COLLECTIVE EFFECTS IN SPEAR 3*

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Abstract

SSRL is investigating an upgrade to run SPEAR with a small emittance (18 nm) and with a $200 - 500$ mA current, significantly greater than the present 100 mA value of SPEAR 2. Using experimental measurements, numerical calculations of impedance, and results from tracking code simulations, an impedance model for SPEAR 3 is calculated. Beam quality and instability thresholds for these results are predicted. Based on these calculations, choices made for RF cavities, vacuum chamber material and cross-section, and BPM design are also discussed. The estimated beam lifetime for 500 mA is 22 hours.

1 INTRODUCTION

SSRL is investigating an upgrade project for its SPEAR electron storage ring that will increase current from the present 100 mA, initially to 200 mA, and ultimately to 500 mA [1]. The emittance of the machine, dedicated to synchrotron radiation production, will be reduced from 160 nm to 18 nm. This proposal calls for the reuse of existing beamlines, and facilities, but SPEAR 3 will have new lattice, magnets, vacuum chambers, power supplies, and RF system.

This paper presents the design considerations concerning impedance, instability thresholds, and lifetime. Specifications for the vacuum chamber material, cross-section, vacuum chamber profile, RF cavities, and feedback systems were based, in part, on this study.

2 IMPEDANCE BUDGET

2.1 RF Cavities

SPEAR 3 will need ~1.2 MW of RF power for 500 mA operation. The power capability of the existing RF system is limited by the 500 kW rating of the two cavities. The original scope of the project called for the reuse of these cavities in the initial stage of SPEAR 3, then upgrading the RF system for 500 mA. A study of the existing RF cavities was performed, showing that they could be tuned to operate stably at currents exceeding 200 mA with the SPEAR 3 parameters [2]. Cost considerations showed that it was more efficient to go immediately to the final RF system. Based on the excellent performance of the RF cavities at PEP II [3], SPEAR 3 has decided to opt for cavities of this style [4].

2.2 Coupled bunch instability thresholds

With the PEP II cavities, even the strongest HOM impedances will be far too small to cause longitudinal instabilities at 500 mA. One transverse mode might be dangerous, but moderate chromaticity will provide sufficient head-tail damping to oppose growth of this mode.

Param.	SPEAR 2	SPEAR 3	SPEAR 3
ρ	12.8	8.4	8.4
U_0 (keV)	560.0	855.6	855.6
h	280	280	372
V_{RF}	1.68	3.2	3.2
α	$1.5 \cdot 10^{-2}$	$1.2 \cdot 10^{-3}$	$1.2 \cdot 10^{-3}$
δ	$7.4 \cdot 10^{-4}$	$9.7 \cdot 10^{-4}$	$9.7 \cdot 10^{-4}$
f_s (kHz)	23	9.6	11
σ_τ (ps)	75	18.8	16.3
τ_x(ms)	8.36	4.24	4.24
τ_y(ms)	8.36	5.14	5.14
τ_z(ms)	4.18	2.87	2.87
$R_\parallel$(kΩ)	200	200	2.2
$R_\perp$(kΩ·m^{-1})	$2 \cdot 10^3$	$2 \cdot 10^3$	161
$I_{th,\parallel}$(mA)	10	72	3600
$I_{th,\perp x}$(mA)	12	47	589
$I_{th,\perp y}$(mA)	137	100	1240

Table 1: SPEAR parameters (SPEAR 2, SPEAR 3 with existing RF system, SPEAR 3 with new RF system)

The operational experience at PEP II has shown all $R_\parallel \leq 2.2$ kΩ and $R_\perp \leq 161$ kΩ·m^{-1}. The threshold currents presented in Table 1 were computed for the case of maximum impedance. As SPEAR 2 is presently stable at 100 mA in both planes, threshold currents presented are very conservative for those narrowband impedances. The broader width of HOM resonances for HOM damped RF cavities makes the calculated thresholds more probable for the PEP II style cavities. However, even if four such cavities were tuned on their strongest 2.2 kΩ longitudinal impedance, SPEAR 3 should be stable up to 900mA. The transverse coupled bunch instability thresholds were computed with $\beta_x/\beta_y = 10.1\,\mathrm{m}/4.8\,\mathrm{m}$. No fast feedback systems should be necessary for stabilizing any coupled bunch instability.

2.3 Vacuum Chamber

Chamber dimensions The arc vacuum chambers will be replaced for SPEAR 3 [5]. These chambers will have an 84×34 mm^2 elliptical cross-section. An antechamber is joined to this chamber via a coupling slot 12 mm high. The dimensions of the antechamber are set by the size of the radiation fans and exit ports which vary greatly around the ring. A high coupling slot allows high pumping conductance, a decrease of power density deposited by the radiation fan, and a large safe steering envelope. The actual slot height is a compromise between this large size and the small size needed to decouple the fields in the antechamber from the main beampipe. The cutoff frequencies of the dominant TM and TE modes have been calculated to be 4.7 GHz and 2.1 GHz, respectively [6]. A slot width needs to be many evanescent lengths of the dominant mode in order to insure this decoupling. For the 12 mm high slot of the chamber, the evanescent length of the TM mode is 3 mm. The minimum slot width of this chamber is 5 cm.

The image current on the elliptical chamber is not azimuthally symmetric; it is concentrated near the vertical axis (figure 1). From this distribution, the azimuthal posi-

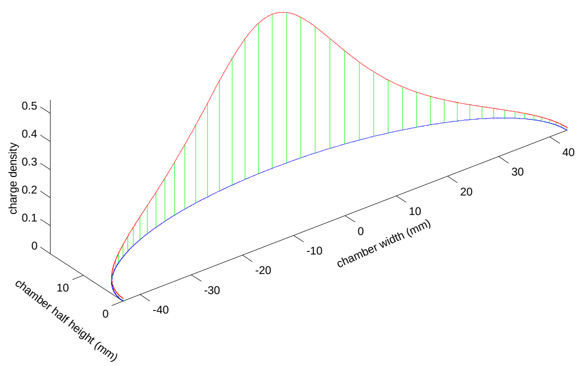

Figure 1: Image current density along the chamber wall.

tions of the beam position monitors were chosen to equalize the sensitivity to vertical and horizontal beam motion; the 15 mm diameter buttons will be placed 12 mm from the vertical axis. The effective radius of the chamber, used for resistive wall calculations, was computed to be 22 mm [7].

Chamber material The two materials under consideration for the chamber are copper and stainless steel. The main issues are the heat conduction and fabrication costs. The higher conductivity of the copper makes it a better choice for impedance minimization.

2.4 Broadband Impedance

The broadband impedance of small discontinuities around the ring was calculated using ABCI [8]. The results, shown in table 2, are consistent with those found for other rings. The total inductance in this table is 60 nH, corresponding to $.5\Omega$. Using a conservative value of 1Ω, a broadband impedance model was constructed with the characteristic parameters: $R_S = 12$ kΩ, $Q = 1$, $f_R = 15$ GHz. The somewhat arbitrary choice of f_R was based on the fact that ABCI showed no strong peaks below 10 GHz, the cutoff frequency of the bunch. Using this impedance model, the tracking code gave a single bunch current threshold of 5 mA beyond which the energy spread starts widening. At 25 mA, the energy width of the bunch was 1.7 and its length was 2.2 times greater than the zero current values.

Element	k_L **(V/pC)**	**No.**	L_{Tot} **(nH)**
bellows shield	0.0107	80	5.8
RF seals	$4.4 \cdot 10^{-4}$	197	3.5
BPM	0.0027	90	3.3
transitions	0.02	10	10
trans. kicker	0.66	2	11
trans. pickup		2	26

Table 2: Broadband impedance

ξ_{norm}	$I_{th,Cu}$ **mA**	$I_{th,SS}$ **mA.**
0	190	103
0.1	506	274
0.2	822	446

Table 3: Resistive wall instability thresholds

2.5 Resistive Wall Impedance

The resistive wall impedance is strongest at low frequencies. The fractional parts of ν_x, ν_y were set below the half-integer to maximize the system stability. Due to the shape of the chamber, this impedance is strongest in the vertical dimension. Since the small-gap insertion devices have small vertical heights, they contribute half of the total resistive wall impedance if the vacuum chamber is made from stainless steel. Using copper for the chamber reduces the total resistive wall impedance by a factor of two. The radiation damping force is not strong enough to compensate for the growth due to the strongest resistive wall growth term. Head-tail damping, calculated with the broadband model given above, adds to the total damping. Table 3 displays the resistive wall instability current thresholds for the two different chamber designs (copper with stainless steel insertion chambers and all stainless steel), at reasonable values of the normalized chromaticity. The $\langle\beta\rangle$ values used in these calculations are 8.5 m in the arc chambers and 4.5 m in the insertion devices.

2.6 Power Dissipation

The power dissipation due to resistive wall heating along the chamber scales as I^2_{Tot}/N_B where N_B is the number of bunches. An advantage of the new RF system is that at the higher harmonic number, N_B increases, so the power dissipation decreases. The chamber materials make a significant difference. The heating in the stainless steel chamber at 500 mA in 279 bunches is 7.5 W/m. For copper, this drops to 1.2 W/m. These values are both small compared to the heating in the insertion devices. The smallest gap undulator (half height 6 mm) heats up at a rate of 209 W/m. Higher order mode losses around the ring are negligible due to the low impedance design of the vacuum chambers.

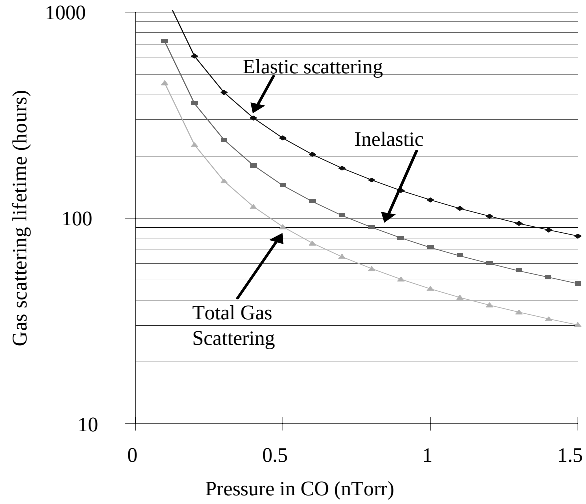

Figure 2: Total gas scattering lifetime as a function of vacuum chamber pressure in CO.

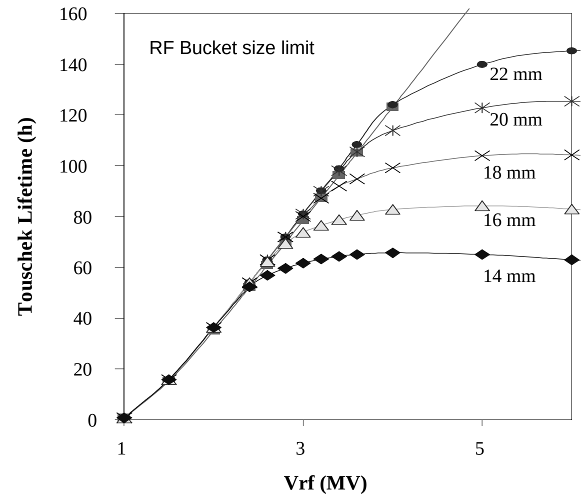

Figure 3: Touschek lifetime as a function of V$_{RF}$ for different values of the mometum dependent dynamic aperture; ("22mm" = 22mm on energy and 19mm at 3%) 500 mA in 279 bunches, 1% vertical coupling;

3 LIFETIME

3.1 Gas Scattering Lifetime

Electrons can be lost due to elastic (Coulomb) or inelastic (bremsstrahlung) collisions with the background gas molecules. The loss rate depends on the local and average β functions, the local gas pressure, and the ring acceptance. For SPEAR 3, the Coulomb and bremsstrahlung lifetimes are estimated to be 275 and 120 hours, respectively, at 200 mA. Taken in parallel, the total gas scattering lifetime is 83 hours at 200 mA, assuming a partial pressure in CO of 0.6 nTorr and an energy acceptance of 3%. This scales to 1.5 nTorr at 500 mA and a gas scattering lifetime of 30 hours.

3.2 Touschek Lifetime

At 3 GeV, SPEAR 3 is moderately sensitive to Touschek scattering. 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 3.2 MV, the bucket size is 3.1%. The lattice has been opimized to provide a momentum dependent dynamic aperture of 3% (particles 3% off-energy with amplitudes up to 20 mm in the 3 m straight sections will be kept in the ring). The energy acceptance will be RF bucket limited at 3.2 MV. For 200 mA beam current distributed in 279 bunches, and emittance coupling of 1%, the Touschek lifetime was computed to be 217 hours. For 500 mA the equivalent number is 87 hours.

3.3 Total electron beam lifetime

Lifetime calculations predict that the total lifetime is 60 hours at 200 mA. At 500 mA, the lifetime is 22 hours. After 24 hours, the initial 500 mA will decay to 200 mA.

4 CONCLUSION

The upgrade of the SPEAR storage ring to run with an 18 nm emittance and 500 mA current is presently under investigation. With a new RF system and new vacuum chamber, SPEAR 3 will be stable in both planes without the need for any fast feedback systems. A 22 hour lifetime is expected at 500mA.

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