DEVELOPMENT OF NON-DESTRUCTIVE EMITTANCE TUNING SYSTEM UTILIZING SYNCHROTRON RADIATION MONITORS

MOP6653

Y. Seimiya* , N. Iida, T. Mori, High Energy Accelerator Research Organization, Tsukuba, Japan

*seimiya@post.kek.jp

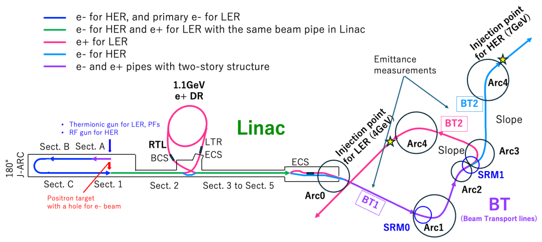
Abstract

In SuperKEKB, the emittance of the injected beam is an essential parameter that significantly affects the injection rate. In the LINAC, the beam tail can be kicked depending on the orbit through the accelerating structures, which leads to a degradation of the emittance. Fortunately, these effects can be minimized by appropriately optimizing the beam oribt. On the other hand, the KEKB LINAC uses pulse steering to supply beams to four different rings. However, the number of pulse steering is limited in the upstream part of the LINAC, and orbit drift in the upstream part often leads to emittance drift, deteriorating injection rate. To address this issue, we have developed a non-destructive emittance tuning system utilizing Synchrotron Radiation Monitors.

Target and actual beam parameters

	Beam	Bunch Charge (nC)	Norm. Emit. (Hor./Ver.) (μm)	Energy Spread (%)
Target	e^-	4	40/20	0.07
	e^+	4	100/15	0.16
Actual (April 2026) (LINAC end)	e^- (1st)	1.9	94/71	0.075
	e^- (2nd)	1.8	136/103	
	e^+ (1st)	3.1	111/3.5	0.068
	e^+ (2nd)	2.9	115/3.9	

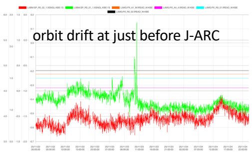
- Emittance improvement for e- is desired for electron beam.
- To operate higher charged electron beam, it is also necessary to improve emittance which affect background of Belle II detector.



Emittance fluctuation

Orbit drift

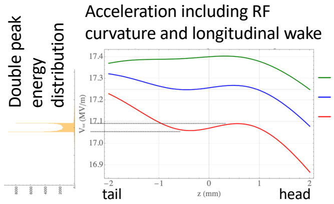
The number of the pulsed steering magnet is limited at the LINAC upstream, Sector A, B, J-ARC, and C. We cannot fix the orbit at the region completely.



SP_R0_02 X pos	EmitX	ΔX	EmitY	ΔY
0 (initial value)	110.067	15.104	115.676	20.801
+0.1mm	174.65	37.921	109.955	29.962
+0.2mm	239.957	66.435	131.835	36.296
+0.3mm	247.566	68.643	121.166	38.906

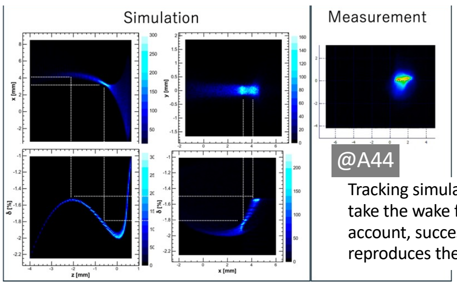
0.1 mm orbital difference causes emittance growth of ～70 μm, which value is non-negligible value, at BT1.

Double peak beam issue



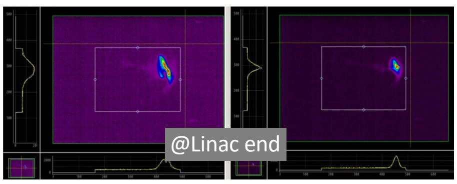
- The beam charge is 2 nC or greater, the energy spread minimization results in a double peaked energy distribution.
- There is a z-δ dependence in which energy peaks appear at the head and tail of the beam.

- The beam is kicked by transverse wake field, which makes x-z dependency.
- The dependencies on both z-δ and x(y)-z eventually lead to a dependency on x(y)-δ, in other words, double peak beam appear in non–dispersive section.



Tracking simulation, which take the wake field into account, successfully reproduces the measurement.

The double peak beam phenomenon disappeared by only the orbit tuning, and the emittance was also significantly improved.



In principle, this double peak beam issue can be mitigated using the energy spread tuning by changing the RF phase; however, this does not provide a fundamental solution. Since RF phases are key parameters for minimizing the energy spread, unless there is a specific reason not to, this issue should be corrected by the orbit.

Emittance auto tuning system (EAT)

Introduction

- Two Synchrotron Radiation Monitors (SRMs) system were installed at BT electron line with different phases at SRM0 and SRM1.
- We established a system that automatically searches for the smallest beam size at BT SRMs, which can perform non-destructive measurement, using several pulsed steerings in LINAC upstream as search parameters.
- This system is called as Emittance Auto Tuning system (EAT), and it can select Downhill Simplex or Bayesian as its optimization method.

objective function:

$$\frac{\Sigma_i \sigma_{x,i}^2/\beta_{x,i} + \mathrm{w}\ \Sigma_i \sigma_{y,i}^2/\beta_{y,i}}{Q_{\mathrm{Linac\ end}}^2/Q_{\mathrm{RF\ gun}}^2}$$

- All steerings and quadrupoles can be selected freely.
- This system is designed to work in conjunction with the orbital feedback systems in Linac and BT to avoid unintentionally disturbing the orbit.
- Since vertical emittance is more important for injection efficiency than horizontal emittance, w=2 is set currently.

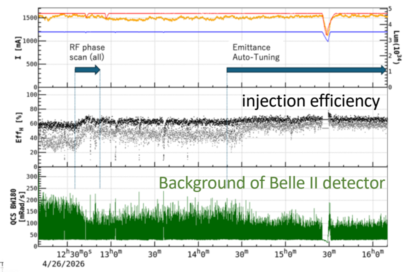
An example of EAT

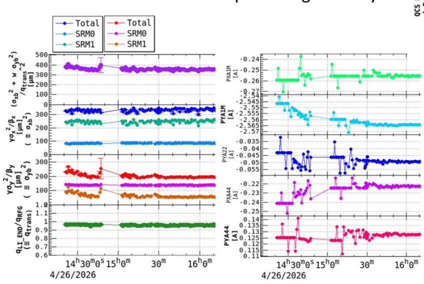
	Bunch	$\gamma\beta\epsilon_x$ [μm]	$\gamma\beta\epsilon_y$ [μm]
Before	1st	81 ± 16	37 ± 10
	2nd	116 ± 18	54 ± 13
After	1st	44 ± 12	21 ± 4
	2nd	66 ± 6	49 ± 6

- EAT optimize to minimize the beam sizes, which is superposition of 1st and 2nd beam.
- Since this optimization is equivalent to minimizing emittance of the superposition, it aligns with the objective of improving injection performance.
- Not only 1st bunch but also 2nd bunch emittance were successfully improved by EAT in this case.

Injection improvement by RF phase (all) and EAT

- By recent study, we found that all RF phase tuning as a unit in the LINAC affects injection efficiency.
- This RF phase (all) tuning is equivalent to changing the laser's phase for RF gun.
- Since the RF phase tuning alters the orbit, the EAT must be run after the RF phase has been tuned.
- Not only injection efficiency but also background of Belle II detector was improved significantly.

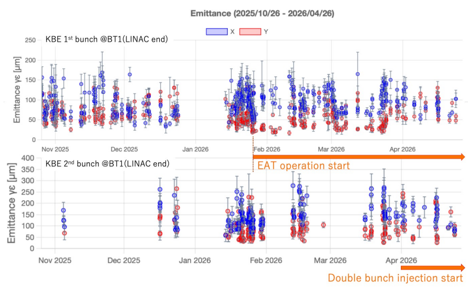




- The left figure shows the trend of objective function value (left top, purple) and the right figure shows pulsed steering current when the EAT was running.
- As time progresses, the objective function value decreased, and in correlation with this, the injection improved as shown in above figure.
- This optimization is performed every few hours, which depends on the beam repetition rate.

Emittance history at BT1

- In the case of only the 1st bunch operation, i.e., during the period when the 2nd bunch plot is not available, the vertical emittance, which affect injection performance significantly, is large and unstable before EAT operation.
- After the EAT operation, the vertical emittance often stabilizes and improve below 50 μm.
- On the other hand, in the case of double bunch operation, the emittance had not improved as much as expected.
- Possible causes include orbital drift between the first and second orbits and RF phase drift.



- We plan to develop this system to achieve higher injection efficiency and stability by tuning the RF phase (all).

Summary

In SuperKEKB injector LINAC, beam emittance is one of the important parameters that affects injection efficiency to the SuperKEKB. The emittance is fluctuating due to beam orbit variation in the LINAC. To mitigate this fluctuation, we developed non-destructive emittance tuning system utilizing synchrotron radiation monitors. This system improved emittance, increased stability, injection efficiency to the SuperKEKB, and background of Belle II. However, the stability of the injection is still insufficient. We plan to develop this system to achieve higher injection efficiency and stability by tuning the RF phase (all), which has been shown to have a significant impact on injection performance, and by adding a Fast kicker parameters that can selectively kick only the second bunch.