IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

PRESENT STATUS OF SOR

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Summary

Recent progress and investigations of an electron storage ring, SOR, are presented. Stored current and beam life time increased considerably. Injection efficiency and the life time were studied critically. Especially the life time was found to depend on the pressure of the ring and effective momentum aperture related to betatron resonance as well as the Touschek effect.

Introduction

Recently a comprehensive machine study of SOR, a 400 MeV electron storage ring dedicated for synchrotron radiation experiments, has been made to investigate the present limitation of stored beam current and its life time as well as the other problems, and a considerable progress has been obtained by several improvements as shown in Fig.1. The ring is presently operated with the beam current 200~350 mA and the life time is 200~250 minutes. Although these values are not unsufficient for many radiation users, there still remain several problems to be solved as described later. In this paper we give the recent progress of the ring and the results of the investigation.

Improvements

As shown in Fig.1, a considerable progress has been obtained after the year 1980 in the stored beam current and the life time. This is maily caused by the following improvements.

1. addition of steering magnets in the beam transport line from injector electron synchrotron,
2. removal of iron bars near the quadrupole magnets of the ring, and of shield pipe just before the injection septum magnet,
3. attachment of shims to the bending magnets of the ring,
4. stabilization of the power supply of septum magnet for beam extraction from the injector, and of the pulse timing circuit for the power supply.

With these simple modifications, the injection rate of the beam current has increased to 3 mA per one pulse from 1 mA at the optimum performance. Furthermore the injection (at 308 MeV) and energy-up to 380 MeV have been made easy with respect to the current control of the bending and quadrupole magnets because of the widening of the good field region. In connection to this, an automatic control circuit of the magnet currents for the energy-up, constructed recently, was operated successfully without beam loss.

Injection efficiency

In the ordinary operation, the beam is stored up to 200~350 mA three times a day. It takes about 5~20 minutes to accumulate the beam current. Practically the injection rate is not so rate, but there still remains the room for a faster injection, since the beam current transported from the injector is about 50 mA per one pulse for a second while the beam captured in the storage ring is only 0.2~3 mA depending on the tuning condition of various magnets as well as the amount of the stored current.

The number of the electrons of the beam current in the transport line was measured just before the injection septum magnet and found to be 42 % of the circulating current in the injector synchrotron. Taking into account the rise time of the extraction kicker magnet, more than 90 % of the injector beam is transported to the point just before the septum magnet.

We have found that following three points are the main neck of the poor injection efficiency.

1. beam expansion in the transport line.
From design parameters of the transport line, the beam size at the injection point is expected to be $2\sigma_x \times 2\sigma_z$ = 11 x 3.0 mm^2. But the size observed with the X-ray film is about 25 ϕ mm.

2. narrow aperture of injection septum magnet,
The physical aperture of the septum magnet is a little smaller than 10 x 5 mm^2. Therefore about 80~90 % of the transported beam is lost here. Another problem of the septum magnet is the fluctuation (about 1 %) of the power supply which results in the miss of the optimum condition.

3. simple one kicker magnet system for the beam injection.
Empirically we have known that the injection rate is the fastest at the betatron oscillation tune ν_x = 1.22 and 1.29. In order to understand the reason, injection rate was measured as a function of exciting current of quadrupole magnets. The ring is composed of eight weak focusing bending magnets and four sets of triplet of FDF quadrupole magnets.

The experimental injection rate on the tune diagram is shown in Fig. 2. The good injection points locate on the lines of the tune ν_x = 1.22 and 1.29, which suggests that the clearance of the injected beam from the septum magnet is severely limited by the betatron oscillation trajectory. The injection system is composed of one septum magnet and one kicker magnet which locate on the opposite side of the ring each other. The kick angle of the kicker varies as KA = k $\exp(-t/\tau)\sin(\omega t)$. Stored beam is also perturbed by the kicker. The injection process of the beams injected and stored was simulated. Figure 3 shows the maximum excursion of the beam injected at the center of the septum magnet (solid line) and of the beam stored on the central line (broken line) as a function of the betatron oscillation tune with the parameter of the kick angle. To

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clear the septum (5 mm thick) the maximum excursion of the beams should be less than about 20 mm from the center line, since the beam widths are both about 10 mm. This condition is satisfied for the tune $\nu_x = 1.21$ with k = 12 mrad and for $\nu_x = 1.29$ with k = 18 mrad as seen in Fig.4. By the experiment with the kicker on or off in the injection process, it was found about one third or one fourth of the injected beam is captured with the kicker on. In the injection process the injected and stored beams are kicked inward and outward many times. Optimization of the decay curve of the exciting current of the kicker might increase the capture efficiency.

For the increase of the stored current, the repetition rate of the beam injection was tentatively increased from 1 Hz to 2$\sim$5 Hz, and the maximum beam current 510 mA was obtained shortly. Since the injection is so rapid, that the stored beam is disturbed much for the beam current about 500 mA and sometimes the stored current is suddenly lost.

Beam size and life time

The beam size of stored current was measured as a function of the beam current. The bunch length and horizontal width increase considerably above a threshold current as shown in Fig. 4. These expansions are induced by the longitudinal coupled bunch instability as explained elsewhere.[1] At the same time vertical width increases with the beam current, which seems due to the increase of the coupling coefficient between the horizontal and vertical betatron oscillations.

The expansion of the beam size brings about the lengthening of the beam life time. Figure 5 shows the life time measured and the Touschek life time calculated with the beam size observed. Because of the expansion the Touschek life time calculated is longer than the life time without the expansion and also than the life time observed. This is partly supported by the fact the real life time was lengthened by the expansion of the good field region as described previously.

Pressure dependence of beam life time

Figure 6 shows the pressure dependence of the beam life time. The pressure P_m, monitored at a straight section, was increased gradually by turning off one by one eight distributed ion pumps in the bending magnets and four ordinary ion pumps in the straight sections. The life time clearly decreased with the increase of the pressure, while the beam current decreased a little during this experiment. Since the Touschek life time should increase for the lower current, the beam life time is not determined by the Touschek effect but mainly by the pressure.

Assuming the beam life time is given by the relation $1/\tau_b = 1/\tau_P + 1/\tau_T$, where τ_P and τ_T are the life times determined by the pressure and the Touschek effect, τ_P was estimated as shown in Table 1.

Gas scattering theory gives the pressure dependent life time, τ_P (min) = $1.4 \times 10^{-6} / \langle P \rangle$ (Torr).[2] With this relation the average pressure $\langle P \rangle$ was estimated, which seems reasonably to fit to the relation $\langle P \rangle = 7.0\ P_m$, as indicated in Fig. 6.

Table 1. Beam life times and average pressure

I	τ_b	τ_T	τ_P	$\langle P \rangle$
mA	min	min	min	Torr
109	256	800	376	3.7×10^{-9}
85	150	880	181	7.7×10^{-9}

Momentum dependence of betatron tune

The betatron oscillation tunes ν_x and ν_z were measured as a function of momentum of the beam current or the RF frequency, using the relation $\Delta p / p = 1/\alpha_p \cdot \Delta\omega_{RF}/\omega_{RF}$, where α_p is the momentum compaction factor. Figure 7 shows the experimental results. The chromaticity is found to be $\xi_x = -12.2$ and $\xi_z = 11.4$, which is explained by linear variation of the field gradient of the bending magnets.

In this experiment we found that the beam is lost for the RF frequency $f_{RF} \geq$ 120.91 MHz and $f_{RF} \leq$ 120.51 MHz, as shown in Fig. 7. This is thought to be due to the third order resonance, which will set an effective momentum aperture ϵ_{max} instead of the RF bucket width $\epsilon_{max}/E = 2.82 \times 10^{-3}$. Taking the effective aperture at the places A, B and C indicated in Fig. 7, we find the quantum life time $\tau_{q\epsilon} = 1.2 \times 10^{-4}$, 6.9 and 7.9×10^{8} hours respectively. Since the estimated life time changes drastically depending on the effective aperture, chromaticity correction may lengthen the beam life time.

Investigations of the bunch lengthening and construction of Landau cavity are described elsewhere.

References

1. S.Asaoka etal, to be published in Nuclear Instru. and Methods.
2. M.Endo, SOR-RING Rept. No 3 (1973) Chap.7.

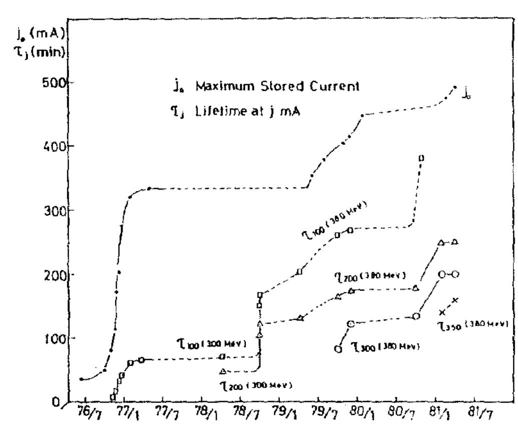

Fig.1 Progress of SOR in the maximum stored current and the life time. Abscissa denotes the year.

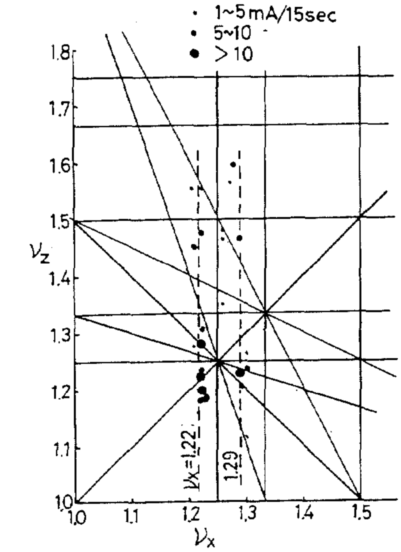

Fig.2 Injection rate on the tune diagram. Good injection points locate on the line ν_x = 1.22 and 1.29.

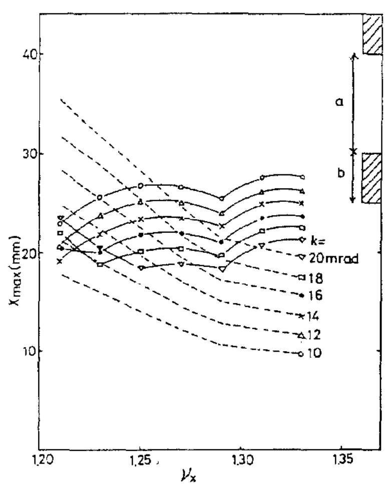

Fig.3 Maximum excursion of injected beam (solid lines) and stored beam (broken lines) in the simulation as a function of horizontal tune with the parameter of kick angle. The symbol a and b indicate the aperture and width of the septum magnet.

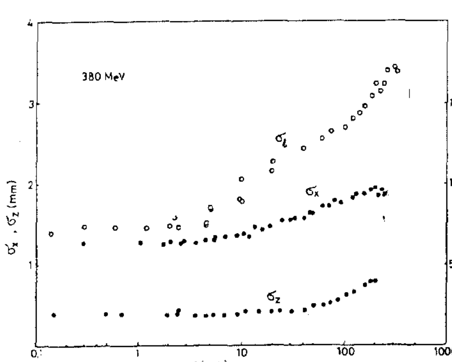

Fig.4 Current dependence of the beam size obserbed at 380 MeV.

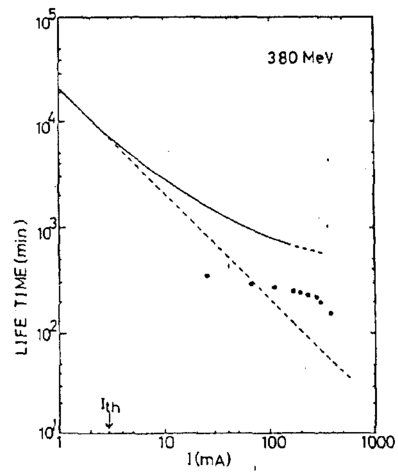

Fig.5 Current dependence of the beam life time obserbed (solid circles) and the Touschek life time calculated with the beam size obserbed or expanded (solid line) and the beam size without the expansion (broken line).

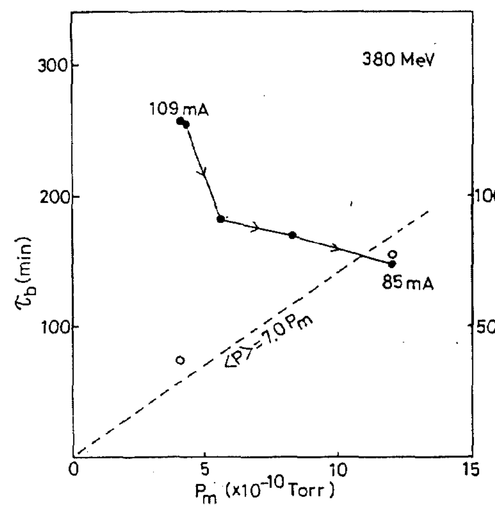

Fig.6 Life time of stored beam current as a function of the pressure of the ring monitored. < P > denotes the average pressure estimated.

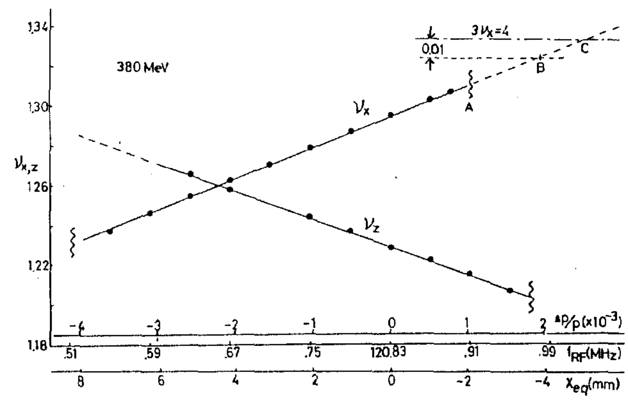

Fig. 7 The betatron oscillation tune as a function of RF frequency being converted to the shift of momentum and equilibrium orbit. Three waves in the figure indicate that the beam was lost there.