Coupler Kick

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The transverse kick due to cavity couplers can negatively affect the beam emittance. For example, in the International Linear Collider (ILC) the intense bunches encounter many hundreds cavities with couplers. In this contribution we estimate two different effects: the kick due to asymmetry of the external accelerating field (coupler RF kick) and the kick due to electromagnetic field of the bunch scattered by the couplers (coupler wake kick). The wakefield due to the couplers could be main source of the emittance dilution in ILC and a new HOM couplers orientation is suggested to reduce the wake by factor ~12.

1 Introduction

The International Linear Collider (ILC) project [2] uses short, intense bunches, which encounter a lot of cavities with couplers. As it is shown in Fig. 1 the couplers violate axial symmetry of the cavities and produce transverse kicks on the axis. It can negatively affect the beam stability and the beam emittance.

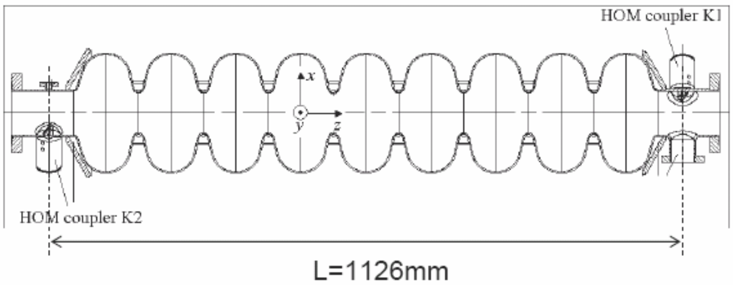

Figure 1: TESLA cavity with couplers.

In this contribution we estimate two different effects: the kick due to asymmetry of the external accelerating field (coupler RF kick) and the kick due to electromagnetic field of the bunch scattered by the couplers (coupler wake kick). In the calculation we consider not only the main coupler but higher order mode (HOM) couplers as well. The wakefield due to the couplers could be main source of the emittance dilution in ILC and a new HOM couplers orientation is suggested to reduce the wake by factor ~12

2 Geometry description and notation

In ILC and European XFEL [4] projects the design of the main accelerator will be based on the TESLA technology [5]. Each TESLA cavity is supplied with one main coupler and two HOM couplers (see Fig. 1). The design and orientation of the couplers in the European XFEL project are shown in Fig.2. The radius of the pipe is equal to 39 mm and the couplers penetrate into the pipe up to the radius of 30 mm.

In the following estimations we consider the Gaussian bunch $\lambda(s)$ with rms width σ. The kick factor and the rms kick for wake potential $W_\perp(s)$ are given by

$$k_\perp = \langle W_\perp \rangle = \int W(s)\lambda(s)ds\,, \qquad k_\perp^{rms} = \left\langle (W_\perp - k_\perp)^2 \right\rangle^{0.5}.$$

The kick factor must be compensated for with orbit correctors. The rms kick gives the head-tail difference in the kick which is very difficult to correct and which leads to "banana" shape of the bunch.

The estimations of wakepotentials are obtained for a quite long bunch $\sigma = 1\text{mm}$. However, the transverse wake has already the capacitive character and we can state that the wake kick remains the same for the shorter bunches [6]

3 Wakefields of the TESLA couplers

3.1 Numerical code and accuracy estimation

To estimate the short range wakefields of the couplers in the pipe (without cavities) we have used a 3D, time-domain finite-difference program ECHO [7]. It has two features that make these 3D calculations tractable: (1) a method to reduce the so-called ‘‘mesh dispersion’’, and (2) an indirect method [8] of calculating wakes in 3D structures that eliminates long downstream beam pipes.

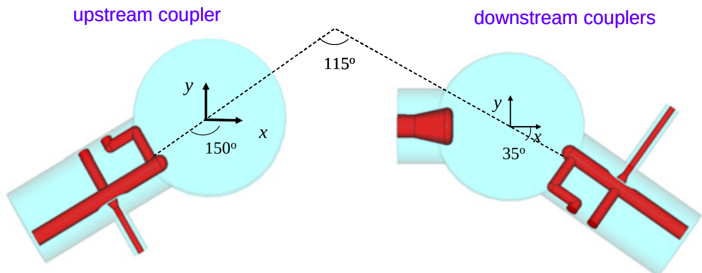

Figure 2: The geometry and the orientation of the TESLA couplers.

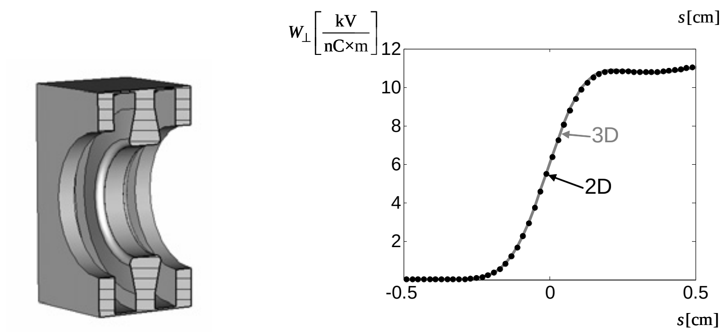

Figure 3: The axially symmetric approximation of the main coupler geometry and the accuracy check.

Table 1: Convergence and accuracy tests.

	2.5D, σ/h=5	2.5D, σ/h=10	3D, σ/h=5	Abs.error
$k_{\|\|}$, kV/nC	2.205	2.195	2.241	0.05
$\partial k_{\perp} / \partial r$, kV/nC/m	5.820	5.817	5.89	0.07
$\lvert k_{\perp}(0) \rvert$, kV/nC	0	0	1e-6	1e-6

In order to choose the mesh and check the accuracy of the 3D results we have considered an axially symmetric approximation of the main coupler geometry (see Fig.3). The results obtained with 2.5D and 3D codes are given in Fig. 3 and Table 1.

3.2 The couplers wake kick near to the axis

The kick factors of *downstream* and *upstream* couplers (see Fig.2) are given as

$$\mathbf{k}_{\perp}^{\text{down}}(x,y) = \begin{pmatrix} -0.0069 \\ -0.0094 \end{pmatrix} + \begin{pmatrix} 3.2 & -1.1 \\ -1.1 & -1.0 \end{pmatrix} \begin{pmatrix} x[\text{m}] \\ y[\text{m}] \end{pmatrix} \left[\frac{\text{kV}}{\text{nC}} \right],$$

$$\mathbf{k}_{\perp}^{\text{up}}(x,y) = \begin{pmatrix} -0.0142 \\ -0.0095 \end{pmatrix} + \begin{pmatrix} 1.02 & 1.15 \\ 1.15 & 0.07 \end{pmatrix} \begin{pmatrix} x[\text{m}] \\ y[\text{m}] \end{pmatrix} \left[\frac{\text{kV}}{\text{nC}} \right].$$

The rms kick can be related to the kick factor as $\mathbf{k}_{\perp}^{\text{rms}} = \mathbf{k}_{\perp} / \sqrt{3}$.

Fig. 4 shows the vector norms of the wake rms kick, RF rms kick (see next section) and the cavity rms kick [9] for the ILC bunch with charge Q=1nC and length σ= 300μm versus offset from the axis.

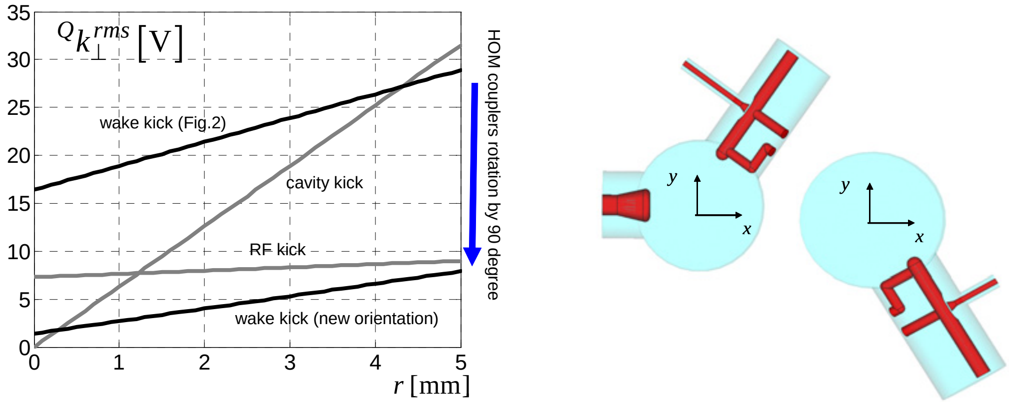

Figure 4: Kicks vs. offset and the new orientation of HOM couplers.

The coupler wake kick makes the main contribution. It can be reduced by factor ~12 with the help of rotation of the HOM couplers by 90 degrees as shown in Fig. 4. The kick factor of this new configuration is

$$\mathbf{k}_{\perp}(x,y)=\begin{pmatrix}-0.0025\\-0.0002\end{pmatrix}+\begin{pmatrix}2.33 & 0.04\\-0.02 & 1.1\end{pmatrix}\begin{pmatrix}x[\mathrm{m}]\\y[\mathrm{m}]\end{pmatrix}\left[\frac{\mathrm{kV}}{\mathrm{nC}}\right].$$

Let us note that we have calculated the coupler kick in infinite pipe without cavities. As the cavity irises have diameter 35 mm which is smaller than the pipe diameter of 39 mm we expect that the coupler wake kick could be reduced by a factor ~1.4.

3.3 The RF coupler kick near the axis

The couplers destroy rotational symmetry of the TESLA cavity. With the help of the MAFIA field solver [10] we have estimated [11] the asymmetry effect on the external accelerating field due to the couplers existence and obtained the rms RF kicks as

$$^{Q}\mathbf{k}_{\perp}^{rms}=\mathrm{Im}(\mathbf{V}_n V_z)\,k\,\sigma\,,\qquad \mathbf{V}_n=\mathbf{V}_n^{down}+\mathbf{V}_n^{up}\,,\qquad k=2\pi c^{-1}f\,,$$

$$\mathbf{V}_n^{down}\cdot 10^4=\begin{pmatrix}-0.25+0.52i\\0.32+0.05i\end{pmatrix}+\begin{pmatrix}-40-20i & 29+37i\\29+5i & 38+18i\end{pmatrix}\begin{pmatrix}x[\mathrm{m}]\\y[\mathrm{m}]\end{pmatrix},$$

$$\mathbf{V}_n^{up}\cdot 10^4=\begin{pmatrix}-0.57+0.07i\\0.41+0.03i\end{pmatrix}+\begin{pmatrix}11-7i & 34+1.5i\\34+2i & -10+6i\end{pmatrix}\begin{pmatrix}x[\mathrm{m}]\\y[\mathrm{m}]\end{pmatrix},$$

where *up* and *down* mean upstream and downstream couplers, correspondingly. Figure 4 shows the total RF kick for accelerating voltage $V_z=15\,\mathrm{MV}$ and frequency $f=1.3\,GHz$.

4 Acknowledgements

We thank CST GmbH for letting us use CST Microwave Studio for the meshing for the ECHO simulations.

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