IMPROVED INPUT AND OUTPUT COUPLERS FOR SC ACCELERATTION STRUCTURE*

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Abstract

Different couplers are described that allow the reduction of both transverse wake potential and RF kick in the SC acceleration structure of ILC. A simple rotation of the couplers reducing the RF kick and transverse wake kick is discussed for both the main linac and bunch compressors, along with possible limitations of this method. Designs of a coupler unit are presented which preserve axial symmetry of the structure, and provide reduced both the RF kick and transverse wake field.

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.

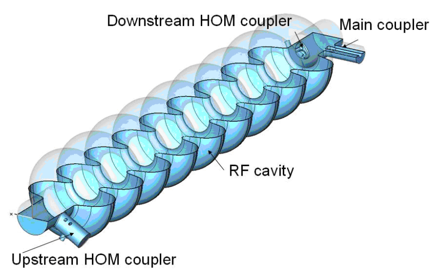

Figure 1: The ILC RF cavity with the main and HOM couplers.

The couplers break the cavity axial symmetry that causes a) main RF field distortion and b) transverse wake field that may cause the beam emittance dilution. Both effects of the rf-kick and coupler wake increase with the bunch length [1,2,3]. The calculation of the influence of rf-kick and wake field on the beam dynamics [4] shows that it is not a serious issue in the ILC main linac, but it is a problem in the ILC bunch compressor, where the bunch length is 6 or 9 mm initially. In two-stage baseline bunch compressor the emittance dilution caused by the couples only, is 4.3 nm (after 1-to-1 correction, Dispersion Free Steering and dispersion–tuning bumps), that is unacceptable, because the total budget for normalized emittance growth in entire RTML system is ~5 nm. Note, the vertical kick and wake slopes along the bunch (that determine the vertical emittance dilution) have the same sign, and there is no mutual compensation of the kick and wake.

Structure symmetrization. There is a natural way to reduce the coupler wakes by symmetrization of the azimuth coupler position. In order to do this, it was suggested [5] to rotate the upstream coupler by 180º versus the axis. It proves to be helpful for compensation of wake fields. In this case the system is almost symmetrical versus horizontal plane, and vertical wake is very small, see Figure 2. However, in the original cavity geometry in a baseline bunch compressor the imaginary part of the rf kick (that determines the kick slope over the bunch length) caused by upstream coupler almost compensates the kick from downstream coupler [2], while in the suggested symmetrical cavity design the kicks from both couplers act in the same direction. For the bunch compressor the resulting ratio of imaginary part of the rf kick to the longitudinal cavity energy gain changes [2] from 4.1×10^{-6} (BC1) and 3.1×10^{-6} (BC2) in the original variant to 90.9×10^{-6} (BC1) and 35.5×10^{-6} (BC2), and emittance dilution is 90 nm, that is quit unacceptable.

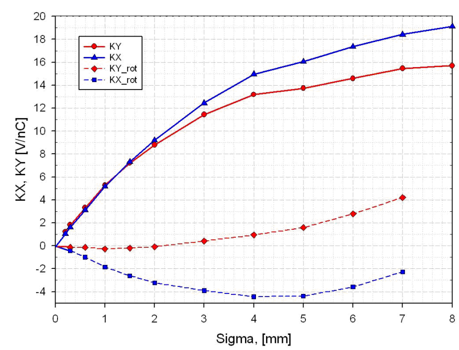

Figure 2: The horizontal (solid blue) and vertical (solid red) kick dependence versus the bunch length σ. Dashed curves show the kick dependences for the upstream coupler rotated by 180º versus the axis.

Cryomodule rotation. Another way to compensate effect of coupler asymmetry is to rotate all the cavities in every three cryomodules fed by one klystron versus the axis by 180º (see Figure 3). The couplers of neighboring groups of cryomodules will have different orientation, and it compensates the rf kick and wake (partially in presence of acceleration). In the main linac this method works pretty well, because the betatron wavelength is about 520 m that is much longer than the length of a 3-cryomodule section. In BC1+BC2 the betatron wavelength is 195 m, and this method of compensation does not work: vertical emittance dilution in this case is 6 nm, and takes place in the first cryomodules of BC2 and in the wigglers.

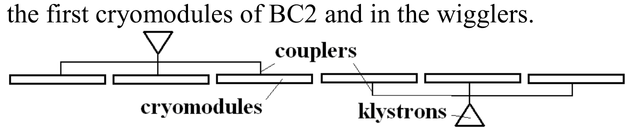

Figure 3: The groups of cryomodules rotated by 180 º.

Crab cavity. In order to compensate the kick spread along the bunch (average kick may be compensated by beam alignment system) a crab cavity may be used [4].

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Calculations show that it is an acceptable way: seven crab cavities in the bunch compressor (3nm in BC1 and 4nm in BC2) compensate the emittance dilution caused by the couplers to 0.3 nm, but it needs a design of the crab cavity.

Girder rotation. It is also possible to compensate the kick spread optimizing the cryomodule girder tilt versus the beam axis: because in BC the cavity operates out of crest, the tilt leads to the transverse kick spread along the bunch caused by the main accelerating field that may compensate the rf kick from the couplers. Simulations [4] give an acceptable emittance dilution for BC1-BC2, ~0.8 nm. However, the movable girder is necessary and precise positioning mechanism (step ~10 µm in 300 µm range)

The axially-symmetric coupler unit. In this paper, we consider the special coupler units [1,6] that do not break axial symmetry of the accelerating channel, and thus, do not lead to the rf kick and coupler wake.

GENERAL

In order to preserve the axial symmetry of the acceleration channel, the coaxial coupler units may be used [6]. In Figure 4a the coaxial coupler unit developed at FNAL [7] is depicted. The main coupler is opened not into the beam pipe, but to the part of a coaxial line, that is coupled to the cavity. The field perturbation caused by the main coupler, is shielded by the internal coaxial electrode. The internal diameter of the coaxial is 60 mm that is smaller than the ILC beam pipe aperture, 78 mm. The field pattern in the coupler unit is shown in Figure 4b. Simulations show that it is free of multipacting. The coupler provides relevant coupling to the HOM modes and operating mode [7].

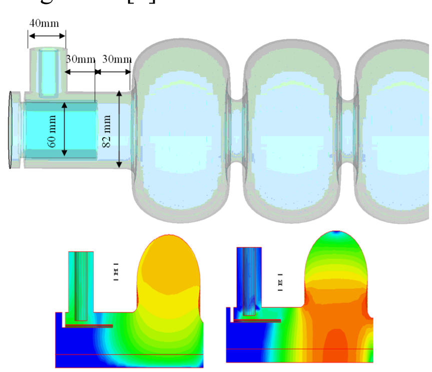


Figure 4: The coaxial coupler unit layout that preserves the axial symmetry of the accelerating channel (a); and rf field pattern (b).

Another version of a coaxial coupler unit free of rf kick and coupler wake is resonant quarter-wave coupler. The geometry and field pattern are shown in the Figure 5. The coupler unit is based on the coaxial resonator that has internal diameter of the ILC beam pipe, 78 mm, and does not disturb the beam aperture. The front aperture of the end cavity is the same as a regular one that does not cause any additional field enhancement in the end cavity. The rf magnetic field in the corner the unit is zero in the ideal case, and thus, there is no rf currents. It allows the possibility to make the unit detachable. The calculated magnetic field behavior in the unit corner is shown in Figure 6. For the acceleration gradient of 31.5 MeV/m the minimal field in the corner is 0.13 mT only, that allows, for example, indium or niobium contacts [9].

The HOM suppression was simulated using HFSS code. The model shown in Figure 7 includes the 9-cell cavity and two HOM ports. In the Table 1 the quality factors are shown for the standard ILC design, and for the quarter-wave couplers. The coaxial Loaded Q for the operating mode is the same, 3.4×10^6. One can see that a quarter - wave couplers provide the HOM damping not worse than in the standard design for the modes with high (r/Q).

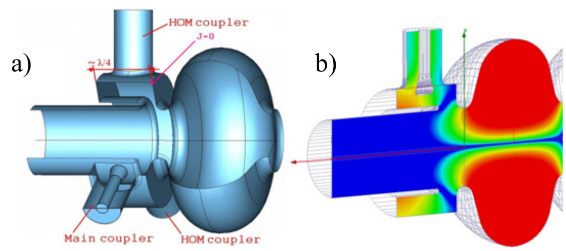


Figure 5: The idea of a resonance quarter-wave coupler unit (a) and rf field pattern (b).

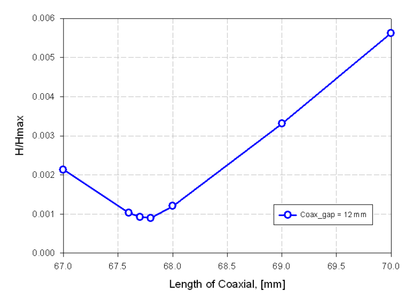


Figure 6: The magnetic field behavior in the cavity corner (see Fig. 5) versus the cavity length. H_{max} is the maximal field in the cavity. Multipactoring analysis was done using Analyst code [11], no multipactoring was found in the coaxial.

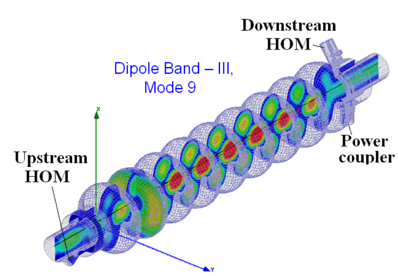


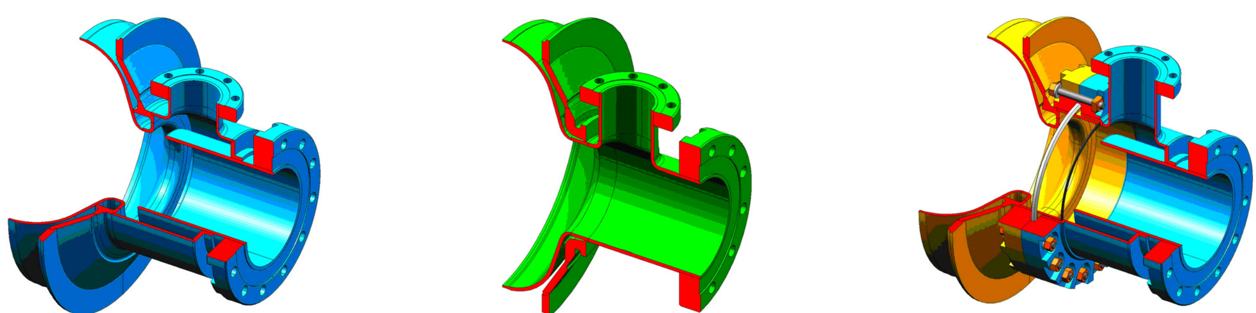
Figure 7. HFSS model of a standard 9-cell TESLA cavity with the two quarter-wave coupling units containing a power coupler, and HOM couplers.

Preliminary mechanical non-detachable design is show on the Figure 8a. It has the same dimensions as the standard unit (Figure 8b) except the length of the beam pipe that is 10 mm longer that may demand decrease of the bellows between cavities. A model of the detachable version is shown in Figure 8c. A modified 6¾" NiTi flange with a diamond seal is used for a junction with the cavity body. Indium gasket provides superconducting contact.

Table 1: High order modes with the largest R/Q, comparison of external quality factors for the standard ILC and proposed quarter-wave coaxial couplers.

Band Type		Frequency, [GHz], (Ordinal Number in a Band)	ILC Coupler, Q_ext, (X&Y polarizations)	Coaxial Coupler, Q_ext, (X&Y polarizations)	R/Q [Ω//cm²] – dipole, [Ω] - monopole
Dipole Modes Band 1		1.708, (6)	7.1 e4 (X), 2.5 e4 (Y)	3.1e4 (X), 8.1e4 (Y)	11.1 [10]
		1.735, (7)	4.8 e4 (X), 2.7 e4 (Y)	2.6 e4 (X), 2.6 e4 (Y)	15.6 [10] 15.4 (HFSS)
		1.763, (8)	1.6 e4 (X), 2.2 e4 (Y)	1.0e4 (X), 3.7 e4 (Y)	2.1 [10]
Dipole Modes Band 2		1.865,(4)	3.3 e3 (X&Y)	3.7e3 (X&Y)	6.4 [10]
		1.875, (5)	2.3e3 (X&Y)	1.4e4 (X), 5.4e4 (Y)	9.0 [10]
		1.881, (6)	3.5e3 (X&Y)	3.1e4 (X), 1.9e5 (Y)	2.1 [10]
Dipole Modes Band 3	HOM1&HOM2	2.577, (9)	3.8e6 (Y), 6.4e5 (X) **	1.2e6 (Y), 3.7e5 (X)**	23.5 [10] 22.0 (HFSS)
	Main Coupler		3.2e7 (Y), 4.1e4 (X)**	6.3e6 (Y), 4.6e5 (X)**	
Dipole Modes Band 4	HOM1&HOM2	2.986, (7)	2.4e4 (Y), 4.5e3 (X)**	1.4e3 (Y), 3.8e3 (X)**	2.5 [10] 2.0 (HFSS)
	Main Coupler		8.4e5 (Y), 5.5 e3 (X)**	4.8e6 (Y), 2.7e5 (X)**	
Dipole Modes Band 5	HOM1&HOM2	3.089, (6)	4.4e6 (Y), 9.9e4 (X)**	8.5e4 (Y), 4.4e4 (X)**	1.1 [10] 1.2 (HFSS)
	Main Coupler		1.5e8 (Y), 6.5e5 (X)**	6.7e6 (Y), 8.1e5 (X)**	
Monopole Modes Band 2		2.442, (7)	6.3e4	9.4e3	20.4 [10]
		2.452, (8)	6.5e4	1.1e4	155 [10]
		2.458, (9)	9.9e4	2.9e4	148 [10]

** Partial Q value. Pipe ends are matched.



a) b) c)

Figure 8: The 3D model of the mechanical design of the non-detachable quarter-wave coupler (a), standard of the coupler unit (b), and the detachable quarter-wave coupler(c).

SUMMARY

In order to compensate the vertical beam emittance dilution caused by the cavity main and HOM couplers in the bunch compressor of ILC, a number of means are discussed. The resonant quarter-wave coupler units are suggested that preserves the axial symmetry of the beam channel and are free of rf-kick. The quarter-wave units provide HOM damping not worse than the standard one. Analysis does not show any multipactoring in the coaxial resonator of the units. A concept of a detachable coupler unit is suggested.

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