TUPEB054

Design of Positron Damping Ring for SuperKEKB

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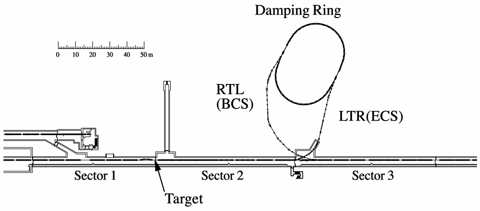
Abstract: Super-KEKB, an upgrade plan of the present KEKB collider, has recently changed its baseline-design from "high current" option to "nano-beam" scheme. The current is relatively low(4A/2.3A for LER/HER ring) compared to that of the high-current option(9.4A/4.1A), while the vertical beam size is squeezed to 60 nm at the interaction point to get the high luminosity. Since the Tousheck lifetime of LER is very short(600 sec), the intensity of the positron beam is as high as 8 nC/pulse. The emittance of the injected positron beam should be small enough to be accepted in the aperture of the LER. A damping ring has been proposed for the high-current option[1]. In this paper an updated design optimized to the nano-beam scheme is presented.



Layout of the System

Table 1: Parameters of the injected beam

	before ECS	after ECS	unit
Energy	1.1		GeV
Repetition frequency	50		Hz
Emittance	1.7		μm
Energy spread†	1.67	0.50	%
Bunch length†	2.67	11.7	mm
Number of bunches	2		
Bunch spacing	98		ns
Bunch charge	8		nC

† defined as extension that contains 99.7% divided by 6.

Table 2: Parameters of the Damping Ring

Energy	1.1		GeV
No. of bunch trains	2		
No. of bunches / train	2		
Circumference	135.50207		m
Max. stored current	70.8		mA
Energy loss / turn	0.091		MV
Hor. damping time	10.87		ms
Inj.-beam emittance	1700		nm
Emittance (h/v)	41.4 / 2.07		nm
Energy spread	5.5×10^{-4}		
Coupling	5		%
Extracted emittance (h/v)	42.5 / 3.15		nm
Cavity voltage	0.5	1.0	MV
Bucket height	0.81	1.24	%
Synchrotron tune	0.0152	0.0216	
Bunch-length	11.01	7.74	mm
Phase advance/cell (h/v)	64.39 / 64.64		deg
Momentum compaction	0.0141		
Bend-angle ratio	0.35		
No. of normal-cells	40		
RF frequency	509		MHz
Chamber diameter	34		mm

Linear Optics

Optics requirements
- Large acceptance
- Fast Damping

Solution: FODO with Reversed Bend

$$\tau = \frac{3T_0}{r_e\gamma^3 J_x I_2} = \frac{3}{2\pi c\, r_e J_x}\frac{\rho}{\gamma^3}C\frac{1-r}{1+|r|}$$
$$= \frac{3}{2\pi c\, r_e J_x}\frac{\rho}{\gamma^3}\left(2\pi\rho + \frac{1-r}{1+|r|}L_1\right)$$

r: Bend ratio $= B1/B2$

(Normal FODO $\longrightarrow$ $r=-1$)

L_1: Total length except bend length

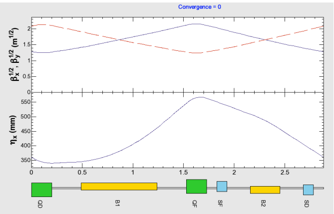
- Short damping time with lower field

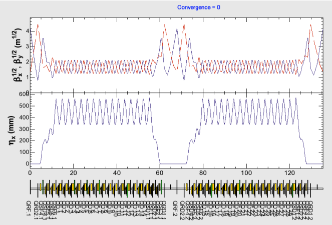
$r = 0.35,\ \rho = 2.7\ \mathrm{m},\ L_1 = 100\ \mathrm{m}$

$(1-r)/(1+|r|) = 0.48$

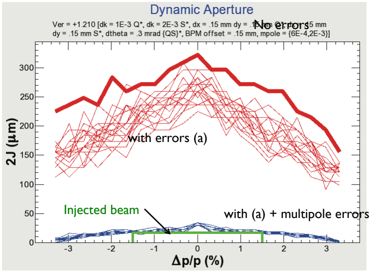
$2\pi\rho = 17\ \mathrm{m}$

$B = 1.35\ \mathrm{T}$





Non-linear Optics



- DA is limited by systematic multipole errors

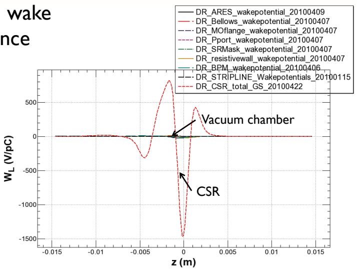
Errors (a):
$\Delta K/K = 0.1\,\%$ for quads
$\Delta K/K = 0.2\,\%$ for sexts
$\Delta\theta = 0.3\,\mathrm{mrad}$ for quads and sexts
Misalignments $=0.15\,\mathrm{mm}$ for quads sexts, and BPM

Table 3: Systematic multipole errors

Magnet				$\Delta B/B$
Bend	K_2/K_0	2.5	m^{-2}	6.0×10^{-4}
	K_4/K_0	2.3×10^{5}	m^{-4}	2.3×10^{-3}
Quad	K_5/K_1	3.1×10^{5}	m^{-4}	6.0×10^{-4}
	K_9/K_1	1.5×10^{16}	m^{-8}	2.3×10^{-3}
Sext	K_8/K_2	1.1×10^{11}	m^{-6}	6.0×10^{-4}
	K_{14}/K_2	7.6×10^{16}	m^{-12}	2.3×10^{-3}

CSR induced instability

- Coherent Synchrotron Radiation wake dominates the longitudinal impedance



- CSR induced microwave instability occurs: the onset is consistent with 1-D theory of Stupakov – Heifets:

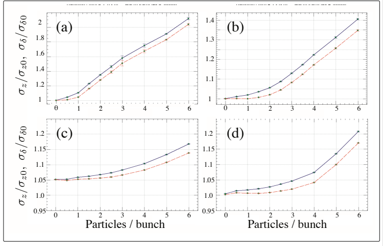
$$N_{b,th} \simeq \frac{\pi^{1/6}}{\sqrt{2}}C\frac{1-r}{1+|r|}\frac{\gamma}{\rho^{1/3}}\alpha_p\sigma_\delta^2\sigma_z\frac{1}{\lambda_c^{2/3}}$$

$$\lambda_c = \min(\,2\sqrt{b^3/\rho},\ \sigma_z^{-1})$$

Table 4: Ring parameters for simulation

	E(GeV)	α	σ_z(mm)	σ_δ	τ_ϵ(ms)	$N_{b,th}$
(a)	1.0	0.0036	5.03	5.25×10^{-4}	6.3	0.35×10^{10}
(b)	1.1	0.0061	7.30	5.57×10^{-4}	6.9	1.1×10^{10}
(c)	1.1	0.0141	11.0	5.50×10^{-4}	5.4	2.9×10^{10}
(d)	1.1	0.0141	7.75	5.50×10^{-4}	5.4	2.6×10^{10}

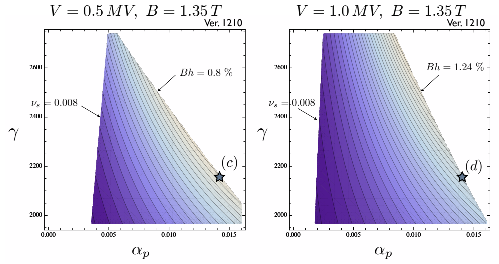
Tracking simulation



- Optics optimization

Maximize the function

$$N_{b,th} = F(\alpha,\gamma,V,B) = C_0(\alpha L)^{3/2}\gamma^{8/3}V^{-1/2}B^{11/6}$$



Electron cloud instability

- Threshold of electron density

$$\rho_{e,th} = \frac{2\ln 2\pi}{3\sqrt{2}}\frac{\gamma\,\nu_s\,\omega_e\sigma_z/c}{KQ\,r_e\beta L}(1+\frac{\sigma_y}{\sigma_x})$$

$$\omega_e^2 = \lambda_+ r_e c^2/\sigma_y(\sigma_x+\sigma_y)$$

$$Q = \min(5,\omega_e\sigma_z/c) \qquad K = 3$$

- For case [c] $\rho_{e,th} = 0.52\times10^{13}\,\mathrm{m}^{-3}$
- Simulation of photo-electron formation
- Integrated electron density =

$$0.51\times10^{14}\,\mathrm{m}^{-2} \ll \rho_{e,th}L = 7.0\times10^{14}\,\mathrm{m}^{-2}$$

Table 5: Electron density for various conditions

Condition	Drift	Bend	Q+Sx	
$\delta_{\max} = 2$, SR=1	1.3	0.6	0.5	$10^{12}\,\mathrm{m}^{-3}$
$\delta_{\max} = 1$, SR=1	0.4	0.5	0.15	$10^{12}\,\mathrm{m}^{-3}$
$\delta_{\max} = 1$, SR=0.1	0.15	0.11	0.03	$10^{12}\,\mathrm{m}^{-3}$

SR: photon flux ratio to the design flux

Conclusion

- Positron damping ring has been designed based on the Reverse-bend FODO.
- Dynamic aperture is limited by the systematic multipole errors.
- CSR dominates the longitudinal impedance.
- Ring parameter was optimized to increase the threshold of the CSR induced instability.
- Proposed ring parameters satisfy the requirements