PERFORMANCE OF THE 1 GeV ELECTRON STORAGE RING FOR THE SYNCHROTRON RADIATION SOURCE AT SORTEC

Y.Yamamoto, M.Takanaka, O.Asai, T.Iida and Y.Kijima
Nuclear Fusion Development Dept., Mitsubishi Electric Corporation,
Marunouchi 2-2-3, Chiyoda-ku, Tokyo 100, Japan

S.Nakamura*, M.Ohno** and N.Awaji
SORTEC Corporation, Wadai 16-1, Tsukuba 300-42, Japan

T.Tomimasu
Electrotechnical Laboratory, Umezono 1-1-4, Tsukuba 305, Japan

The 1 GeV electron, conventional storage ring with 8 FODO cells started first operation on September 27, 1989. With the beam cleaning of about 30 A·h the e-folding lifetime at the energy of 1 GeV reached 8 hours at 200 mA in December. The vacuum pressure is 3×10^{-11} Torr with beam off and 1×10^{-9} Torr with beam on. The low energy operation was done for the investigation of the beam behavior in April 1990. The beam current of 160 mA was stored at the energy of 180 MeV.

Introduction

The SORTEC synchrotron radiation facility [1] has provided soft X-rays (of the wave length around 1 nm) from bending sections for the study of application fields including X-ray lithography since February 1990.

The design of the whole accelerator system (a 40 MeV linac [2], a 1 GeV synchrotron [3], and a 1 GeV storage ring [4][5]) started in December 1987, the manufacture around July 1988, and the setting and installation in October. The first operation of the whole system started in July 1989, and the first beam was injected to the storage ring on September 27. The stored current reached 200 mA on October 23. On December 4-6 the vacuum chamber was opened to the atmosphere for the purpose of installation of the beam lines and an SR monitor system. On the end of December the lifetime became as long as before the exposure with the beam cleaning but without baking.

The lower the injection energy becomes, the more easily the beam instability occurs. The full energy injection and normal conducting magnets have been chosen because the synchrotron radiation facility can be constructed fast and surely with only established technologies. Figure 1 shows the layout of the ring. Table 1 shows the main parameters of the ring.

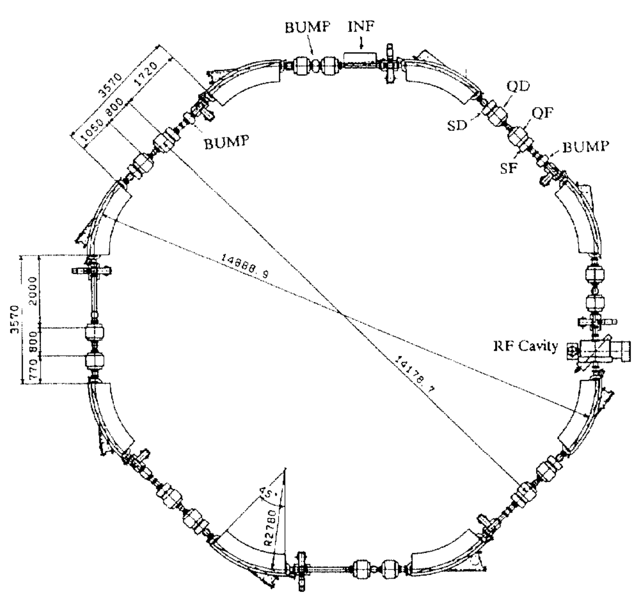

Fig. 1 Layout of the ring.

Table 1 Main parameters of the storage ring

Beam Energy (GeV)		1
Injection Energy (GeV)		1
Circumference (m)		45.73
Average Radius (m)		7.28
Bending Field (T)		1.2
Number of Bending Magnets		8
Number of Quadrupoles	QF	8
	QD	8
Number of Sextupoles	SF	4
	SD	4
Focusing Structure		FODO
Superperiodicity		4
Betatron Tunes	ν_x	2.235
	ν_y	2.215
Momentum Compaction Factor		0.17
Radiation Loss (keV/turn)		32
RF Frequency (MHz)		118
RF Voltage Vc (kV)		90
Harmonic Number		18
Natural Emittance (πm·rad)	ε_{x0}	5×10^{-7}
Maximum Beam Size		
σ_x(mm) for $\varepsilon_x/\varepsilon_{x0}$=0.1		2.0
σ_y(mm) for $\varepsilon_y/\varepsilon_{x0}$=0.4		0.7
Calculated Touschek Lifetime at 200 mA (hour)		40
Calculated Quantum Lifetime (hour)		140

General Description of the Ring

Eleven SR beam ports are installed at the bending sections, and one at the straight section which is reserved for an insertion device (wiggler as a candidate). The 4 ports have been already used for the study of lithography.

In the case of such a ring of large emittance as this ring, FODO lattice surpasses double achromatic lattice in the respect of large tie diagram, and small and smooth betatron function. The function makes the expected value of COD small, the acceptance large and the beam lifetime long. There were 3 candidates of operating points at the stage of the conceptual design. Table 2 shows the characteristics of each operating point. As a normal operating point (ν_x, ν_y)=(2.235, 2.215) was chosen, because the Touschek lifetime is longer, the strength of sextupoles smaller, and the emittance larger than at the other points. The ring does not have to be a ring of low emittance for our purpose. So, the normal operating point is the most suitable for the ring. Figure 2 shows the betatron and dispersion functions.

The ring has a septum magnet and three bump magnets. The three bump magnets can make a right bump orbit at each operating point in Table 2. The beam has been designed to be injected with the dispersion function of $\eta_x=\eta_x'=\eta_y=\eta_y'$ = 0 at the entrance of the septum

* Present Address: Mitsubishi Electric Corporation, Central Research Laboratory, 1-1 Tsukaguchi-Honmachi 8-chome, Amagasaki, Hyogo 661,Japan.
**Present Address: Oki Electric Industry Co.,Ltd., Semiconductor Research Laboratory, 550-5 Higashiasakawa-cho, Hachioji-shi, Tokyo 193, Japan.

magnet. The beam is small in the septum and can pass through it efficiently.

The reentrant-typed RF cavity was designed with SUPERFISH. Table 3 shows parameters of the RF cavity.

The ring has two types of vacuum sections [6]: the straight sections and the bending sections. Every straight section has a 300 l/sec Ti sublimation pump, a 1000 l/sec one, and a 400 l/sec sputter ion pump. Every bending section has a distributed ion pump along the beam orbit and a 1000 l/sec Ti sublimation pump. The latter is mounted on the antechamber which is located outside the bending magnet and is connected with the beam aperture. Most of photo-induced gas is immediately pumped out in the antechamber. This system can achieve easily the vacuum pressure of 1×10^{-9} Torr with beam on. Figure 3 shows the chamber of the bending section.

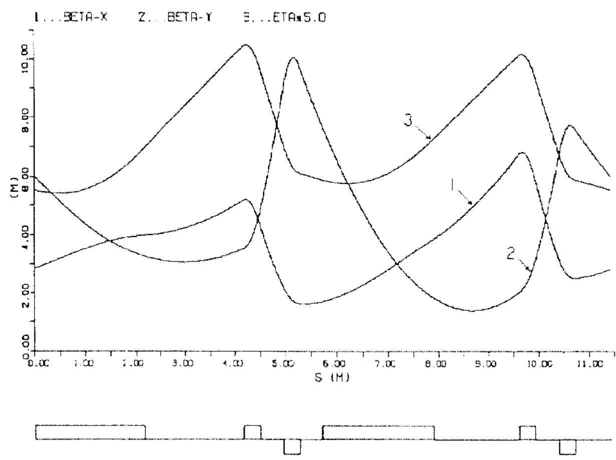

Fig. 2 Betatron and dispersion functions.

Table 2 Parameters of operating points in design

ν_x / ν_y		2.235 / 2.215	2.59 / 2.56	2.785 / 1.765
Emittance (πmm·mrad)		0.47	0.21	0.15
Expected C O D (mm)	H. / V.	5.4 / 2.1	4.6 / 2.0	6.9 / 3.1
Natural Chromaticity	H. / V.	-2.3 / -3.4	-2.9 / -4.3	-3.0 / -3.0
B'' l/(Bρ) of Sextupole (m^{-2})	SF / SD	1.0 / -1.7	1.3 / -2.5	1.4 / -2.3
Touschek Lifetime (hr)		40	30	20

Table 3 Parameters of RF cavity

Q	calculated	24400
	measured	20100
Shunt Impedance (MΩ)	(defined as $Rs=Vc^2/(2W)$, W = RF power)	
	calculated	2.00
	estimated from synchrotron frequency	1.35

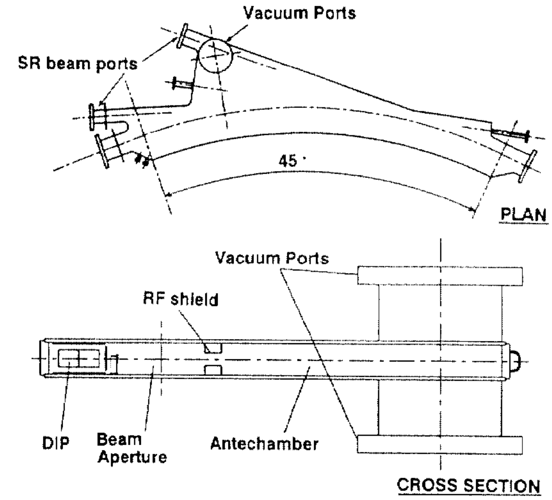

Fig. 3 Chamber of the bending section.

Performance at the Energy of 1 GeV

Beam Accumulation

On the first operation, horizontal instability appeared beyond the beam current 30～90 mA during injection. The instability was suppressed easily with the use of sextupoles. Figure 4 shows a beam accumulation. The injection was done with one shot per 3.2 seconds. An accumulated beam current per shot was about 3.5 mA, when the average beam current of the synchrotron was about 25 mA.

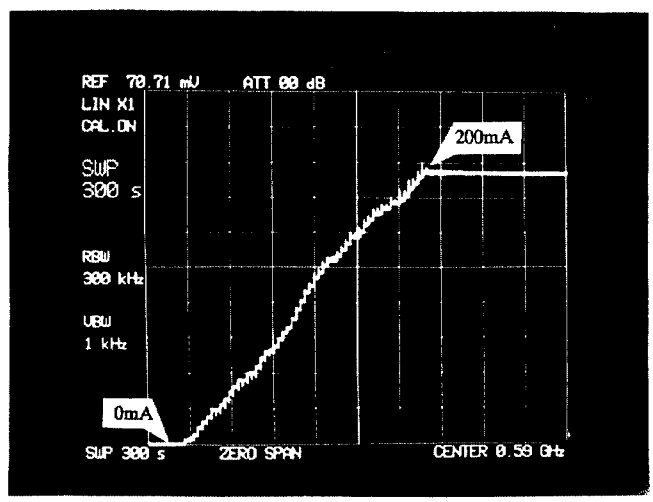

Fig. 4 Accumulation of the beam.

Since tuning the timing and the level of excitation of 3 bump magnets, the beam has been accumulated more stably up to 200 mA. The operating point around (2.235, 2.215) was surveyed to make the injection efficiency high. The present operating point is (2.20, 2.22) at which the lifetime is as long as at (2.235, 2.215). The accumulation up to 200 mA takes about 2 minutes with one shot per 3.2 seconds, and about 1 minute with one shot per 0.8 second.

Lifetime and Ion Clearing

Figure 5 shows the brief history of the beam lifetime. The ion clearing electrodes (ϕ53 mm disk typed) are located between the QF and the bending magnet in 7 of 8 straight sections. The e-folding lifetime at 200 mA had been 2.1, 2.7, 3.2, 3.3, 3.4, and 3.5 hours under the electrode's DC voltage of 0, -100, -200, -300, -400, and -800, respectively. The e-folding lifetime at 200 mA reached 8 hours in December 1989 with -400 volts on the 7 ion clearing electrodes.

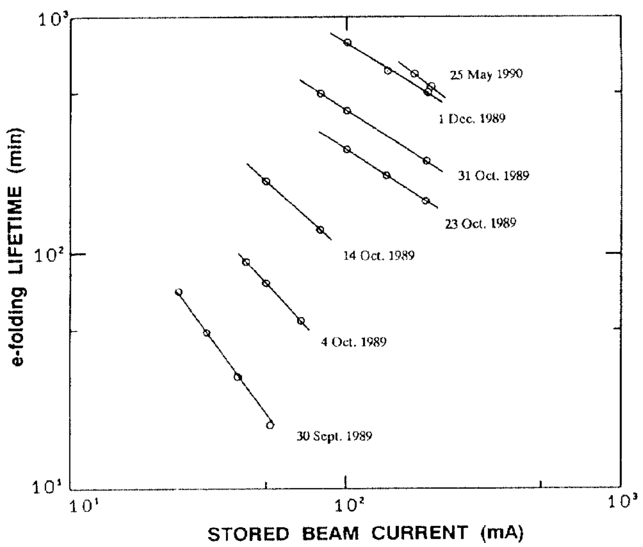

Fig. 5 History of the beam lifetime. The ion clearing has worked since Oct. 23.

Performance at the low energy

The machine study at low energies 100~400 MeV has been done for the investigation of ion trapping, bunch lengthening, and intrabeam scattering.

The injection and extraction devices did not work well at the low energies. Therefore, after the accumulation to 200 mA at the energy of 600 MeV or 1 GeV, the beam was decelerated to the energy at which the beam behavior was measured. The deceleration was realized by sending the reference values from the computer to the power supplies step by step, and by keeping the operating point constant. The deceleration took about 15 minutes.

Beam Current

Down to 180 MeV, the beam was stable and remained about 160 mA. Below the energy of 180 MeV, the beam current rapidly decreased during deceleration and became about 50 mA at the energy of 100 MeV.

Lifetime

Figure 6 shows the half lifetime. The Touschek lifetime was calculated with ZAP [7]. The RF voltage Vc was 50 kV at all energies. The measured lifetime below 400 MeV is in good agreement with the calculated one.

Beam Size

Figure 7 shows the beam size. The voltage on the ion clearing electrodes was -400 volts. The beam size was measured by the SR monitoring system consisting of two photo diode arrays (PCD linear image sensor - Hamamatsu Photonics) which have 512 photo elements each. The calculation of the beam size was done with ZAP in consideration of the broad band impedance of the vacuum chamber which was roughly estimated at $Z_L/n=10\ \Omega$. Below 300 MeV, the lower the energy becomes, the larger the calculated beam size σ_x becomes. This phenomenon is due to intrabeam scattering which is very small at the high energy. There is little difference among curves for 100, 150, and 200 mA. The measured beam sizes have the difference of 0.25-1.2 mm from the calculated ones. The lower the energy is, the larger the difference is.

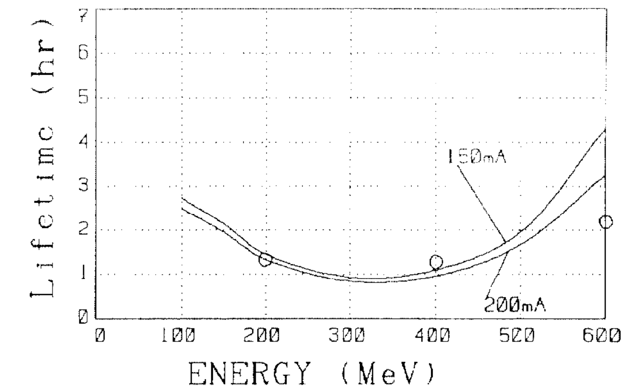

Fig. 6 Half lifetime at the low energy. Circles mean the measured lifetimes of 175 mA, and curves the calculated Touschek lifetime.

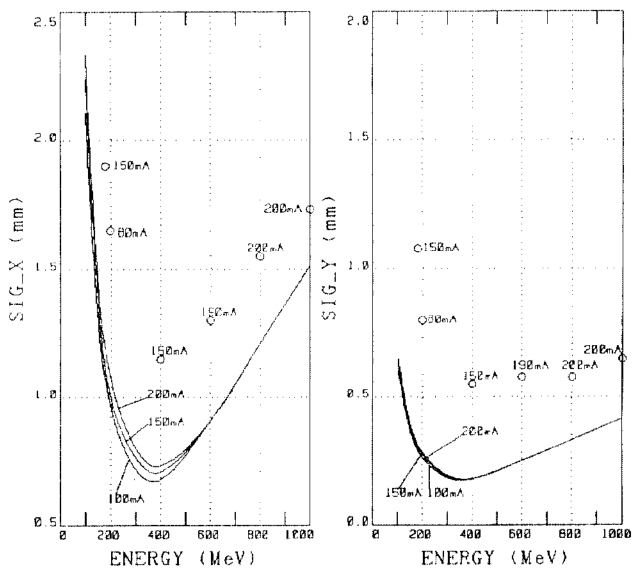

Fig.7 Beam size at the low energy. The circles mean the measured beam sizes, and curves the calculated ones.

References

[1] S.Nakamura, et al., this proceedings.

[2] M.Shiota, et al., "Design and Performance of the 40 MeV Linac and Beam Transport System for the 1 GeV Synchrotron Radiation Source at SORTEC," in Proc. of 7th Symp. on Acc. Sci. and Tech., 1989, pp. 10-12.

[3] M.Kodaira, et al., this proceedings.

[4] M.Takanaka, et al., "Construction and First Operation of the 1 GeV Electron Storage Ring for the Synchrotron Radiation Source at SORTEC," in Proc. of 7th Symp. on Acc. Sci. and Tech., 1989, pp. 16-19.

[5] M.Takanaka, et al., "First Operation of the 1 GeV Electron Storage Ring for the Synchrotron Radiation Source at SORTEC," in Proc. of the 2nd International Symp. on Advanced Nuclear Energy Research, 1990, pp. 298-301.

[6] M.Ohno, et al., this proceedings.

[7] M.S.Zisman, S.Chattopadhyay, and J.Bisognano, "ZAP User's Manual," LBL-21270, 1986.