HOM-BBU simulation for KEK ERL light source

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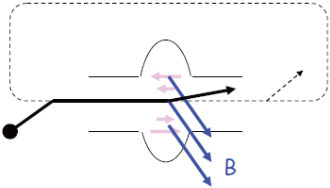
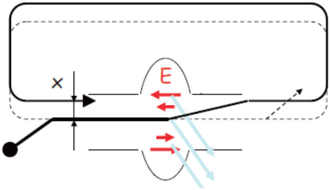
in cERL mini-workshop

2015.01.19

HOM-BBU in ERL



- Positive feedback between recirculated beam with not well damped HOMs
- Limit the maximum average current of ERL facility.



$$I_{th} = -\frac{2V_b}{k(\frac{R_d}{Q_0})Q_L} \cdot \frac{1}{R^*_{12}\sin\omega T_r}$$

$$R^*_{12} = R_{12}\cos^2\theta + (R_{14}+R_{23})\sin\theta\cos\theta + R_{34}\sin$$

where $V_b = pc/e, k = \omega/c$。

9-cell KEK-ERL mode-2 cavity

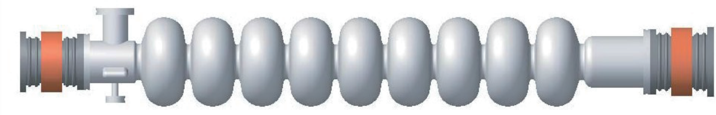


Table: Main HOM parameters in KEK-ERL mode-2 cavity[1]

f [GHz]	Q_e	R/Q [Ω/cm^2]	$(R/Q)Q_e \cdot f$ [$\Omega/cm^2/GHz$]
1.835	1.1010×10^3	8.087	4852
1.856	1.6980×10^3	7.312	6691
2.428	1.6890×10^3	6.801	4732
3.002	2.9990×10^4	0.325	3246
4.011	1.1410×10^4	3.210	9135
4.330	6.0680×10^5	0.018	2522

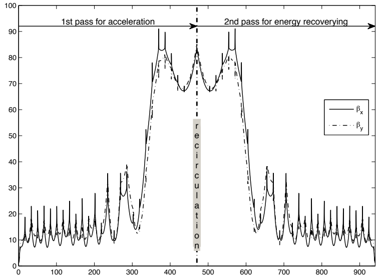
- BBU threshold current simulated by code "bi"[2]
- Two linac designs: 3.0-GeV ERL & 3.4-GeV ERL[3]

[1] R. Hajima, R. Nagai, in Proceedings of ERL07, (2007)

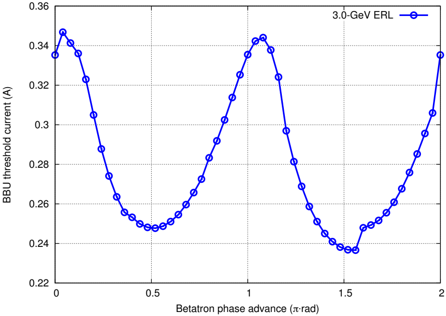
[2] bi, http:// www.lepp.cornell.edu/ ib38/ bbu/

[3] Lattice file provided by Miho Shimada

3.0-GeV linac design: without HOM frequency randomization

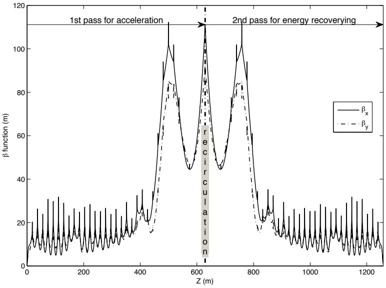


- 28 modules × 8cavities,
  E_{inj}=10MeV,
  E_{acc}=13.4MV/m,
  $E_{full} \approx$3.0GeV.
- $\beta_{x,y} \approx$83m at the end of linac.

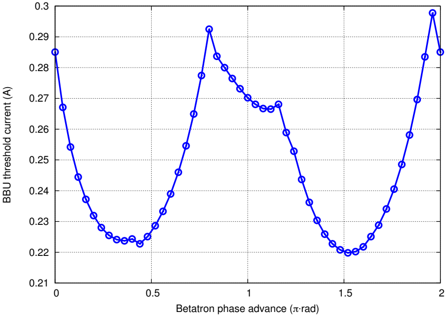


- $0 \sim 2\pi$ betatron phase shift:
  $I_{th,min} \approx$ 238mA,
  $I_{th,max} \approx$ 345mA.

3.4-GeV linac design: without HOM frequency randomization



- 34 modules × 8cavities,
  E_{inj}=10MeV,
  E_{acc}=12.5MV/m,
  E_{full} ≈3.4GeV.
- $\beta_{x,y}$ ≈100m at the end of linac



- $0 \sim 2\pi$ betatron phase shift:
  $I_{th,min} \approx$ 220mA,
  $I_{th,max} \approx$ 300mA.

HOM frequency randomization

- Gaussian frequency distribution; 1000 random seeds; $\sigma_f = 1\text{MHz}$;

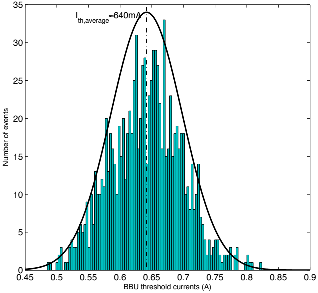


Figure: 3.0-GeV ERL

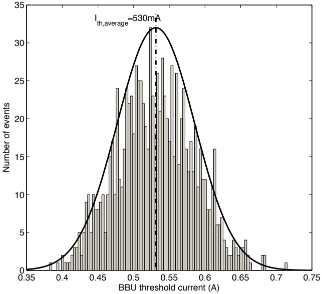


Figure: 3.4-GeV ERL

- $\sigma_f = 1\text{MHz}$,
  $\overline{I_{th}^{(1)}} \approx 640\text{mA}, \ \ \sigma_I^{(1)} \approx 56\text{mA}, \ \ \sigma_I^{(1)}/\bar{I}_{th}^{(1)} \approx 8.75\%$;
  $\overline{I_{th}^{(2)}} \approx 530\text{mA}, \ \ \sigma_I^{(1)} \approx 54.2\text{mA}, \ \ \sigma_I^{(1)}/\bar{I}_{th}^{(1)} \approx 10.2\%$。

HOM frequency randomization

- Average value of threshold current $\bar{I}_{th}$ vs. σ_f.

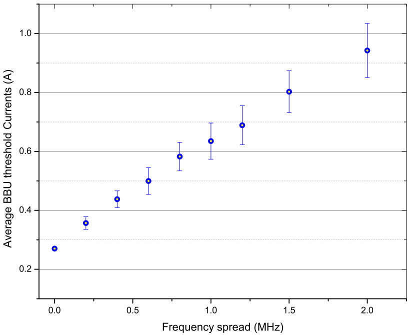


Figure: 3.0-GeV ERL

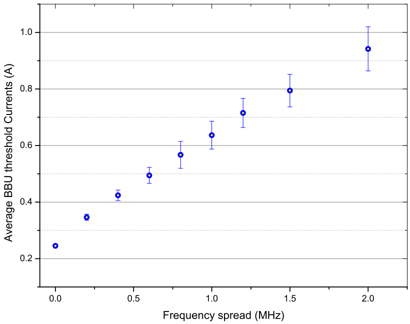
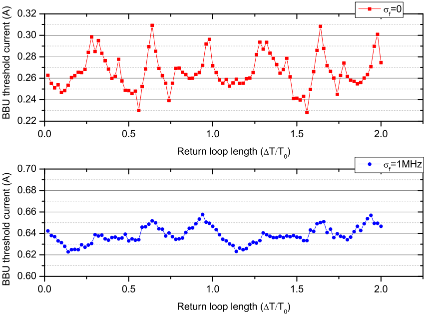


Figure: 3.4-GeV ERL

- $\sigma_f = 2\text{MHz}$， $\bar{I}_{th} \approx 940\text{mA}$。

Threshold current vs. Return loop length

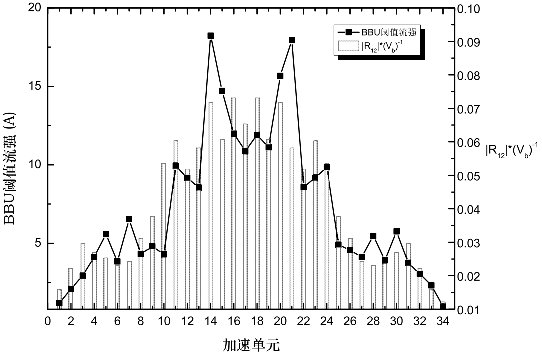
- Adjust the return loop length to change the value of $\sin \omega T_r$: possible to improve the BBU threshold current.



- BBU threshold current vs. Return loop length variation (in unit of $\Delta T/T_0$).
- The HOM with frequency 4.011GHz determines a approximately periodic oscillation of BBU threshold current (Shown in the upper picture).
- The periodic oscillation is smeared due to the frequency randomization (Shown in the lower picture).

- It is not so efficient to improve the BBU threshold current by adjusting the return loop length.

Contribute of single module to BBU threshold current



- The distribution of BBU threshold current of each module in the linac is roughly consistent with the distribution of $R_{12} \cdot V_b{}^{-1}$ of each module.
- BBU is much easier to happen in those modules at the start or the end of the linac.

Comparison

Table: BBU threshold current comparison of two designs

	3.4-GeV ERL	3.0-GeV ERL
E_{inj}[MeV]	10	10
E_{full}[MeV]	3410	3010
Number of modules	34	28
E_{acc}[MV/m]	12.5	13.4
$I_{th,min}(\sigma_f=0)$[mA]	220	238
$I_{th,average}(\sigma_f=2\text{MHz})$[mA]	940	940

- Both the two designs have BBU threshold current larger than 100mA.

Thank you for attention!