FINAL RESULTS ON RF AND WAKE KICKS CAUSED BY THE COUPLERS FOR THE ILC CAVITY

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Abstract

In the paper the results are presented for calculation of the transverse wake and RF kick from the power and HOM couplers of the ILC acceleration structure. The RF kick was calculated stand-alone by HFSS, CST MWS and COMSOL codes while the wake kick was calculated by GdfidL. The calculation precision and convergence for both cases are discussed and compared to the results obtained independently by other group.

INTRODUCTION

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

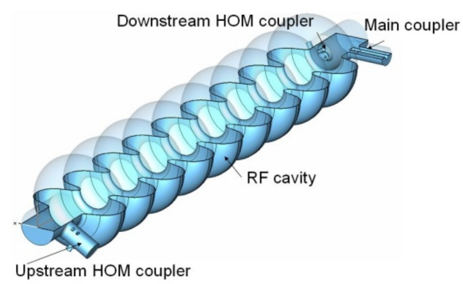

Figure 1: The ILC RF cavity with the main and HOM couplers.

The couplers break the cavity axial symmetry that causes a) main RF field distortion and b) transverse wake field. These effects may cause beam emittance dilution. RF-kick and coupler wake increase with the bunch length. Calculations of RF kick and transverse wake kick for the ILC cavity have been performed by different groups, with mismatching results[1,2,3,4].

In order to understand the difference we carefully investigated the convergence of both RF and wake kicks calculations and cross checked the final results with alternative RF codes.

RF KICK

For the reliable estimation of the RF kick we used the following approaches: (i) different mesh geometry, (ii) different mesh size, (iii) different order of finite elements, (iv) different methods of the kick calculations (direct and Panofsky – Wenzel theorem), (v) different codes (HFSS, CST, COMSOL, OMEGA3P), and (vi) unified post processing algorithm.

A special symmetric mesh patterns were used in order to reduce the mesh noise. For HFSS case a gradual three-zone mesh was applied to improve the field approximation near the axis; the fully symmetrical hexahedral mesh locked to the axis was used for CST MWS calculation; and highly regularized tetrahedral mesh was built by versatile COMSOL mesh generator (see Fig. 2).

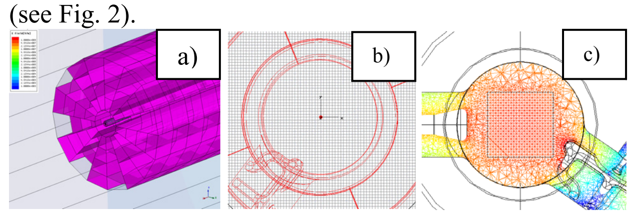

Figure 2: The three variant of meshes: a) HFSS, b) CST MWS, c) COMSOL used for RF kick simulations

The above mentioned mesh techniques enable to calculate smooth transverse field components on the axis and therefore obtain reliable results of RF kick after the data post processing. The comparison of electric and magnetic fields calculated by different RF codes is shown in Fig. 3. The OMEGA3P simulation was done independently by SLAC team [4]. All codes give almost the same results of electric field while OMEGA3P gives about 20% lower magnetic field. The HFSS shows a high noise in the magnetic component because of the rough method used to restore a magnetic field from an electric.

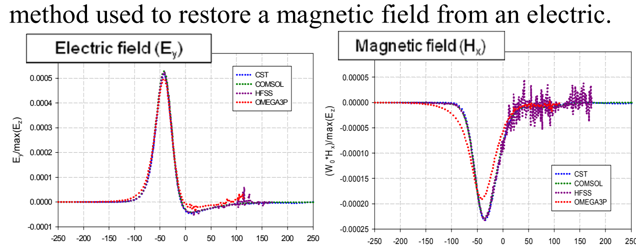

Figure 3: The field pattern on the axis of upstream coupler calculated by different RF codes.

For the last step we developed a universal data processing code which calculates the RF kick by the direct integration of transverse field components and also, using Panofsky-Wenzel (PW) theorem, by the integration of the longitudinal component. The calculated RF-kick was normalized on the real part of the voltage amplitude along the ILC cavity with a phase-lock to the middle cell [5]. This allows calculate the kicks of upstream and downstream couplers independently.

Finally we investigated the RF kick convergence versus mesh size for each codes we used except OMEGA3P. The results of the upstream coupler RF kick convergence studies are shown on Fig.4. The estimated errors for both upstream and downstream groups are better than 10% for

HFSS and less than 5% for CST and COMSOL simulations.

The total RF-kick was calculated as a sum of upstream and downstream kicks, see Table 2. For the reference purpose (to exclude a possible phase lock error) we simulated the full ILC structure by COMSOL code. The total RF kick is close to what was calculated separately. Additionally we processed the OMEGA3P data for the upstream coupler and the derived RF kick is very close to results of other codes that however differ from the numbers calculated by SLAC.

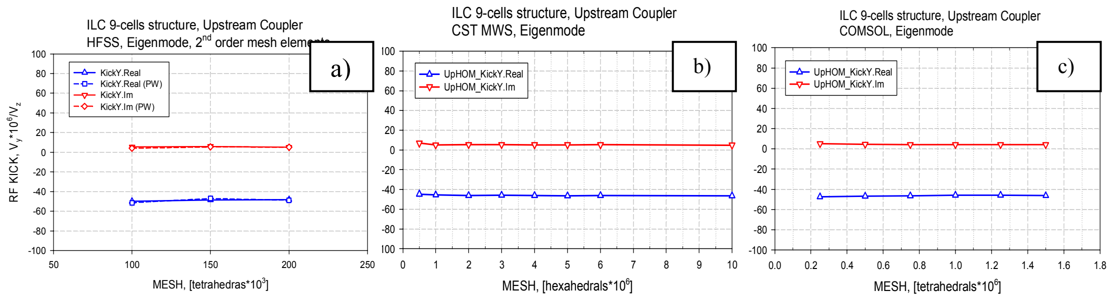

Figure 4: The upstream coupler RF kick convergence studies: a) HFSS, b) CST MWS and c) COMSOL.

Table 2. RF-kick calculated separately for the Upstream Group (a), the Downstream Group (b) and Total RF-kick (c) of the ILC structure

a) **Upstream Group**

	NEW FNAL* (HFSS & CST MWS & COMSOL)		OLD FNAL** (HFSS, Eigenmode)		SLAC (Omega3P)	DESY (Mafia)
	Direct	PW	Direct	PW	Direct	Direct
KickX $\frac{10^6 \cdot V_x}{V_z}$	-64.5+19.5*i* (HFSS) -64.8+19.6*i* (CST) -64.9+18.6*i* (COMSOL) **-64.7+19.2*i* (average)**	-65.1+19.6*i* -64.8+19.5*i* -64.9+15.9*i*	-68.8+3.7*i*	-65.6+7.6*i*	-57.8+7.0*i* FNAL calc*. 54.6+19.3*i*	-57.1+6.6*i*
KickY $\frac{10^6 \cdot V_y}{V_z}$	-47.3+4.6*i* (HFSS) -46.1+4.8*i* (CST) -46.5+4.1*i* (COMSOL) - **-46.6+4.5*i* (average)**	-46.4+4.8*i* -46.2+4.9*i* -46.4+2.7*i*	-48.3-3.4*i*	-53.1-2.1*i*	-40.9-3.5*i* FNAL calc.* -40.3+4.6*i*	-41.4-3.5*i*

b) **Downstream Group**

	NEW FNAL* (HFSS & CST&COMSOL)		OLD FNAL** (HFSS, Driven Modal)		SLAC (Omega3P)	DESY (Mafia)
	Direct	PW	Direct	PW	Direct	Direct
KickX $\frac{10^6 \cdot V_x}{V_z}$	-34.0+65.7*i* (HFSS) -32.2+68.4*i* (CST) -34.6+68.7*i* (COMSOL) **-33.6+67.6*i* (average)**	-33.1+66.1*i* -32.2+68.4*i* -33.9+68.8*i*	-36.5+66.1*i*	-27.3+67.2*i*	-25.1+51.4*i*	25.0+51.5*i*
KickY $\frac{10^6 \cdot V_y}{V_z}$	39.4+14.9*i* (HFSS) 41.2+15.8*i* (CST) 41.3+14.7*i* (COMSOL) **-38.6+15.3*i* (average)**	39.8+12.4*i* 41.1+15.9*i* 41.5+14.4*i*	41.0+14.5*i*	40.9+12.8*i*	36.5+8.9*i*	32.2+5.2*i*

c) **Total RF-kick**

	NEW FNAL* (HFSS & CST MWS & COMSOL)		OLD FNAL** (HFSS)	SLAC (Omega3P)	DESY (Mafia)
	Up & Down Groups	Full Structure***	Up & Down	Full	Up & Down
KickX $\frac{10^6 \cdot V_x}{V_z}$	-98.5+85.2*i* (HFSS) -97.0+88.0*i* (CST) -99.5+87.3*i* (COMSOL) **-98.6+86.8*i* (average)**	- - -104.3+80.0*i*	-105.3+69.8*i*	-86.0+60.7*i*	-82.1+58.1*i*
KickY $\frac{10^6 \cdot V_y}{V_z}$	-7.9+19.5*i* (HFSS) -4.9+20.6*i* (CST) -5.2+18.8*i* (COMSOL) **-6.0+19.6*i* (average)**	- - -8.3+17.1*i*	-7.3+11.1*i*	-4.6+5.6*i*	-9.2+1.8*i*

* The accurate RF-kick post processing was used.
** A phase-lock mistake was found and rough normalization was applied in the post processing.
*** For reference only, results were not checked for convergence

WAKE KICK

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:

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

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].

However, the transverse wake of the periodic system that includes the cavities and couplers depends on the bunch length. Thus, it is necessary to study the effects of the coupler kicks both in the ILC main linac and in the ILC bunch compressors. The ILC baseline configuration contain the double stage bunch compressor designed to compress the bunch length from 6 mm to 300 µm, passing by an intermediate length of ~ 1 mm

The wake calculation for a periodic system 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 [7]. The author have fixed few serious bugs since we published our first results in 2008 [8]. Therefore we repeated all wakefield simulations of the ILC structure and processed data more accurately in order to exclude possible errors introduced by the mesh itself.

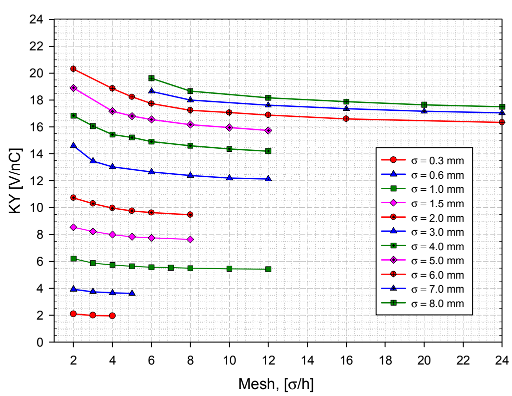

Figure 6: Convergence of the vertical wakefield kick calculated by GdfidL code for various bunch lengths.

The idea is to approximate the kick factor convergence behavior with an analytical function and, thus, find the limit which kick approaches. The convergence of the vertical wakefield kick versus mesh size for various bunch lengths is shown in Figure 6. First of all a simple function $f(x)=Ax^{-1}+C$ was taken for the approximation. Then we found coefficients A and C corresponding to a minimum approximation error. The typical result is illustrated in Figure 7.

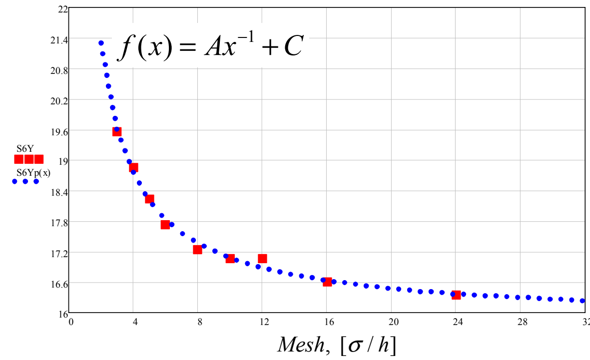

Figure 7. Wake kick (red points) convergence approximation (blue dots).

Finally the limiting values (coefficient C) of both horizontal and vertical transverse wakes kick factors were calculated. The Figure 8 shows the plots of wake kick factors versus bunch sigma with error bars computed individually for each point. The maximum approximation error is less than 5%.

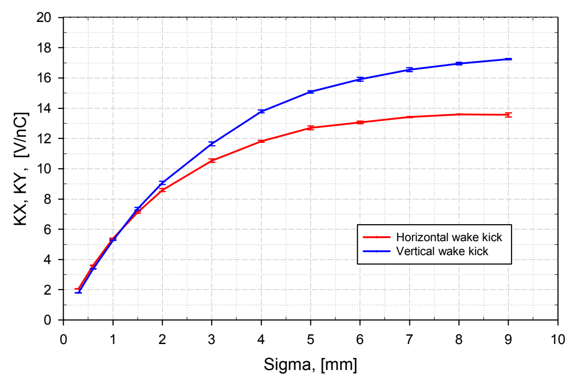

Figure 8. Horizontal and vertical wake kicks of the ILC structure with couplers versus a bunch size.

CONCLUSIONS

Reliable estimations are presented for both RF-kick and wake caused by the couplers for the ILC cavity. Convergences were checked. Estimated errors for RF kick and wake simulation are better than 5%.

REFERENCES

[1] N. Solyak, et al, EPAC2008, MOPP042
[2] I. Zagorodnov, and M. Dohlus, LCWS/ILC 2007
[3] K.L.F. Bane, et al, EPAC2008, TUPP019
[4] Zenghai Li, "Omega3P & S3P simulation of coupler RF kicks," SLAC Wakefest 2007
[5] A. Lunin "ILC structure RF kick computation", FNAL internal report, 2010
[6] N. Solyak, et al, PAC2009, TU5PFP061
[7] W. Bruns, "The GdfidL Electromagnetic Field Simulator," http://www.gdfidl.de.
[8] N. Solyak, et al, EPAC 08, MOPP043