COLLECTIVE EFFECTS IN SSRF

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Abstract

SSRF is a third generation light source optimized to provide high brightness and high flux X-ray photon beams in energy from 0.1 to 40 keV. Using numerical calculations of impedance and results from KEK, an impedance model for SSRF is calculated. Beam quality and instability thresholds for these results are presented. The estimated beam lifetime for 300mA is 30 hours.

1 INTRODUCTION

SSRF is a third generation light source with its electron storage ring current of 300mA[1], and its beam lifetime larger than 20 hours. This paper presents the design considerations concerning impedance, instability thresholds, and lifetime.

2 IMPEDANCE BUDGET

In SSRF, the dominant contributors to the impedance of the storage ring come from the RF cavities and the resistive wall of the vacuum chamber. The structure like bellows shields, rf seals, BPMs, and tapered transitions add inductive impedance further.

2.1 RF Cavities

The RF cavities are the main sources of narrow band impedance in SSRF storage ring. To insure good beam stability, the RF cavities are optimized using URMEL code (see table 1 and 2). If needed appropriate tuning of the RF cavities and feedback systems will be considered. Based on the excellent performance of the RF cavities at PEP II [2], SSRF will opt for cavities of this style.

Table 1: Longitudinal HOMs

f (MHz)	R/Q (Ω)	Q
773.52	46.12	39800
1080.49	0.20	43700
1243.22	24.29	37700
1312.37	8.37	75000
1612.80	12.55	42000
1796.36	5.06	70700
1821.80	0.498	55000
1865.81	1.67	46700
2164.85	1.29	74000

Table 2: Transverse HOMs

f (MHz)	R/Q (Ω at r=3 cm)	Q
697.5	0.18	47900
828.2	4.68	60900
1066.1	7.98	48900
1194.7	0.15	56700
1438.4	4.17	65200
1516.2	6.54	47300
1529.8	0.20	71600
1615.9	0.12	71020
1788.7	0.19	86200
1848.6	17.52	51600
2012.5	2.48	80400
2078.6	2.26	57000

2.2 Coupled Bunch Instabilities

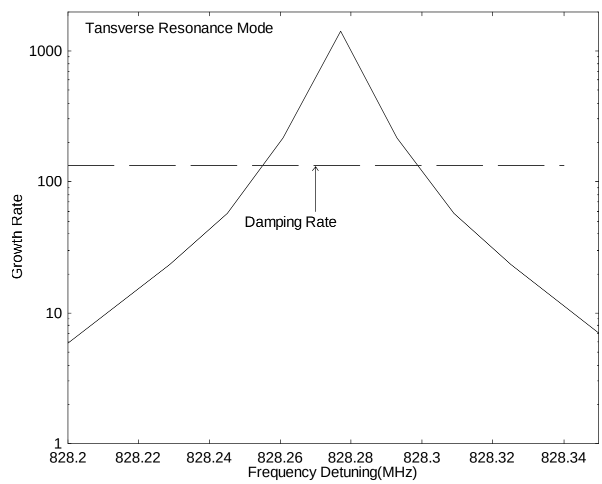

Figure 1: Growth rate due to the HOM with frequency 828.20 MHz

The coupled bunch instabilities are long-range wake field effects, which can be excited by high Q structures such as RF cavities. With the RF HOMs parameters listed above, the CB instability thresholds are calculated in the uniform filling using ZAP program. Both the growth rates in the longitudinal and transverse planes are quite large. It is impossible to run our ring with such RF cavities. In order to improve the RF cavities, the growth rates for each dangerous HOM are then calculated one by one. The growth rate due to HOM with frequency 828.20, as an example, is shown in figure 1. If this HOM were on resonance, the growth time is much faster than the damping time, and the beam then would be lost. To run the SSRF ring safely, the requirements of impedance and Q factor for each dangerous HOM are then given. The results show that the RF group will improve SSRF cavities as good as PEP II.

With the cavities best as PEP II, even the strongest HOM impedances will be far too small to cause longitudinal and transverse instabilities at 300 mA. Therefore, no fast feedback systems should be necessary for stabilizing any coupled bunch instability.

Table 3: SSRF storage ring parameters

Parameter	Value
E (GeV)	3.5
ε_N (nm.rad)	11.8
C_0 (m)	396. 0
ρ (m)	10.57
U_0 (keV)	1256
V_{RF} (MV)	4.0
f_{RF} (MHz)	499.654
H	660
α	6.9×10^{-3}
σ_E	9.23×10^{-4}
f_S (kHz)	780.7
σ_Z (cm)	0.46
$\tau_x/\tau_y/\tau_z$ (ms)	7.35/7.36/3.68
a/b (mm)	35/20
g (mm)	4.0
$<\beta_x>$	8.3 m
$<\beta_y>$	12.0 m
β_y (m) at ID	3.5
P	1.0 nTorr

2.3 Resistive Wall impedance

The resistive wall impedance is strongest at low frequencies. Calculations show that the resistive wall effect of the Aluminum vacuum chamber on transverse coupled bunch instabilities is small at present, since the estimated growth time is 77 ms, much longer than the damping time 7.4 ms. Therefore no transverse feedback is needed. However, If the narrow-gap insertion devices would be installed, the computed growth time shorten to 3 ms, less than the damping time 7.4 ms, then a transverse feedback system should be needed to damp the resistive wall induced instability.

2.4 Broadband Impedance

The broadband impedance of small discontinuities around the ring is calculated using analytical formulae. The results are shown in table 4. The total impeance is 0.9Ω. However, many small elements and transitions are not accounted for in the estimate given above. So a more realistic and conservative value of 1.8Ω will be used to construct the broad impedance model. Using this impedance model, the ZAP code gives a single bunch current threshold of 2.5 mA beyond which the energy spread starts widening.

Table 4: The broadband impedance of main contributors

Element(N)	Total inductive impedance Im Z(ω)/n[Ω]	Total loss factor k[V/pC]	Power (kW) (300mA in 150 bunches)
BPM(150)	0.18	0.75	0.6
Bellow(130)	0.09	1.4	1.1
Anti-chamber(40)	0.013	-	-
RF cavity(8)	0.6	5.4	4.0
Resistivity wall	0.0004 (at 2.1GHz)	0.4	0.31
Flange(132)	0.00053	-	-
Transverse feedback kicker(2)	-	1.32	1.0
sum	0.88	9.3	7.0

2.5 Ion Trapping

The electron beam circulating in the storage ring ionizes the molecules of any residual gas, leading to an accumulation of ions under certain conditions. Accumulation of ions can adversely affect the performance of an electron storage ring. The stability of the ion motion under the influence of the passing bunches occurs in a particular storage ring design.

Since the ions move with thermal velocity, the magnetic force is negligible and only the electric forces need to be considered. For small ion displacements from the beam center, this space charge force can be approximated by a focusing parameter. For the linear approximation, the principles of linear stability can be applied. The motion is stable, if $-2<\mathrm{Tr}(M)<2$, where M is the total transfer matrix to the ions. If the bunches are equally spaced, the critical ion mass, $A_{C,}$ can be obtained analytically. With ion mass less than $A_{C,}$ all ion are unstable, no ions will be trapped. With 640 bunches, full filling mode, the critical masses related the total beam current is written as

$$A_C = 2.88\times10^{-5} I_t[mA]$$

For the expected beam current of 300mA, all ion masses in the relevant mass range are trapped in the multi-bunch filling. So some gap is necessary to be introduced in the multi-bunch filling. In such case, numerical simulation results are shown in figure 2. Since 150 bunches will be injected into the ring for each injection, so the filling mode can be 150, 2×300, 3×150, 4×150 bunches. The simulations show that (1) the critical ion masses will be much higher in the continuous filling than in the equally spaced filling; (2) we may not operate the machine with 4×150 bunches filling at total beam current of 300mA for the sake of ion trapping.

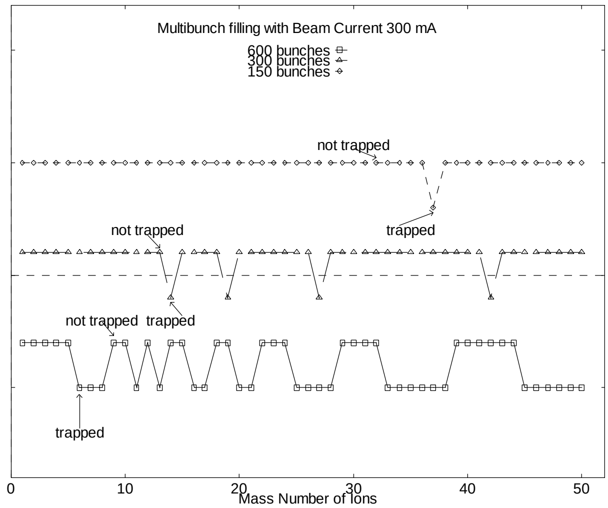

Figure 2: Ion stability for continuous multi-bunch filling with total beam current 300mA (a) 600 bunches, (b) 450 bunches, (c) 300 bunches, and (d) 150 bunches.

3 BEAM LIFETIME

3.1 Gas Scattering Lifetime

Electrons can be lost to elastic (Coulomb) or inelastic (Bremsstrahlung) collisions with the residual gas atoms. The loss rate depends on the local beta functions, the local gas pressure and the storage ring acceptance. For SSRF, the coulomb and bremsstrahlung lifetimes are estimated to be 244 and 57 hours, respectively, at 300 mA. Taken in parallel, the total gas scattering lifetime is 46 hours at 300 mA, assuming a partial pressure in N_2 of 1 nTorr and energy acceptance of 2.5%.

3.2 Touschek Lifetime

The energy acceptance, which sets the Touschek lifetime, is the minimum between the RF bucket size and the momentum dependent dynamic aperture. For a gap voltage of 4 MV, the bucket size is 2.7%. The lattice has been optimised to provide a momentum dependent dynamic aperture of 3%. The energy accptance will be RF bucket limited at 4 MV. For 300 mA beam current distributed in 300 bunches, the emittance coupling of 1%, the Touschek lifetime was estimated to be 87 hours.

3.3 Total electron beam lifetime

Lifetime calculations predict that the total lifetime is 30 hours at 300mA. After 24 hours, the initial 300 mA will decay to about 150 mA.

4 CONCLUSIONS

The SSRF storage ring to run with an emittance of 12 nm.rad and beam current of 300 mA is presently under investigation. With the RF cavities best as PEP II, the SSRF will be stable in both planes without the need for any fast feedback systems. However, If we push the insertion device full gap to small as 8 mm, then a transverse feedback system should be necessary to combat the resistive wall instability. The beam lifetime is expected to be 30 hours at 300 mA.

REFERENCES

[1] S.Y. Chen, H.J. Xu and Z.T. Zhao, ‘Shanghai Synchrotron Facility’, in PAC99, New York, 1999

[2] R.A. Rimmer et al., ‘Updated impedance estimate of PEP II RF cavity ,’ in proc. Of 1997 ICFA Conference, (Frascati), 1997.