Impedance model for SuperKEKB

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SuperKEKB mini optics meeting, Feb. 26, 2015

Outline

- ➤ **Impedance model for SuperKEKB**
  - **To address the concerns from the 20th ARC**

1. Impedance budget for SuperKEKB

➤ Impedance budget with σ_z=5/4.9mm:

- Loss factors, resistance and inductance are calculated at nominal bunch lengths

Table 2: Key parameters of SuperKEKB main rings for MWI simulations.

Parameter	LER	HER
Circumference (m)	3016.25	3016.25
Beam energy (GeV)	4	7.007
Bunch population (10^{10})	9.04	6.53
Nominal bunch length (mm)	5	4.9
Synchrotron tune	0.0244	0.028
Long. damping time (ms)	21.6	29.0
Energy spread (10^{-4})	8.1	6.37

Component	LER			HER		
	$k_{\|\|}$	R	L	$k_{\|\|}$	R	L
ARES cavity	8.9	524	-	3.3	190	-
SC cavity	-	-	-	7.8	454	-
Collimator	1.1	62.4	13.0	5.3	309	10.8
Res. wall	3.9	231	5.7	5.9	340	8.2
Bellows	2.7	159	5.1	4.6	265	16.0
Flange	0.2	13.7	4.1	0.6	34.1	19.3
Pump. port	0.0	0.0	0.0	0.6	34.1	6.6
SR mask	0.0	0.0	0.0	0.4	21.4	0.7
IR duct	0.0	2.2	0.5	0.0	2.2	0.5
BPM	0.1	8.2	0.6	0.0	0.0	0.0
FB kicker	0.4	26.3	0.0	0.5	26.2	0.0
FB BPM	0.0	1.1	0.0	0.0	1.1	0.0
Long. kicker	1.8	105	1.2	-	-	-
Groove pipe	0.1	5.7	0.9	-	-	-
Electrode	0.0	2.2	2.3	-	-	-
Total	19.2	1141	33.4	29.0	1677	62.1

Ref. D. Zhou et al., IPAC14, TUPRI021

1. Impedance budget for SuperKEKB

➤ **People think that KEKB's impedance should be in the same level as other machines (such as PEP-II)**

- **But I cannot agree, because the vacuum chambers in KEKB were more smooth. SuperKEKB does even better …**
- **Let us compare PEP-II and SuperKEKB:**

Table 1. The PEP-II HER inductive impedance

Parameter	L (nH)	k_l (V/pC)
Dipole screens	0.10	
BPM	11.	0.8
Arc bellow module	13.5	1.41
Collimators	18.9	0.24
Pump slots	0.8	
Flange/gap rings	0.47	0.03
Tapers oct/round	3.6	0.06
IR chamber	5.0	0.12
Feedback kickers	29.8	0.66
Injection port	0.17	0.004
Abort dump port	0.23	0.005
Total	83.3	3.4

From slac-pub-6798

Component	LER			HER		
	$k_{\|\|}$	R	L	$k_{\|\|}$	R	L
ARES cavity	8.9	524	-	3.3	190	-
SC cavity	-	-	-	7.8	454	-
Collimator	1.1	62.4	13.0	5.3	309	10.8
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BPM	0.1	8.2	0.6	0.0	0.0	0.0
FB kicker	0.4	26.3	0.0	0.5	26.2	0.0
FB BPM	0.0	1.1	0.0	0.0	1.1	0.0
Long. kicker	1.8	105	1.2	-	-	-
Groove pipe	0.1	5.7	0.9	-	-	-
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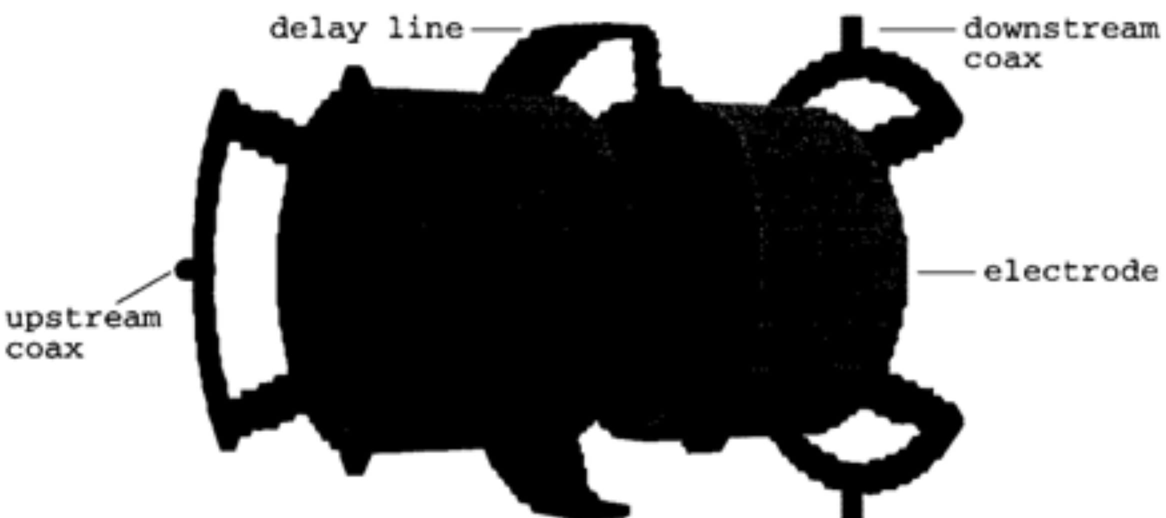
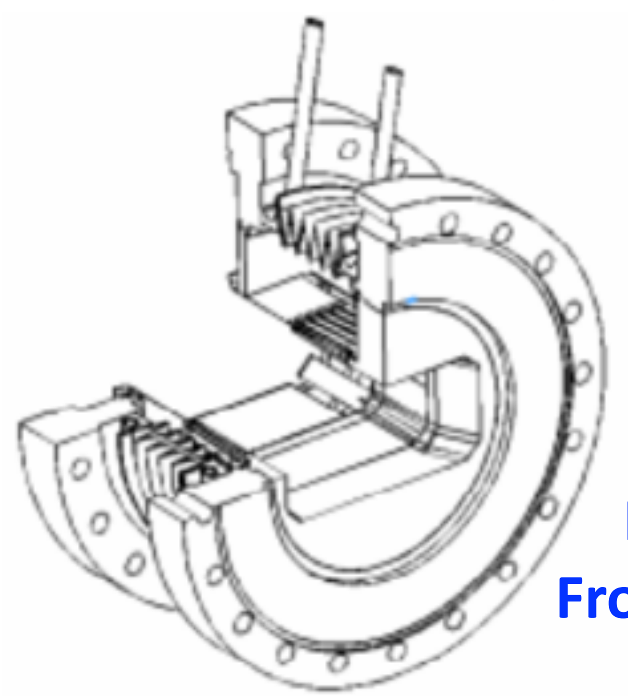
1. Impedance budget for SuperKEKB

➤ **People think that KEKB's impedance should be in the same level as other machines (such as PEP-II)**

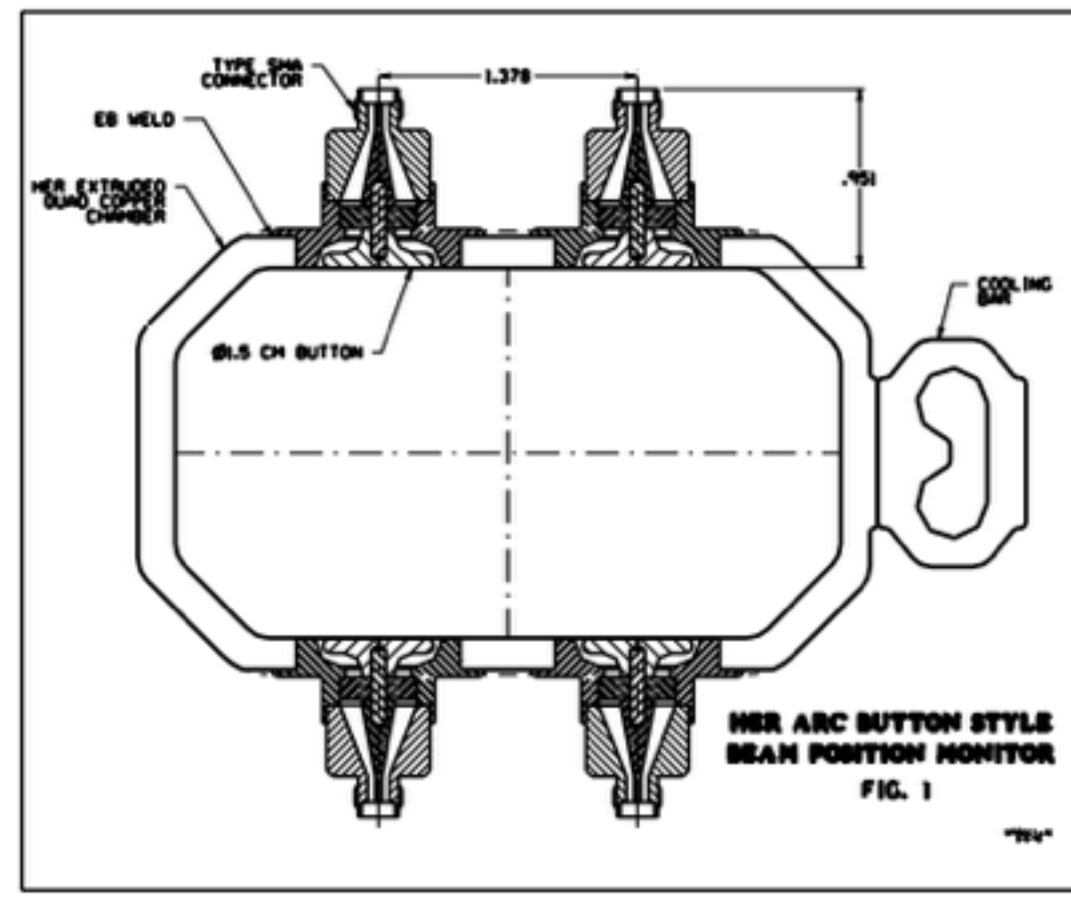
- **We can take a look at some structures in PEP-II:**



PEP-II long. feedback kicker,
From slac-pub-7349



PEP-II bellows,
From slac-pub-6992



PEP-II BPM,
From slac-pub-7009

1. Impedance budget for SuperKEKB

➤ How people think that KEKB's impedance was in the same level as other machines?

- **They might draw conclusion from beam measurement …**

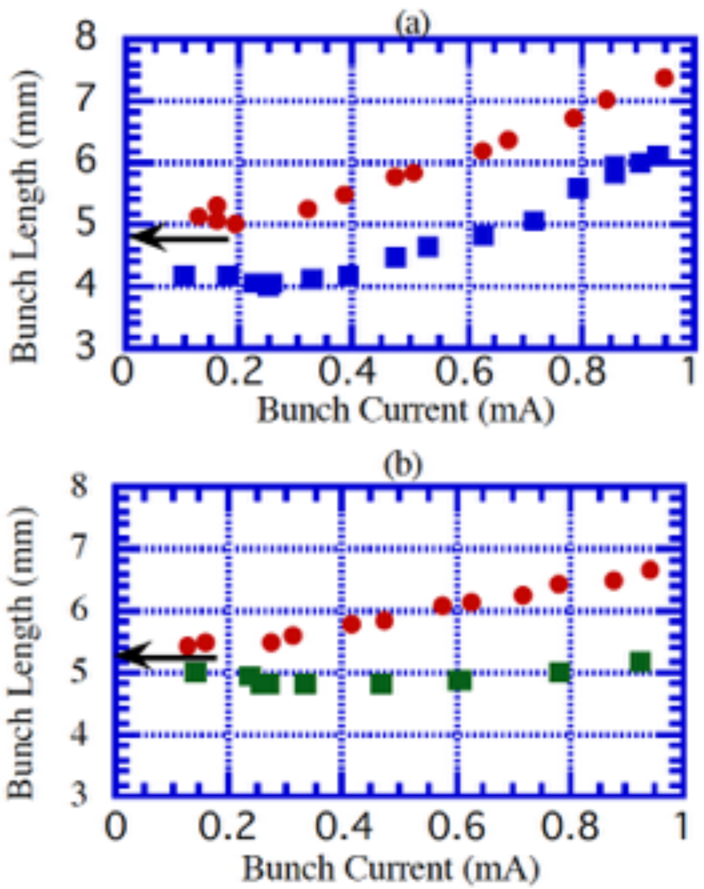


Figure 3: Bunch length as a function of the average bunch current, (a) dots in the cases of $\alpha > 0$ and squares $\alpha < 0$ at the LER, (b) dots in the cases of $\alpha > 0$ and squares $\alpha < 0$ at the HER. The arrows indicate the natural bunch length, 4.74 mm at the LER and 5.22 mm at the HER.

Table 1: Inductive impedance.

Impedance	1999	2003
LER $\lvert Z_i/n \rvert$ (Ω)	0.072 ± 0.011	0.060 ± 0.01
HER $\lvert Z_i/n \rvert$ (Ω)	0.076 ± 0.006	0.065 ± 0.006

$$\left(\frac{\sigma}{\sigma_{l0}}\right)^3 - \left(\frac{\sigma}{\sigma_{l0}}\right) = \frac{e\alpha I_b}{4\sqrt{\pi}\gamma_s^2 E}\left(\frac{R}{\sigma_{l0}}\right)^3\left(\frac{Z_i(\omega)}{n}\right)$$

$$|Z_i/n| = \omega_0 L = 2\pi c L/C$$

$$\longrightarrow \quad L(\mathrm{LER}) \approx 96\mathrm{nH}$$

From T. Ieiri, sast 2003

1. Impedance budget for SuperKEKB

➤ **How people think that KEKB's impedance was in the same level as other machines?**

- **But I found something strange …**

Zotter's formula [Ref. J. Corbett, TUPP028, EPAC08]:

$$\left(\frac{\sigma_z}{\sigma_{z0}}\right)^3 - \frac{\sigma_z}{\sigma_{z0}} - \frac{\alpha I_b \mathrm{Im}\left\{Z_{\|}/n\right\}_{eff}}{\sqrt{2\pi}(E/e)\nu_{s0}^2}\left(\frac{R}{\sigma_{z0}}\right)^3 = 0$$

Ieiri's formula:

$$\left(\frac{\sigma}{\sigma_{l0}}\right)^3 - \left(\frac{\sigma}{\sigma_{l0}}\right) = \frac{e\alpha I_b}{4\sqrt{\pi}\gamma_s^2 E}\left(\frac{R}{\sigma_{l0}}\right)^3\left(\frac{Z_i(\omega)}{n}\right)$$

My question: Why they differ by a factor of $2\sqrt{2}$?

1. Impedance budget for SuperKEKB

➤ **How people think that KEKB's impedance was in the same level as other machines?**

- **We should not miss the condition of using the formula**

Zotter's formula:

$$\left(\frac{\sigma_z}{\sigma_{z0}}\right)^3 - \frac{\sigma_z}{\sigma_{z0}} - \frac{\alpha I_b \mathrm{Im}\left\{Z_{\|}/n\right\}_{eff}}{\sqrt{2\pi}(E/e)\nu_{s0}^2}\left(\frac{R}{\sigma_{z0}}\right)^3 = 0$$

Note: When sigma_z << b with b the vacuum chamber radius, where resonant impedances dominate, the formula does not apply. It means Zotter's formula is not good enough for KEKB/SuperKEKB?

1. Impedance budget for SuperKEKB

➤ **How people think that KEKB's impedance was in the same level as other machines?**

- **And note that calculated inductance is not necessarily equal to effective inductance … [Question: how to correlate them?]**

$$\left(\frac{\sigma_z}{\sigma_{z0}}\right)^3 - \frac{\sigma_z}{\sigma_{z0}} - \frac{\alpha I_b \mathrm{Im}\{Z_{\|}/n\}_{eff}}{\sqrt{2\pi}(E/e)\nu_{s0}^2}\left(\frac{R}{\sigma_{z0}}\right)^3 = 0$$

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1. Impedance budget for SuperKEKB

➤ **How people think that KEKB's impedance was in the same level as other machines?**

- **If Ieiri was wrong …**

Zotter's formula:

$$\left(\frac{\sigma_z}{\sigma_{z0}}\right)^3 - \frac{\sigma_z}{\sigma_{z0}} - \frac{\alpha I_b \mathrm{Im}\left\{Z_{\|}/n\right\}_{eff}}{\sqrt{2\pi}(E/e)\nu_{s0}^2}\left(\frac{R}{\sigma_{z0}}\right)^3 = 0$$

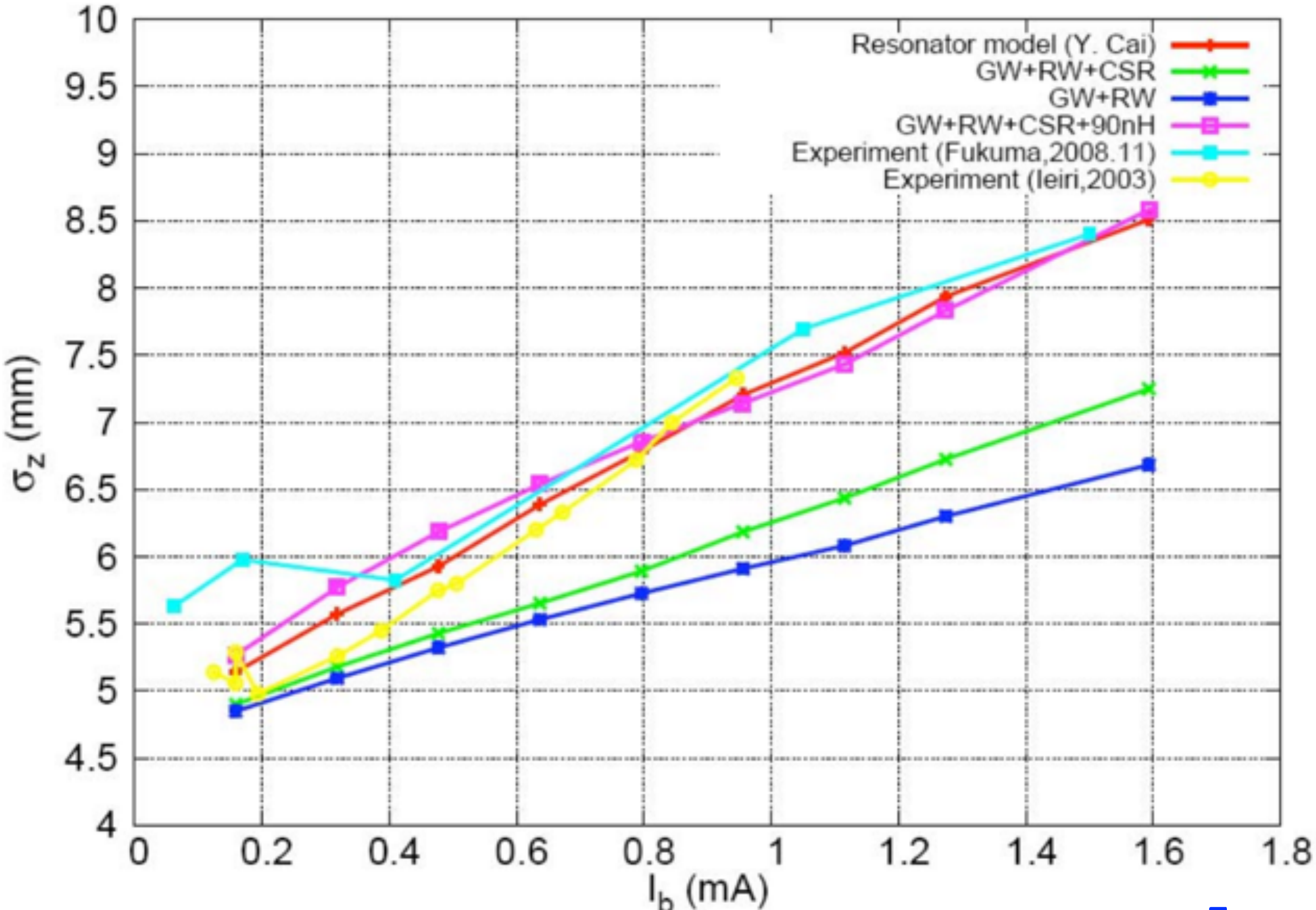
Ok, let us just accept the above formula, and say Ieiri-san was wrong. Then, I only need an inductance of 34nH to drive the (measured) bunch lengthening in KEKB LER?!

Please double-check my question!

1. Impedance budget for SuperKEKB

➤ **The truth is that there is no good impedance model available for KEKB. It is still mysterious to me.**

- **I struggled in 2009 to find the answer, but failed …**
- **CSR was always a headache to me …**



From D. Zhou, ICAP2009

1. Impedance budget for SuperKEKB

➤ **The truth is that there is no good impedance model available for KEKB. It is still mysterious to me.**

- **Then, if we assume the empirical observation, and say that the realistic impedance will be 2-4 times that of computed impedance, what will happen? I will have nightmares …**
- **I have to wait for the beam commissioning of SuperKEKB.**

$$L = L_0 R_{H\theta}$$

$$L_0 = \frac{N_e N_p f_0 N_b}{2\pi\sqrt{\sigma_{xe}^{*2} + \sigma_{xp}^{*2}}\sqrt{\sigma_{ye}^{*2} + \sigma_{yp}^{*2}}}$$

$$R_{H\theta} \approx \frac{1}{\sqrt{1 + \frac{\sigma_{ze}^2 + \sigma_{zp}^2}{\sigma_{xe}^2 + \sigma_{xp}^2} \tan^2 \frac{\theta}{2}}}$$