TRANSVERSE WAKE FIELD SIMULATIONS FOR THE ILC ACCELERATION STRUCTURE*

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Abstract

Details of wake potential simulation in the acceleration structure of ILC, including the RF cavities and input/HOM couplers are presented. Transverse wake potential dependence is described versus the bunch length. Beam emittance dilution caused by main and HOM couplers is estimated, followed by a discussion of possible structural modifications allowing a reduction of transverse wake potential.

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.

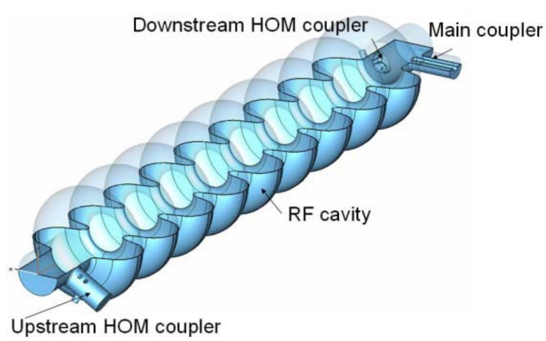

Figure 1: The ILC RF cavity with the main and HOM couplers.

The couplers break the cavity axial symmetry that causes a) main RF field distortion and b) transverse wake field. The wake field estimations [1,2] show that wake fields may be a serious problem that could require the cavity improvement.

GENERAL

Transverse wake caused by the couplers is not zero even if the bunch propagates along the cavity axis. The wake dependence *vs.* transverse coordinates *x,y* may be expressed the following way:

$$\begin{pmatrix} W_x(x,y,s) \\ W_y(x,y,s) \end{pmatrix} = \begin{pmatrix} W_x(0,0,s) \\ W_y(0,0,s) \end{pmatrix} + \begin{pmatrix} \frac{\partial W_x}{\partial x} & \frac{\partial W_x}{\partial y} \\ \frac{\partial W_y}{\partial x} & \frac{\partial W_y}{\partial y} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \quad (1)$$

The second term is determined mainly by the acceleration structure while the first on is determined by the couplers. The transverse wake from a small single obstacle doesn't depend on the bunch length, it has capacitive character for short bunches [2,3].

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However, the transverse wake of the periodic system that includes the cavities and couplers depends on the bunch length as shown later, and it is necessary to calculate the wake induced by the short bunch. For ILC the r.m.s. bunch length is 0.3 mm. The wake calculation for a periodic system shown in Figure 1 with the short bunch present serious difficulties because the mesh size should be small enough in order to provide calculation stability and accuracy.

The calculations of wake field on the cavity axis for the ILC cavities with the couplers were performed by GdfidL code [4]. The code utilized the moving mesh and Strang splitting scheme, that allows fulfill these simulations successfully using a cluster of multi-core CPUs.

First of all, the wake filed for a single HOM coupler was calculated. In the Figure 2 layout of the coupler unit is presented as well as the transverse wake dependence on the longitudinal coordinate *s* for different bunch lengths σ. One can see that the wake is almost the same for the bunches with the length from 1 mm to 3mm.

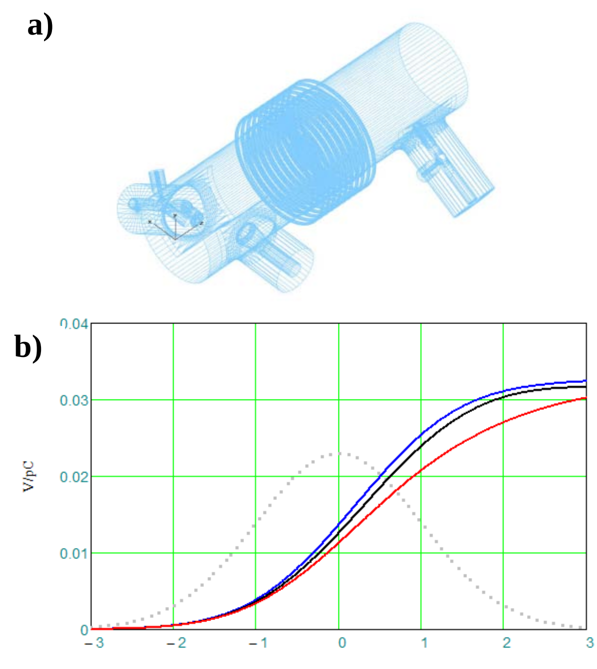

Figure 2: The coupler unit layout (a), and horizontal wake (b) vs. *s* for σ =1 mm (red), 2 mm (black) and 3 mm (blue).

The GdfidL model of the periodic structure containing the cavity and HOM couplers is shown in Fig. 3. The wake was calculated without indirect integration for the structure containing up to 8 periods. The vertical and horizontal kick per period after the different number of periods is shown in Figure 4. One can see that the difference does not change after 4th period even for σ = 0.2 mm.

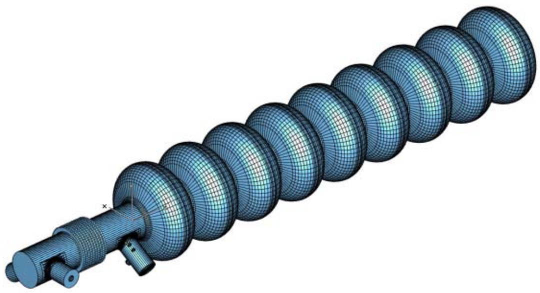

Figure 3: One period of the ILC RF system containing the cavity and couplers.

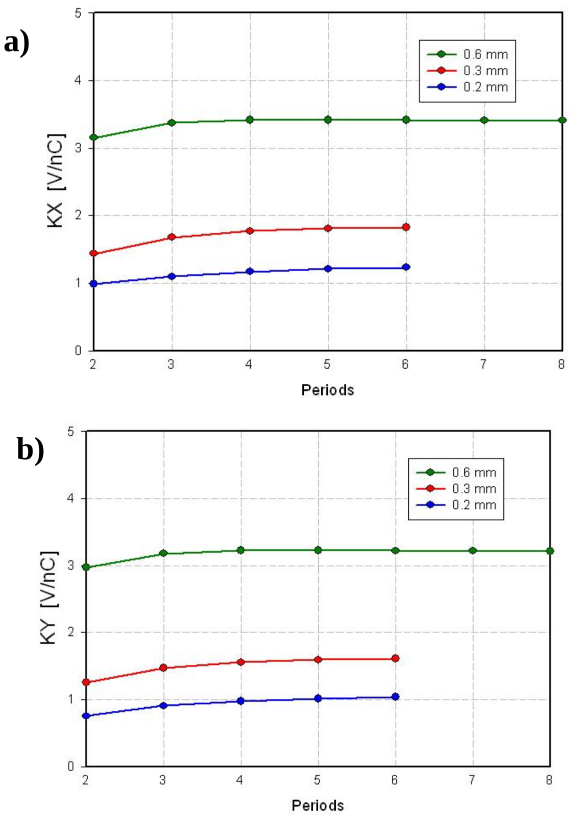

Figure 4: Horizontal (a) and vertical (b) kick per period after the different number of periods for σ = 0.2 mm (blue), 0.3 mm (red), and 0.6 mm (green).

The kick dependence versus the mesh size h is shown in Figure 5. One can see, that the kick does not change when σ/h = 6. In Figure 6 the wake field dependence on the longitudinal coordinate s is shown for different mesh sizes for σ =0.3 mm. One can see that the wake is the same for σ/h =3, and for σ/h =4. The kick dependence on the bunch length for is shown in Figure 7 (solid curves). For σ < 2 mm the kick depends linearly on the bunch length. Dashed curves show the kick dependence versus the bunch length for the upstream coupler rotated by 180º versus the axis as suggested in [5]. In this case the system is almost symmetrical versus horizontal plane, and vertical kick is very small. Note that horizontal and vertical kicks are close for the original geometry, but for modified geometry vertical kick is well compensated, but horizontal kick is not compensated perfectly.

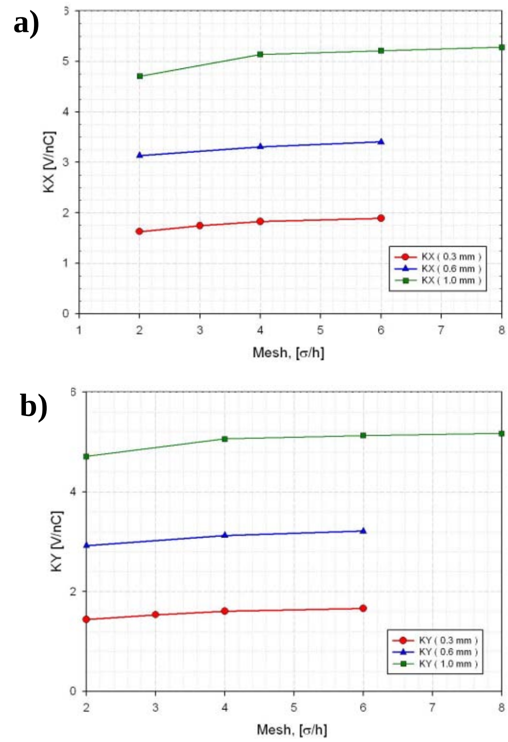

Figure 5: Horizontal (a) and vertical (b) kick per period versus the mesh size for σ = 0.3 mm (blue), 0.6 mm (red), and 1.0 mm (green).

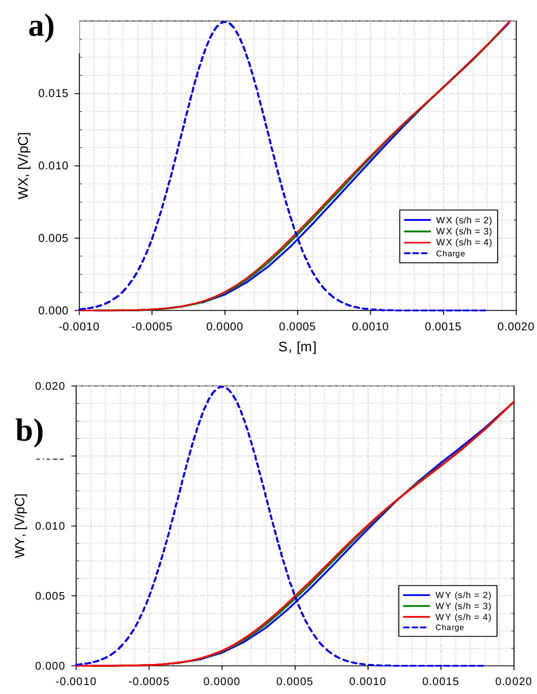

Figure 6: The wake field wake dependence on the longitudinal coordinate s for different mesh size for σ =0.3 mm.

The wake caused by the couplers leads to the emittance dilution. In order to make simple estimations of the emittance dilution, it is possible to consider the focusing system in smooth approximation. In this case the equation of motion of the particle having the distance s from the bunch center is the following:

$$\frac{d}{dz}\left(\gamma(z)\frac{dy}{dz}\right)+\gamma(z)y/\beta^2=\frac{QW_y(0,0,s)\gamma(0)}{U_0}, \qquad (2)$$

where y is vertical coordinate, z is longitudinal coordinate, $\gamma(z)$ is relativistic factor, β is average β–function, Q is the bunch charge, and U_0 is the beam initial energy. For $(d\gamma/dz)\beta/\gamma(z)<<1$ one can obtain solution of (2) with the initial conditions of $y(0)=0$ and $y'(0)=0$:

$$x(z)\approx\frac{QW_y(0,0,s)\beta^2}{U_0}\left(\frac{\gamma(0)}{\gamma(z)}\right)^{\frac{1}{2}}\left[\cos(z/\beta)-\left(\frac{\gamma(0)}{\gamma(z)}\right)^{\frac{1}{2}}\right], \qquad (3)$$

$$x'(z)\approx-\frac{QW_y(0,0,s)\beta}{U_0}\left(\frac{\gamma(0)}{\gamma(z)}\right)^{\frac{1}{2}}\sin(z/\beta),$$

The order of r.m.s. emittance dilution may be estimated from (3) the following way:

$$\Delta(\gamma\varepsilon)\approx\frac{1}{3}\gamma(z_{\max})<x_{\max}x'_{\max}>=$$

$$=\frac{Q^2<W_y^2(0,0,s)>\beta^3\gamma(0)}{3U_0^2}\left[1+\left(\frac{\gamma(0)}{\gamma(z_{\max})}\right)^{\frac{1}{2}}\right]\approx \qquad (4)$$

$$\approx\frac{Q^2<W_y^2(0,0,s)>\beta^3\gamma(0)}{3U_0^2}.$$

For ILC parameters Q=3.2 nC, β=83 m, U_0=15 GeV and $<W_y^2(0,0,s)>$=9.4·10^{-5} V^{2}pC^{-2}m^{-2} (see Figure 6) the emittance dilution is about 24 nm, that is unacceptable. For the cavity with the upstream coupler rotated by 180° $<W_y^2(0,0,s)>$=2.6·10^{-6} V^{2}pC^{-2}m^{-2} and one has $\Delta(\gamma\varepsilon)$ ~ 0.7 nm, that is much smaller that the total acceptable value of 5 nm. Thus, the upstream coupler rotation allows reduce the emittance dilution caused by the wake from the couplers to acceptable level.

SUMMARY

The wake fields in the ILC SC cavity caused by the main and HOM couplers are calculated for wide range of the bunch lengths form 0.2 mm to 8 mm using the code GdfidL. Calculations were made for periodic structure that contains the downstream HOM coupler, main coupler, bellows, upstream coupler, and acceleration structure. Calculation convergence versus the mesh size was tested and achieved. Convergence versus the number of periods was achieved also. It is shown that for short bunches the kick factor depends linearly versus the bunch length. The emittance dilution caused by the wake is estimated and found unacceptable. It is shown that for the structure with the upstream coupler rotated by 180° the vertical wake is small enough, and the vertical emittance dilution is acceptable.

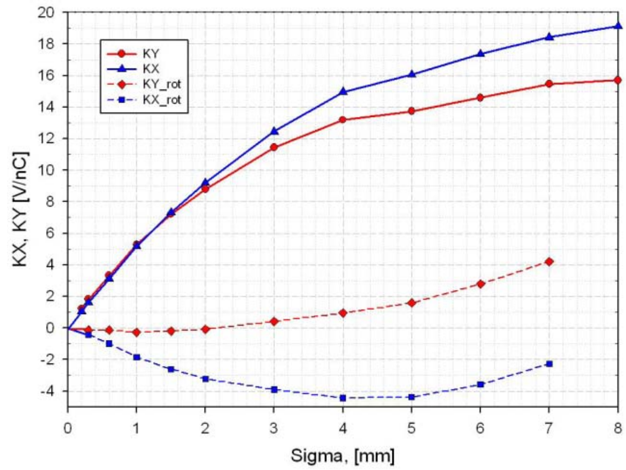

Figure 7: The horizontal (solid blue) and vertical (solid red) kick dependence versus the bunch length σ. Dashed curves show the kick dependences for the upstream coupler rotated by 180º versus the axis.

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