High Current Beam Storage Experiments in SORTEC SR Source

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Abstract

Beam behavior under high beam current has been investigated at low energy on SORTEC SR ring. Horizontal head-tail effect is stabilized with a positive chromaticity. A longitudinal coupled bunch signal related to the higher modes of the accelerating cavity is observed. Applying a high accelerating voltage, beam storage of 1150mA has been confirmed and the beam lifetime was investigated.

1.Introduction

SORTEC SR ring is the dedicated machine for the SR source operating successfully since 1989. Recently, as the feasibility study of an upgrade of the ring to 500mA at 1GeV[1], machine studies have been done at low beam energy, mainly at 600MeV, where a high beam current is attainable with the existing RF system. Various collective effects are clearly seen at low energy due to the low rigidity of the beam and the results are compared to our nominal 1 GeV data. Our operation parameters are summarized in Table 1.

2.Beam Behavior at High Current

2.1 Horizontal Head-Tail Effect

During injection, a horizontal beam oscillation is appeared. Since the natural chromaticity of the ring is negative, the effect is considered as the head-tail oscillation. The oscillation stopped by increasing the chromaticity ξ (defined as $\Delta\nu/(\Delta p/p)$) by the sextupole magnet. The necessary chromaticity on beam current is shown in Fig.1 for 600MeV and 1GeV.

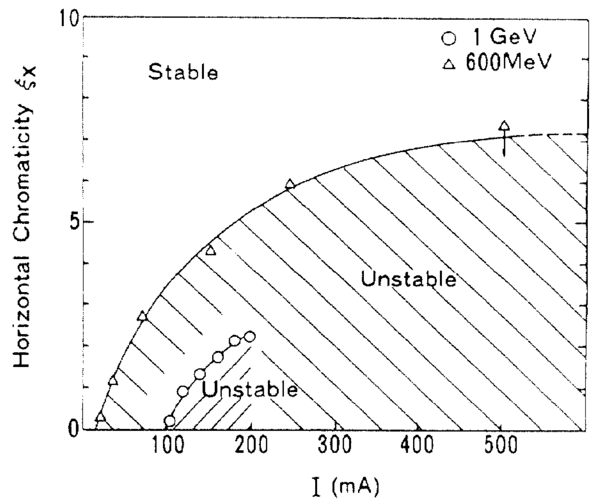

Fig.1 Necessary chromaticity for the suppression of the head tail effect.

Table 1 . Summary of the operation parameters.

Operation mode		"Flat"	"Round"	"Flat"	"Round"
E(GeV)	beam energy	1		0.6	
I(mA)	beam current	200		1000	
τ(h)	beam lifetime	20	60	0.5	3
f inj (Hz)	injection cycle	0.31		0.62	
ν_H/ν_V	betatron tune	2.20/2.23	2.143/2.149	2.142/2.20	2.191/2.182
β_H/β_V(m)	avg. beta function	4.36/6.55	4.41/5.93	4.23/6.47	4.27/5.75
κ	coupling of beta func.	0.1	1	0.1	1
$\varepsilon_H/\varepsilon_V$($\mu$m rad)	emittance	0.622/0.062	0.35/0.35	0.193/0.019	0.11/0.11
ξ_{H0}/ξ_{V0}	natural chromaticity	-2.99/-0.20		-2.10/-1.61	
ξ_H/ξ_V	chromaticity	2.26/-1.63		10.75/6.84	
α	momentum compaction	0.185	0.184	0.172	0.174
$\Delta p/p(\times10^{-3})$	momentum spread	0.462		0.278	
L(m)	ring circumference	45.73			
fRF(MHz)	RF frequency	118			
frev(MHz)	revolution frequency	6.5556			
h/B	harmonics/bunch no.	18/18			
Rsh(Mohm)	shunt impedance	1.35			
β(0)	coupling factor	1.77			
U0(keV)	radiation loss	31.83		4.126	
Vc(kV)	cavity gap voltage	100		83	
fs(kHz)	synchrotron frequency	46.3	46.1	54.3	54.1
P(kW)	RF power(Max 14kW)	12		12	

2.2 Tune Shift Measurements

A high chromaticity and a high beam current can modulate the betatron tune of the beam. The tune shift on beam current was measured at 600MeV and the results are shown in Fig.2. In addition to the main peak (m=0), peaks from the transverse dipole mode (m=±1) excited by the high chromaticity appeared from the low current. An effective transverse ring impedance can be extracted from these data[2] and the results are as follows.

$$Z_T^{eff} = 0.35 \text{ (Mohm/m)}$$

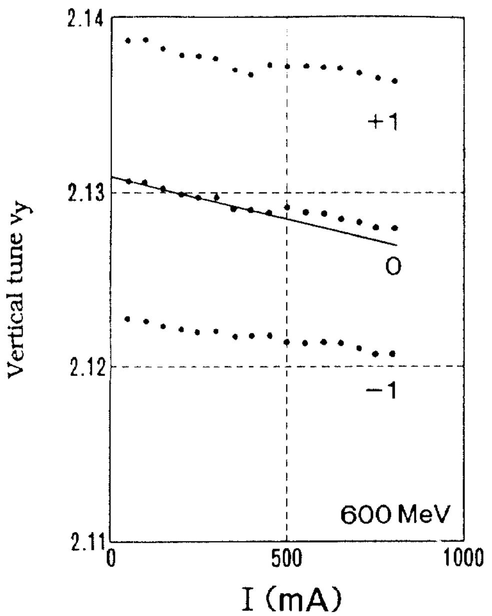

Fig.2 Tune shift on beam current at 600MeV.

Fortunately, the tune shift is small compared to the synchrotron tune and the mode coupling instability reported from several rings[2][3] was not seen. On the other hand, cares are paid on the operation tune to avoid the synchro-betatron resonances at

$\nu x - \nu y = \pm n\nu s$ (n=1,2), νs: synchrotron tune

where an injection efficiency drops.

2.3 Longitudinal Coupled Bunch Oscillation

Side bands due to the bunch oscillation are seen in the frequency spectra of the pick up signal as shown in Fig.3 for 1GeV and 600MeV. Observed threshold currents (I_{th}) for the side bands was 120mA for 1GeV and 4mA for 600MeV. Since their frequency can be decomposed as

$$f = nf_{RF} \pm (8f_{rev}+f_s) \quad \text{(n: integer)}$$

these peaks are related to the longitudinal coupled bunch oscillation with its mode number 8. Actually the measured resonant frequencies of RF cavity at high frequency region, shown in Fig.4, has a strong peak at 1245.5MHz that coincide to the observed side band.

According to ref.4, the threshold current of the effect scales to the beam energy with the power of 6, above values are reasonable.

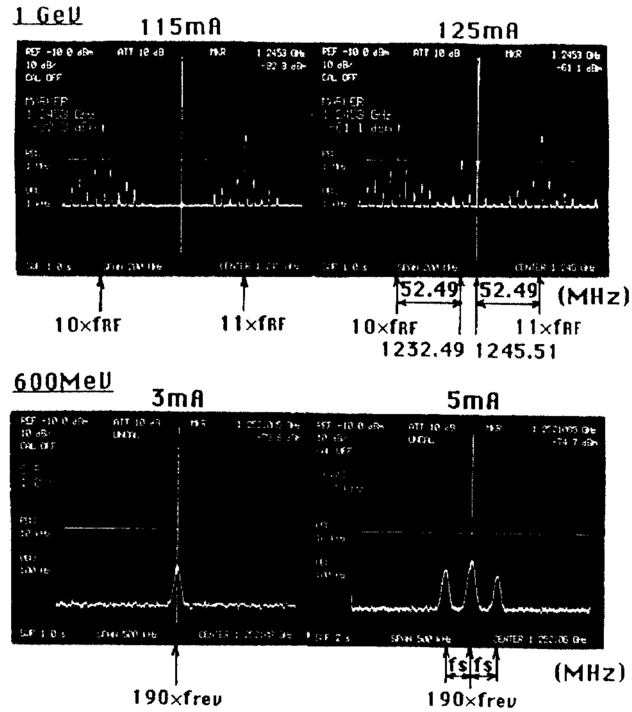

Fig.3 Frequency spectra below and above the threshold currents.

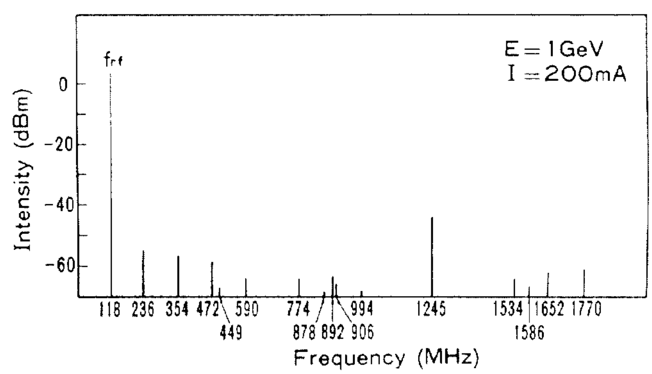

Fig.4 A measured resonant frequency spectrum of RF cavity.

To investigate the longitudinal behavior, we measured the bunch length of the beam[5]. A system consisting of a fast photo diode sensor and a sampling oscilloscope has been applied to measure the bunch length. Figure 5 shows the results for 600MeV and 1GeV. A kink can be seen on the figure at the same position as I_{th} for the 1GeV data while no clear kink can be seen for the 600MeV data. The fitted power, 0.22, on beam of the bunch length above I_{th} at 1GeV agree well to the theoretical value 1/5 in the ref.4 while the value 0.05 for 600MeV disagrees to it. Since the measured region is much higher than the threshold current for latter case, the measurement seems affected by the longitudinal oscillation of the bunch. The longitudinal ring impedance extracted from the I_{th} obtained for the 1GeV data gives the following value.

$$|Z_{//}/n| = 5.23 \text{(ohm)}$$

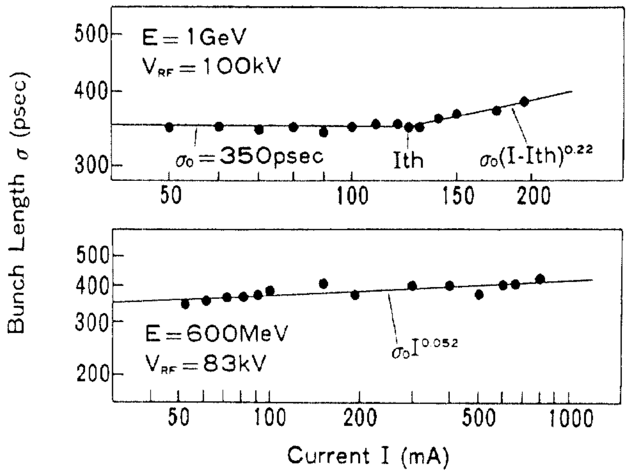

Fig.5 Bunch length versus beam current.

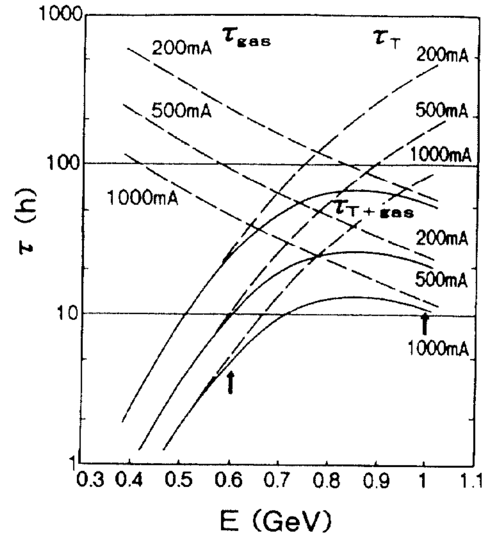

Fig.7 Calculated beam lifetime based on Touschek and beam-gas lifetime.

3.Beam Performance under High Current

A typical operation pattern of high current beam storage experiment at 600MeV is shown in Fig.6. A higher chromaticity around 10 and an accelerating voltage 83kV that is higher than the value requested by the RF phase stability under high beam load[6] are applied to reduce the drop of the injection efficiency above 700mA. The phenomena seem the combined effects of the longitudinal coupled bunch, shortening of beam lifetime or the effect due to the trapped ion. The confirmed maximum beam current 1150mA was simply limited by the RF power. The applied ion clearing voltage to cancel the beam potential was -2kV. The beam is stable during the storage mode. In the figure, the usual "flat beam" mode is applied during injection while the "round beam" mode whose operating point is close to the difference resonance $\nu x-\nu y \cong 0$ [7] is applied for the storage. The beam lifetime at 1000mA is 3h for "round beam" and 30min for "flat beam" that is much short compared to 60h at 1GeV, 200mA.

Figure 7 shows the lifetime calculated for the "round beam" based on the Touschek lifetime and beam-gas lifetime for different beam energy and current. As seen from the figure, at 600MeV, the beam lifetime is mainly determined by the Touschek lifetime. Calculated lifetime 5h is not far from the measured 3h.

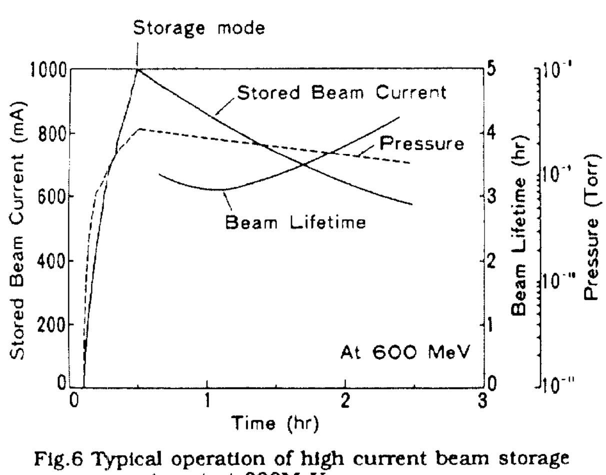

Fig.6 Typical operation of high current beam storage experiment at 600MeV.

4.Conclusions

Several collective effects are seen at the low beam energy and compared to the theory. We confirmed the stable beam storage over 1000mA at 600MeV with the properly chosen parameters in spite of these collective effects. Since the instability threshold increases at 1GeV and the beam lifetime extends as it is free from the limiting Touschek term, our upgrade to 500mA at 1GeV with the beam lifetime around 20h turned out feasible. If the heat problems are properly treated, beam storage over 1000mA at the beam energy around 1GeV seems possible on this type of the ring.

5.Acknowledgement

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6.References

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