Beam dynamics simulations in the CLIC RTML

Update of BBA on Turn Aroud Loop of RTML

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Ring To Main Linac(RTML) [1]

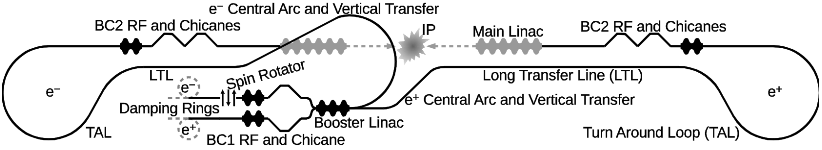


Figure: Sketch of RTML

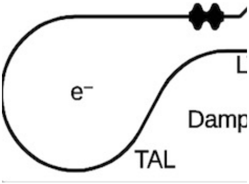
- RTML connects the damping rings and the main linac
- Match beam properties
- We focus on the electron part

Table: Beam properties at the start and end of the RTML for 3 TeV machine

Properties [unites]		Value at the start	Value at the end
Particle energy [GeV]	E_0	2.86	9
r.m.s. bunch length [μm]	σ_s	1800	44
r.m.s energy spread [%]	σ_E	0.12	1.7
Normalized emittance [nm rad]	$\epsilon_{n,x}$	500	600
	$\epsilon_{n,y}$	5	10

Turn Around Loop(TAL) [2]

- TAL directs the outgoing beam towards the interaction point (IP).
- Turn-left arc (10 cells), matching lattice and turn-right arc (40 cells).
- The lattice is rather complex and total length is 1944 m
  - achromatic, i.e. $R_{16} = 0$
  - isochronous, i.e. $R_{56} = 0$
  - minimize ISR emittance growth
- Emittance growth budget of TAL for static BBA is $\Delta\epsilon_x < 100\ \mathrm{nm \cdot rad}$ and $\Delta\epsilon_y < 1\ \mathrm{nm \cdot rad}$. *This is our motivation.*



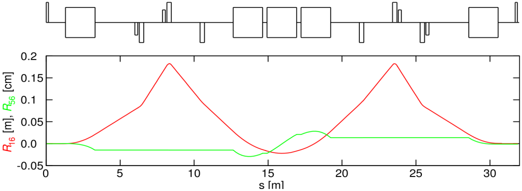


Figure: TAL (left), Dispersion and momentum compaction along an arc cell (right)

Split of Bins—Correct the the lattice step by step

- *Each bin contain 8 cells with 4 cells overlapping with the neighbor bins*
- *Turn-left arc: 2 Bins; Match part: 1 Bin; Turn-right arc: 9 Bins.*

Response Matrix

This is a matrix between the strength of correctors and Beam Position Monitors (BPMs) readings.

- This matrix is got from BPMs readings when give correctors a kick.
- For beams with different energy, response matrix are different. For this study, we use a matrix with energy offset 0.5%
- It is very important to get an accurate response matrix. We use a bunch with 100,000 particles to get this.

$$\begin{pmatrix} u_1 \\ u_2 \\ u_3 \\ \vdots \\ u_m \end{pmatrix} = \begin{bmatrix} R_{11} & R_{12} & R_{13} & \cdots & R_{1n} \\ R_{21} & R_{22} & R_{23} & \cdots & R_{2n} \\ R_{31} & R_{32} & R_{33} & \cdots & R_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ R_{m1} & R_{m2} & R_{m3} & \cdots & R_{mn} \end{bmatrix} \begin{pmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \vdots \\ \theta_n \end{pmatrix}$$

Because we have split the TAL to several bins, not all elements of the matrix are used.

Correction Methods

One to One (1:1)

- *BPM measurements:* $\boldsymbol{u}$. ($\boldsymbol{u}_0$: *results on perfect machine*)
- *Correctors strength:* θ.
- *Response Matrix:* $\boldsymbol{R}$
- $\theta = min\ \{\ ||\ \Delta\boldsymbol{u} - \boldsymbol{R}\theta||_2^2 + \beta^2\ ||\theta||_2^2\ \}$, *here* $\Delta\boldsymbol{u} = \boldsymbol{u} - \boldsymbol{u}_0$, β *is parameter.*

Dispersion Free Steering (DFS)—Correct the errors from BPM positions

- *Normal beam through the Lattice, response matrix* R_1, *BPM* $\boldsymbol{u}_1$, ($\boldsymbol{u}_{d1}$, *perfect machine*)
- *Beam with energy* $E_0(1+\delta)$ *through the Lattice,response matrix* R_2, *BPM* $\boldsymbol{u}_2$ ($\boldsymbol{u}_{d2}$, *perfect machine*)
- *Dispersion matrix* $D = R_2 - R_1$, *Dispersion* $\eta = \boldsymbol{u}_2 - \boldsymbol{u}_1 - (\boldsymbol{u}_{d2} - \boldsymbol{u}_{d1})$
- $\theta = min\ \{\ ||\ \Delta\boldsymbol{u} - R_1\theta||_2^2 + \omega^2||\eta - D\theta||_2^2 + \beta^2\ ||\theta||_2^2\ \};$

Previous Result

Thibaut Lienart has done the BBA of RTML in 2012. About the TAL he gave result [3]:

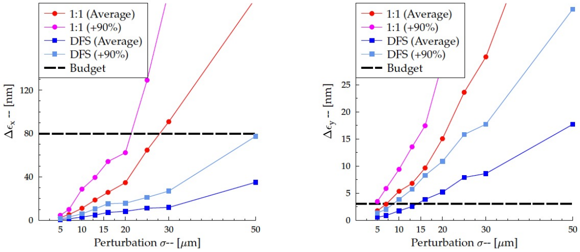


Figure: Emitance growth along σ_{pos}

- Emittance budget he used here is $\Delta\epsilon_x < 80\ \text{nm}\cdot\text{rad}$ and $\Delta\epsilon_y < 3\ \text{nm}\cdot\text{rad}$
- On horizontal plane, DFS can keep the emittance in the budget when σ_{pos} reached 50 μm. σ_{pos} represents the mis-aligned position errors.
- On vertical plane, using the budget $\Delta\epsilon_y < 1\ \text{nm}\cdot\text{rad}$, the tolerance is about 5 μm

Test of 1:1 correction

Quadrupoles are mis-aligned 30 μm. BPM is perfectly aligned. 20,000 particles are used.

- In the first bin

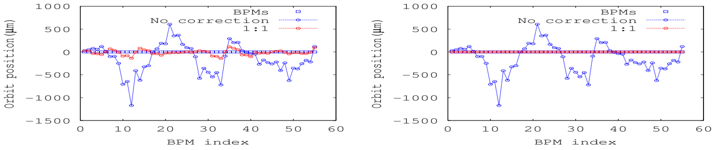


Figure: Orbit along BPM. Left, control larger fluctuation ($\beta = 5$); Right, no controlment ($\beta = 0$)

- The whole TAL
  - No correction gives NaN
  - $\beta = 5$ gives $\Delta\epsilon_x = 193\ \mathrm{nm} \cdot \mathrm{rad}$ and $\Delta\epsilon_y = 4.63\ \mathrm{nm} \cdot \mathrm{rad}$
  - $\beta = 0$ gives $\Delta\epsilon_x = 24\ \mathrm{nm} \cdot \mathrm{rad}$ and $\Delta\epsilon_y = 0.8\ \mathrm{nm} \cdot \mathrm{rad}$

We control the fluctuation of dipole ($\beta = 5$) because this will help DFS.

Test of DFS correction

Only BPMs are mis-aligned with 30 μm. $\beta = 3$ and $\omega = 25$

- In the first bin

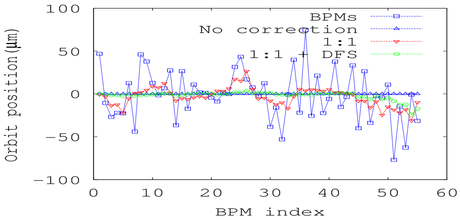


Figure: Orbit along BPM

- The whole TAL
  - 1:1 gives $\Delta\epsilon_x = 25.5\ \mathrm{nm}\cdot\mathrm{rad}$ and $\Delta\epsilon_y = 0.96\ \mathrm{nm}\cdot\mathrm{rad}$
  - DFS gives $\Delta\epsilon_x = 24.5\ \mathrm{nm}\cdot\mathrm{rad}$ and $\Delta\epsilon_y = 0.07\ \mathrm{nm}\cdot\mathrm{rad}$

Results—Simulation conditions

- Only TAL part of RTML is simulated.
- One dipole corrector is added to each quadrupole
- BPM resolution is $\sigma_{\text{res}} = 1\mu\text{m}$.
- The positions of both quadrupoles and BPMs are mis-aligned with σ_{pos}
- For each σ_{pos}, 100 machines are studied.
- 20,000 particles in one bunch are used in one machine.
- ISR and wake field are included.

Results—Scan the weight in DFS

- We mis-align the lattice on $\sigma_{\text{pos}} = 30\mu\text{m}$
- 10 points from 2 to 1024 are scanned

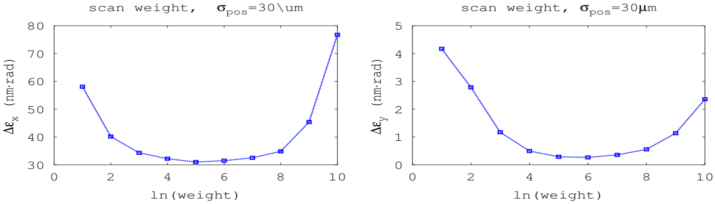


Figure: Emittance growth v.s. the DFS weight

Conclusions from scanning

- *For $\omega \in [2^4, 2^8]$, the emittance growth changes small.*
- *For different σ_{pos}, the weight dependence should be different. Theoretically, $\omega^2 = \frac{\sigma_{\text{pos}}^2 + \sigma_{\text{res}}^2}{2\sigma_{\text{res}}^2}$.*
- *We choose $\omega = 25$ for the whole DFS correction.*

Results—Mean emittance growth along the lattice

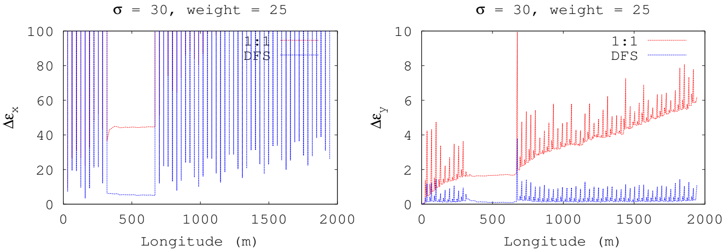


Figure: Emittance growth along the lattice

- The fluctuation is due to dispersion.
- For the vertical emittance, we take last valley instead of final emittance. The last growth is due to that there is no more BPMs to constrain the emittance and we think that after considering the following part of TAL, i.e. BC2, the emittance will go down.

Results—Number of machines along the emittance growth

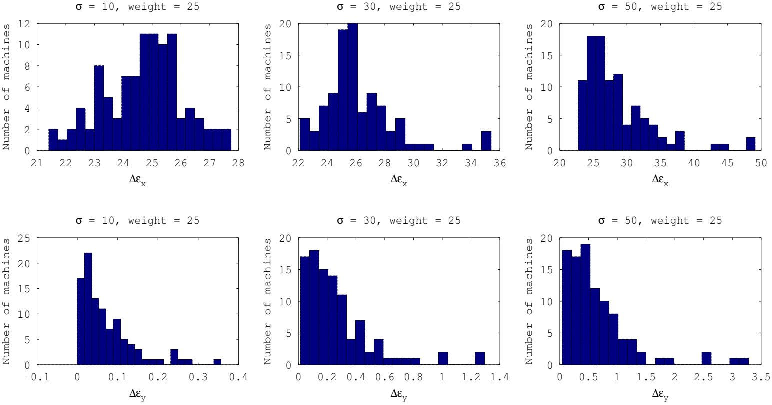


Figure: Number of machines v.s. emittance growth

- All machines stay in the budget on horizontal direction for $\sigma_{\text{pos}} = 50\mu\text{m}$
- Some machines (< 10%) go out the budget on vertical direction for $\sigma_{\text{pos}} = 30, 50\mu\text{m}$

Results

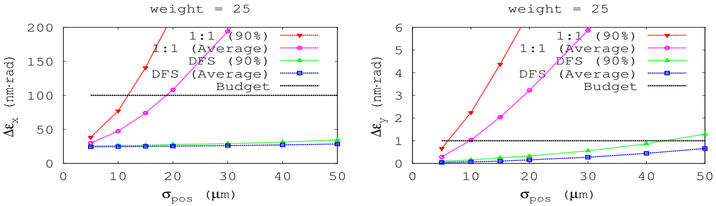


Figure: Emittance growth for different mis-aligned σ_{pos}

- The DFS can align the quadrupoles and BPMs on horizontal direction up to $50\mu\text{m}$
- If $\sigma_{\text{pos}} < 40\ \mu\text{m}$, DFS can also align the lattice within the budget.

In process work—RTML coupling correction

Up to 50 μrad, the emittance growth on horizontal direction stays in budget. While in vertical direction, the rotation errors must be aligned if the errors are larger than 10 μrad

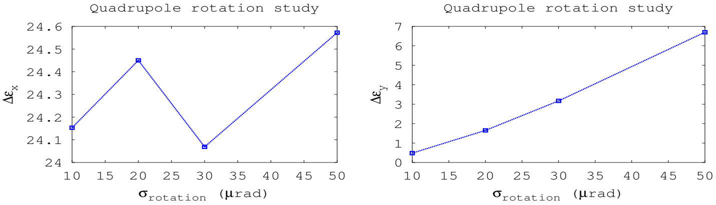


Figure: Emittance growth for different mis-aligned σ rotation

- Study the best location for two coupling correction sections (like ILC).
  - The beginning of the Long Transfer Line
  - The end of the TAL
- Rotate the beam at the two points to study how better we can reach.
- Then design lattice to put skew quadrupoles to correct the coupling.

Summary

- With 1:1 and DFS, the error tolerance for quadrupoles and BPMs are aligned to 40 $\mu\mathrm{m}$ (about 5 $\mu\mathrm{m}$ before) on vertical direction.
- Next step we will study more about the coupling correction .

Thank you!

- CLIC CDR-Volume1, page 138
- CLIC CDR-Volume1, page 141
- Thibaut Lienart, CLIC Note 943, page 33.

Backup

What we improve is:

- Use *placet_get_response_matrix_attribute* to get response matrix in 1:1 correction
- In DFS, we use $\beta^2 \, ||\theta||_2^2$ to control the correctors' strength fluctuation instead of $\beta^2 \, ||\theta_{current}||_2^2$

In process work

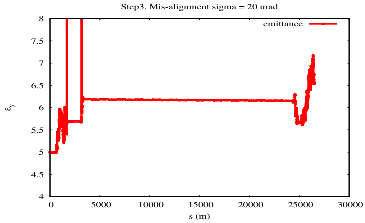


Figure: Emittance growth from boost linac to the end of TAL