ALIGNMENT ISSUES FOR C-BAND LINEAR COLLIDER

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Abstract

For future linear colliders, very low emittance beams will be required to achieve high luminosity. To preserve the low emittance through the main linacs, precise alignment of accelerating structures and magnets will be one of the most important issues. For our design of C-band Linear Collider, tolerances of misalignment in the main linacs are estimated and techniques to achieve the requirements are discussed.

1. ACCELERATING STRUCTURES

1.1 Estimation of Alignment Tolerance

Alignment tolerances of accelerating structures were estimated using tracking simulations and a numerical method[1] taking into account short range transverse wakefields, which was assumed to be a linear function of the distance. Multibunch effects caused by long range wakefields are ignored because we will choose choke mode cavity structures[2] in which higher order mode fields will be heavily damped.

For short bunch beams, alignment tolerance of accelerating structures is proportional to inverse of the slope of the short range transverse wake field, W', which was assumed to be constant (see Appendix). The short range transverse wake fields were calculated by Yokoya[3] for constant impedance disc-loaded structures. The strength of the wake fields depends on the aperture of the structures. Fixing the resonant frequency of the fundamental mode and the length of a cell, W' at distance 400 μm, which is 2σ of the bunch length, is found to be approximately proportional to $a^{-3.5}$ where a is the aperture radius. Because our structures are designed to be constant gradient with different cell to cell apertures, we took the average of $a^{-3.5}$ of all cells to estimate the wake fields. We used $a/\lambda(average)=8.0\mathrm{mm}$ or $a/\lambda(average)=0.152$ and obtained $W'=1.0\times10^{19}\ V/C/m^3$ where λ is the wave length of the fundamental mode.

Parameters used for the simulation are listed in the table 1[4]. The injection energy and final beam energy were set to be 20 GeV and 250 GeV respectively. The lattice was a FODO lattice with a beta function that varies approximately as square root of the beam energy. Number of accelerating structures between quadrupole magnets is even number and varies also approximately as square root of the beam energy.

Table 1. Parameters used for the simulation.

Accelerating frequency	5.712 GHz
Beam energy	from 20 to 25o GeV
Loaded gradient	31.3 MeV
Phase advance/FODO cell	45 ~ 90^{o}
Length of a FODO cell	from 8.7 to 25.5 m
Charge per bunch	$1.11\times10^{10}\,e$
Bunch length (σ)	200 μm
Normalized emittance	3×10^{-8} m-rad
Length of acc. structure	1.8 m
Average aperture radius	8.0 mm
Slope of transverse wake	1.0×10^{19} V/C/m^3

As discussed in the reference [1], tolerances depend on the length of the alignment unit. Assuming that structures are perfectly straight in each unit and that each unit is aligned with respect to the beam line with random transverse offset, the alignment tolerance is proportional to inverse of square root of the unit length if the length is small compared with the beta function. The reason is that the effects of the wakefields can be averaged over the length comparable to the beta function, phase advance of betatron oscillation by one radian.

In the case that each 1.8 m long structure is an alignment unit, the estimated tolerance for vertical displacement is 30 μm for 25% emittance growth.

1.2 Alignment

Because it will be necessary to align accelerating structures with respect to the beam in rather tight tolerances, a cavity type BPM will be attached at each end of structures and the transverse positions will be adjusted by fine movers.

The accuracy of this kind of BPMs was tested in the FFTB facility at SLAC[5]. The test showed that BPMs can be constructed and attached using usual machining and brazing techniques in accuracy of a few microns. This accuracy is small compared with the alignment tolerance of structures assuming that each structure is constructed perfectly straight. It means that there is no difficulties to align each structure.

In practice, two or more structures will be set on an alignment girder which has fine movers. It is not necessary to adjust all BPMs on a girder to exact zero points because the effects of the wakefields will depend only on the average of misalignment. Then, how many structures on a girder or how many movers for one girder is not essentially important. The number of BPMs for a structure is important to measure the average displacement of structures (in length comparable to the beta function) on a girder.

1.3 Requirement for straightens

Assuming that both ends of each structure is placed precisely, effects of wakefields will be proportional to the average transverse displacement caused by construction error of the structure. Tolerance of cell-to-cell displacement will be much loser than alignment tolerance of whole structure if the displacement of cells are randomly distributed. In practice, bow of each structure, which will come both the construction error and deformation after construction, will be most important. Assuming the shape of a structure is sinusoidal, the transverse displacement at position z of a structure with length l is

$$\Delta y(z) = b\sin(\pi z / l) \ ,$$

the average from 0 to l is

$$\overline{\Delta y} = \frac{2}{\pi} b \approx 0.64b$$

where b is the peak of the deformation. It means that the tolerance for this kind of deformations is loser than the tolerance of alignment of a whole structure by factor of about 1/0.64, 50 μm for 25% emittance growth.

We expect it is not difficult to achieve this requirement. To make it easier, we will apply a low temperature brazing technique[6] to fabricate the structure[2]. It would be also possible to make some mechanical correction measuring the deformation after construction of the structure.

2. QUADRUPOLE MAGNETS

The main source of emittance growth due to misalignment of quadrupole magnets is dispersion created from a non straight orbit. The precise value of the tolerance depends on energy spread, both initial spread at injection and spread created in the linac by position dependence of the accelerating field and longitudinal wakefields.

In practical designs, tolerance for random displacement of magnets without any corrections (feedbacks) is about 50 nm. This gives requirements for vibrations of magnets and ground motions faster than feedback routines. The alignment tolerance of quadrupole magnets with feedbacks, which means tolerance for the random displacements with respect to the beam, is a few microns.

Every quadrupole magnet will be set on an individual table which have fine movers for transverse alignment. Changing strength of quadrupole magnets and measuring beam positions by BPMs, transverse displacement of the magnets with respect to the beam can be evaluated. The accuracy of the displacements will depend on the resolution of the BPMs, measurement to measurement error. It will not depend on fixed errors as the alignment error of BPMs which is usually much larger than the resolution. We expect the resolution of BPMs and the accuracy of movers can be as small as 1 μm, which will give better alignment than the requirements. After the initial alignment, to make the feedback faster, steering magnets will be used instead of movers. Only after large ground motions, the alignment will be needed again[7].

It should be noticed that in general, a stronger focusing lattice design (it means a small beta function) gives tighter tolerance for quadrupole magnets but loser tolerance for accelerating structures. And weaker focusing gives the opposite. There is possibility to change strength of focusing to ease the alignment requirement for either quadrupole magnets or accelerating structures if the requirement for the other can be tightened.

3. SUMMARY

From our estimation, accelerating structures should be aligned with accuracy better than 30 μm and fabricated with straightness within 50 μm. Tolerance for the alignment of quadrupole magnets is a few microns. We expect those requirements are not difficult to achieve using techniques which have been or being established.

APPENDIX

As discussed in references [1],[8] and [9], assuming that the beam oscillation is negligibly small compared with typical misalignment of structures and all structures have the same shape of wake function, expected increase of emmitance is proportional to square of "r.m.s. of sum wake" defined as

$$S_{rms}^2 = \sum_m q_m S_{a,m}^2 \Big/ \sum_m q_m$$

where m is index of particles, q_m is the charge m-th particle and

$$S_{a,m} \equiv S_m - \sum_m q_m S_m \Big/ \sum_m q_m$$

$$S_m \equiv \sum_k q_k W_1(z_m - z_k)$$

where z_m and z_k are longitudinal positions of m-th and k-th particles, $W_1(z)$ wake function and summations are taken for all particles in the beam. Introducing longitudinal charge distribution $\rho(z)$,

$$S_{rms}^2 = \int_{-\infty}^{\infty} dz'\, \rho(z') S_a^2(z') \Big/ \int_{-\infty}^{\infty} dz'\, \rho(z')$$

$$S_a(z) \equiv S(z) - \int_{-\infty}^{\infty} dz'\, \rho(z') S(z') \Big/ \int_{-\infty}^{\infty} dz'\, \rho(z')$$

$$S(z) \equiv \int_{-\infty}^{\infty} dz'\, \rho(z') W_1(z - z') \ .$$

In the case of a short single bunch beam, wake function is approximately linear,

$$W_1(z) = \begin{cases} zW' & (z > 0) \\ 0 & (z \le 0) \end{cases}$$

$$S(z) = \int_{-\infty}^{z} dz'\, \rho(z')(z - z')W'$$

For Gaussian distribution with r.m.s. σ_z,

$$S_{rms}^2 \approx \frac{0.91}{\pi} \sigma_z^2 W'^2 \ .$$

Because expected increase of emmitance is also proportional to square of r.m.s. misalignment of accelerating structures, the tolerance for some increase will be proportional to bunch length σ_z and slope of wake function W'.

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