# BEAM DYNAMICS IN ACCELERATING STRUCTURES OF THE JLC MAIN LINAC

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**Abstract :** Multibunch and single bunch motion with transverse wake field in the X-band accelerating structures in the JLC main linac was studied by tracking simulation.

## 1. Introduction

In JLC (Japan Linear Collider), 20 bunches, 1.4 nsec spacing, will be accelerated in one RF pulse. Each bunch is to have $2\times10^{10}$ particles. The vertical and horizontal normalized emittance is designed to be $3\times10^{-8}$ and $3\times10^{-6}$, respectively.

In section 2, tracking simulation for multibunch motion is reported. Because of the narrow spacing between bunches, the beams may become unstable due to the long range wake field in the accelerating structures. In the simulation, each bunch was assumed to be completely rigid, represented by one macroparticle. No longitudinal wake, but only transverse wake was taken into account. To suppress the instabilities, two types of cures have been considered. The first one is accelerating structures with very low Q-values (called 'damped structure'). The second is multicell structures with frequency spread (cell to cell frequency differences, called 'detuned structure'). Details of the structures for JLC are described in other reports[1],[2],[3]. Only damped structure was studied in this report.

In section 3, simulation for single bunch motion is reported. One bunch was divided into several slices in longitudinal direction and each slice was represented by a macroparticle. Energy distribution in a bunch and therefore 'BNS damping' was considered with the accelerating field and longitudinal short range wake field. Transverse short range wake function was assumed to be linear.

## 1. Multibunch

The simulation was performed for a simple model linac as follows.

Optics : FODO singlet cells, and averaged beta function is proportional to square root of the energy
Beta at the injection : 3 m
Phase advance per cell : $\pi/2$
Accelerating cavities' length : about 70 cm
Accelerating field : 80 MV/m.
Injection energy : 10 GeV
Final energy : 750 GeV
Total length : 9.2 Km
Total number of quadrupole magnets : 800
Total number of accelerating cavities : 13000

Transverse wake function of a dipole mode field can be written as follows.

$$W_T(s) = (1/2)(R/Q)\omega\sin(\omega t)\exp[-(\omega/2Q)t] \qquad (1)$$

where $\omega$ is frequency of the mode, Q is the loaded Q value of the mode.

Transverse momentum change of n-th bunch in a train can be written as

$$\Delta P_{Tn} = \Sigma_m q(1/2)(R/Q)_m(\omega_m/c)q\Sigma_{k=1}^{n-1} x_k\sin[\omega_m(n-k)t_b]\exp[-(\omega_m/2Q)(n-k)t_b] \qquad (2)$$

where q is the charge of bunches, $x_k$ is the displacement of k-th bunch and $t_b$ is the time spacing between bunches. m is an index for dipole modes. In JLC,

$q = 2\times10^{10}e$ and $t_b = 1.4$ nsec.

Parameters of three modes with large R/Q are as follows[1].

| R/Q (MΩ/m²) | ω/2π (GHz) | mode |
|---|---|---|
| 2.2 | 16 | $TM_{110}$ |
| 0.2 | 26 | $TM_{111}$ |
| 0.1 | 36 | $TM_{121}$ |

Because TM110 mode has the largest R/Q value and that of the other modes are one order smaller, only $TM_{110}$ mode was considered here.

Equation (2) shows that small Q and/or nearly integer $ft_b$ will suppress the effect of wake field. The dependence of the beam behaviors on the Q and f was studied.

Considering cavity alignment error, cavities were assumed to have vertical offset with respect to the center axis of the linac. Assuming that the offset is independent of each other and distributed randomly in a gaussian distribution with a standard deviation $\sigma_y$ but limited by a maximum $3\sigma_y$. Note that the vertical alignment tolerance is to be much tight than the horizontal one.

To measure beam qualities, consider total luminosity per train (20 bunches). Assume that the error distributes as gaussian and the shape of each bunch in the phase space is an ellipse of gaussian distribution which have emittance $\varepsilon_0$. Assuming that both electron and positron beams have the same qualities, then the total luminosity will be proportional to the inverse of square root of 'effective emittance'.

$$L \propto \Sigma\,(1/\varepsilon_{eff})^{1/2} \qquad (3)$$

where the summation should be taken for all bunches and 'effective emittance' of each bunch is defined as follows.

$$\varepsilon_{eff} = \varepsilon_0 + \varepsilon_{cm} \qquad (4)$$

where $\varepsilon_{cm}$ is 'emittance of center of mass' defined as

$$\varepsilon_{cm} = \gamma x^2 + 2\alpha x x' + \beta x'^2 \qquad (5)$$

where x and x' are obtained by the tracking simulation.

Let us define 'normalized luminosity',

$$L_n = \Sigma\,(\varepsilon_0/\varepsilon_{eff})^{1/2} \qquad (6)$$

which will be 20 if $\varepsilon_{cm}$=0. In this report, $\varepsilon_0$ is vertical emittance designed as follows.

$$(E/mc^2)\varepsilon_0 = 3 \times 10^{-8} \text{ rad m (vertical).} \qquad (7)$$

Fig. 1(a)-(d) show $L_n$ vs. frequency of the mode for Q=20 or 30 and $\sigma_y$=10 μm or $\sigma_y$=30 μm. Tracking with twenty different sets of random numbers (which were used for transverse misalignment distribution) were performed for each plot. Lines are drown for mean values and error bars show r.m.s. of the twenty results.

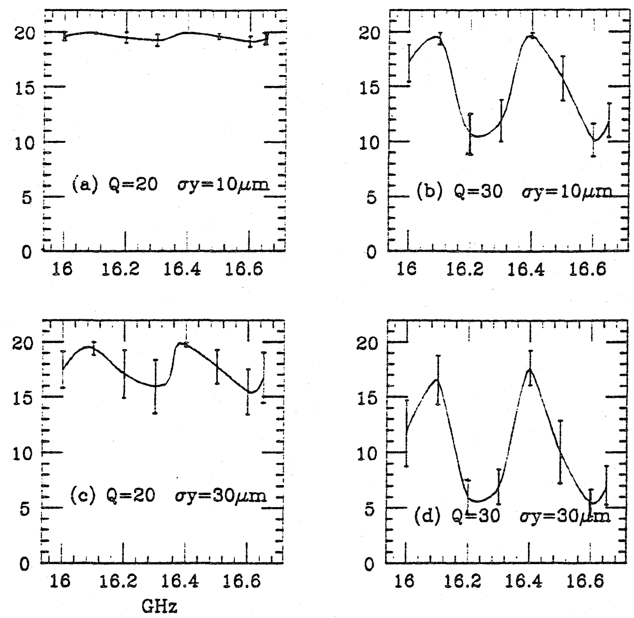


Fig. 1, $L_n$ vs. frequency of TM110, (a) Q=20, $\sigma_y$=10 μm, (b) Q=30, $\sigma_y$=10 μm, (c) Q=20, $\sigma_y$=30 μm, (d) Q=30, $\sigma_y$=30 μm

## 3. Single bunch

Single bunch motion was studied with short range longitudinal and transverse wake field. A bunch was divided into 41 macroparticles with uniform longitudinal spacing. Charge of each macro particle was calculated assuming gaussian like distribution where length between the head macro particle and the tail one was set to be 5-sigma of bunch length.

Parameters of the model linac are as follows.

| | |
|---|---|
| Injection Energy | 10 GeV |
| RF peak field | 100 MeV/m |
| Total length of RF structure | 7.4 Km |
| RF frequency | 11.42 GHz |
| Total bunch charge | $2\times10^{10}$ e |
| Bunch length ($\sigma_z$) | 75 μm |

Short range wake functions at z (m) were set to be as follows.

$$\text{Transverse}: W_T(z) = 2.3\times10^{20}\, z \quad (\text{V/C/m}^2) \qquad (8)$$

$$\text{Longitudinal}: W_L(z) = 2.6\times10^{15} - 9.7\times10^{16}\sqrt{z} + 1.1\times10^{18}\, z \quad (\text{V/C/m}) \qquad (9)$$

To avoid beam breakup due to transverse wake field, 'BNS damping' was incorporated. Energy spread can be controlled by changing the phase of RF field with respect to the bunch. A parameter 'offcrest ($\Delta z$)' is defined as the advanced distance of the bunch center with respect to the peak of RF. Fig. 2 shows energy spread at the end of linac (r.m.s.) vs. $\Delta z$. Note that minimum energy spread will be obtained with positive $\Delta z$ ($\approx$2 mm), because of the longitudinal wake field.

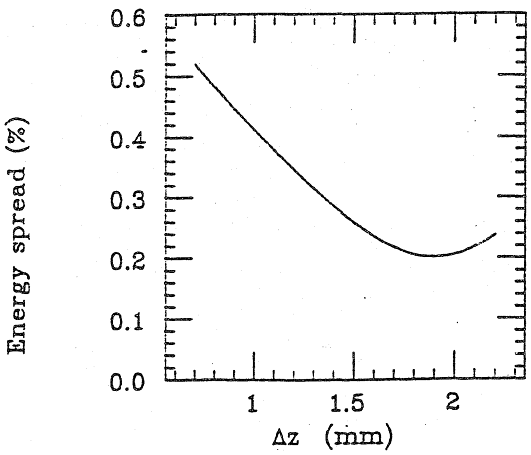


Fig. 2, Energy spread at the end of linac (r.m.s.) vs. $\Delta z$.

(a) Injection error

Fig. 3 shows normalized emittance at the end of the linac vs. $\Delta z$ with vertical injection error of 1 $\mu$m where the initial normalized emittance was $3\times10^{-8}$ rad•m. It shows $\Delta z$=1.4 mm is too large and 1.2 mm or less gives enough energy spread for BNS damping.

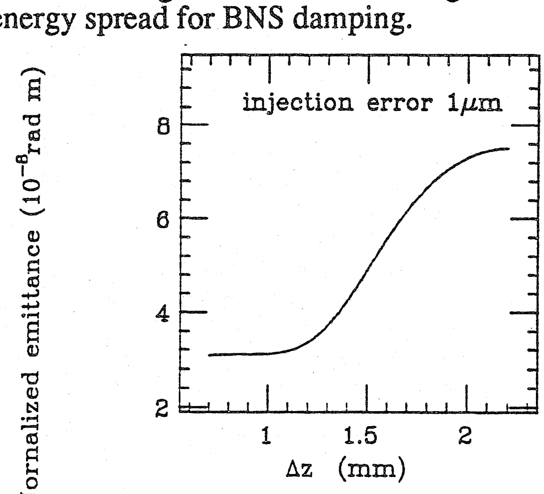


Fig. 3, Normalized emittance at the end of the linac vs. $\Delta z$

Energy spread should not be so large at the end of the linac, because energy acceptance of the final focus system will be $\approx\pm0.6$ %. Considering bunch to bunch energy difference, energy acceptance of a single bunch will be about $\pm0.45$ %. As it is necessary to reduce the energy spread only at the end, $\Delta z$ can be changed along the linac. Because beams with higher energy are more rigid, $\Delta z$ can be set larger at the last part of the linac than at the lower energy part.

(b) Cavity misalignment

With vertical misalignment of the accelerating structures, emittance at the end of the linac were calculated (Offcrest was chosen as $\Delta z$=1.0 mm. Because the misalignment is random and is much larger than beam oscillation amplitude, 'BNS damping' will not be effective). 10 different sets of random numbers for misalignment were used for $\sigma_y$=10$\mu$m and 30$\mu$m. The results were as follows (where the initial normalized emittance was $3\times10^{-8}$ rad•m).

| | | |
|---|---|---|
| $\sigma_y$=10$\mu$m | 3.94 $\pm$0.58 | ($\times10^{-8}$rad•m) |
| $\sigma_y$=30$\mu$m | 11.3 $\pm$4.9 | ($\times10^{-8}$rad•m) |

It is shown that the structures should be aligned within an accuracy of 10 $\mu$m with respect to the beam orbit.

## 4. summary

Simulation of multibunch motion showed that damped structure of Q$\approx$20 for the most important dipole mode (TM110) is acceptable, and that alignment tolerance of the accelerating structures is about 10 $\mu$m with respect to the beam.

Simulation of single bunch motion showed that 'BNS damping' is effective to suppress beam break up due to injection error, and that alignment tolerance of the accelerating structures is about 10 $\mu$m with respect to the beam.

## References


[1] T.Higo et al. 1991 IEEE Particle Accelerator Conference. KEK preprint 91-32.

[2] M.Yamamoto et al. This workshop.

[3] T.Taniuchi et al. This workshop.