Operation time versus fiscal year

Therefore, we changed the operating point to a new one, near the difference resonance of $\nu_x - \nu_y = 0$, as shown in Fig. 4. 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. 3

(b). Figure 5 shows an example of the lifetime when the operating point is the new one but no DC voltage is applied on the electrodes.

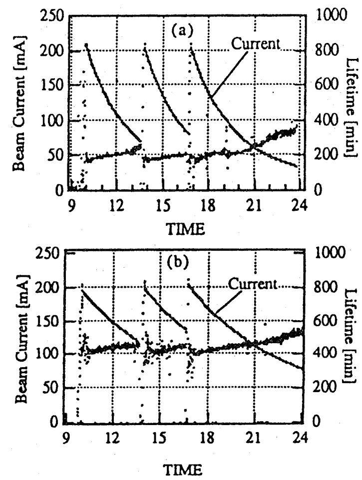

Fig. 3 Daily operation of SOR-RING (a) in 1992 and (b) from 1993 April

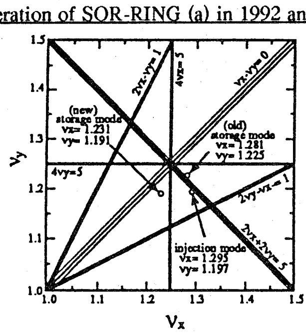

Fig. 4 Tune diagram

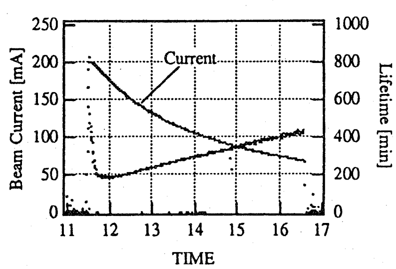

Fig. 5 Lifetime without DC voltage applied on the electrodes

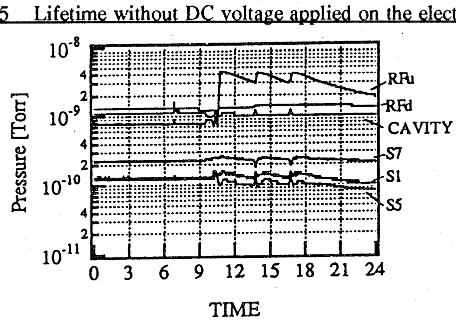

Fig. 6 Vacuum pressure in the ring

We have estimated the lifetime due to residual gas (coulomb scattering and bremsstrahlung) using the measured vacuum pressure around the ring (see Fig. 6). The estimated result is shown in Fig. 7. We have also estimated the lifetime due to trapped ions; this lifetime may be inversely proportional to the beam current, if the density ratio of trapped ions to stored electrons is kept constant. The calculation using measured lifetimes indicated that the density of trapped ions would be about 5 percent of the average density of electron beam. Here it was assumed that the electrodes with a few kV completely cleared otherwise trapped ions outside the beam orbit; in Fig. 3 (b) the lifetime does not apparently depend on the beam current, while in Fig. 5 it increases inversely proportional to the beam current. For the Touschek lifetime, the calculated value is much less than the measured one as seen in Fig. 7, where we assume that zero coupling horizontal emittance be the natural one, x-y coupling the full coupling, and the bunch length 16 cm, which is the measured one at 200 mA [6]. The discrepancy between calculation and measurement has not been settled yet; probably the actual beam size would be larger than the calculated one.

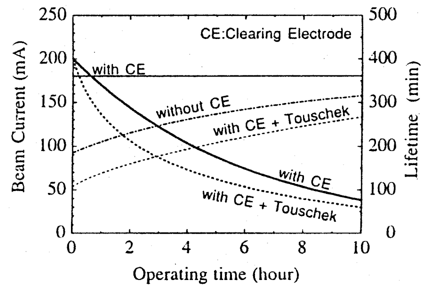

Fig. 7 Estimated lifetime (Touschek + gas-scattering)

There are accelerator problems in SOR-RING yet to be solved; (1) relatively high vacuum pressure around the RF-cavity probably due to outgassing from the elastic vacuum seals of the cavity, and pressure growth with the beam current, which might be caused by heating of two glass windows near the cavity due to synchrotron light (see Fig. 6), (2) 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, and (3) the biggest problem is that every ring component is aging rapidly. The first problem will be fixed in this summer shutdown by replacing the elastic seals with HELICOFLEX seals and also by replacing an existing light port with a new one; two glass windows of the port being used for profile and current monitors are directly irradiated by synchrotron light and at present the temperatures on the windows become more than 100 °C. The second will be cured, for example, by inserting damping antennas in the RF-cavity. Finally, the best solution for the third one is to construct a new ring, a high-brilliant light source.

III. Recent Machine Study

It was found with the BPM system that maximum values of uncorrected C.O.D.'s are horizontally about 3 mm and vertically 4 mm at 380 MeV, as shown in Fig. 8 (a). It was also found that the present RF frequency does not conform to the ring circumference since the average of horizontal C.O.D. along the ring is 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. To correct both horizontal and vertical C.O.D.'s, we excited the beam steerings. In addition, we changed RF frequency by about 100 kHz to correct the horizontal C.O.D. As a result, both horizontal and vertical C.O.D.'s were corrected within 0.3 mm as shown in Fig. 8 (b). The user run with the corrected C.O.D. is, however, postponed until the next autumn, since the SR beamlines have to be realigned to meet the new orbit.

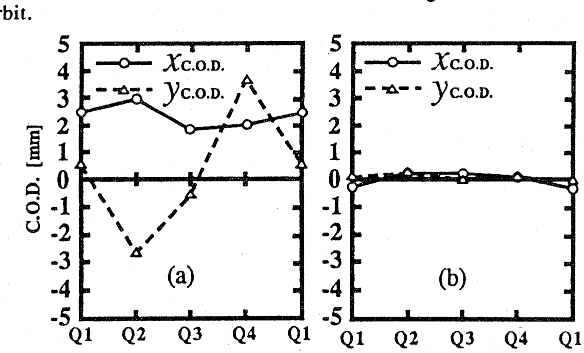

Fig. 8 (a) uncorrected C.O.D. and (b) corrected C.O.D.

Continuous measurement of the beam orbit revealed that (1) the orbit slowly varies by the order of several tens of μm during a storage mode, (2) before and after injection it also jumps by several tens of μm, and (3) horizontal orbit sometimes fluctuates in a period of a few ten minutes or have variations like square waves. A typical orbit drift is shown in Fig. 9.

We measured betatron function β at quadrupole magnets by exciting auxiliary coils wound around the magnet poles, and dispersion function η at BPM's. The measured fractional variation, Δβ/β, was within 20 percent, and the distortion of η within 0.2 m (see Ref. 5 for these figures).

We also measured chromaticity. The measurement showed that the chromaticities in both directions are positive and large in spite of a small ring, whereas their theoretical values are horizontally -2 and vertically 0.2 (also see Ref. 5 for these figures). This discrepancy has not been settled yet.

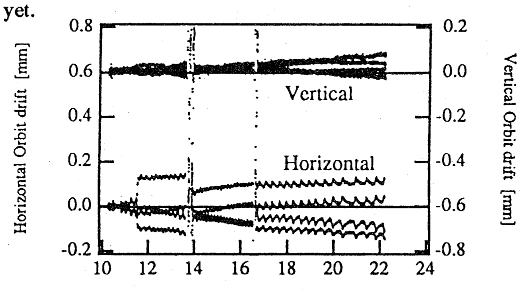

Fig. 9 Orbit drift

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, but 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

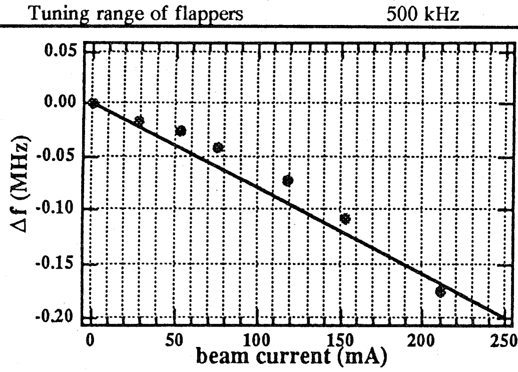

Fig. 10 Measured beam loading
The solid line is the theoretical calculation.

Using these data, we measured the beam loading of RF-cavity. Generally the 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. Figure 10 shows the measured result, which well agrees with the theoretical prediction.

In a recent machine study, one of the BPM's 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 and in turn into a FFT analyzer in order to find how the beam positions were fluctuating in a low frequency region. Figure 11 shows the Fourier-analyzed signals of vertical beam position. In the figure, (a) is the case where the synchrotron, ES, is operated with a repetition rate of 21.25 Hz, while (b) is the case where ES is turned off. Clearly, some of low-frequency fluctuations have their sources in ES. On the other hand, the frequency spectra around 10 Hz seen in both figures are probably generated from SOR-RING itself. Presently, however, we are not sure which sources cause the fluctuations; magnetic field, AC line noise or mechanical vibration of ES, and air-conditioner, cooling water system or the other systems of SOR-RING. With ES operational, the amplitudes of fluctuation were horizontally 2.6 μm and vertically 0.6 μm at 21 Hz.

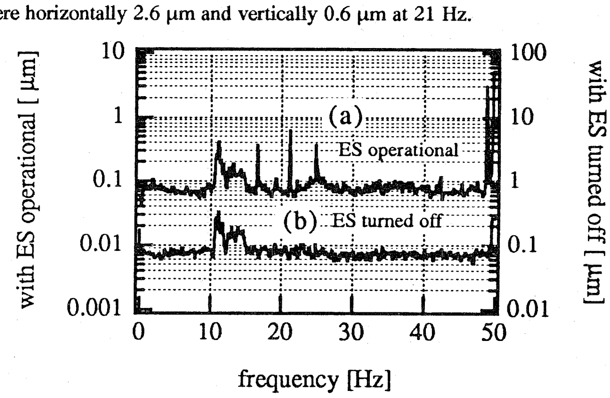

Fig. 11 Frequency spectra of vertical beam position

It was proved that SOR-RING has a capability of accelerating the beam up to 450 MeV or more with a 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. To accelerate a high-current beam as much as in the present user run, however, we have to replace the glass windows as described in Sec. II. After replacing them in this summer shutdown, we will try the 450-MeV operation for a high current.

VII. Acknowledgments

We would like to thank Prof. T. Ishii, Director of Synchrotron Radiation Laboratory of ISSP, and the other staff members for their continuous encouragement and full support.

VIII. References

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