LOW KICK COUPLER FOR SUPERCONDUCTING CAVITIES*

R. Eichhorn, C. Egerer and V. Veshcherevich†
Cornell University, Ithaca, NY 14853, U.S.A.

Abstract

Results from the high current, low emittance photo injector at Cornell revealed that even with two opposing input couplers, the beam emittance is affected by the coupler kick. As a result, a coupler with low transverse kick is proposed for use in superconducting accelerating cavities. In this coupler, a rectangular waveguide transforms into a coaxial line inside the beam pipe. The geometry of the coupler is tuned to minimize the transverse kick that is important for linear accelerators with low emittance. The coupler can be used in ERL injectors or other linacs for high brightness light sources.

INTRODUCTION

The proposed Cornell Energy Recovery Linac (ERL) [1] and other new ultra high brightness synchrotron light sources need high quality low emittance electron beams. That means that beam has to be formed by electron gun and accelerated with minimal destructive effects. The starting part of the accelerator, the injector, produces the strongest effect on the beam due to low beam energy.

The input coupler of superconducting cavities is usually an antenna type coupler attached to a side port in the beam pipe near the cavity. Due to axial asymmetry of this design, electromagnetic fields in the vicinity of the coupler have transverse components and produce a transverse kick to the electron beam. That leads to the emittance dilution of the beam.

To reduce this effect, the injector cavities of Cornell ERL are equipped with two identical input couplers symmetrically placed on two sides of the beam pipe [2]. That design eliminates the dipole transverse kick. However, there exist quadrupole field components and this quadrupole focusing distorts the beam [3].

Therefore we consider a possibility to build a new coupler which produces axially symmetric fields and generates very low transverse kick to the beam. That coupler has a tube inside the beam pipe which forms a coaxial line with the beam pipe. This coaxial line is coupled to a power transmission line. Couplers of that type were designed, built and used for S-DALINAC superconducting cavities in early 90s [4]. In that design the coaxial transmission line was coupled to the coaxial line in the beam pipe by movable antenna. Later similar couplers were considered at DESY [5] and FNAL [6].

Unfortunately, these designs were not perfect. For practical sizes of the beam pipe, two modes can propagate in the beam pipe coaxial line: a fully axially symmetric TEM mode and a dipole TE_{11} mode. The TE_{11} mode is excited in the coaxial line due to asymmetric coupling to the transmission line. This dipole mode produces a transverse kick to the beam.

During the early study of ERL injector design, a symmetric coupler inside the beam pipe of small diameter was considered [7]. In such a case, the TE_{11} mode could not propagate along the coaxial line of that smaller size. Unfortunately, this was not compatible with the HOM and BBU requirements set by the linac design.

A similar solution was also found at Darmstadt, operating at 3 GHz The idea was to use a rectangular waveguide instead of a coaxial transmission line to and to optimize the geometry of the field transformer between the waveguide and the beam pipe coaxial line for minimizing the excitation of the TE_{11} mode [8].

SYMMETRIC COUPLER FOR ERL INJECTOR CAVITY

Figure 1 shows the model of the ERL injector cavity with the Darmstadt type of symmetric coupler. The

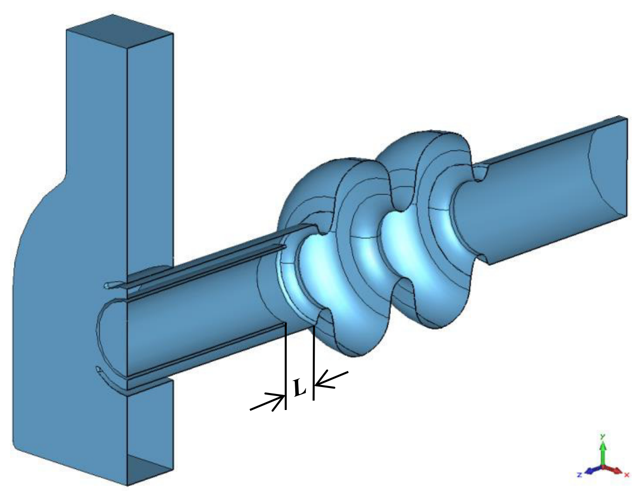

Figure 1: 2-cell cavity with the symmetric coupler.

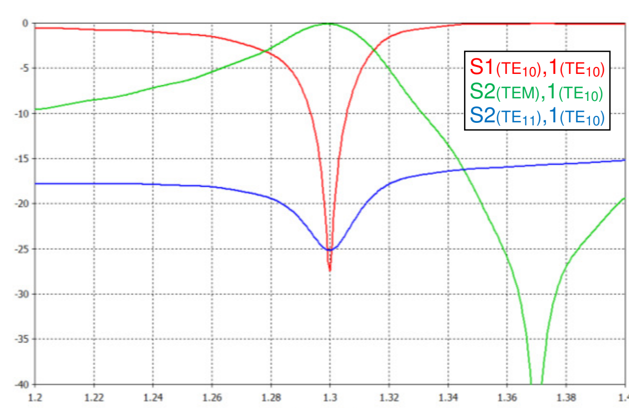

Figure 2: Calculated S-parameters of the coupler wave-guide-to-coax field transformer (in dB).

* Work is supported by NSF Grants NSF DMR-0807731 and NSF PHY-1002467.
† vgv1@cornell.edu

geometry of the 3 GHz coupler has been scaled and adjusted for 1.3 GHz injector cavity. The coupler is attached to the 106 mm beam pipe; the inner diameter of the inner tube is 78 mm. For optimizing the parameters of the field transformer one can play with the sizes of two diaphragms, the width of the wide waveguide section and the distance to the short. The simulated S-parameters of the coupler field transformer are shown in Figure 2.

Due to exponential decay of the fields in the beam pipe, the logarithm of the coupler Q_{ext} is a linear function of the distance to the cavity (see Figure 3). Figure 4 shows the transverse kick of the coupler.

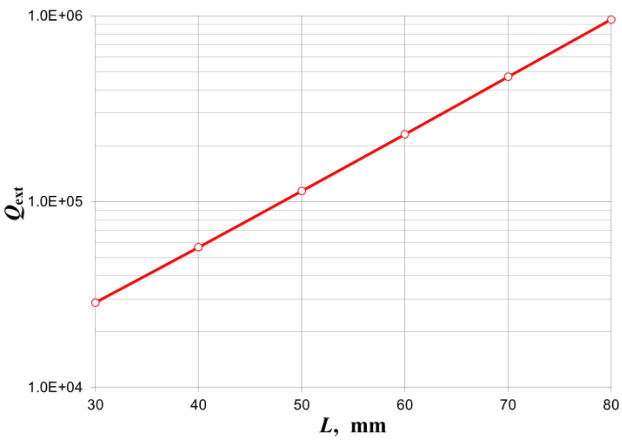

Figure 3: Dependence of coupling on the distance from the cavity to the coaxial line.

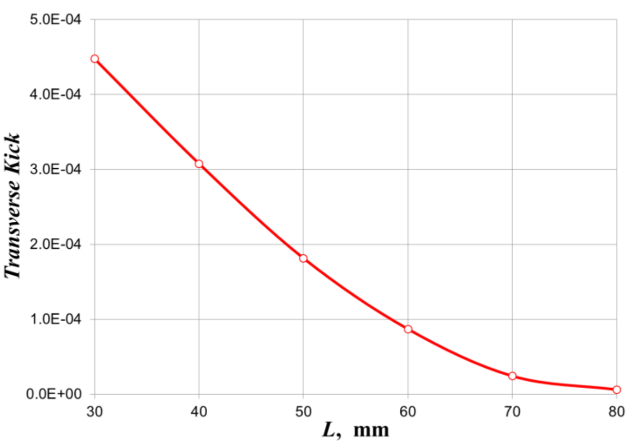

Figure 4: Transverse kick as a function of distance to the cavity.

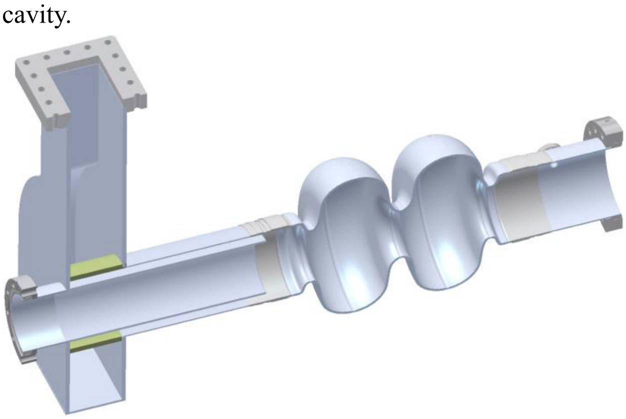

Figure 5: ERL injector cavity with symmetric coupler.

Symmetric coupler can be integrated in the design of the superconducting cavity. In that case it should be made of niobium as the cavity. That makes the cavity design more complicated as well as the cavity treatment process. But on the other hand, the risk of cavity contamination during coupler mounting is excluded due to this integrated design. The design of the cavity with symmetric coupler is shown in Figure 5.

SYMMETRIC COUPLER FOR ILC CAVITY

The influence of the transverse kick of input coupler might be significant for other linacs, especially for injectors. One of those machines is LCLS-II, in which 9-cell ILC cavities will be used. We simulated the ILC cavity with a symmetric coupler similar to the ERL injector coupler (see Figure 6).

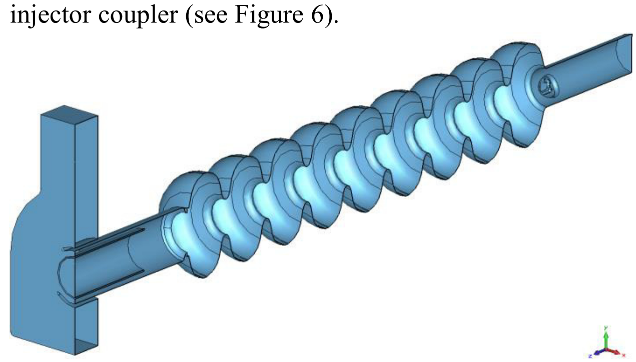

Figure 6: Model of ILC cavity with symmetric coupler.

While optimizing the coupler, it is important to choose the right length of the tube inside the beam pipe. The coaxial line formed by this tube and the beam pipe is open on the cavity end and shorted on the other end and can resonate [9]. It can resonate on both TEM and TE_{11} modes. TEM resonances boost the coupling (see Figure 7). Resonances of TE_{11} mode enhance the kick and have to be avoided. Figure 8 shows the kick as a function of the length of coaxial line for a fixed Q_{ext} = 1.1×10^7.

One can see that the kick has the lowest value in the vicinity of the resonant length for the TEM mode. The

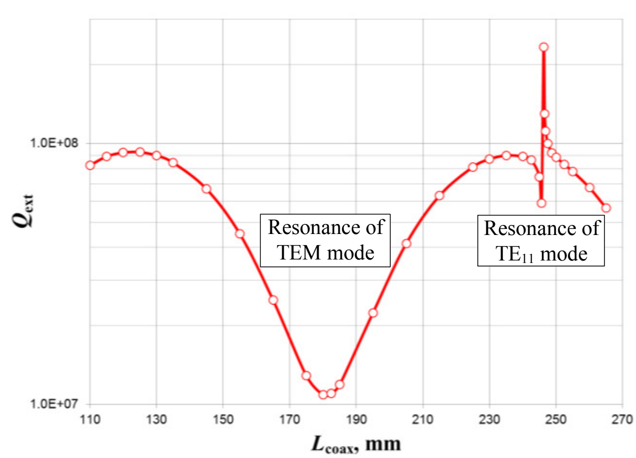

Figure 7: Coupling as a function of the length of the coaxial line for a fixed distance to the cavity.

ISBN 978-3-95450-142-7

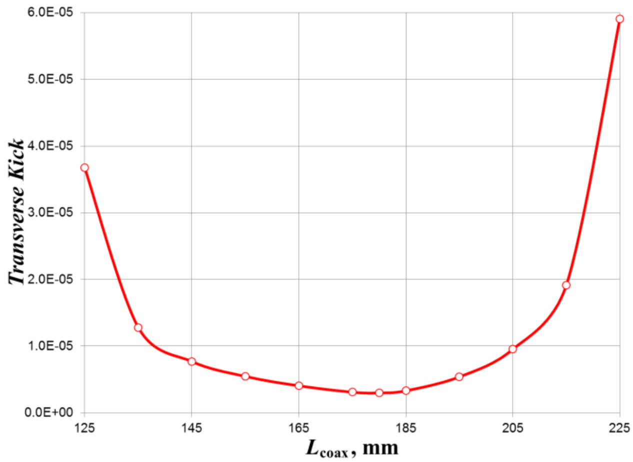

Figure 8: Dependence of kick on the length of coaxial line for a constant Q_{ext}.

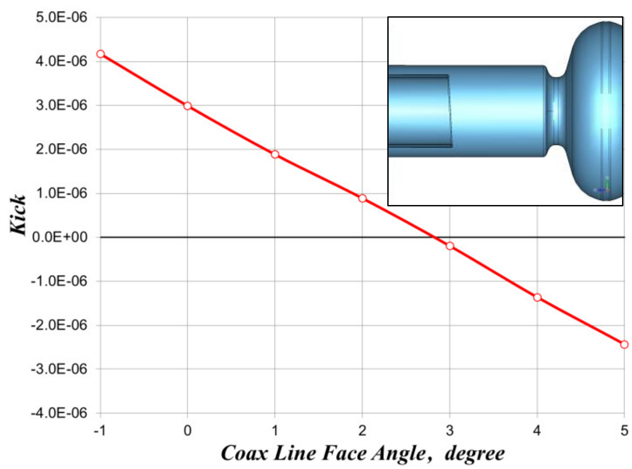

Figure 9: Dependence of transverse kick on cut angle of the coaxial tube.

minimum value is around ($3\times10^{-6} - i\cdot3\times10^{-7}$). However, the kick may be significantly reduced if the cavity end of the coaxial line is cut with a small angle to the square plane (Figure 9). As one can see, the kick is getting to zero at the angle around 2.8°.

It is possible to get better suppression of the TE_{11} mode for a bigger diameter of the beam pipe and a thicker coaxial tube. Figure 10 shows the result of optimization for a beam pipe diameter of 126 mm and a coaxial tube thickness of 8 mm. Comparing Figure 10 with Figure 2 one can see that the S_{21} parameter for the dipole TE_{11} mode is smaller by 24 dB. It means that the transverse kick of this coupler might be much smaller than the kick for the original coupler. Having a hollow cylinder, cooled by helium would also avoid thermal runaway in case the beam hits.

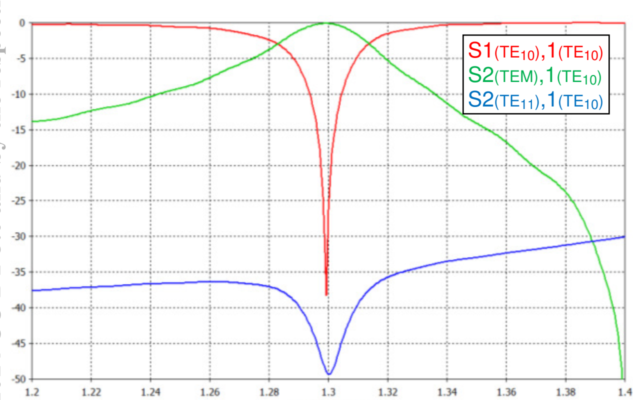

Figure 10: Calculated S-parameters of the improved coupler waveguide-to-coax field transformer (in dB).

SUMMARY

A symmetric input coupler developed earlier for 3 GHz S-DALINAC cavities was adapted for Cornell ERL injector cavities and for ILC cavities. The coupler produces a small transverse kick to the beam. The kick can be reduced even more after appropriate optimization of the coupler shape and the size of the cavity beam pipe. A first design has been made and is mature for fabrication.

REFERENCES

[1] G. H. Hoffstaetter, S. Gruner, M. Tigner, eds., “Cornell Energy Recovery Linac: Project Definition Design Report,” http://erl.chess.cornell.edu/PDDR.

[2] V. Shemelin et al., “Dipole-Mode-Free and Kick-Free 2-Cell Cavity for the SC ERL Injector,” in Proceedings of the 2003 Particle Accelerator Conference, Portland, OR (2003), pp. 2059–2061.

[3] B. Dunham, “High Brightness and High Average Current Performance of the Cornell ERL Injector,” ERL2013-WG103, http://jacow.org

[4] J. Auerhammer et al., “Progress and Status of the S-DALINAC,” in Proceedings of the 6th Workshop on RF Superconductivity, Newport News, VA, USA (1993), pp. 1203–1211.

[5] J. Sekutowicz et al., “Status of Nb-Pb Superconducting RF-Gun Cavities,” in Proceedings of the 2007 Particle Accelerator Conference, Albuquerque, NM, USA (2007), pp. 962–964.

[6] N. Solyak et al., “Improved Input and Output Couplers for SC Acceleration Structure,” in Proceedings of the 2009 Particle Accelerator Conference, Vancouver, BC, Canada (2009), pp. 966–968.

[7] V. Shemelin et al., Low-Kick Twin-Coaxial and Waveguide-Coaxial Couplers for ERL, Cornell Report SRF 021028-08, 2002.

[8] M. Kunze et al., “Electromagnetic Design of New RF Power Couplers for the S-DALINAC,” in Proceedings of the Ninth European Particle Accelerator Conference, Lucerne, Switzerland (2004), pp. 988–990.

[9] T. Rietdorf, Entwurf und Realisierung einer variablen supraleitenden Hochfrequenz-Einkopplung für die Beschleunigungsstrukturen des supraleitenden Darmstädter Elektronenbeschleunigers S-DALINAC, PhD Thesis, Technische Hochschule Darmstadt, 1993.

ISBN 978-3-95450-142-7