RF KICK IN THE ILC ACCELERATION STRUCTURE*

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Abstract

Detailed results of estimations and simulations for the RF kick caused by input and HOM couplers of the ILC acceleration structure are presented. Results of possible beam emittance dilution caused by RF kick are discussed for the main LINAC acceleration structure, and the RF structures of the ILC bunch compressors BC1 and BC2. Methods of the RF kick reduction are discussed.

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INTRODUCTION

The standard 1.3 GHz SC RF cavity of the ILC linac contains 9 cells, the input coupler, and two HOM couplers, upstream and downstream, see Figure 1.

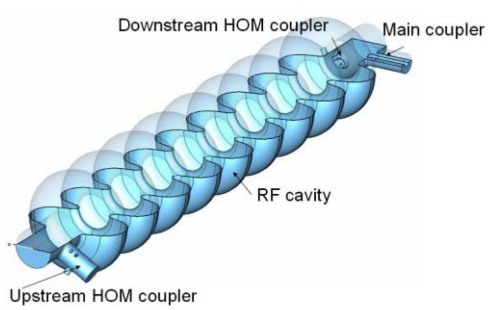

Figure 1. The ILC RF cavity with the main and HOM couplers.

The couplers break the cavity axial symmetry that causes a) main RF field distortion and b) transverse wake field. This RF field distortion may cause a transverse kick that may result in turn in the beam emittance dilution. The first estimations [1,2] of this RF kick showed that it may be a serious problem.

GENERAL

It is possible to estimate of the RF kick caused by the main coupler, see Figure 2. The RF voltage U in the coaxial line may be estimated as $U = (2PZ)^{1/2}$, where P is an input power and Z is the coaxial line impedance. For P=300 kW and Z= 70 Ohms one has U=6 kV. Transverse kick

$$\Delta p_y c \approx e\int E_y(z)dz \approx \frac{eU}{D}\cdot\frac{D}{2} = \frac{eU}{2}, \qquad (1)$$

where E_y is transverse electric field of the coupler on the axis, D is the beam pipe diameter. The ratio of the RF kick over the acceleration gain per 9-cell cavity V_a is

$$\frac{\Delta p_y c}{V_a} \approx \frac{U}{2V_a} = \frac{6kV}{2\times 30MV} = 100\times 10^{-6} \qquad (2)$$

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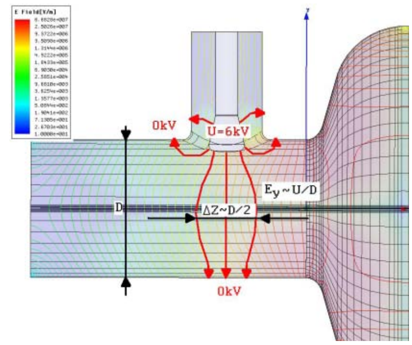


Figure 2. Layout and the field pattern of the input coupler.

The kicks from the HOM coupler have the same order. Transverse kick caused by the couplers acts on a bunch the same direction for all the RF cavities of the linac. Real part may be corrected by Beam-Based Alignment techniques; imaginary part dives the beam emittance dilution.

For RF kick calculations ANSOFT HFSS code [3] was used. Note, that according to (2), in order to provide reliable data of the RF kick, the field calculation precision is to be better than 10^{-5}. To provide this precision, the fine mesh near the cavity axis was used, see Figure 3. The total number of the mesh nodes was up to 500,000. Driven modal method was used for the calculations.

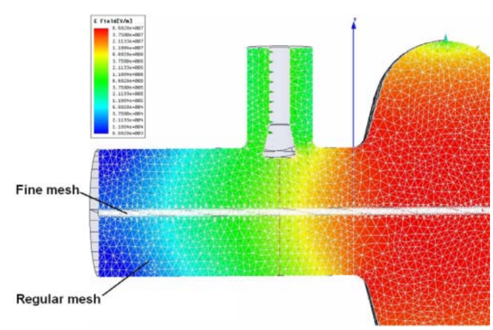
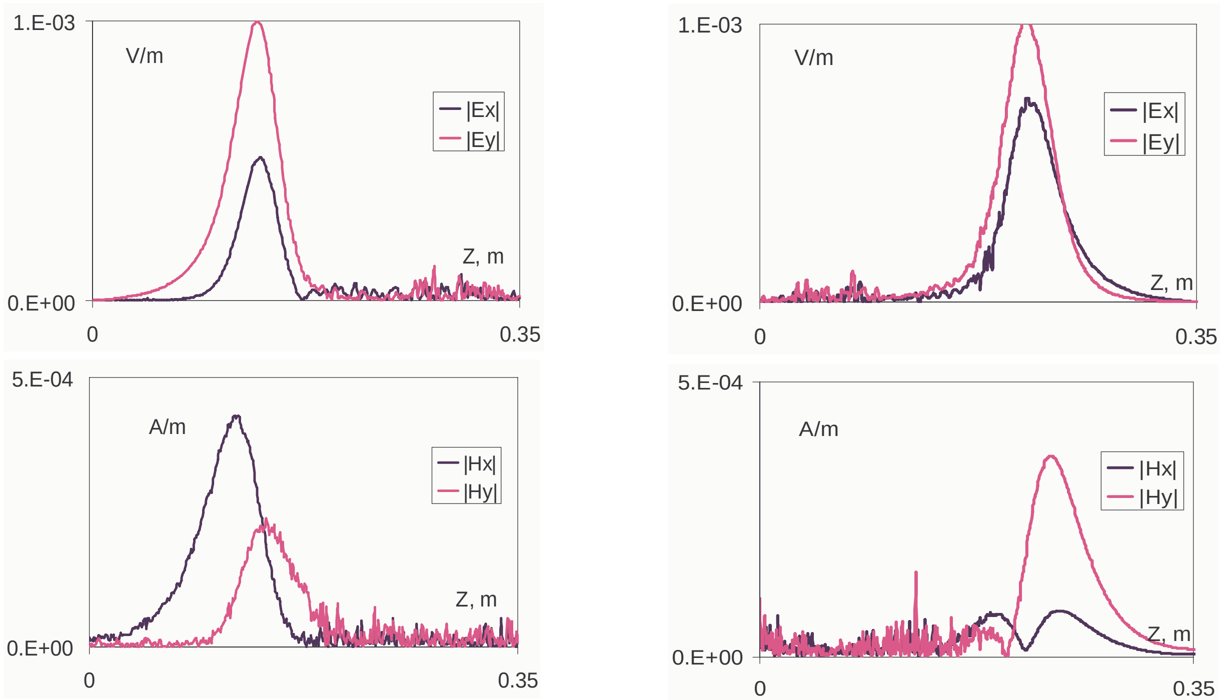


Figure 3. The mesh used for RF-kick calculations.

The axial distributions of RF fields for upstream and downstream couplers are shown in Figure 4. In blue are shown the amplitudes of x components of electric and magnetic fields and in red the y components. One can see the noise in the cavity, where the longitudinal (accelerating) field is high, but transverse (kick) field is small. In order to cross-check the results of direct integration of transverse field components, the kick was calculated also using Panofsky-Wenzel (PW) theorem after integration of the longitudinal component. In Table I the final results of the RF kick calculation are presented. The kick module for downstream couplers is close to the simple estimation (2). One can see a good agreement between the direct integration and PW.



Upstream coupler Downstream coupler

Figure 4. Transverse electric and magnetic fields along the axis for upstream and downstream couplers. The fields are normalized to the maximal axial acceleration field in the cavity.

Table I. The RF kick for upstream and downstream couplers.

		Direct integration	P-W theorem
Upstream HOM coupler	$10^6 V_{0x}/V_a$	-68.8+3.7i	-65.6+7.6i
	$10^6 V_{0y}/V_a$	-48.3-3.4i	-53.1-2.1i
Downstream HOM&main couplers	$10^6 V_{0x}/V_a$	-36.5+66.1i	-27.3+67.2i
	$10^6 V_{0y}/V_a$	41.0+14.5i	40.9+12.8i

The results are in agreement with calculations presented in [1,2]. In general case, if the cavity operation phase is φ, the kick may be expressed the following way:

$$\vec{V}/V_a = (\vec{V}_0/V_a)e^{i\varphi} \qquad (3)$$

The RF-kick for the main linac, for the first stage of a bunch compressor (BC1) and for the first stage of a bunch compressor (BC2) are shown in Table II.

The RF kick influence on the vertical emittance is the most critical. The vertical r.m.s. emittance increase $\delta(\gamma\varepsilon)_y$ in the main linac caused by RF kick may be estimated in smooth approximation for the focusing system (i.e., for β=*const* along the linac) the following way [4]:

$$\delta(\gamma\varepsilon)_y \approx \frac{4\pi^2[\mathrm{Im}(V_y/V_a)]^2 G^2\sigma^2\beta^3\gamma_0}{3\lambda_{RF}^2 U_0^2} \qquad (4)$$

Table II. The RF kick for the main linac, BC1 and BC2.

Main linac, φ=-5.1°	Upstream	$10^6 V_x/V_a$	-82.2+9.8i
		$10^6 V_y/V_a$	-48.4+0.9i
	Downstream	$10^6 V_x/V_a$	-30.5+60.1i
		$10^6 V_y/V_a$	42.1+10.8i
BC1, φ=-105°	Upstream	$10^6 V_x/V_a$	21.4+65.5i
		$10^6 V_y/V_a$	9.2+47.5i
	Downstream	$10^6 V_x/V_a$	73.3+18.1i
		$10^6 V_y/V_a$	3.4-43.4i
BC2, φ=-27.6°	Upstream	$10^6 V_x/V_a$	-56.3+35.2i
		$10^6 V_y/V_a$	-44.4+19.3i
	Downstream	$10^6 V_x/V_a$	-1.7+75.5i
		$10^6 V_y/V_a$	43.1-16.2i

where G is an average acceleration gradient, σ is the r.m.s. bunch length, β is an average β–function, λ_{RF} is the RF wavelength, U_0 is the beam initial energy, and γ_0 is a relativistic factor that corresponds to this energy. For G=23.9 MeV/m (that corresponds to the gradient in the 1.3 GHz ILC cavity of 31.5 MeV/m), σ =0.3mm, β =83 m, U_0 =15 GeV one has $\delta(\gamma\varepsilon)_y$ ~0.13 nm.

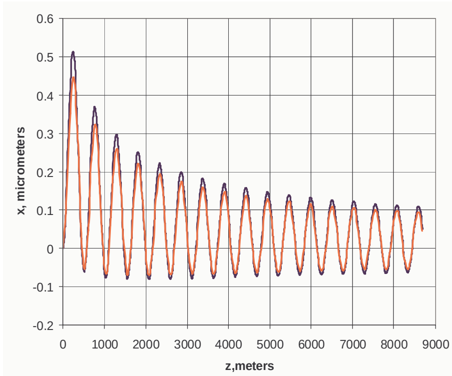


Figure 5. The electron trajectory calculated by PLACET (red) and analytically, based on the smooth approximation for the focusing system (blue).

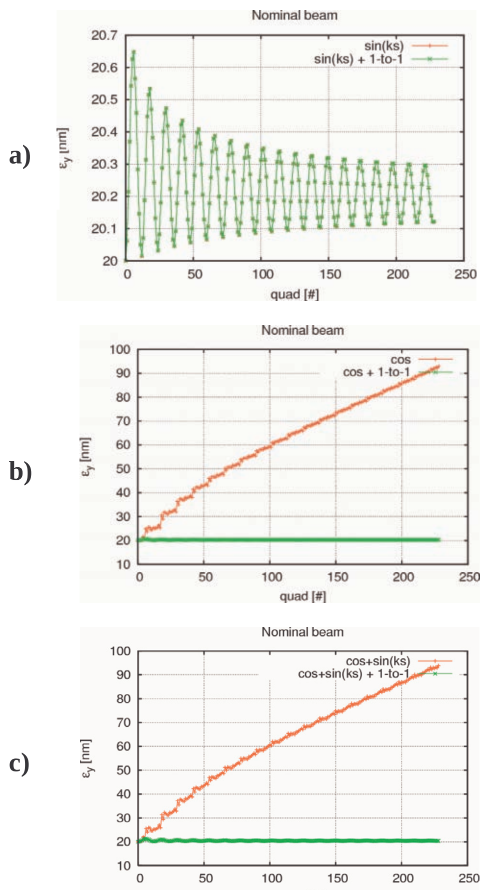


Figure 6. The emittance behavior along the main linac. On the horizontal axis the quad number is shown.

Simulations using PLACET code [5] were made in order to estimate the emittance dilution caused by RF kick. First of all, in order to validate the code, one particle dynamics were calculated. In Figure 5 the particle trajectory is shown evaluated by PLACET, and calculated analytically based on smooth approximation for the focusing system. One can see a good agreement. Figure 6a the vertical emittance evolution is shown for the initial emittance of 20 nm, when only imaginary part of the kick was taken into account. One can see that the emittance dilution is about 0.1 nm that is in good agreement with the estimation (4). In Figure 6b the emittance evolution is shown when the real part of the kick is taken into account that is corrected by Beam-Based Alignment techniques (green curve), and without correction (red curve). The emittance dilution is 73 nm without correction, and 0.23 nm with 1-to-1 correction. In Figure 6c the emittance behavior is shown when both imaginary and real part of the kick is considered in presence of the correction by Beam-Based Alignment (green curve) and without correction (red curve). The emittance dilution is 73.8 nm without correction, and 0.35 nm with 1-to-1 correction, that is not significant taking into account that the maximal emitance growth in the linac should not exceed 5 nm. However, in the bunch compressors BC1 and BC2, where the bunch length is equal to 9 mm and 1 mm respectively, the influence of the kick is more significant. In Figure 7 the emittance evolution in BC1 and BC2 is shown calculated by LUCRETIA [6]. The vertical emittance increase after BC1 is about 1.8 nm, and after BC2 is 4 nm, that is not acceptable. Note that for BC1 and BC2 rotation of the HOM couplers around the axis [2] doesn't help, and another means should be used, e.g., rotation of the entire cavity [2], or design of the new couplers that do not break axial symmetry [4]. Another approach is to redesign the focusing system in order to achieve the total betatron phase advance 360º, or 720º. In this case the r.m.s. emittance has a minimum, see Figure 7.

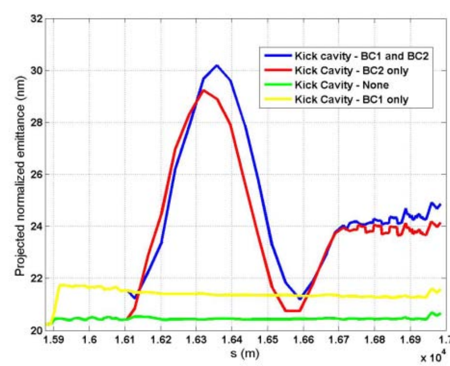


Figure 7. Emittance evolution in the bunch compressor.

REFERENCES

[1] M. Dohlus, "Field asymmetries and kicks," http://www.desy.de/~dohlus/2004/2004.09.holgers_seminar/asym&kick_sep2004.pdf

[2] I. Zagorodnov and M. Dohlus, "Coupler kick," http://www-zeuthen.desy.de/ILC/lcws07/pdf/ML/zagorodnov_igor.pdf

[3] http://www.ansoft.com

[4] V. Yakovlev, *et al*, "Coupler RF kick simulations," SLAC Wakefest2007, http://ilcagenda.linearcollider.org/getFile.py/access?contribId=2&sessionId=0&resId=1&materialId=slides&confId=2378

[5] Tracking code PLACET, https://savannah.cern.ch/projects /placet/

[6] The LUCRETIA Project, http://www.slac.stanford.edu/accel/ilc/codes/Lucretia-orig/web/overview.html