# Beam Phase Space Jitter and Effective Emittance for SuperKEKB Injector Linac

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MOPMF074


## ABSTRACT

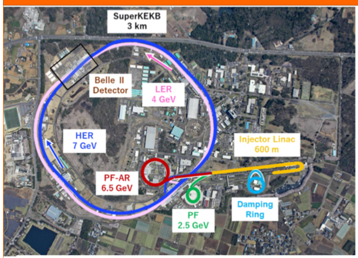
- In SuperKEKB linac, stable high charged low emittance beam is necessary.
- Transported beam to MR must be stable to the extent that the beam can be injected inside MR acceptance.
- SuperKEKB requirement must be satisfied for emittance including beam phase space jitter, called as effective emittance.
- Large amplitude beam position jitter has been measured at LINAC end.
- We evaluated that the effect of the beam position jitter to effective emittance and investigated the cause of the beam position jitter.

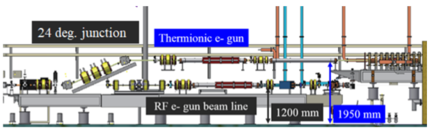


## SUMMARY

- Beam phase space jitter and effective emittance are reduced by dispersion suppression after J-ARC section.
- While, enhanced factor, which is ratio of before to after jitter emittance, is not significantly changed.
- Dependence on flux concentrator, solenoid, bridge coil, pulsed magnet, and chicane is small.
- Though the target hole is being suspected as a beam jitter source, both measured and simulated data (assumed design β) suggest that the wake field effect is small. We must check beta function after the target.

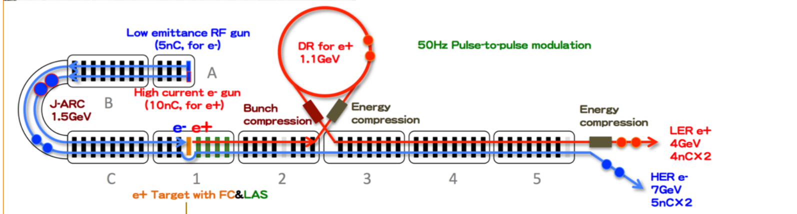

## SuperKEKB injector linac

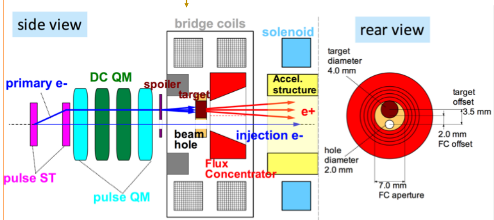


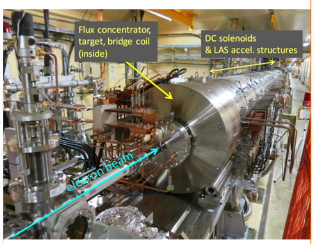




There are two type of electron gun in the LINAC; thermionic gun and RF gun.

- RF gun: SuperKEKB e- for low emittance beam.
- Thermionic gun: e- for SuperKEKB e+ generation or for PF and PF-AR.



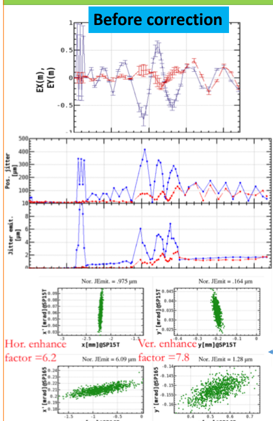




- Electron beam straightly pass through the positron generation target hole, which diameter is 2 mm.
- Electron come from upstream and pass through FC, target, bridge coil, and DC solenoid.
- After the DC solenoid, chicane for dump electron beam, that is generated together with positron beam.

## Dispersion suppression effect

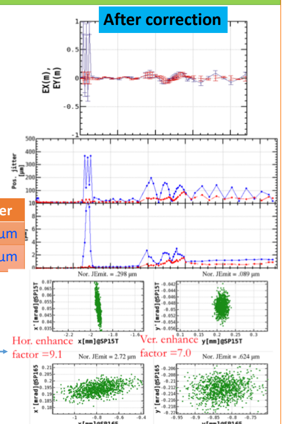
### Thermionic gun, 1nC



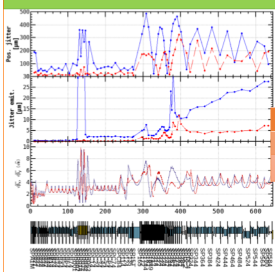

Dispersion correction

| Jitter emit. | Before | After |
|---|---|---|
| $\varepsilon_{xj}$ | 1.8 µm | 1.3 µm |
| $\varepsilon_{yj}$ | 1.8 µm | 0.9 µm |

No noticeable differences

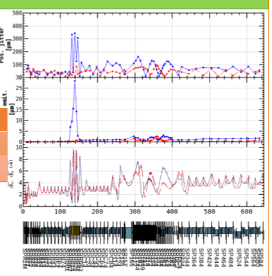



### RF gun, 1nC



Dispersion correction

| Jitter emit. | Before | After |
|---|---|---|
| $\varepsilon_{xj}$ | 28 µm | 1.8 µm |
| $\varepsilon_{yj}$ | 7 µm | 0.9 µm |



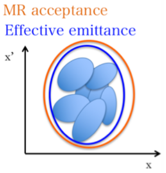
- Position jitter and effective emittance are reduced by dispersion suppression after J-ARC.
- While, enhanced factors, which is ratio of before to after jitter emittance, are not so changed. After the target, position jitter is still remained.

## Requirement to LINAC for SuperKEKB

- Low emittance & high charged beam transportation is required for SuperKEKB.
- Transported beam to MR must be stable to the extent that the beam can be injected inside MR acceptance.
- SuperKEKB requirement must be satisfied for emittance including beam phase space jitter, called as effective emittance.

SuperKEKB requirement for electron

| | H/V nor. emittance (µm) | Charge (nC) | Energy spread (σ) |
|---|---|---|---|
| Phase 2 | 150/150 | 1 | 0.1% |
| Phase 3 (goal) | 40/20 | 4 | 0.07% |




## Effective emittance and jitter emittance

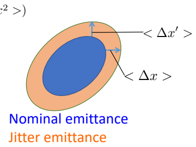
- Assuming that beam position and transfer matrix between two BPMs are identified, we can derive beam angle. Using the beam position and angle, effective emittance is derived by

$$\epsilon_{eff} = \sqrt{<(x+\Delta x)^2><(x'+\Delta x')^2> - <(x+\Delta x)(x'+\Delta x')>^2}.$$

- If beam jitter is independent of particle motion,

$$\epsilon_{eff} = \sqrt{\epsilon_0^2+\epsilon_j^2+\epsilon_0(\gamma_0<\Delta x^2>+2\alpha_0<\Delta x\Delta x'>+\beta_0<\Delta x^2>)}$$
$$= \sqrt{\epsilon_0^2+\epsilon_j^2+2\epsilon_0\epsilon_j(\frac{\gamma_0\beta-2\alpha_0\alpha+\beta_0\gamma}{2})}$$
$$= \sqrt{\epsilon_0^2+\epsilon_j^2+2\epsilon_0\epsilon_j B_{mag}}$$

$$\epsilon_0 = \sqrt{<x^2><x^2> - <xx'>^2},$$
$$\epsilon_j = \sqrt{<\Delta x^2><\Delta x^2> - <\Delta x\Delta x'>^2}.$$



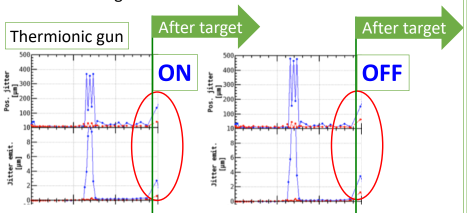

- $B_{mag}$ shows mismatch between measured Twiss parameters and that of design. The $B_{mag}$ is larger than or equal to 1. If there is not mismatch, $B_{mag}$ =1 and effective emittance is just $\epsilon_0 + \epsilon_j$.

$$B_{mag} = \frac{1}{2}(\gamma_0\beta - 2\alpha_0\alpha + \beta_0\gamma) = \frac{1}{2}\left[\frac{\beta}{\beta_0}+\frac{\beta_0}{\beta}+\left(\alpha_0\sqrt{\frac{\beta}{\beta_0}}-\alpha\sqrt{\frac{\beta_0}{\beta}}\right)^2\right] \geq 1$$

## Beam jitter source investigation around positron generation target

**Dependence on flux concentrator, solenoid, bridge coil, pulsed magnet, and chicane**

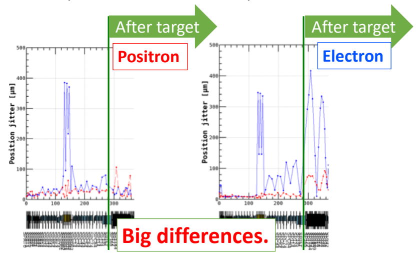
- We check whether these components are sources of jitter or not by turn off these components between BPMs before and after target.




No noticeable differences

**Positron beam, that does not pass though the target hole**

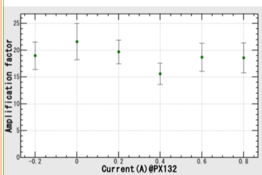
- Difference of positron beam (hits the target) and electron beam (through the target hole).
- It seems that target hole enhance beam position jitter remarkably. Wake field effect is suspected.



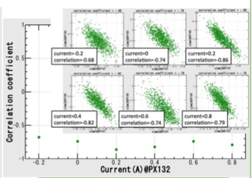

Big differences.

**Amplification factor and correlation coefficients**

- To find the wake field effect, beam position pass through the target hole was changed by steering magnet.
- From the beam position before and after target, amplification factor and correlation coefficients are derived.
- It seems that beam jitter dependence on beam position pass through the target is small.
- Wake effect is not found from this result.



Amplification factor

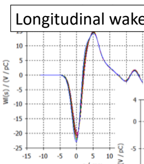


Correlation coefficients

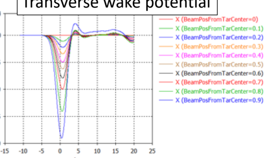
No noticeable differences

**Wake potential induced by the target hole.**

- Simulation analysis is also performing (CST studio).
- Though target hole size is small (ϕ2 mm), higher order wake field affect beam.
- Longitudinal wake has little position dependence. While, transverse wake increase nonlinearly.
- Enlargement factor is about 2 (assumed design β) even beam pass through the hole at 0.9mm from the center. This is smaller than the measured factor, ~20. We must check beta function after the target.



Longitudinal wake potential



Transverse wake potential

X = Beam position from the center of target hole.