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BEAM PROPERTIES OF UVSOR STORAGE RING

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Abstract

UVSOR constructed at the IMS (Institute for Molecular Science) is an electron storage ring dedicated to synchrotron radiation research in molecular science and its related fields. The first beam was stored on 10th Nov. in 1983. From that time on, efforts have been devoted to improvement of the performance of the ring. During the accelerator studies, some inconvenient phenomena were found. One of the big problems is ion trapping effect. Trapped ions change the operating point and enhance the coupling between horizontal and vertical oscillations. As a result, the beam height is enlarged considerably at high beam current. The beam is shaken slightly in the vertical plane and the electrostatic clearing field is applied to solve this problem. The bunch length is somewhat longer than the expected value. This effect is also a problem to be solved.

Introduction

Since the success of the storage of electron beam, the beam properties were investigated and some inconvenient phenomena had to be solved. Experimental works using the synchrotron radiation from the UVSOR started in Oct. 1984. In commissioning the UVSOR, matters of primary concern were the maximum stored current and the lifetime of the beam. The maximum stored current is more than 200 mA, and the lifetime is about 2 hrs at the beam current of 100 mA. The lifetime is determined not only by the pressure of the vacuum system but also by the Touschek effect. Since the growth of the beam size reduces the brightness of the synchrotron radiation, the mechanism of the beam size growth must be investigated in detail. This effect is explained by the ion trapping and cured by the RF excitation of the betatron oscillation.

The bunch length was measured by some methods. The results of measurement show that the length is somewhat longer than the natural bunch length. The detailed investigation of the phenomenon was not done yet.

Detailed descriptions of the UVSOR storage ring will appear in this proceedings. Design parameters of the UVSOR storage ring is tabulated in Table 1, and the plane view of the UVSOR storage ring is shown in Fig.1.

Stored Current and Lifetime

Efforts have been devoted to increase of the stored current since the success of the first beam. The maximum current of 170 mA was achieved in December 1983. We have not tried to increase the beam current more than 200 mA, since the rated current of a beam current monitor was 200 mA.

The lifetime of the stored beam is important as it determines the number of times of injection in a day and the radiation level in the experimental area around the storage ring. We define the lifetime τ as follows;

$$\tau = \frac{I}{\Delta I/\Delta t} \qquad (1)$$

where I is the beam current, ΔI is decrease of the beam current in time interval Δt. If Δt is short and $\Delta I/I\Delta t$ is independnt of the beam current, then τ agrees with the time τ_0 while the beam current decreases to the 1/e of the initial beam current. As $\Delta I/I\Delta t$ increases with the beam current, the lifetime τ defined by eq.(1) is shorter than τ_0. The beam current was measured by a DC current transformer. The current was monitored every five minutes (i.e. Δt=5min.) by a micro-computer system and the lifetime was calculated by eq. (1).

The improvement of lifetime in one year (Dec. 1983~ Dec. 1984) is shown in Fig.2. Lines and dots in Fig.2 show the lifetimes at various beam currents. Suffix of each line shows date on which the lifetime was measured. The lifetime at the beam current of 10 mA was only several minutes in mid-December 1983.

The pressure of the vacuum system without stored beam was measured every day. The pressure averaged over the ring was 2×10^{-10} Torr in the end of December 1983, and 7×10^{-10} Torr in the end of December 1984. The change for worse is due to the beam lines which are linked to the storage ring directly. Baking and argon discharge cleaning of the vacuum system were made in

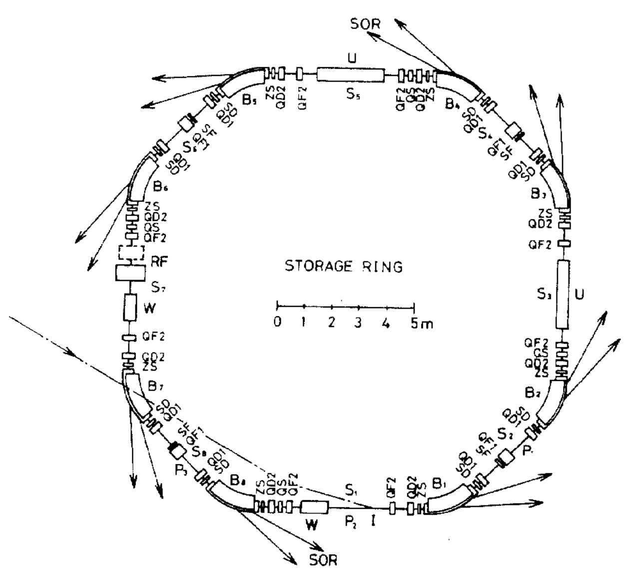

Fig.1 Plane View of UVSOR Storage Ring

Table 1 Parameters of UVSOR

	Designed	Achieved
Energy	600 MeV (max 750 MeV)	750 MeV
Critical Wavelength	56.9 Å	
Current	500 mA	> 200 mA
Lifetime	1 hr (500 mA)	2 hr (100 mA)
Mean Radius	8.47 m	
Bending Radius	2.2 m	
Tune (Q_H, Q_V)	(3.25, 2.75)	
Harmonic Number	16	
Radio Frequency	90.1 MHz	
Emittance		
ε_x	$8\pi\times10^{-8}$ m.rad*	$16\pi\times10^{-8}$ m.rad
ε_z	$8\pi\times10^{-9}$ m.rad	
Beam Size at Bending Section		
σ_x	0.32 mm*	0.45 mm
σ_z	0.23 mm	
Injection Rate	1~3 Hz	2.5 Hz

(* 10% coupling is assumed.)

the end of September 1984. Unfortunately, we were not able to monitor the pressure in the control room when the electron beam was stored in the ring. However, it seems that the pressure with stored beam was improved during the period of time not only by baking of the vacuum system but also by the daily operation of the ring. The lifetime of 25 min.at 100 mA just after the baking increased up to 100 min. in one month. An accident in the vacuum system of the beam line for the synchrotron radiation happened in the end of October 1984. The pressure of the vacuum system seems to have become several mTorr by the accident. Though the lifetime fell to 30 min. after the accident, it recovered in 2 weeks through routine operation of the ring without baking. At present, the lifetime at 100 mA is more than 2 hrs.

The lifetime predicted by the Touschek effect is about 130 min. at 100mA assuming the natural bunch length and size (10% horizontal and vertical coupling is assumed). As the actual bunch length is somewhat longer than the natural length, the lifetime must be improved moreover. However, the Touschek effect is not negligible at higher beam current, and the RF acceleration voltage must be increased.

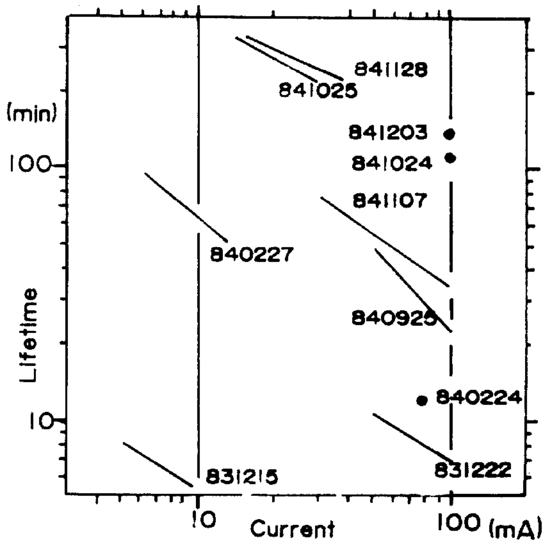

Fig.2 Lifetime of Beam

Survey of Tune Diagram

The lifetime and the profile of the stored beam were observed at various operating points. The horizontal and vertical tunes were determined by means of the RF knockout method on condition that the beam current was constant (10 mA). The profile of the beam was observed using a television camera and the beam size was estimated by the video signal from the camera. The intensity of the incident ray into the camera was controlled not to saturate the video signal by means of the light-reducing filters. These filters whose transmission factors were 1/2, 1/4 and 1/8 were mounted on a turret,and one of them could be selected remotely from the control room.

An example of surveyed operating line is shown in Fig.3, and all lines which were surveyed are summarized in the tune diagram Fig. 4. The regions where the lifetime is very short or the injection is difficult are shown by shade. Thin lines in the tune diagram are the sum resonance line ($Q_H+Q_V=6$), and third resonance lines ($Q_H=10/3$, $Q_V=8/3$). The beam properties were observed along marked lines in the diagram. Solid lines, dotted lines and wavy lines show operating lines where the lifetime is short, the beam properties are acceptable and the vertical beam size is large respectively. Crosses in the diagram are unstable operating points.

The characteristic features are summarized as follows;

1. There is no stable area except a few small areas above the sum resonance line $Q_H+Q_V=6$.
2. The lifetime is short along the third resonance lines $Q_H=10/3$ and $Q_V=8/3$.
3. The lifetime is long in the region below the sum resonance line except along the third resonance line $Q_V=8/3$, but the vertical beam size grows at the high beam current in almost all the region.
4. The only area where the lifetime is long and the beam size does not grow is situated around the operating point $(Q_H, Q_V)=(3.2, 2.6)$ which is shown by circle in the tune diagram.

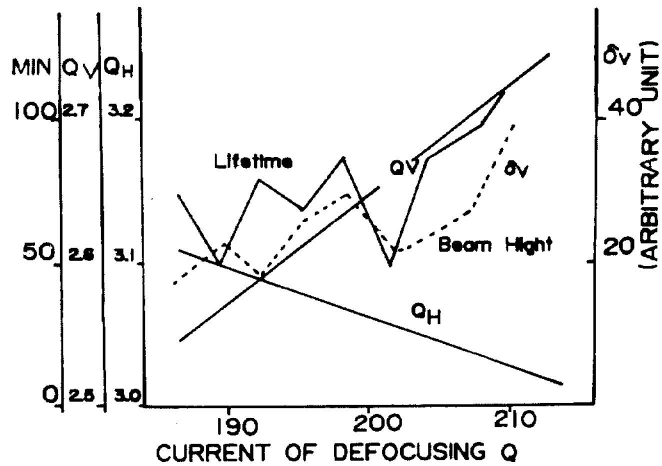

Fig.3 Example of Surveyed Operating Line

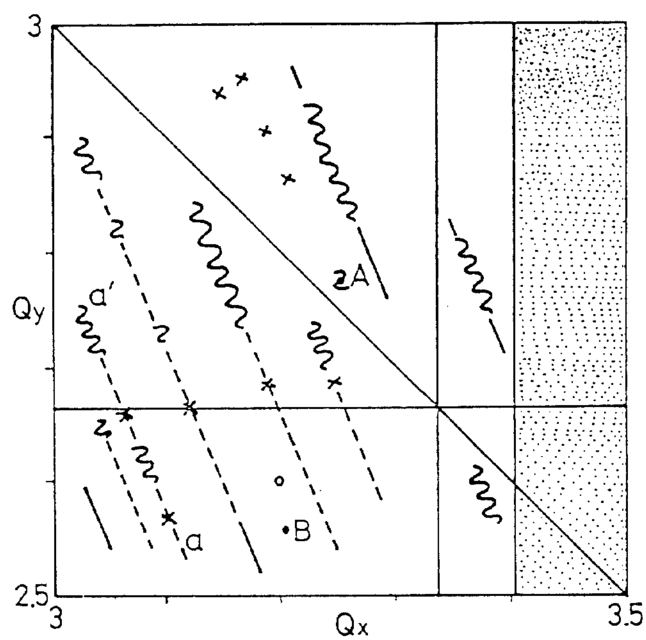

Fig.4 Beam Property Map

Ion Trapping

The severe problem of the stored beam was the enlargement of the vertical beam size. The enlargement is accompanied by the positive tune shifts in both of horizontal and vertical planes. The positive tune shifts in both planes suggest the focusing force acting on the electron beam due to positive ions.

The designed operating point of the UVSOR storage ring is $(Q_H, Q_V) = (3.25, 2.75)$. This operating point sits on a dangerous resonance line $Q_H + Q_V = 6$. The motion of the electron beam is unstable around the resonance line and the coupling between the horizontal and vertical oscillation becomes full on the border lines which separate the stable and unstable regions. Namely, the emittances of the horizontal and vertical planes are equal on the border lines. The coefficient of coupling becomes large when the operating point approaches the border lines around the resonance line.

If the operating point (Q_H, Q_V) is located below the resonance line, i.e. $Q_H + Q_V < 6$, then the operating point moves toward the line, the coefficient of coupling becomes large, and as a result, the vertical beam size grows. As the growth of the vertical beam size reduces the vertical component of the electric field induced by ions whose density distribution is assumed to be a copy of one of electrons, the tune shift is suppressed. Namely, if the operating point is located below the resonance line, the tune shift is suppressed by the negative feedback mechanism at the cost of the vertical beam size. In contrast with this, if the operating point is positioned above the resonance line, i.e. $Q_H + Q_V > 6$, the tune shift is energized by the positive feedback effect. The characteristic features 1 and 3 described in the previous section can be explained by the ion trapping effect.

The tune shifts δQ_H and δQ_V due to the ion trapping effect are given by[1]

$$\delta Q_{H,V} = \frac{e}{4\pi\varepsilon_0 cE} \langle\eta\rangle \langle f,g\rangle \frac{C}{\varepsilon_T} \tag{2}$$

where e the electronic charge, ε_0 the permittivity of free space, c the light velocity, E the electron energy, I the current, $\langle\eta\rangle$ the average neutralization factor, C the circumference of the ring, and ε_T is the emittance. f and g are functions of the beta functions β_H, β_V and the coefficient of coupling K (vertical emittance = K × horizontal emittance[2]);

$$f(K) = \frac{\sqrt{\beta_H}(1+K)}{\sqrt{\beta_H} + \sqrt{K\beta_V}}$$

$$g(K) = \frac{\sqrt{\beta_V}(1+K)}{\sqrt{K}(\sqrt{\beta_H} + \sqrt{K\beta_V})} \tag{3}$$

The symbol $\langle\ \rangle$ shows the average over the entire circumference of the ring.

The coefficient of coupling K and the neutralization factor are determined by the tune shifts due to the ion trapping effect. The ratio of the vertical tune shift to the horizontal one becomes $\langle g\rangle/\langle f\rangle$. When these tune shifts are measured, it is easy to estimate the coefficient of coupling K using an approximation $\langle g\rangle/\langle f\rangle \doteqdot \langle\sqrt{\beta_V/\beta_H}\rangle/\sqrt{K}$. The results are tabulated in Table 2.

The coefficient is more than 10% (assummed coefficient) when the operating point is close to the resonance line. The average neutralization $\langle\eta\rangle$ can be estimated by eqs.(2) when the emittance ε_T is known. The first equation of eqs. (2) is appropriate to estimated the $\langle\eta\rangle$, because the dependence of $\langle f\rangle$ on K is small and the $\langle f\rangle$ is close to unity. The emittance of $16\pi \times 10^{-8}$ m.rad was obtained from the beta functions and the beam size. The neutralization $\langle\eta\rangle$ of 1.2×10^{-2} was obtained substituting $16\pi \times 10^{-8}$ m.rad for ε_T and 0.056 1/A (measured tune shift) for $\delta Q_H/I$ into eq.(2).

Some tests to clear the ions were tried. The DC clearing voltage was applied on electrodes. Though the vertical beam size was reduced slightly, the improvement was not satisfactory. The excitation of the transverse oscillation was also tried. The vertical betatron oscillation of the electron beam was excited by means of the RF knockout system which had been installed to measure the tune. When the frequency and the amplitude of the excitation were appropriate, the beam size was improved almost perfectly. The improvement of the beam profile is shown in Fig. 5. (a) and (b) are the pictures of the beam profile without and with the ion clearing by the RF excitation respectively. The RF excitation method is powerful for the ion clearing and it is indispensable to the routine operation of our ring.

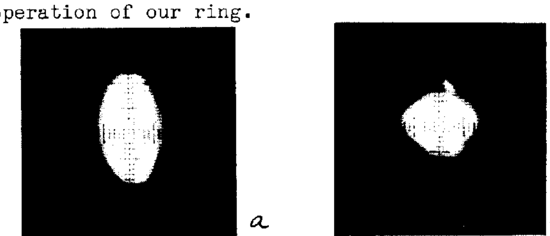

Fig.5 Beam Profile without (a)/ with (b) Ion Clearing

Table 2 Coefficient of Coupling

Operating Point	$\delta Q_V/\delta Q_H$	K
A(3.25, 2.77)	2.3	0.23
B(3.20, 2.56)	26	0.001

References

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2 M. Sands, " The Physics of Electron Storage Rings - An Introduction," SLAC Rep. SLAC - 1211, November 1970.